Four-Band Planar Patch Antenna for Digital Audio Broadcasting, Universal Mobile Telecommunications and WiMax Frequency Signal Integration

Falih M. Alnahwi, Naz E. Islam

Abstract — *A single planer patch antenna that can be used in devices that utilizes signals from digital audio broadcasting (DAB), the universal mobile telecommunication systems (UMTS) and two WiMax frequency bands is presented. All the frequency bands that are generated by the proposed antenna are in the same polarization plane. The planar design, four-band antenna is easy to fabricate and has applications in modern communications devices that use different antennas to integrate signals from various devices operating at different frequencies. The structure analysis is done through an in-house developed FDTD code and compared with a commercial simulation suite. Results are in good agreement and a slight discrepancy in the return loss parameters is due the mesh generation technique in each of the codes. The development of the in-house code for analysis allows for an in-depth study of the physics of the radiation mechanisms.*

Key Words — Four Band Antenna, Planar Patch Antenna, Finite Difference Time Domain, Return Losses.

I. Introduction

Microstrip antennas, the workhorse of the modern day communication systems, have significant advantages over other antennas types because of its small size, low cost, and easy fabrication technique [1]. The structure has been analyzed and used in many small size devices since its inception in the early 70's of the previous century. With the advent of gadgets that functions by utilizing and integrating varies devices that operate in different frequency bands, research in microstrip analysis has moved towards designing multi-band structures. For example, cellphones operate on signals modulated by different wireless frequencies such as GSM, Bluetooth, and the GPS band. The use of one antenna instead of three in such applications will saves resources, time and will be cost effective.

Recent years have seen a surge in the design and analysis of two- and three-band antennas [2]-[10]. This includes a Bluetooth and IEEE 802.11a bands slotted patch antenna using a pair of T-match stubs [2], an aperture feed double layer microstrip antenna in the UHF and GSM/CDMA band [3], a double-band circularly polarized stacked antenna for satellite navigation systems [4] and a three port feeding network based dual-band dual-polarized patch antenna that operates at 1.9 GHz and 2.4 GHz [5].

Three-band antennas reported include a microstrip antenna with three overlapped square patches that serves WLAN applications [6]. A double layer microstrip antenna has been designed to generate three bands using two U-shaped slots with conventional coaxial feed [7]. Li et al. [8], in 2012, have used the dipole antenna concept to design a directional triple-band planer antenna operating in WLAN/WiMax access point applications while the same year Noori et al. [9] have designed triple-band antenna with the aid of h-shaped slot embedded in the center of the patch. Also in 2012, Falade et al. [10] designed three-band circularly polarized antenna for GPS receivers using single feed stacked patch antenna. All such designs reported, however, use double layer, multi feed, or complex design to obtain multi-band antenna to be used for specific application.

In this paper, we propose a planer single feed microstrip antenna that generates four frequency bands in the same polarization plane. This antenna utilizes a U-shaped slot and a pair of bent slots that are embedded in the middle of the patch surface. This design is not only easy to fabricate, but it uses a thin substrate to overcome the problem of large size that is caused by the stacked designs presented earlier. Simulation and analysis show that the proposed antenna has applications in the Digital Audio Broadcasting (DAB) band, in the Universal Mobile Telecommunications System (UMTS) band, and two in the WiMax frequency bands.

Following this brief introduction, we discuss the structure of the proposed four-band antenna in detail in Section III. The simulation method that is used to design this antenna is explained in Section IV. Section V presents the simulation results and a comparison between the simulation results and those of the industrial software CST Microwave Studio. Finally, we conclude in section VI.

II. Antenna Structure

Fig. 1 illustrates the top and the side view of the proposed antenna. The designed four-band microstrip antenna consists of copper patch of length L=36mm and width w=40mm; a copper ground plane of length L'=46mm and width w'=50mm, and a substrate whose length and width are exactly the same as that of the ground plane and height, h=1.6mm. The material of the substrate is lossy FR4 ($\varepsilon_r = 4.4$, $\mu_r = 1$, $\sigma = 0.02\mho/\text{m}$). A U-shaped slot having regular width equal to 1mm is embedded on the surface of the patch and shifted by 8mm away from the patch edge to provide another resonance to the patch [11]. The two parallel arms of the U-shaped slot are located along the length of the patch, and they have length of 18mm, while the line that connects these two arms has length of 16mm. A pair of bent slots with 1mm width is engraved inside the U-shaped slot. The separation between the U-shaped slot arms and the bent slots arms is 1mm. The length of longer arm of the bent slot is 15mm, whereas the length of the shorter one is 4mm only.

