AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECRONICS ENGINEERING AND ELECTRICAL COMMUNICATION

EBG-based Wideband Antenna Arrays

A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the Electrical Engineering

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STATEMENT

This Thesis is submitted for the degree of Doctor of Philosophy to the Department of Electronics and Communication Engineering, Faculty of Engineering of Ain Shams University, 2015.

The work included in this thesis was carried out by the author in the Department of Electronics and Communication Engineering, Ain Shams University and Electronics Research Institute, Microstrip Department.

No part of this Thesis has been submitted for a degree or a qualification at any other university or institute.

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Published Papers

1. M. I. Ahmed, A. A. Sebak, Esmat A. Abdallah, and Hadia M. Elhennawy, "Mutual Coupling Reduction using Defected Ground Structure (DGS) for Array Application", 15^{th} International Symposium of Antenna Technology and Applied ElectroMagnetics (ANTEM), Toulouse, France, June 25-28, 2012.

2. M. I. Ahmed, A. A. Sebak, Esmat A. Abdallah, and Hadia M. Elhennawy, "Novel Flag Shape Microstrip Antenna Array Mutual Coupling Reduction," *Proceedings of 2^{nd} Advanced Electromagnetics Symposium (AES)*, University of Sharjah, UAE, March 2013.

3. M. I. Ahmed, A. A. Sebak, Esmat A. Abdallah, and Hadia M. Elhennawy, "Novel KSA Sign Shape Microstrip Antenna Array Mutual Coupling Reduction," *Proceedings of 2^{nd} Advanced Electromagnetics Symposium (AES)*, University of Sharjah, UAE, March 2013.

4. M. I. Ahmed, Esmat A. Abdallah, and Hadia M. Elhennawy, "Novel UWB Eagle Shape Slot Microstrip Antenna Array Mutual Coupling Reduction for Official Applications," *Proceedings of New Paradigms in Electronics and Information Technologies (PEIT)*, Luxor, Egypt, 30Nov. - 3 Dec., 2013

5. M. I. Ahmed, Esmat A. Abdallah, and Hadia M. Elhennawy "Design, Simulation, Fabrication, and Measurement of Antenna Array with Low Mutual Coupling for ISM Band Wireless Applications," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 3, no. 10, pp. 12275-12287, Oct. 2014.

6. M. I. Ahmed, Esmat A. Abdallah, and Hadia M. Elhennawy, "UWB KSA Sign Shape Slot Microstrip Antenna Array Mutual Coupling Reduction for Official Applications," *International Journal of Engineering and Technology*, vol. 6, no.6, pp. 513-519, 2014.

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8 M. I. Ahmed, Esmat A. Abdallah, and Hadia M. Elhennawy, "SAR Investigation of Novel Wearable Reduced-Coupling Microstrip Antenna Array" *International Journal of Engineering and Technology-IJENS*, vol. 15, no.3, pp. 78-87, June 2015.

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SUMMARY

Printed monopole antennas are indispensable candidates for WLAN, UWB, and RFID applications. Along with the small size, the antenna should preferably be low cost, light weight, less fragile and low profile. The main aim of this thesis is design, simulation, fabrication, and measurement of wideband antenna array. The printed monopole antenna array is studied. The derived transmission line model was found for a slot antenna by two methods. First, a simple and accurate model of the offset fed transverse slot radiator is introduced. The second method is equating the delivered power to a lossy transmission line and the radiated power by a slot. From these, the total radiated power is found in terms of the radiated loss per-unit-length (α). The input impedance of printed linear slot antenna simplified derivations are presented. Next, the electric field equation and radiated power of the slot are corrected and proofread. Also, the input impedance and performance of printed monopole antenna array are discussed. The mutual coupling between the array elements is reduced using Electromagnetic Band Gap (EBG) structures. The EBG structures are divided to: Defected ground structure (DGS), mushroom-like EBG, and uni-planar EBG. All the three types are discussed.

The rapid expansion of wireless technology during the last years has drawn new demands on integrated components including also antennas. The existence of an immense infrastructure worldwide for the 2.4 GHz Industrial, Scientific and Medical (ISM) band along with the release of the 5.6 GHz ISM band, combined with its increasing popularity, related to the Bluetooth and/or WLAN systems applications. A low mutual coupling design for two and four elements microstrip antenna array are proposed. A new distribution for dumbbell shaped defect on the ground plane of the antenna is inserted between the patches creating a band gap in the operation frequency band of the antenna. By suppressing the surface waves, it provides a very low mutual

coupling between array elements. The DGS antenna is analyzed using a finite integration technique (FIT) and a mutual coupling reduction of 35.6dB is achieved. The analysis indicates that increasing number of dumbbells reduces the mutual coupling between elements. Radiation patterns have minimal change in the broadside direction but back lobe level is increased. However, the gain and the efficiency are decreased due to penetration of DGS in the ground plane. The results agree with those obtained by the full wave simulator method. It is noticed that the ground plane penetration is the DGS main problem.

