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Micromachined Circuits and Devices

Microwave to Sub-millimeter Applications

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Preface

Micromachining technology has been exhibiting in the last 25–30 years a paramount potential with respect to the manufacturing and fabrication of passive components for radio frequency (RF) applications, such as variable capacitors (varactors), inductors, switches, phase shifters, filters, antennas, and so on, commonly referred to as RF MEMS. The motivation for the fabrication of high frequency circuits using micromachining technology is due to high levels of functionality with low power consumption, precise dimensions and electrically activated moving parts. The most relevant advantages of passive components in MEMS technology compared to their standard counterparts (e.g., in semiconductor technologies or based on discrete components) reside in their high-performance and low fabrication cost, as well as in the possibility of integrating RF micromachined devices to yield circuits and functional blocks entirely based on such a technology. For example, varactors and inductors in MEMS technology present good linearity and large tuning ranges.

One of the significant and successful exploitations of RF micromachining technology is in the manufacturing of reconfigurable functional blocks for RF circuits and telecommunication platforms. The smartphone market segment started to generate a factual need for highly reconfigurable and high-performance RF passive networks, and this increased the momentum of RF micromachining technology that was expected to take place more than one decade ago. On a broader landscape, the Internet of Things (IoT) and even the wider paradigm of the Internet of Everything (IoE) seem to be potential fields of exploitation for high-performance and highly reconfigurable passive components using RF micromachining technology.

Over the past few years, micromachined-based on-chip resonators have shown significant potential for sensing and high frequency signal processing applications. This is due to their excellent features like small size, large frequency-quality factor product, low power consumption, low-cost batch fabrication, and integrability with CMOS IC technology. Radio frequency communication circuits like reference oscillators, filters, and mixers based on such MEMS resonators can be utilized for meeting the increasing count of RF components likely to be demanded by the next-generation multi-band/multi-mode wireless devices. Micromachined resonators can provide a feasible alternative to the present-day well-established quartz crystal technology that is riddled with major drawbacks like relatively large size, high cost, and low compatibility with IC chips.

The book is divided into 11 Chapters covering wide varieties of RF micromachined devices starting from 1 GHz to 0.1 THz frequency range. The Chap. 1 serving as an introduction to radio frequency micro-electro-mechanical systems where an overview of different micromachined passive and active circuits are given followed by applications in modern transceiver architectures. Chapter 2 starts with the discussion on different micromachined passive circuits. The main emphasises is given on the understanding of micromachined Conductor Backed Coplanar Waveguide (CBCPW) lines with its discontinuities. Other different types of micromachined passive components are also discussed in this Chapter that includes varactor, inductor, power divider, and couplers. Chapter 3 discusses design, development, and complete characterization of micromachined single-pole-single-throw switches. The motivation is to observe the switch functionalities in-terms of mechanical behaviour, electrical behaviour, transient analysis, linearity, power handling, temperature behaviour, and S-parameters. Chapter 4 discusses design and implementation of different micromachined single-pole-multi-throw switching networks with respect to vertical and horizontal actuation movements. It includes single-pole-double-throw to single-pole-fourteen-throw configurations. Chapter 5 presents design and implementation of micromachined resonator and resonator-based circuits. Different types of micromachined resonance modes are discussed in this Chapter followed by discussion on three different transduction mechanisms. Finally, applications of micromachined resonator are presented for timing and oscillator circuits. Chapter 6 reports theory, design, and analysis of different types of micromachined phase shifters at microwave frequencies. It includes narrowband, wideband, and reconfigurable micromachined phase shifters. Chapter 7 describes two compact, high power, and reliable tunable bandpass filter for millimetre wave RF front end for 5G and radar applications at 28 GHz and 24 GHz, respectively. A comprehensive design guideline of tunable micromachined bandpass filters is given in this Chapter with special attention to bandwidth and center frequency reconfigurations. Chapter 8 discuses reliability analysis of RF micromachined devices with emphasis on multiport switching networks, 4 to 5-bit digital phase shifters and tunable filters. Chapter 9 presents different types of micromachined antennas at mmWave frequencies. Detail design guidelines are given on antenna designs at 60 GHz and 77 GHz. In addition, a comprehensive design analysis is given in this Chapter on one specific type of active antenna. Chapter 10 describes design and development of metamaterial inspired micromachined switches at submillimetre wave frequency. Design guidelines outlined here including design layout and Casimir repulsive force inspired resistive contact and capacitive micromachined switches. Finally, Chapter 11 describes future scope of RF micromachining in the design and development of different types of metamaterial-based frequency selective surfaces, absorbers, and other 3D-micromachined devices at THz regime.

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Contents

Abbreviations

D	Directivity of Antenna
G	Gain
c	Velocity of Light
E	Electric Plane
H	Magnetic Plane
ε_r	Dielectric Constant of the Substrate
ε_{reff}	Effective Dielectric Constant
λ	Free Space Wavelength
f_o	Resonant Frequency
μ_0	Permeability of Free Space
ε_o	Permittivity of Free Space
S_{11}	S-parameter indicating forward reflection
S_{21}	Insertion loss/isolation
ADS	Advanced Design System
AR	Axial Ratio
BAN	Body Area Network
CST	Computer Simulation Technology
FEM	Finite Element Method
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HFSS	High Frequency Structure Simulator
IEEE	Institute of Electronics & Electrical Engineering
IOT	Internet of Things
ISM	Industrial Scientific Medical
LCP	Liquid Crystal Polymer
LDV	Laser Doppler Vibrometer
MEMS	Microelectromechanical System
MOM	Methods of Moments
PDA	Personal Digital Assistant
PSM	Phase Change Material
RF	Radio Frequency

RFID	Radio Frequency Identification
SAR	Specific Absorption Rates
UWB	Ultra-Wideband
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network