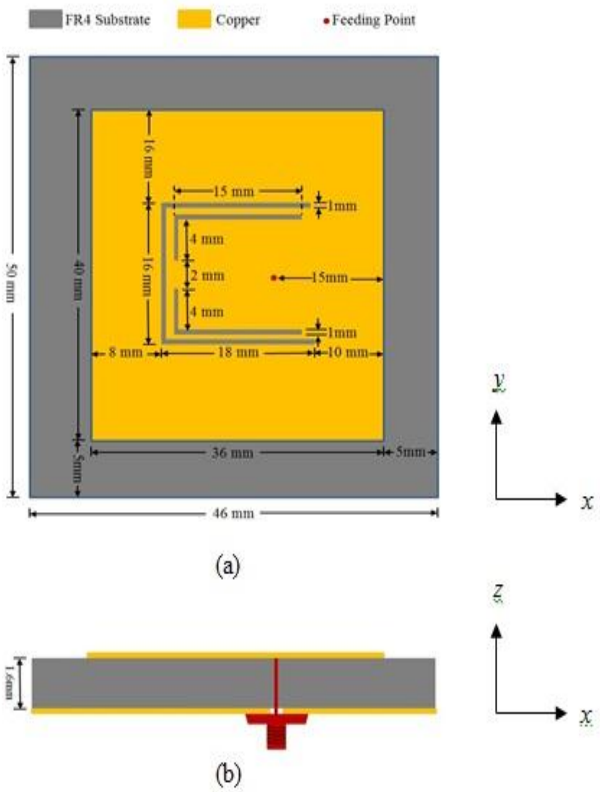

Fig. 1. The structure of the four-band antenna (a) Top view and (b) Side view.

The pair of bent slots can generate two operating frequencies that are associated with the TM10 and TM30 modes of the unslotted patch antenna [11]. As a result, four frequency bands can be generated using this configuration. The selection of the feed point position at which a good matching for the four bands can be achieved is the main problem associated with the design. The optimum feed point is found to be at 15mm away from the patch edge that is far from the U-shaped slot position. In addition, the feed point is located in the middle of the patch width in order to avoid any radiation toward the width and to insure that all the operating frequencies are in the same polarization plane.

III. Simulation Setup

The four-band antenna simulation is based on an in-house developed Finite Difference Time Domain (FDTD) based code using MATLAB [12], and compared with results from an industry standard simulation suite [CST Microwave Studio] to check for accuracy.

For the FDTD based code, the dimensions of the Yee cell was chosen to be $\Delta x = 1mm$, $\Delta y = 1mm$, and$\Delta z = 0.533mm$. Therefore, the total mesh dimensions are 46×50×3 *cells* in the *x*, *y*, and *z* direction, respectively. The antenna was excited at the feed point using voltage source with an internal resistance of 50Ω. A Gaussian pulse with 20 cells per wavelength accuracy parameter (n_c) is selected as a source waveform and is represented by (1),

$$g(t) = e^{-(\frac{t-t_o}{\tau})^2} \tag{1}$$

where t_o represents a specific time shift, and τ denotes the pulse width, and their optimum values are given by (2) and (3) respectively [12]:

$$t_o \cong 4.5\tau \tag{2}$$

$$\tau \cong \frac{\max(\Delta x,\ \Delta y, \Delta z)\, n_c}{2c} \tag{3}$$

where c denotes the speed of light in freespace, and (max) denotes the maximum value. From equations (2) and (3), the values of t_o and τ were found to be $150ps$ and $33.33ps$, respectively. The source is a coaxial feeding positioned along z-axis at the feed point. A suitable time step (Δt) was chosen for stability, using (4) [12],

$$\Delta t = 0.9\frac{1}{c\sqrt{\frac{1}{(\Delta x)^2}+\frac{1}{(\Delta y)^2}+\frac{1}{(\Delta z)^2}}} \tag{4}$$

The value of the time step was determined to be 1.3ps.

A perfectly absorbing boundary condition was applied to the simulation structure surrounding the antenna with 10cells air buffer followed by $8cells$ Convolutional Perfect Matched Layer (CPML) [12]. The CPML ensures that no field component is reflecting back to the antenna.

IV. Results and Discussion

Fig. 2 and Fig. 3 illustrate the distribution of electric and magnetic fields, respectively, in the xy plane. The electric and magnetic fields equal to zero at the boundaries, thus ensuring that there are no field reflecting back to the problem space. The transient voltage and current, which are sampled at the feed point, are shown in Fig. 4 and Fig. 5, respectively. After 5000Δt time steps the transient voltage and current are approximately reach to zero, so the simulation is stopped at this time instant.

