UNIVERSITI PUTRA MALAYSIA

DESIGN AND ANALYSIS OF MICROSTRIP ANTENNA USING NEGATIVE INDEX METAMATERIAL APPROACH

ADAM REDA HASAN ALHAWARI

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By

ADAM REDA HASAN ALHAWARI

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Thesis Submitted to the School Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

June 2012

DEDICATION

To my ever-encouraging parents…

To my altruistic and beloved wife…

To my lovely daughters (Alia and Shifa)…

To my supportive siblings…

To my understanding parents in laws…

To every striving muhsin person who is constantly improving aspects of life…

To those who are compassionate towards achieving perfection (ihsaan)…

To the consistent pursuers of knowledge aiming for positive change…

A special contribution to my home country Jordan and to Malaysia;

with lots of gratitude…

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DESIGN AND ANALYSIS OF MICROSTRIP ANTENNA USING NEGATIVE INDEX METAMATERIAL APPROACH

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June 2012

Chairman: Assoc. Prof. Alyani Binti Ismail, PhD

Faculty: Engineering

Negative Index Metamaterials (NIMs) are extraordinary engineered materials. NIMs are the in-thing in the track of current research interest. It discovered a wide range of futuristic potential applications on super lenses, cloaking devices, filters and antennas. Hence, now it continuously sparks diverse areas of research to explore beyond previous discoveries, especially to produce more efficient microwave devices, specifically antennas.

This study presents two different types of NIM structures. It is an attempt to improve the performance characteristics of two different classes of antenna designs. Parameters retrieval algorithm and full-wave simulation of prism-shaped structure were carried out to validate the negative index of refraction property of the proposed NIM structures. The results emphasize the prospect of the proposed NIM designs for being very promising alternatives to the conventional ones due to its broader

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spectrum of application and compatibility for various potential microwave devices, mainly when wideband or dual-band function is required.

First, a three-unit cell NIM antenna is presented for ultra-wideband (UWB) applications. It was etched on FR4 epoxy substrate at an evident compact size of 25 x 25 x 1.6 mm^3. This antenna exhibited a return loss of 94% bandwidth for voltage standing wave ratio (VSWR) less than 2 over the frequency band of 5.2–13.9 GHz, with a maximum gain and directivity of 3.85 dB and 5.45 dB, respectively, at 10.5 GHz. These measurement results show good agreement with those of simulations as well as good omni-directional characteristics within operating frequency band of the antenna. It does contribute compactness and high performance at low cost.

Second, the conventional antipodal Vivaldi antennas (AVAs) suffer from some design problems like tilted beam; low or inconsistent directivity and gain; and larger size. A new compact AVA is introduced using linearly-tapered shape-loading structure due to crucial dependence on the space between the antenna arms, to further boost its performance especially when combined with NIM technology. Primarily, incorporation of NIM into this antenna design considerably overcomes the setbacks. A unique slitting approach harmoniously integrates the AVA with NIM where a single layer NIM piece is simply snug into the slit perpendicular to the middle antenna substrate. The final dimensions of the NIM antenna were 48 x 96 x 24 mm^3. The NIM amplifies the capability to focus the entire beam to radiate onto the targeted direction. The measurement results are similar to simulations in terms of high gain, where the gain of the antenna was increased about 5 dB; directivity; and design flexibility within its operating frequency band (6.5–20 GHz). The contrast of

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overall performance between the new plain AVA and the NIM-improved ones evidently asserts the anticipated contribution of snug and boost method applied and significant potentials for a broad range of UWB applications, for instance, see-through-wall imaging and breast tumour detection.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKABENTUK DAN ANALISIS ANTENA MIKROSTRIP MENGGUNAKAN PENDEKATAN METAMATERIAL BERINDEKS NEGATIF

Oleh

ADAM REDA HASAN ALHAWARI

Jun 2012

Pengerusi: Prof. Madya Alyani Binti Ismail, PhD

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Metamaterial Berindeks Negatif (NIM) adalah bahan luar biasa yang telah diolah. NIM adalah topik kajian yang sedang hangat dikaji dalam aliran penyelidikan semasa. Ia menemui pelbagai aplikasi futuristik yang berpotensi besar untuk kanta super, peranti penyembunyi, penapis dan antena. Oleh itu, hingga kini ia berterusan menggalakkan pelbagai bidang penyelidikan untuk meneroka lebih jauh melangkaui penemuan sebelumnya, terutamanya untuk menghasilkan peranti gelombang mikro yang lebih cekap, khususnya antena.

