

Contents

CONTENTS	I
LIST OF TABLES	IV
LIST OF FIGURES	V
CHAPTER 1 INTRODUCTION	1
1-1. Motivation and Review of MEMS Antennas	1
1-2. Motivation and Review of Active Scanning LWAs	4
1-3. Thesis Organization	6
1-4. References	8
CHAPTER 2 MICROMACHINING PROCESS AND BASIC ANTENNA THEORY	17
2-1. Micro-Electro-Mechanical Technology	17
2-1.1 Surface Micromachining	18
2-1.2 Bulk Micromachining	19
2-1.3 LIGA	20
2-2. Basic Dipole Antenna Theory	21
2-2.1 Dipole and monopole Antenna	21
2-2.2 Meandered Structure	24
2-3. Theory of Leaky-wave Antenna	25
2-3.1 The leaky mode of leaky-wave in microstrip line	25
2-3.2 Microstrip Leaky Wave Antenna radiation considerations	27
2-3.3 Characteristics of LWA	28
2-4. References	29

CHAPTER 3 FLEXIBLE DUAL-BAND ANTENNA FABRICATED ON SILICON

SUSPENDED PARYLENE MEMBRANE	40
3-1. Motivation	40
3-2. Design and Fabrication	42
3-2.1 Antenna Design	42
3-2.2 Deposition of Parylene membrane	44
3-2.3 Process of Antenna Fabrication on Parylene	44
3-3. Measurement Results and Discussion	45
3-3.1 Return Loss of Dual-band Monopole Antenna	45
3-3.2 Antenna Radiation Characteristics	46
3-4. Folded Dual-Band Antenna Type	47
3-5. Conclusions	48
3-6. References	49



CHAPTER 4 DESIGN OF 3-D MEMS-MENDER ANTENNA FOR SYSTEM IN

PACKAGE APPLICATION	63
4-1. Introduction	63
4-2. Design and Fabrication	65
4-2.1 Antenna Design	65
4-2.2 Antenna fabrication	67
4-3. Results and Discussion	69
4-3.1 Return Loss of the 3D Monopole Antenna	69
4-3.2 Antenna Radiation Characteristics	69
4-4. Silicon-Based 3D Antenna	70
4-4.1 Silicon-Based Dimensions	70
4-4.2 Silicon-Based Fabrication Process	71

4-5. Conclusions	72
4-6. References	73
CHAPTER 5 STUDIES OF SUPPRESSION OF THE REFLECTED WAVE AND BEAM-SCANNING FEATURES OF THE ANTENNA ARRAYS	85
5-1. Introduction	86
5-2. Circuit Design	88
5-2.1 Design of short LWA integrated with an aperture coupled antenna	88
5-2.2 Design of varactor-tuned phase shifter	89
5-3. Results and Discussion	89
5-3.1 Antenna Characteristics	89
5-3.2 Antenna with beam-scanning ability	91
5-4. Conclusions	92
5.5 References	93
CHAPTER 6 CONCLUSION AND FUTURE STUDY	104
6-1. Conclusion	104
6-2. Future Study	105
6-2.1 Design of the novel RF MEMS switch and phase shifter	106
6-2.2 Fabrication of Lateral Micro Switch/Relay	107
6-3. References	109



Table captions

Table 3-1: Main properties of parylene.



Figure captions

- Figure 1-1: System-level schematic detail of the front-end design for a typical wireless transceiver.
- Figure 1-2: Micromachined microstrip antenna with a portion of substrate material below the patch removed by backside etching.
- Figure 1-3: Microstrip antenna with micromachined trenches below its radiating edges.
- Figure 1-4: A micromachined horn antenna for W-band application: (a) schematic; (b) photograph of fabricated antenna in test jig.
- Figure 1-5: Micromachined microstrip antenna with the ability of beam steering.
- Figure 1-6: Micromachined Vee antenna for both beam shaping and beam steering.
- Figure 1-7: (a) Schematic of the proposed reconfigurable pixel-patch antenna architecture; RF MEMS actuator; (b) top view; (c) side view (down position); (d) side view (up position).
- Figure 1-8: The open-end effect with different length ($2\lambda_0$, $4\lambda_0$).
- Figure 1-9: (a) Array topology for the suppression of the reflected wave. (b) Taper end and active feed back for the suppression of the reflected wave.
- Figure 1-10: A dual-band monopole antenna fabricated on a parylene membrane.
- Figure 1-11: A compact three-dimensional MEMS antenna.
- Figure 2-1: Schematic illustration of the basic process steps in surface micromachining.
- Figure 2-2: Illustration of possible bulk-micromachined structures.
(a) Rounded, isotropically etched pits in a silicon substrate.

(b) Pyramidal pits etched into (100) and (110) silicon using anisotropic wet etchants, bounded by (111) crystal planes.

(c) A pyramidal pit etched down to a buried etch-stop layer in (100) silicon, with an undercut cantilever beam.

Figure 2-3: Typical sequence for the production of a microstructure based on the LIGA technique.

Figure 2-4: Three dimensional plot of the radiation pattern of the dipole antenna.

Figure 2-5: Current distribution of a monopole antenna and its equalized dipole antenna.

Figure 2-6: The radiation pattern of the ideal monopole antenna.

Figure 2-7: Meander line antenna with a finite ground plane.

Figure 2-8: The frequency of a meander line antenna vs. L_{ax} .

