ACTIVE INTEGRATED ANTENNA WITH IMAGE REJECT MIXER

CHONG WAH KIAT

UNIVERSITI TEKNOLOGI MALAYSIA

To my parents and girlfriend, with love

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ABSTRACT

Active integrated antenna (AIA) with image reject mixer (IRM) operating at licenseless frequency of 2.4 GHz and intermediate frequency (IF) of 50 MHz is proposed. The opted IF of 50 MHz proves to yield satisfactory result in previous rather similar work. In this work, IRM is integrated with microstrip patch antenna on the similar substrate to attain size, weight and cost reduction. The suitable substrate that serves as the common platform for all integral components is FR-4 with dielectric constant of 4.7 and thickness of 1.6mm. This AIA with IRM employs at different phase manipulation approach from that of the previous research in which the RF signal from the antenna feed is initially fed to an 180^0 rat race coupler instead of a 90^0 coupler. Practically, this system is able to achieve image suppression with an isolation of approximately 20 dB between the image and desired frequency with 7 dBm LO drive at 2.35 GHz. The method of moment (MoM) and lumped circuit element simulation using Agilent's ADS software are employed in this work. The integral components of AIA with IRM consist of microstrip 2-elements patch antenna, singly balanced schottky diode mixers, low pass filter, branch-line 90^0 hybrid coupler lumped element 90^0 coupler and 180^0 rat race coupler. The purpose and significance of this research emerge from the disadvantages that superheterodyne receiver presents in achieving image suppression. Relatively, IRM can reasonably suppress image at a lower size, weight, complexity and cost by means of phase cancellation. The design of AIA with IRM requires the achievement of balance between several inevitable design trade-offs involved. Generally, the trade-offs in this design are between size, simplicity and performance.

ABSTRAK

Antenna padat (AIA) dengan penghapus frekuensi bayang(AIA with IRM) telah dicadangkan dengan frekuensi kendalian 2.4 GHz iaitu frekuensi tanpa lesen. Frekuensi pertengahan (IF) sebanyak 50 MHz yang dipilih membuktikan menghasilkan keputusan yang memuaskan pada kajian-kajian lepas. Dalam kajian ini, IRM digabungkan dengan antenna jalur pada substrat yang sama untuk mencapai pengurangan saiz, keberatan dan kos. Substrat yang dipilih merupakan FR-4 yang mempunyai pemalar dielektrik 4.5 dan ketebalan 1.6 mm. Antenna padat dengan penghapus frekuensi bayang memanipulasi fasa dengan cara yang berlainan daripada yang digunakan dalam kajian-kajian lepas di mana isyarat radio dialurkan ke penggading 180^0 terlebih dahulu dan bukannya penggading 90^0. Secara praktikal, sistem ini berupaya mencapai penghapusan bayang dengan isolasi sebanyak lebih kurang 20 dB di antara frekuensi bayang dan frekuensi yang dikehendaki dengan pemacuan LO sebanyak 7 dBm pada 2.35 GHz. Simulasi secara momen (MoM) dan elemen litar menggunakan perisian ADS dari Agilent. Komponen gabungan bagi projek ini ialah antenna microstrip 2-elemen, penggabung, penapis laluan rendah dan penggading 90^0 , penggading 90^0 unsur tergumpal dan penggading 180^0. Haluan dan kepentingan bagi kajian ini adalah susulan kelemahan yang dipamerkan oleh penerima superheterodyne dalam mencapai penghapusan frekuensi baying. Penghapus frekuensi bayang boleh mencapai penghapusan bayang pada kos, keberatan, kompleksiti dan size yang lebih rendah. Perekaan antenna padat dengan IRM (AIA with IRM) memerlukan pencapaian keseimbangan antara beberapa kelemahan dan kebaikan. Secara keseluruhan, keseimbangan antara kebaikan dan keburukan bagi projek ini adalah antara saiz, keringkasan dan prestasi.

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LIST OF ABBREVIATIONS

ADS	-	Advanced Design System
AIA	-	Active Integrated Antenna
AIA with IRM	-	Active Integrated Antenna with Image Reject Mixer
BW	-	Bandwidth
CAD	-	Computer Aided Design
DCR	-	Direct Conversion Receiver
dB	-	Decibel
GHz	-	Giga Hertz
IF	-	Intermediate Frequency
kHz	-	Kilo Hertz
L	-	Length
LAN	-	Local Area Network
LO	-	Local Oscillator
MHz	-	Mega Hertz
mm	-	millimeter
^0C	-	degree Celcius
^0K	-	degree Kelvin
R	-	Radius
RF	-	Radio Frequency
VTO	-	Voltage Tuned Oscillator
W	-	Width
Z_0	-	Characteristic Impedance

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The terminology of "active integrated antenna" indicates specifically that the passive antenna elements and the active circuitry are integrated on the same substrate. Due to the mature technology of microwave integrated circuit (MIC) and monolithic microwave integrated circuit (MMIC), the active integrated antenna (AIA) became an area of growing interest in recent years[1]. Incorporation of active devices functions directly into active integrated antenna reduces the size, weight, and cost of many microwave systems[2].

