Design and Development of Microwave Patch Antennas using Conductive Polymers

By

Akhilesh Verma

B.E. (Electronics and Telecommunication)
University of Jabalpur, India, 1988

M.Tech (Radar and Communication Engineering)
Indian Institute of Technology, New Delhi, India, 1996

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THE UNIVERSITY OF ADELAIDE
AUSTRALIA
SUB CRUCE LUMEN

The School of Electrical and Electronics Engineering,
The Faculty of Engineering, Computer and Mathematical Sciences
The University of Adelaide, Australia

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Dedicated to my parents

Abstract

Recent advances in the electrical conductivity levels of Conducting Polymers (CP) and impressive improvements in their stability are making these materials very attractive potential alternatives to copper in planar antennas. This is particularly so in applications where light weight, inexpensive and/or wearable/conformal antennas are a consideration. There have been isolated efforts in the past towards using CP as material for antenna and transmission line design. This thesis endeavours to provide a systematic study of key factors that are important for the understanding of these materials, their design and simulation as basis material for building microwave antennas.

The thesis could be considered as made up of two parts. The first part (Chapter 2 and Appendix A) presents a mathematical model of electrical conduction and permittivity in CPs as a function of dopant concentration and frequency. The electrical conduction and permittivity are very dispersive for these materials primarily due to different relaxation times exhibited by the conduction electrons. This part also develops closed-form expressions formulas for rapid estimation of the effective permittivity of microstrip lines on multi-layer substrates. A 2D finite element eigen-mode analysis leading to the effective permittivity for two and three layer microstrip line structures is used as a reference solution and successfully validates the closed-form expressions.

The second part (Chapter 3 and 4) presents the design, simulation and fabrication of microwave antennas using thin CP films. Results on CP based microstrip patch antennas operating at 2 GHz, 4.5 GHz and 6 GHz are presented. This part also presents a systematic study on the impact of CP film thickness, conductivity and fabrication method on antenna performance. An indirect method for determination of the permittivity of non-standard RF substrates and detection of dispersion in the electrical conductivity of CP film has been demonstrated. This part validates the possibility of using CPs as microwave antennas and gives credence to many possibilities in the field of conformal antennas, wearable antennas, sports and medical applications.

The thesis is concluded in chapter 5 by summarising the results and presenting some exciting possibilities that these exotic materials open for future applications in the field of antenna applications.

Declarations

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institutions to **Akhilesh Verma** 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.

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Date: **Aug 2011** ____________________________

(**Akhilesh Verma**)

Place: **Adelaide**

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Contents

List of Figures

List of Tables

List of Symbols

ϕ	Concentration in inclusions (dopants)
ϕ_c	The critical concentration at percolation threshold
ω_p	Plasma frequency
f	Frequency
ϵ	Complex permittivity
ε'	Real part of permittivity
ε''	Imaginary part of permittivity
$\boldsymbol{\tau}$	Relaxation time
$\boldsymbol{\varepsilon}_{\infty}$	permittivity at very high frequency
$\boldsymbol{\varepsilon}_0$	static permittivity (at frequency=0)
$\sigma_{AC}(\omega)$	Electrical AC conductivity
σ_{DC}	Electrical DC conductivity
ε^*	Complex permittivity ($\varepsilon^* = \varepsilon^{'} - i\varepsilon^{''}$)
E_0	Peak applied electric field
γ	Propagation Constant
δ	Skin depth
e	Electronic Charge
g	The transmission coefficient of chain-links across grains
$N_{\perp}$	N perpendicular chains
$N_{\parallel}$	N parallel chains
z	Number of nearest neighbouring grains

R	The mean distance between neighbouring grains
g_c	Critical transmission coefficient
$\tan\delta$	Loss tangent
ϵ_s	The relative dielectric constant of a single layered dielectric in a Microstrip transmission line
ϵ_{e0}	The quasi-static effective dielectric constant
q	The effective filling fraction of the dielectric material
ϵ_{seq}	The equivalent relative dielectric constant
$Z_{\mathbf{0}}$	Characteristic impedance
η_0	Free space impedance
Z_{0i}	Characteristic impedance of i^{th} layer
ξ	The crystalline domain coherence length

Glossary

List of Acronyms

BW	Band width
CP	Conducting Polymer
CCP	Conjugated Conductive Polymer
CPC	Conductive Polymer Composites
CSA	Camphor Sulphonic acid
EM	Electromagnetic
EMI	Electromagnetic Interference
FSS	Frequency selective surfaces
GEM	General Effective Media
ICP	Intrinsically Conductive Polymers
IMT	Insulator-Metal transition
LSE	Longitudinal Section Electric
MPA	Microstrip Patch Antenna
OEM	Original Equipment Manufacturer
OPC	Organic Polymers Conductors
PA	Polyacetylene
PANi	Polyaniline
PEC	Perfect Electric Conductor
PMC	Perfect Magnetic Conductor
PML	Perfectly Matched Layer

PMT	Poly3-methylthiophene
PPy	Polypyrrole
PSS	Polystyrene Sulphonic acid
PT	Polythiophenes
PU	Polyurethane
PVS	Polyvinyl Sulphonic acid
RF	Radio frequency
RT	Room temperature
SEM	Scanning Electron Microscope
SLR	Single Layer Reduction
SPDR	Split Post Dielectric Resonator
TL	Transmission Line
TR	Transverse Resonance
UDM	Unified Dispersion Model
VLT	Visual Light Transmission

Scope of Thesis

The scope of this thesis is bounded in terms of materials defined as conducting plastics, mechanism of conductivity in such materials and the models ascribed to simulate the conduction mechanism in these materials. This work will not be dwelling in depth into molecular structure of CPs at the quantum level. However, different models for describing conductivity and permittivity variation are discussed in brief in chapter 2. Following salient points defining the scope of this thesis are as follows:

❖ A number of materials which are conductive do not necessarily fall in the category of CPs and these are excluded from the scope of this work. Some of such excluded materials are :

- Metallo-phthalocyanines (such as copper or cobalt-phthalocyanines etc)

- Tetrathiafulvalene/ Tetracyanoquinodimethanide (TTF/TCNQ); such charge-transfer materials that are based on donor-acceptor complexes.

- Polysilanes. These materials are quite similar to CPs in properties such as conductivity and non-linear optical properties. They differ essentially in their conjugation structure. They are σ based rather than π based in the case of CPs.

- Ion Conductive Polymers; such as Polyethylene oxide impregnated with $LiClO_4^-$ cations. These materials find application as solid electrolyte in dry cells and the mechanism of conduction is through ion exchange process.

- Organic polymers such as $(SN)_x$, Polythiazyl. They are very conductive at room temperature (RT) and become super conductive at temperatures below 0.26^0K. The conductivity in these materials is highly directional and is mostly along the polymer chain.

- Polymer materials with conductive fillers such as graphite or metallic powder for introducing conductivity in otherwise non-conductive polymer.

❖ No effort is made in this work to present models for depicting other (physical or chemical) properties of CPs (such as environmental stability, temperature, aging, thermal conduction etc.) and describing a detailed account of the quantum mechanism for observed conductivity in CPs. Further, the research in this work is also constrained to Polypyrrole and PEDOT CPs due to ease of availability and inherent stability of these materials over other CPs such as PA, PT etc.