Flexible, Wearable and Reconfigurable Antennas Based on Novel Conductive Materials: Graphene, Polymers and Textiles

by

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To my dearest parents,
my stunning wife, Deyan
my two gorgeous daughters Bojin and Boyi
and my parents-in-law
with all my love.

Contents

Abstract

DUE to high demand and ubiquity of novel wireless communication systems, numerous new technical challenges have risen in modern antenna design to satisfy emerging unconventional system requirements. Typical examples include radio frequency identification (RFID) systems and wearable electronic systems. RFID systems usually consist of a reader and a tag integrated with an antenna which is attached to the item(s) to be tracked. Therefore, for the commercial viability of the system, it is desired to have flexible, light-weight, highly integratable and low-cost antennas for the tags. These characteristics are also desired for the antennas used in wearable electronic systems, with an additional critical requirement, namely electrical and mechanical robustness to the loading effect from the human body when worn. Hence traditional metallic conductors and dielectric materials such as ceramics are usually not suitable, as these materials lack mechanical flexibility and resilience while having a high intrinsic cost.

In this context, flexible, wearable and reconfigurable antennas based on novel conductive and dielectric materials are of significant interest. This is in line with the goals of this thesis which comprise four main different objectives. Firstly, the dissertation presents the development of non-metallic, highly efficient and flexible antennas based on conductive polymers and graphene thin films as conductors. Through efficiency-driven and material-oriented engineering methods, it is shown that these antennas can overcome the process-related inherent limitations of the non-metallic conductors, demonstrating the excellent potential of these novel materials. Secondly, the thesis also focuses on the investigation of appropriate shorting strategies and connection solutions for textile antennas, in terms of ease of fabrication, connection reliability and antenna efficiency. This work aims to provide reliable and efficient solutions to the critical connection requirement between flexible textile antennas and rigid electronic components. Thirdly, modular and reconfigurable wearable textile antennas which provide passive and/or active system reconfigurability are proposed, based on commercial snap-on buttons operating as shorting vias and connectors. The modular wearable antenna concept utilizes different modules which are designed to achieve specific antenna characteristics and fulfill various functionalities. The reconfigurable antenna is based on a reconfigurable module which integrates varactors and a dedicated bias circuit board inside snap-on buttons. This button module can solve the main challenge in realizing reliable connections between bias circuit, lump components and textiles, which arises because of the very different physical properties of rigid and flexible components. Fourthly, the last part of the thesis presents a compact and high efficiency series-fed microstrip patch array and a flexible dielectric resonator antenna, as examples of novel designs suitable for wearable applications.

All the results and findings in this thesis illustrate that, antennas realized in novel conductive and dielectric materials including conductive polymers, graphene, conductive textiles and polydimethylsiloxane (PDMS), can potentially satisfy the unconventional characteristics desired for future wearable electronic systems. Furthermore, the interdisciplinary combination of antenna technology and material science paves a promising path for advanced antenna developments, towards next generations of mobile wireless communication systems.

Originality Declaration

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 other 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.

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Shengjian Jammy Chen
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Adelaide, Australia

Thesis Conventions

The following conventions have been adopted in this Thesis:

Typesetting

This document was compiled using LaTeX2e. TeXstudio is used as text editor interfaced to LaTeX2e. Inkscape was used to produce schematic diagrams and other drawings.

Referencing

The referencing and citation style adopted in this thesis are based on the Institute of Electrical and Electronics Engineers (IEEE) Transaction style.

System of units

The units comply with the international system of units recommended in an Australian Standard: AS ISO 1000–1998 (Standards Australia Committee ME/71, Quantities, Units and Conversions 1998).

Spelling

American English spelling is adopted in this thesis.

Abbreviation

AR	Axial Ratio
CNT	Carbon Nanotubes
CPW	Coplanar Waveguide
DR	Dielectric Resonator
DRA	Dielectric Resonator Antenna
EMI	Electromagnetic Interference
G/PANI/PSS	Graphene/Polyaniline/Poly(4-styrenesulfonate)
GO	Graphene Oxide
HMSIW	Half-Mode Substrate-Integrated Waveguide
ISM	Industrial, Scientific and Medical
LHCP	Left-hand Circular Polarization
LP	Linear Polarization
PANI	Polyaniline
PCB	Printed Circuit Board
PDMS	Polydimethylsiloxane
PEC	Perfect Electrical Conductor
PEDOT	Poly(3,4-ethylenedioxythiophene)
PEDOT:PSS	Poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate)
PIFA	Planar Inverted-F Antenna
PPV	Polyphenylenevinylene
PPy	Polypyrrole
RCS	Radar Cross Section
RF	Radio Frequency
RFID	Radio Frequency Identification
RGO	Reduced Graphene Oxide
RHCP	Right-hand Circular Polarization
SEM	Scanning Electron Microscopy
SIW	Substrate-Integrated Waveguide
SMA	SubMiniature Version A
SPP	Surface Plasmon Polariton

TeM	Transmission Electron Microscopy
TEM	Transverse Electromagnetic
THz	Terahertz
TM	Transverse Magnetic
UWB	Ultra-Wideband
VSWR	Voltage Standing Wave Ratio
WBAN	Wireless Body Area Network

Awards and Scholarships

2017

- Honorable Mention, IEEE AP-S Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI 2017)

2016

- Young Scientist Best Paper Award, International Conference on Electromagnetics in Advanced Applications (ICEAA 2016)
- Travel Bursary Award, International Conference on Electromagnetics in Advanced Applications (ICEAA 2016)

2015

- Young Scientist Best Paper Award, International Conference on Electromagnetics in Advanced Applications (ICEAA 2015)
- Simon Rockliff Scholarship, Australia's Defence Science and Technology Group (DSTG)

2013

- Australian Postgraduate Award (APA), The Australian Government

Publications

Journal Articles

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