One of the dominant research topics in antennas for body-centric communications is the wearable, and the fabric-based antennas. Commonly, wearable antennas for all modern applications require light weight, low cost, almost maintenance-free and no installation. There are number of specialized occupation segments that utilize body centric communication systems, such as paramedics, fire fighters, and military. Besides, wearable antennas also can be applied for youngsters, the aged, and athletes for the purpose of monitoring. A new concept of a wearable antenna is easily integrated into clothing. A novel eagle shape and KSA slogan microstrip antenna are presented. The single- and two-element antenna array are designed and fabricated on a substrate with dielectric constant of 2.2, thickness of 1.5748 mm, and tan δ = 0.001. The microstrip array was studied by CST simulator and fabricated by proto laser machine with precision 25µm. The antenna can be used in the official or RFID applications. Also, this antenna may be used in soldier belts, any commodity for the official application, etc. The novel EBG cells in the shape of small size eagles and KSA slogan are inserted between the adjacent coupled elements in the array to suppress the pronounced surface waves. A mutual coupling reduction of 36 dB is achieved at first band (1.68 - 2.65) GHz and 22.1 dB at second band (6.5 – 8.86) GHz for a novel eagle shape antenna array. Also, a mutual coupling reduction of 11.9 dB is achieved at 2.542 GHz for a novel KSA slogan. The measured results agree well with those obtained by the CST. SAR calculation was carried out to measure the effect of those antennas on Human bodies. Maximum SAR of eagle shape antennas result is 1.95 W/Kg, while, maximum SAR of KSA slogan antennas result is 1.64 W/Kg that are acceptable to the IEEE C95.1: 2005 and the ICNIRP standards.

A novel UWB Eagle shape and KSA slogan shape slot microstrip antenna are presented. The single and two element antennas were designed and fabricated on a substrate with dielectric constant of 4.4, thickness of 1.6 mm, and tan δ = 0.02. The microstrip array was simulated and fabricated. A reduction in mutual coupling of 6 dB is achieved in the Eagle shape at first band (1.71 - 2.98) GHz, 10 dB at second band (4.26 – 5.62) GHz, and 6 dB at third band (6.57 – 9.16) GHz. A reduction in mutual coupling of 3 dB is achieved in the KSA slogan shape at first band (2.1 - 2.99) GHz and 33 dB at second band (4.92 – 6.73) GHz, and 7 dB at third band (6.73 – 9.28) GHz. The measured results agree well with those obtained by the CST. The antennas can be used in the military or RFID applications. These configurations are chosen because the eagle shape and KSA sign shape are the official badges for any military application. The antennas is an excellent candidate for use as internal elements in modern laptop computers. The antennas is tested among three opening angles. The EBG cells in the shape of small size eagles and KSA slogan shape are inserted between the adjacent coupled elements in the array to suppress the pronounced surface waves.

Finally, for future work, it is desired to implement these designs in MIMO system to achieve overall better performance.

Table of Contents

List of Abbreviations

ADS	Advanced Design System
BPF	Band Pass Filter
BSF	Band Stop Filter
CPW	Coplanar Waveguide
CST	Computer Simulation Technology
DGS	Defected Ground Structure
EBG	Electromagnetic Bandgap Structure
EM	Electromagnetic
FIM	Finite Integral Method
FIT	Finite Integral Technique
GPS	Global Positioning System
GSM	Global System for Mobile
GUI	Graphical User Interface
IC	Integrated Circuits
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
LMDS	Local Multipoint Distribution Systems
LPF	Low Pass Filter
LTE	Long Term Evolutions
MCC	Mutual Coupling Compensation
MEMS	Micro Electro Mechanical Systems
MLS	Microwave Landing System
MMDS	Multipoint Multichannel Distribution Systems
MMIC	Monolithic Microwave Integrated Circuits
MoM	Method-of-Moments
NFC	Near Field Communication
PBG	Photonic Band Gap
PCB	Printed Circuit Board
PCS	Personal Communication System
RF	Radio Frequency
RFIC	Radio Frequency Integrated Circuits
TV	Television
UMTS	Universal Mobile Telecommunications System
UWB	Ultra-Wide-Bandwidth
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
Wi-MAX	Worldwide Interoperability For Microwave Access
WLAN	Wireless Local Area Network