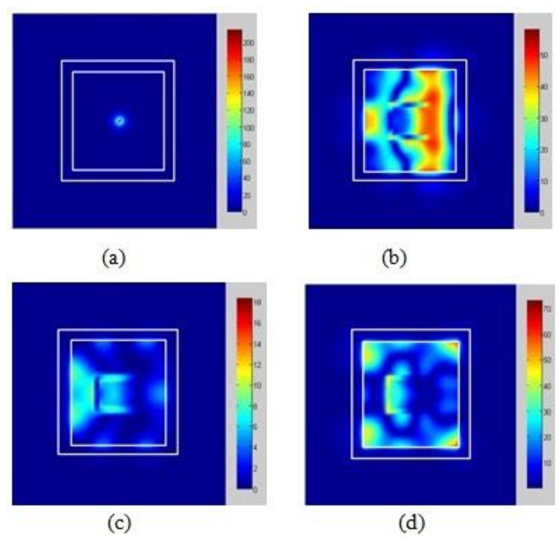

Fig. 2. Distribution of the electric field at (a)100Δt, (b) 700Δt, (c) 1000Δt, (d) 3000Δt.

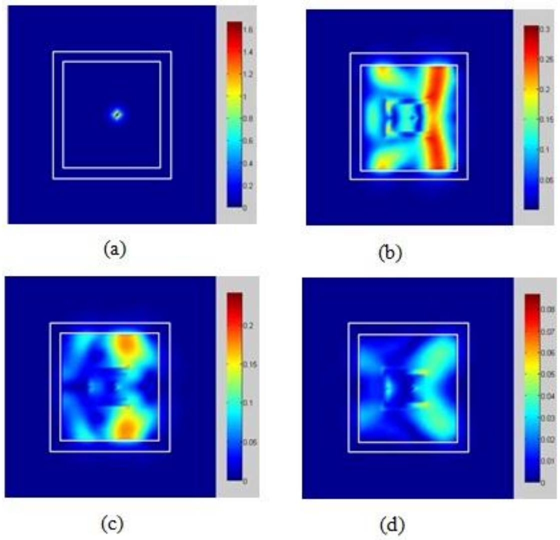

Fig. 3. Distribution of the magnetic field at (a)100Δt, (b) 700Δt, (c) 1000Δt, (d) 3000Δt.

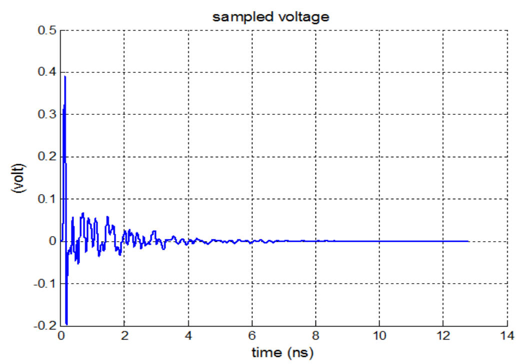

Fig. 4. Sampled transient voltage for 100000 time steps.

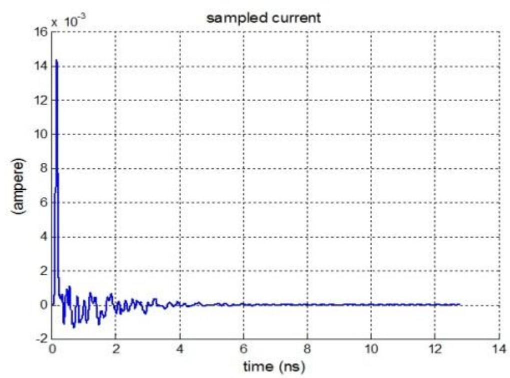

Fig. 5. Sampled transient current for 100000 time steps.

The calculated return losses are shown in Fig. 6. This figure clearly demonstrates the four operating frequency bands of the proposed antenna. The first band is located at 1.48GHz in the Digital Audio Broadcasting (DAB) band. The second band is located at 2.15GHz in the UMTS band. The last two bands are useful in WiMax applications, and they are located at 4.08GHz and 4.38GHz.The return losses at each resonant frequency are -15dB, -28dB, -22dB, and -25dB, respectively. The bandwidth values, which are calculated at$|S_{11}| \leq -10dB$, around the center frequency of each band are given in Table I.

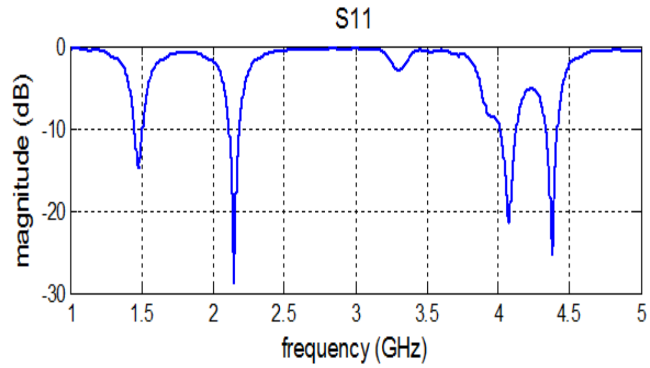

Fig. 6. Return losses |S_11 | of the four-band antenna.

