الجامعة الإسلامية العالمية ماليزيا
INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DESIGN OF A 2.45 GHz RF-CMOS POWER SPLITTER CIRCUIT FOR ISM RFID READERS

BY

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The dissertation submitted in fulfilment of the requirement for the degree of Master of Science (Computer and Information Engineering)

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ABSTRACT

The recent demand for automatic radio frequency identification (RFID) tags, has triggered research for accompanying miniature, low-power reader circuits. Implementation of such circuits using conventional integrated fabrication techniques such as RF complementary metal-oxide-semiconductor (CMOS) is desirable due to the low cost, reduction in parasitics and small-size. This research illustrates the design of a RF-CMOS power splitter for an RFID reader circuit to serve the ISM 2.45 GHz band. The power splitter design is based on a Wilkinson power splitter and utilizes spiral inductors, metal finger capacitors and high sheet poly resistors. The design utilizes the 0.18 µm Silterra RF-CMOS technology. Low return loss of 6.9 dB, low insertion loss 3 dB and high isolation 10dB were obtained from pre-layout simulations. The low insertion loss 1.496 dB was found from post-layout simulation. The overall power splitter circuit is simulated using AWR Microwave Office®, indicating its S-parameters. The individual inductors were designed using Sonnet® to obtain the appropriate inductance at 2.45 GHz. Further refinement of the inductor layout design was done using CST® to incorporate the effect of composite CMOS layers. Simulation results indicate that inductors core diameters must be adequately large (more than 100 µm) to ensure high quality factor characteristics and its conductor spacing should be minimal to obtain larger per unit area inductive value. Capacitor and resistor layout and extraction were performed using Cadence®. It shows the desired capacitance value of 1.39 pF required 101 fingers and the 2.2 pF required 105 fingers respectively. The high sheet poly resistor is used to implement the 300 Ohms resistor. The h-poly resistor had dimensions of 5.08 µm × 7.96 µm. Layout versus schematic simulations were performed using Cadence®. The floor plan for the power splitter was designed to fit two 1800 µm × 1800 µm chips. The post layout simulation results indicated satisfactory results which matched all the design requirements.

ملخص البحث

ازدادت الحاجة مؤخرا الى علامات التعرف الاوتوماتيكي عبر ترددات الراديو المحددة (RFID) مما أثار البحوث حول المرافقة المصغرة ، والدارات القارئة ذات الحاجة لطاقة منخفضة. تطبيقات هذه الدوائر التقليدية باستخدام تقنيات تصنيع متكاملة مثل الترددات اللاسلكية المعدنية المكملة أكسيد اشباه الموصلات (CMOS)مرغوبة نظرا لقلة التكلفة وانخفاض وزنها وصغر حجمها. ويوضح هذا البحث تصميم RF-CMOS لموزع الطاقة لدائرة RFID القارئة لتخدم حزام 2.45 غيغاهيرتز.

ان تصميم تشقق الطاقة يعتمد على قوة ويلكنسون المتشققة وعلى استخدام المسار الحثي الحلزوني.المكثف الكهربائي من المعدن الذي هو على شكل الاصبع و البريق الصفيحي العالي المقاوم. يستخدم التصميم الترددات اللاسلكية المستخدمة في التكنولوجيا (0.18 µm Silterra RF-CMOS).ويكون انخفاض العائد بمقدار 6.9 dB وكما وتكون خسارة الادخال بقيمة3 dB،وان مقدار العزل العالي يكون 10dB والذي حصلنا علية من قبل تخطيط عمليات المحاكاة. ان الانخفاض في خسارة الادخال 1.4961 dB والتي كانت موجودة من بعد تخطيط عمليات المحاكاة.وبشكل عام فان الطاقه المنشقة من الدوائر الالكترونية سوف يتم معالجتها وتخطيطها عن طريق استخدام برنامج (AWR Microwave Office®) ،والذي يدل على (S-parameters).الملفات الفردية و التي صممت باستخدام (Sonnet®) للحصول على او الاستيلاء على الملفات الحثية المناسبة والتي تكون قريبة من 2.45 GHz، وبالاضافة الى ذلك فان تعزيز وتصفية الملفات يزيد من التحسينات على التصميم وقد كان ذلك باستخدام (CST®) وذلك من اجل دمج وتسوية التاثير على طبقات كومس (CMOS). ان نتائج المحاكاة تشير إلى أن أدوات الحث بالاقطارالأساسية يجب أن تكون كافية و كبيرة (أكثر من 100 ميكرون) لضمان الجودة العالية للعامل، والخصائص لمسافة الموصل ينبغي أن يكون الحد الأدنى للحصول على أكبر قيمة لكل وحدة مساحة استقرائي. المكثف وتخطيط المقاوم تم استخراجهم وتنفيذهم عن طريق استخدام برنامج (Cadence®) ،كما انه يظهر مطلوب السعة والتي قيمتها (1.39 pF)و101 من الاصابع و105من الاصابع (2.2 pF)على التوالي. ان البريق الصفيحي العالي المقاوم يستخدم لتنفيذ 300 أوم .و(h-poly) المقاوم للبولي فان ابعاده 5.08 ميكرومتر × 7.96 ميكرون. وايضا التصميم التخطيطي في المحث أجريت باستخدام(Cadence®). وخطة التقسيم للقوة المنشقه صممت لتناسب اثنين 1800 ميكرومتر × 1800 ميكرومتر رقائق شظايا صغيرة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science (Computer and Information Engineering).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Md. Jasim Uddin