Kajian ini membentangkan dua jenis struktur NIM. Ia satu cubaan untuk memperbaiki ciri-ciri prestasi dua jenis rekabentuk antena yang berbeza. Perolehan algoritma parameter dan simulasi gelombang penuh dari struktur berbentuk prisma telah dijalankan untuk mengesahkan ciri-ciri pembiasan indeks negatif dari struktur NIM yang dicadangkan. Keputusan mengesahkan prospek rekabentuk NIM yang

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dicadangkan sebagai alternatif yang sangat berpotensi kepada rekabentuk konvensional kerana spektrum aplikasinya yang lebih luas dan sesuai untuk pelbagai peranti gelombang mikro, terutamanya jika diperlukan untuk fungsi jalur lebar atau dwi-jalur.

Pertama, tiga unit sel antena NIM dibentangkan untuk aplikasi jalur lebar ultra (UWB). Ia ditanggam pada substrat FR4 epoksi dengan saiz yang jelas kompak pada 25 x 25 x 1.6 mm^3. Antena ini mengalami kehilangan kembalian (gelombang) sebanyak 94% dari jalur lebar untuk nisbah tempoh voltan per gelombang (VSWR) kurang daripada 2 pada jalur frekuensi 5.2-13.9 GHz, dengan pulangan maksimum dan direktiviti sebanyak 3.85 dB dan 5.45 dB, masing-masing, pada 10.5 GHz. Keputusan pengukuran menunjukkan keserasian yang baik dengan keputusan simulasi, serta mempunyai ciri-ciri arah-omni yang baik dalam jalur frekuensi operasi antena. Ia sememangnya menyumbang prestasi yang tinggi walaupun kompak, pada kos yang rendah.

Kedua, antena antipodal Vivaldi konvensional (AVA) yang mengalami beberapa masalah reka bentuk seperti kecondongan alur pancaran; direktiviti dan pulangan yang rendah atau tidak konsisten; dan saiz yang lebih besar. AVA baru yang kompak diperkenalkan ini menggunakan struktur muatan berbentuk tirus selari kerana peningkatan prestasi amat bergantung kepada ukuran ruang di antara lengan antena, terutamanya apabila digabungkan dengan teknologi NIM. Yang paling utama, penggabungan NIM ke dalam reka bentuk antena ini berupaya mengatasi masalah-masalah tersebut. Pendekatan menanggam yang unik dapat mengintegrasikan AVA dengan NIM secara harmoni di mana sekeping lapisan

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tunggal NIM diselit ke celah satu ruang beserenjang di bahagian tengah substrat antena. Dimensi muktamad antena NIM berukuran 48 x 96 x 24 mm^3. NIM menggandakan keupayaan untuk menumpukan keseluruhan alur pancaran ke arah sasaran. Keputusan pengukuran agak sama dengan keputusan simulasi dari segi pulangan antena yang tinggi iaitu peningkatan sebanyak kira-kira 5 dB; pulangan direktiviti juga tinggi; serta fleksibiliti reka bentuk dalam jalur frekuensi operasi (6.5-20 GHz). Perbandingan di antara AVA baru dengan yang ditambahbaik dengan NIM jelas membuktikan sumbangan kaedah ‘selit dan ransang’ yang diaplikasikan adalah seperti yang dijangkakan dan berpotensi besar untuk pelbagai aplikasi UWB, sebagai contoh, pengimejan lihat-menerusi-dinding dan pengesanan tumor payudara.

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I certify that an Examination Committee met on 13th June 2012 to conduct the final examination of Adam Reda Hasan Alhawari on his thesis entitled "Design and Analysis of Microstrip Antenna Using Negative Index Metamaterial Approach" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

ADAM REDA HASAN ALHAWARI

Date: 13 June 2012

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