Active integrated antenna can be categorized by the function of active devices they integrate. Depending on the function of the active device, the active integrated antennas can be categorized into the oscillator type, the amplifier type and the frequency conversion type[3, 4, 5, 6]. An active integrated antenna is classified as frequency conversion type when a microstrip antenna is integrated with an active device for the intention of frequency translation.

In this work, Image Reject Mixer (IRM) is integrated with microstrip patch antenna for the purpose of translating radio frequency (RF) to Intermediate Frequency (IF) and provide isolation to two possible IF namely Upper Sideband (USB) and Lower Sideband (LSB) in which USB or LSB might be the desired frequency while the other one is the image frequency. Hence, active integrated antenna (AIA) with Image Reject Mixer (IRM) can be categorized as frequency conversion type active integrated antenna. The IF frequency chosen for this work is 50 MHz which directly indicate that the LO frequency might be 2.35 GHz or 2.45 GHz depending on whether low or high side injection is utilized. The 2.35 GHz is the LO frequency of this work as low side injection is employed. The 50 MHz IF frequency is chosen with reference to several approximately similar IRM work which prove to yield acceptable and good results by using this IF frequency.

In heterodyne receiver, often, it is not practical to filter out the image because the IF frequency is low, and the image is therefore too close to RF and LO frequencies to filter out the image signal high-Q image-reject filter has to be used between low noise amplifier (LNA) and mixer. The shortcomings of utilizing external image-reject filter are increased cost, increased board area, reduced reliability and increased weight[7]. Besides, double conversion is employed in most of the superheterodyne receiver for better image suppression at the expense of increased circuit complexity and cost As such, one cost effective and practical way of rejecting image signal is to use IRM which remove the need of external image-reject filter and one or more stages of up/down conversion[8].

In this work, by integrating IRM with antenna, size reduction is achieved by two means; the removal of space consuming external image-reject filter and incorporation of IRM directly into active integrated antenna. Meanwhile, cost reduction is achieved by removing the need of using external image-reject filter.

1.2 Statement and Background of the problem

In reducing the cost and the size of a communication system to meet the growing demand in these aspect, active integrated antennas appear as one of the ideal choices as they can reduce size, weight and cost of many communication systems[2]. In this work, IRM is incorporated directly in AIA to achieve size, weight and cost reduction. Moreover, using IRM instead of heterodyne architecture which requires expensive and space-consuming external image-filter has already served to reduce the cost and size.

In most of the previous research, IRM and antenna are two separate entity connected via transmission line which consumes spaces and introduce losses.

J-M Mourant and S. Jurgiel[9] has proposed a 6-18 GHz IRM that is smaller and less expensive than the suspended stripline technology products. The cost was reduced by designing a novel building blocks that could all coexist on a single microstrip substrate. The whole IRM is put together and characterized.

P.B. Khannur and S.L Koh[7] design a 2.45GHz IRM for Bluetooth application using low-cost 0.35um, double-poly four-metal standarad CMOS process with the metal-insulator-metal (MIM) capacitor option.

T.N. Ton, T.H. Chen, K.W. Chang, H. Wang, K.L. Tan, G.S. Dow, G.M. Hayashibara, B. Allen and J. Berenz[10] developed a W-band monolithic image reject mixer utilizing pseudomorphic InGaAs/GaAs HEMT diodes. The monolithic circuit integrated two single-balanced HEMT schottky diode mixers, a W-band lange coupler, and a Wilkinson power divider on one chip.

The above-mentioned works share a common characteristic; there is no direct integration with active integrated antenna which otherwise can further reduce the size, cost and improve the performance.

1.3 Objective

To design, simulate and fabricate a compact Active Integrated Antenna with Image Reject Mixer at RF of 2.4GHz and IF of 50MHz.