Figure 2-9: The impedance of a meander line antenna vs. L_{ax} .

Figure 2-10: Dispersion curve for the lowest mode and the first higher modes in microstrip line with a top cover. The figure is copied from the A.A Oliner's paper.

Figure 2-11: Top view and Rough sketch cross view of open microstrip line operated in the first higher mode.

Figure 2-12: The variations of β/K_0 and α/K_0 with frequency for a particular microstrip line with $W=433\text{mil}$ and $\epsilon\gamma=2.2$ and $H = 20\text{mil}$.

Figure 2-13: Geometry and coordinate system for the microstrip leaky-wave antenna.

Figure 2-14: Coordinate system and the physical meaning of θ_m , and $\Delta\theta$.

Figure 3-1: Detailed geometry and dimensions of designed dual-band meander monopole antenna.

Figure 3-2: Simulation of the dual-band monopole antenna.

Figure 3-3: Equipment for parylene deposition, PDS 200.

Figure 3-4: Deposition process of parylene.

Figure 3-5: Fabrication process of designed antenna on parylene-coated silicon substrate.

Figure 3-6: Fabricated dual-band meander monopole antenna (a) before and (b) after being stacked on Bluetooth dongle.

Figure 3-7: Measured and simulated return losses for the dual-band monopole antenna (2.4 and 5.2 GHz for Bluetooth and WLAN).

Figure 3-8: x-z plane radiation pattern measurement setup of MEMS membrane monopole antenna under far-field conditions.

Figure 3-9: Measured x-z and y-z plane radiation patterns for the proposed antenna at 2.4GHz.

Figure 3-10: Measured x-z and y-z plane radiation patterns for the proposed antenna at 5.2GHz.

Figure 3-11: Geometry of dual-band monopole antenna with another design. (a) Detail geometry and dimensions (b) On parylene substrate (c) Fabricated on a Bluetooth dongle

Figure 3-12: Measured and simulated return loss for the dual-band monopole antenna with another design (2.4 and 5.2 GHz for Bluetooth and WLAN).

Figure 3-13: Measured x-z and y-z plane radiation patterns at 2.4 GHz of the antenna with G-shape design.

Figure 3-14: Measured x-z and y-z plane radiation patterns at 5.2 GHz of the antenna with G-shape design.

Figure 3-15: RFID antennas with different dimensions were fabricated on a flexible parylene membrane.

Figure 4-1: (a) the structure of the 3-D MEMS monopole antenna, (b) Top view of the antenna. (Not to scale)

Figure 4-2: Simulation of the 3D monopole antenna.

Figure 4-3: the process flow of the 3-D MEMS helical meander antenna.

Figure 4-4: The schematic set of the electroplating equipment.

Figure 4-5: The photo of the equipment for electroplating experiment.

Figure 4-6: The SEM photograph of the cross section of the copper via.

Figure 4-7: The photograph of the 3D monopole antenna.

Figure 4-8: Measured and simulated return losses for the proposed antenna.

Figure 4-9: The setup for radiation pattern measurement.

Figure 4-10: Measured radiation patterns for the proposed antenna.

Figure 4-11: EM fields neutralization between adjacent lines.

Figure 4-12: The structure of the 3D antenna on silicon base

Figure 4-13: The process flow of the 3-D MEMS helical meander antenna.

Figure 4-14: Frequency-tunable 3-D MEMS monopole antenna.

Figure 5-1: The configuration of the short leaky-wave antenna integrated with the 1-, 2- and 4-element aperture-fed patch antenna arrays.

Figure 5-2: The geometry and coordinate system for the aperture-coupled patch antenna.

Figure 5-3: The schematic diagram of the varactor-tuned phase shifter.

Figure 5-4: The simulated and measured return loss of the short LWA with the open end.

Figure 5-5: The simulated and measured return loss of the short LWA integrated with an aperture-coupled patch antenna.

Figure 5-6: The comparison of the measured radiation patterns of the proposed antenna structure comparing to the traditional LWA at 10.5 GHz.

Figure 5-7: The measured radiation patterns of the short LWA integrated with an aperture-coupled patch antenna at 9.0GHz and 10.5GHz.

Figure 5-8: The simulated and measured return loss of the short LWA integrated with 2-element aperture-coupled patch antenna arrays.

Figure 5-9: The comparison between the short LWA integrated with the 2-element aperture-coupled patch arrays and the traditional LWA.

Figure 5-10: The comparison between the short LWA integrated with the 2-element aperture-coupled patch arrays and the traditional LWA.

Figure 5-11: The simulated and measured radiation pattern of the 2-element aperture-coupled patch antenna arrays.

Figure 5-12: The comparison between the short LWA integrated with the 4-element aperture-coupled patch arrays and the traditional LWA.

Figure 5-13: The measured radiation pattern of the short LWA integrated with 2-element aperture-coupled patch arrays at the bias of -15V .

Figure 6-1: Layout of torsion RF MEMS switch and CPW circuit

Figure 6-2: The schematic of CPW nonlinear delay line

Figure 6-3: Tunable RF nonlinear delay line

Figure 6-4: Brief describe of EPIES process.

Figure 6-5: The cross-section SEM photography of Cu structure after the XeF₂ isotropic Si etching.

Figure 6-6: The SEM photography of Cu (a) relay/switch and (b) tunable capacitor after the XeF₂ isotropic Si etching.