Signature …………………………………… Date ……………………..

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This dissertation is dedicated to:

My father Md. Hafiz Uddin
&
My mother Mrs. Laily Begum

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LIST OF ABBREVIATIONS

WLAN	Wireless Local Area Network
GPS	Global Position Systems
3G	Third Generation
IC	Integrated Circuits
SoC	System-on-Chip
RF-CMOS	Radio Frequency Complementary Metal Oxide Semiconductor
RFID	Radio Frequency Identification
ISM	The Industrial, Scientific and Medical
CRLH	Composite Right/Left Handed
CPW	Coplanar Waveguide
UHF	Ultra High Frequency
MFC	Metal Finger Capacitors
H-poly	High Sheet Poly
PCB	Printed Circuit Board
TEM	Transverse Electromagnetic
CMRR	Common-mode Rejection Ratio
LQPS	Lumped Element Quadrature Power Splitter
IDC	Interdigital Capacitor
SSIs	Short Circuited Stub Inductors
PDK	Process Design Kit
RH	Right Handed
LH	Left Handed
PPS	Phase and Power Splitter
ITU	International Telecommunication Union
TCXO	Temperature Compensated Crystal Oscillator
PLL	Phase Locked Loop
PE	Power Efficiency
PAE	Power Added Efficiency
IF	Intermediate Frequency
FEA	Finite Element Analysis
EIA	Electronics Industry Alliance
MIM	Metal-Insulator-Metal
H-Poly	High Sheet Poly

LIST OF SYMBOLS

L_1	Length
θ_x	Electrical Length for π Network
θ_T	Electrical Length for T Network
C	The Equivalent of Capacitor Value
f	The Centre Frequency Required for The Quarter-Wavelength
Z	The Required Impedance for The Quarter-Wavelength
$Z_{i,in}^{e}$	Input Impedance
$\Gamma_i^e (i = 1,2)$	Reflection Coefficients
Z_C	The Characteristic Impedance
ω_0	Center Frequency Effective Capacitor C_{eff}
Y_{in}	The Input Admittance
β	The Wave Number or Propagation Constant for Lossless Lines
Γ	The Reflection Coefficient
P_{in}	Input Power
P_{out}	Output Power
$\rho(\Omega.m)$	Metal Resistivity
δ	The Depth of The Conductor
μ	The Permeability of The Conductor
d_{avg}	The Average Diameter
C_{si}	The Parasitic Capacitance Between The Metal Trace and The Ground Plane
R_s	The Resistance Associated with Lossy Silicon Substrate
ε_r	The Relativity Permittivity of The Dielectric
ε_0	The Permittivity of Free Space (8.85×10^{-12} F/m)
A	The Area of Active Dielectric Material (m^2)
J	The Energy Density (J/cm^3)
E	The Applied Electric Field (V/m)
ε_r	The Relative Permittivity
ε_0	The Permittivity of Free Space (F/m)
J	The Volumetric Energy Density (J/cm^3)
$C(T_0)$	The Capacitance at T_0
K_C	The Mismatch Coefficient of Capacitance

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The telecommunication industry is growing explosively with the increasing demand for wireless communication, with applications such as wireless local area networks (WLAN), global position systems (GPS), and third-generation (3G) wireless data-centric services. The key issues in the wireless chip industries are the cost, circuit integration, mass production reliability, and low power consumption of the integrated circuit (IC) devices. Currently, CMOS integrated circuits instead of III-V compound based circuits used in early 1980's, has become the most cost effective way to implement a system-on-chip (SoC) (Cusmai, et al., 2006). Although active components such as transistors and diodes can be reliably integrated using modern semiconductor processing techniques, not all passive components that meet the high-performance requirements of modern RF circuit designs can be easily fabricated on chip.