1.4 Scope of Project

The scope of this project comprises the design, simulation and fabrication of a microstrip antenna integrated with image reject mixer (IRM). The integral parts of IRM consist of 90^0 RF hybrids, local oscillator, low pass filters and mixer. The frequency chosen is at 2.4GHz, which is of particular interest for RFID application and wireless LAN. Besides, 2.4GHz frequency is chosen since it is within the license free frequency bands, Industrial, Scientific and Medical (ISM) bands. This design will be aided by simulation using Advance Design System (ADS). Method of Moments (MoM) will be employed in executing the simulation. A hierarchical approach will be used in this design. In other words, the integral parts of the Image Reject Mixer Active Integrated Antenna (AIA with IRM) will be designed, simulated and fabricated part by part at first before integrating them onto one board. Mixer diodes and an oscillator with operating frequency within 2.4GHz should be selected. This IRM AIA should be able to detect 2.4GHz signal and isolate the two responses; upper sidebands (USB) and lower sidebands (LSB) into separate output signals.

1.5 Organization of Thesis

This thesis is subsclassified into 7 chapters. Chapter I is introduction, Chapter II is Active Integrated Antennas, Chapter III is Types Of Receiver, Chapter IV is Elementary Parameters, Chapter V is Research Methodology, Chapter VI is Preliminary Results and Discussions and lastly, Chapter VII is conlcusion

Chapter I generally serves to introduce the problem and purpose of study. Introduction consist of the basic issue of concern by indicating field of interest which is active integrated antenna and image reject mixer with which the study is associated.In statement and background of problem, the circumstances which established the need and purpose of this research is presented on the basis of referring to previous studies and researchs. The objective section defines the specific research objectives. Last but not least, scope of project describes the work and relevant issues or element covered in this project.

Chapter II serve to provide explanation on active integrated antenna and the types of AIA associated with it which leads to define the category that this design (AIA with IRM) falls in. Also, the advantages of microstrip antenna over conventional antenna and its inherent limitation is covered which leads to the reasoning behind choosing microstrip antenna

Chapter III provides discussion on the type of receiver available to address image problem with definition on image frequency as the starter. Superheterodyne receiver is revised with main discussion on the weaknesses of superheterodyne receiver in suppressing image that prove IRM worthy of note. Subsequent discussion on IRM begins with the long-well-known Hartley and Weaver architecture before proceding to the more contemporary common basic IRM.

Chapter IV touch on the related subsystem namely the regarding parameters that ought to be given attention such as return loss of antenna and conversion loss of mixers. This chapter is mainly categorized to elementary parameters associated with mixer and antenna.

A discussion of the research design, method and procedures used is provided in this chapter. It discusses on the how the project is implemented by means of flow chart illustration. In this chapter, the block diagram of this system is included which serve as a guide to the following discussion. Design methodology of the integral parts of AIA and IRM is explained a step-by-step approach. Also, selection methodology is discussed with the relevant factors included. Nevertheless, Gantt chart is presented to show the general steps taken in semester I and II.

Chapter VI present the results achieved and its corresponding discussion. In this context, the layout dimensions and relevant circuit of the integral parts as well as the whole system is presented. The integral parts or susbsystems of the AIA with IRM are 2-elements patch antenna, 90^0 hybrid coupler, 180^0 rat race coupler, lumped element low pass filter are lumped element 90^0 coupler. The simulation and measurement results are discussed for each and every integral part before proceeding to the discussion on the final results achieved by the AIA with IRM.

Finally in Chapter VII, presentation of the conclusions drawn from the findings gathered and work done is focused. The conclusions is discussed according to the studies and work done. And, few proposed future works are make for future improvement of the project

1.6 Summary

This chapter generally serves to introduce the problem and purpose of study. Introduction consist of the basic issue of concern by indicating field of interest which is active integrated antenna and image reject mixer with which the study is associated. In statement and background of problem, the circumstances which established the need and purpose of this research is presented on the basis of referring to previous studies and researchs. The objective section defines the specific research objectives. Last but not least, scope of project describes the work and relevant issues or element covered in this project.

REFERENCES

[1] J. Lin and T. Itoh, *Active Integrated Antennas,* IEEE Transactions On Microwave Theory and Techniques, Vol. 42, No. 12, pp. 2186-2194, December 1994.

[2] Robert A. Flynt, Lu Fan, J. A. Navarro and Kai Chang, *Low Cost and Compact Active Integrated Antenna Transceiver for System Application,* IEEE Transactions On Microwave Theory and Techniques, Vol. 44, No. 10, pp. 1642-1649, October 1996.

[3] York, R. A., and Z. B. Popovic (Eds), *Active and Quasi-Optical Arrays for Solid-State Power Combining,* John Wiley & Sons, New York, 1997.

[4] Navaro, J. A., and K. Chang, *Integrated Active Antennas and Spatial Power Combining,* John Wiley & Sons, New York, 1996.