TABLE I
THE RESONANT FREQUENCIES AND THEIR CORRESPONDING BANDWIDTH.

Band	f_c (GHz)	f_L (GHz)	f_H (GHz)	10dB BW (MHz, %)
1	1.48	1.45	1.5	50, 3.4
2	2.15	2.11	2.19	80, 3.72
3	4.08	4.01	4.13	120, 3
4	4.38	4.33	4.42	90, 2.1

In order to check accuracy of the FDTD simulation results, the return losses are compared with a commercial simulation suite [CST Microwave Studio]. The results are shown in Fig. 7, which includes the four frequency band for the antenna. Comparisons of the return losses show small deviation between the two codes. This deviation could be attributed to the incorporation of dynamic mesh size in the commercial code, where the mesh size can automatically change the number of Yee cells at different locations for better convergence. The in-house FDTD code has fixed cell size for all the problem space. Moreover, the in-house code is based on the assumption of zero thickness conductor (for the patch and the ground plane), whereas auto mesh property of CST microwave Studio enables it to include the thickness of the conductor that is used to fabricate the ground plane and the patch.

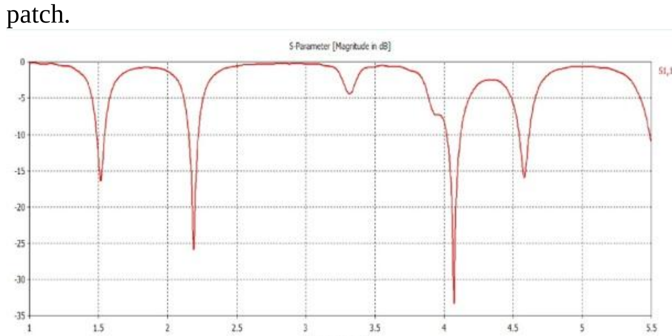

Fig. 7. The return losses using CST Microwave Studio.

However, the in-house programming is more flexible than industrial software. Use of in-house program enables us to avoid calculating unwanted parameters so that the speed of the program can be increased significantly. In addition, additional parameters can be added to the in-house program easily to improve the performance of the program.

V. Conclusion

With the introduction of new devices, specifically in the wireless telecommunication areas that integrates components operating at different frequency bands, the development of a single antenna that can generate all such frequencies is a priority for many researchers. The use of one antenna instead of three in such devices saves resources, time, and cost effectiveness. Dual and three band antennas have been developed in recent years, but most of them are designed for specific applications and use double layer, multi feed, or complex design to obtain multi-band antenna that are used for these applications.

This work proposes and analyzes a patch antenna that can operate at four frequency bands in the same polarization plane and has applications in the DAB, UMTS and two WiMax bands. The proposed design of a U-shaped slot and a pair of bent slots embedded in the middle of the patch surface is easy to fabricate, and uses a thin substrate to overcome the problem of large size encountered in the stacked designs. The development and analysis through an in-house code provides greater flexibility in defining the physics of the radiation mechanism which may not be possible through a commercial code.

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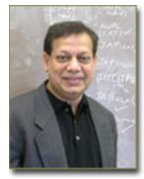
Biographies

Falih M. Alnahwi was born in Iraq on Jan.9, 1983. He is a PHD candidate at electrical and computer engineering/University of Missouri-Columbia in the United States. He received a B.Sc. in electrical engineering and M.Sc in communications engineering from University of Basra in Iraq. His field of interest is antennas and wireless propagations especially the multiband, broadband, and Ultrawide band antennas.



Naz E. Islam (M'96–SM'04) received the Ph.D. degree in engineering physics from the Department of Nuclear Engineering and Engineering Physics (NEER), Rensselaer Polytechnic Institute, Troy, NY, in 1992. His Ph.D. dissertation was the study of the effects of space and nuclear radiation on circuits and electronics. Following his postdoctoral work at NEER, he was a National Research Council Fellow with the Air Force Research Laboratory, Kirtland Air Force Base, Albuquerque, NM. In July 1997, he was with the Electrical and Computer Engineering Department, University of New Mexico, Albuquerque, as a Research Associate Professor. Since 2003, he has been a Faculty Member with the Department of Electrical and Computer Engineering, University of Missouri, Columbia, as a LaPierre Professor. He has a number of research papers to his credit and has also contributed articles to the book entitled Ultra-Wideband Short-Pulse Electromagnetics (Kluwer, 2007). His research interests include the physics and technology of energetic charged particle's interactions with semiconductor devices, dose rate and total dose effects, study of photonic devices used in the generation of high-power microwaves, and semiconductor-device simulation studies.