1.2 RFID

Radio frequency identification, or RFID, is a generic term for technologies that use radio waves to identify automatically people or objects. RFID is based on wireless communication making use of radio waves, which is a part of the electromagnetic spectrum. The purpose of RFID is to enable data to be transmitted into devices which is read by a RFID reader and processed for the particular application. The data transmitted can provide identification or location information about the product, such as date of purchase or price. RFID has been more attracting for industry and academic institutes. It has gained wide range of adaptation for low-cost and ubiquitous computing application, such as vehicle tracking, container tracking, object tracking, supply chain management tracking, asset tracking. The first RFID technologies were used in Second World War, in IFF (identification friend or foe) systems. These are consisted of tag installed on vehicle tracking. RFID also used widely for container tracking systems. Perhaps, it started in 1960, but the technology started in the early of 1990s. Container tracking is the epicenter of RFID and its adoption curve is primed off now (Thinking about RFID, 2005). In the early 1960s, biologists first used object tracking for radio transponders to track large mammals. In 1990, Scientists observed that RFID could be used in a variety of object tracking applications such as contact-less ID cards, marathon timing systems. RFID tags are used in rapid payment systems in gas stations and toll booths (Lampe & Strassner, 2004). RFID also can be considered as a smart asset in asset management which has a unique ID, and a memory. (Fano & Gershman, 2002) presented an efficient asset management that can be created by using the RFID infrastructure. In November 2003, Wal-Mart informed the largest 100 vendors that they would be required to start using RFID tags on pallets. The appeal of RFID technology lies in its capability to allow retailers to know the exact location and quantity of inventory without conducting time consuming counts. Retailers seek to fulfill customer demand by ensuring that inventory is at the right place at the right time in the right amount.

An RFID system consists of three basic components, such as transponder (tag), interrogator (reader), and antenna. RFID tag is a tiny radio device that is called as a transponder, smart tag, smart label or radio barcode. The tag composes a simple silicon microchip that is attached to a small flat aerial and mounted on a substrate.

RFID antenna is a component that is attached to the reader and tag separately (Chen & Thomas, 2001). It is responsible for the wireless communication between these (tag and reader) two device. RFID reader communicates with a tag that transmits wirelessly via radio waves. This communication is non-contact and generally does not require a line of sight between those devices. The main features of RFID reader consists of three essential blocks: (i) transmitting block (ii) receiving block (iii) data processing block. Transmitting block sends request commands to RF-tag in the recognition field, the receiving block receives data from RF-tag through the antenna, and data processing block deals with data acquisition.

The industrial, scientific and medical (ISM) radio bands were originally reserved internationally for the use of RF electromagnetic fields for industrial, scientific and medical purposes other than communications. In general, communications equipment must accept any interference generated by ISM equipment.

Nowadays, ISM band is very important frequency band for RF and high frequency circuit. Our power splitter is designed to operate in the ISM band. The ISM band is accepting the range from 2.4 GHz to 246 GHz accordingly. The most commonly encountered ISM device is the home microwave operating at 2.45 GHz. The ISM bands also have been shared with license-free error-tolerant communications applications such as wireless LANs and cordless phones in the 915 MHz, 2450 MHz, and 5800 MHz bands (Razavi, 2002). Because unlicensed devices already are required to be tolerant of ISM emissions in these bands, unlicensed low power uses are generally able to operate in these bands without causing problems for ISM users.

1.4 RF-CMOS AND ITS SIGNIFICANCE

Radio frequency (RF) is the range of electromagnetic frequencies above the audio range and below infrared light (from 10 kHz to 300 GHz). Complementary metal oxide semiconductor (CMOS) is a type of semi-conductor chip that holds data without requiring an external power source. The demand for silicon CMOS RF chips with improved RF performance continues to increase due to the aggressive device scaling. The available transition frequency f_T of MOS transistors increases with every new technology generation (Guan & Hajimiri, 2003). A silicon CMOS-based implementation is advantageous in that it has both lower cost and higher integration capability with baseband circuits. CMOS process offer a higher yield than other processes such as GaAs, a significant financial incentive which makes it the most appropriate technology for the implementation of a single chip solution, which was the main motivation behind the choice of a CMOS process (Burghartz, et al., 2005).

RF-CMOS is a critical manufacturing process for important application areas such as wireless communications, consumer entertainment products and devices requiring media processing and graphics chips. Products incorporating and emerging standards such as 802.11, Bluetooth, IC design and fiber optic applications need high-performance and reliable manufacturing solutions based on RF-CMOS, which offers designers a cost-effective approach to implement these types of applications. It provides strong support for RF-CMOS with process nodes at 0.35µm, 0.25µm, 0.22µm, 0.18µm, 0.16µm, 0.13µm and 0.11µm. That broad range of support is built on our complete solution approach, which includes highly accurate device models (for both low frequency and RF), and compatibility with standard design flows from the leading EDA vendors. This technology solution is production proven in numerous designs and leverages extensive experience in IC design and communications-related applications.