[5] Mortazawi, A., T. Itoh, and J. Harvey (Eds.), *Active Antennas and Quasi-Optical Arrays,* IEEE Press, New York, 1998.

[6] Lin, J., and T. Itoh, *Active Integrated Antennas,* IEEE Trans. Microwave Theory and Techniques, Vol. MTT-42, 1994, pp. 2186-2194.

[7] P. B. Khannur and S.L. Koh, *A 2.45GHz Fully-Differential CMOS Image-Reject Mixer for Bluetooth Application,* IEEE Radio Frequency Integrated Circuits Symposium, pp. 439-442, 2002.

[8] Bert C. Handerson, James A. Cook, *Image-Reject and Single-Sideband Mxers,* Watkins-Johnson Company Technical Notes, Vol. 12 No.3 May/June 1985 pp.1.

[9] Jean-Marc Mourant and Stephen Jurgiel, *A Broadband Planar Image Reject Mixer*, IEEE MTT-S Digest, pp. 1637-1640, 1994.

[10] T.N. Toh, T.H. Chen, K.W. Change, H. Wang, K.L. Tan, G.S. Dow, G.M Hayashibara, B. Allen and J. Berenz, *A W-Band Monolithic InGaAs/GaAs HEMT Schottky Diode Image Reject Mixer,* IEEE GaAs IC symposium, pp. 63-67, 1992.

[11] Dahlgren, U., et al., *An Integrated Millimeterwave BCB Patch Antenna HEMT Receiver,* IEEE MTT-S Int. Microwave Symp. Digest, 1994, pp. 661-664

[12] Martinez, R.D., and R. C. Compton, *A Quasi-Optical Oscillator/Modulator for Wireless Transmission,* IEE MTT-S Int. Microwave Symp. Digest, 1994, pp. 839-842

[13] Angelove, I., H. Zirath, and J. Svedin, *A New Mixer for Sensor Applications,* IEEE MTT-S Int. Microwave Symp. Digest, 1998, pp. 1051-1054

[14] Montiel, C. M., L. Fan, and K. Chang, *A Novel Active Antenna With Self-Mixing and Wideband Varactor-Tuning Capabilities for Communication and Vehicle Identification Application,* IEEE Trans. Microwave Theory and Techniques, Vol. MTT-44, 1996, pp. 2421-2430

[15] Lin, S., Y. Qian, and T. Itoh, *A Quasi-Optical Subharmonic Self-Oscillating Mixer,* Proc. 28th European Microwave Conf., 1998, pp. 412-414

[16] D.M. Pozar, *Microwave Engineering*, John Wiley & Sons, New York, 3rd Ed. 2005.

[17] R. Hartley, *Single-sideband Modulator,* U.S. Patent No. 1666206, April 1928

[18] Behzad Razavi, *RF Microelectronics*, Prentice Hall PTR, University of California, Los Angeles 1998

[19] D.K Weeaver, *A Third Method of Generation and Detection of Single sideband Signals,* Proc. IRE, Vol. 44, pp. 1703-1705, December 1956

[20] IRE Subcommittee 7.9 on Noise, *Description of the Noise Performance of Receiving Systems,* Proc, IRE, vol. 51, 1963, p. 436

[21] ***S*** **.** Maas, " Microwave Mixer," Artech House, Norwood, MA, 1986.

[22] Jack R.Smith, *Modern Communication Circuits*, University of Florida, 2nd Ed, 2000.

[23] James, J.R. and Hall, P. S(1989), *Handbook of Microstrip Antennas,* London, Peter Peregrinus Ltd.

[24] C. A. Balanis, *Antenna Theory Analysis and Design,* 2nd Edition, Arizona State University, John Wiley & Sons, Inc., 1997.

[25] Kapsidis, D., Chryssomallis, M.T., and Christodoulou, C.G. (2003). An Accurate Circuit Model of a Microstrip Patch Antenna for CAD Applications. *Antennas and Propagation Society International Symposium*. 22-27 June. Greece: IEEE, 120-123

[26] Sainati, R.A. (1996). CAD for Microstrip Antennas for Wireless Application. Boston: Artech House

[27] Richards, W. F., Y. T. Lo, and D. D. Harrison, *An Improved theory for Microstrip Antennas and Applications,* IEEE Trans. On Antennas and Propagation, Vol. AP-29, 1981, pp. 38-46

[28] Kara, M., *The Resonant Frequency of Rectangular Microstrip Antenna Elements With Various Substrate Thickness,* Microwave and Opt. Technol. Lett., Vol. 11, 1996, pp. 55-59

[29] Hammerstad, E. O., *Equations for Microstrip Circuit Design,* 5th European Microwave Conf., 1975, pp. 268-272