RF CMOS is expected to replace bipolar and GaAs MESFET's in RF front-end IC's for mobile telecommunications devices in the near future. In order for the RF CMOS to be popularly used in this application, compatibility of its process for high-speed logic CMOS and low supply voltage operation is important for low fabrication cost and low power consumption (Hassan, Anis, & Elmasry, 2004). RF CMOS technology uses low voltage operation because the fabrication process is the same as the high-speed logic CMOS, manufacturability of this technology is excellent. Some of the passive elements can be integrated without changing the process and others can be integrated with the addition of a few optional processes. Mixed RF and logic CMOS devices in a one-chip LSI can be realized with relatively low cost. Excellent high-frequency characteristics of small geometry silicon MOSFET's with low-power supply voltage are demonstrated. Cutoff frequency of 42 GHz of n-MOSFET's, which is almost the same level at that of general high-performance silicon bipolar transistors (Burghartz, et al., 2005). Moreover, it was confirmed that degradation of minimum noise Figure for deep submicron MOSFET's with 0.5 V operation is sufficiently small compared with 2.0 V operation. These excellent high-frequency characteristics of small geometry silicon MOSFET's under low voltage operation are suitable for mobile telecommunications applications.

1.5 POWER SPLITTER

In a communication system, we often need to split an input power into some load circuits by a certain percentage, which could be actualized by power splitter. Capacitors, inductors and resistors are typically the main components of splitter.

Microwave power splitters such as Wilkinson splitters are commonly used, mainly in microstrip circuits. Some of their applications include balanced amplifiers, high-power transmitters, RFID, and antenna array feed networks (Kim, Jung, & Yun, 2004). Various types of power splitters are currently under research, such as, (i) transformer type Wilkinson splitter, (ii) lumped element quadrature Wilkinson power splitter; hybrid splitter, phase splitter, composite right/left handed (CRLH) coplanar waveguide (CPW) splitter, mixed lumped distributed element power splitter. Moreover, power splitter can fit into standard frequency ranges which are low frequency (120-135 KHz), high frequency (10-15 MHz), ultra high frequency (UHF) (850-950 MHz), and microwave frequency (2.45 GHz).

The overall proposed power splitter is reducing the insertion loss and parasitics. It can be reduced high lossy because 1/4λ microstrip lines can be replaced to the lumped element. Moreover, the whole entire system has been designed using Silterra's CMOS process which was suitable and achieved minimum extracted parasitics. The proposed design is mainly works with a specific 2.45 GHz Microwave frequency band which will cover ISM.

1.6 PROBLEM STATEMENT

Many modern communication systems are required to handle both very small signals and very large signals with precision. This in turn requires a power splitter which is low insertion loss, low return loss and high isolation. Many papers and books have discussed the design of RF-CMOS power splitter. Most of the design are fabricate on printed circuit board (PCB), one such example Wilkinson (Kim, Jung, & Yun, 2004), employing 1/4λ micro-strip or strip lines, which are discrete and cannot be fabricated on-chip (Noriega & González, 2002). The major drawback of this design is its large size, originating from the use of a 1/4λ micro-strip. Moreover, many of the circuit blocks in the RFID reader architecture are already implemented in CMOS. Therefore, connections to discrete power splitters produce parasitics and are lossy. Thus, our goal is to design power splitter using the same CMOS technology so that the entire system would be the more efficient and productive.

Many of the researchers have been developed different types of power splitter such as in 1993, Hideki et al. presented 7.2-21.6 GHz power splitter; in 2004, Rick Campbell et al. presented 2 GHz power splitter. However, they could not be able to change their frequency range because of tolerance and process mismatch of the design. On the contrary, my design is tried to solve this problem and finalize to use Silterra's CMOS process.

1.7 RESEARCH OBJECTIVES

This thesis involves the design and simulation of a 2.4GHz power splitter for RFID reader circuits. The power splitter will be fabricated in 0.18 μm RF-CMOS technology. The specific research objectives of this thesis include:

Design of a power splitter to satisfy certain specifications that has minimum return loss, minimum insertion loss, and high isolation.

- Design and development of power splitter using ISM band and 0.18 μm RF-CMOS technology for RFID readers.
- Design of rectangular spiral inductors with minimum area.
- Layout design of metal finger capacitors (MFC) and high sheet polysilicon (H-poly) resistor. Integrate all components on 1 chip which can be accessed using probe pads. Finally testing and post simulation the entire design