

Novel Microstrip-Monopole-Integrated Ultra-Wideband Antenna For Mobile UWB Devices

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Abstract: A small ultra-wideband antenna for mobile UWB devices has been developed theoretically and experimentally. The broadband operation of the antenna is achieved by integrating a single square-microstrip-patch with a monopole and by introducing a cylindrical-cap-loaded probe-feed and three tiny shorting-pins. This microstrip-monopole-integrated antenna is electrically easy to be integrated into printed circuit boards or plastic cases of the UWB devices, and also mechanically rigid to facilitate the reduction of the overall dimensions of the UWB devices. Sensitive to both vertically and horizontally polarised electromagnetic waves, it features a fractional bandwidth of around 1.5 with the centre frequency of 6.1GHz, which will most likely satisfy the UWB frequency band requirements as proposed by the latest FCC Part15 specifications. The planar dimensions of the antenna are less than 4cm by 4cm. The details of its design, analyses, and performance characteristics are presented and discussed.

Keywords: Ultra-wideband, UWB antenna, microstrip antenna, and wireless communications.

I. INTRODUCTION

From cellular handsets and wireless telephones to wireless Internet and Intranet access to networked appliances and peripherals, there is increasingly an essential reliance on wireless communications to provide or enhance operation functionality for both industrial products and business services [1]. The enormity of the opportunities presented by the current explosion of wireless applications, such as the third-generation (3G) and ultra-wideband (UWB) technologies, is accompanied by compatible design and manufacturing challenges. One such example is the antenna design and integration in terms of its size miniaturisation, broadband or ultra-wideband operation, and radiation pattern control. Particularly, as communications devices become smaller and more compact, owing to greater integration and functionality of electronics and smaller printed circuit board (PCB) configuration, the antenna becomes a

significantly larger part of the overall package volume. Finding space for the antenna without compromising its performance characteristics is increasingly demanding.

The UWB technology was referred as base-band, carrier-free, or impulse technology during its earliest research work in 1960s. It had also been classified by the US military for more than three decades. The term of "ultra-wideband" was not applied until year 1989 by US Department of Defence [2]. It has been creating excitement in the wireless segment since then. Part of the reasons why UWB is so appealing is its inherent high precision (say sub-centimetre ranging), high data rate (much faster than 802.11a-based 54Mbps WLANs), multi-path tolerance, least interference from or to other services, and low cost, to name a few.

The basic concept of driving the UWB technology is to develop, transmit and receive extremely short duration pulses of electromagnetic energy (typically a few tens of picoseconds to a few nanoseconds in duration) that, in the frequency-domain, transform to very wide bandwidth (spanning over several Gigahertz of frequency spectra) [3]. With suitable engineering design, the resultant energy density (power per unit Hertz of bandwidth) is very low, due to which the UWB signals cause minimum interference if operated in the frequency spectra already occupied by existing radio or communications services, except potential interference to global positioning systems (GPS). On the other hand, by dividing transmitted information into tiny pulses instead of continuous sine waves, the UWB transmission becomes less vulnerable to either intentional or unintentional interruption.

This paper is to investigate the possibility of developing a small and compact wideband antenna suitable for mobile UWB devices or terminals, by properly integrating different antenna types. One critical requirement for the UWB antenna is to achieve several Gigahertz of frequency range with a specified centre frequency in the order of Gigahertz.

II. UWB FREQUENCY SPECTRA

After more than a decade of debate and over 900 documents filed in the docket on UWB, the Federal Communications Commission (FCC) of USA acted to approve a new set of rules to permit the commercial operation of the UWB techniques and devices on Feb.14, 2002. The documentation of the First Report and Order (R&O) was released to the public on Apr.22, 2002 [4]. The new rules for unlicensed UWB operation will allow the introduction of imaging, tracking, vehicular radars, communications and measurement systems, etc. It is anticipated that more and more UWB products will be approved and appear on the market to address various applications in the near future.

As proposed by the latest FCC Part 15 specifications for UWB devices (Subpart F: 15.501-15.525), the UWB bandwidth is defined as the frequency band bounded by the points that are -10dB below the highest radiated emission, as based on the complete transmission system including the UWB antenna. It is designated by a fractional bandwidth equalling $2(f_H - f_L)/(f_H + f_L)$, where f_H and f_L are the upper and lower boundary frequencies, respectively [4]. The centre frequency of the UWB antenna is defined as the average of the upper and lower -10dB points, i.e. $(f_H + f_L)/2$ [5].

Under the new rules, UWB communications measurement and medical systems will be restricted to intentional operation in the frequency spectra 3.1GHz-10.6GHz (with the -10dB bandwidth), surveillance systems restricted in the frequency spectra 1.99GHz-10.6GHz, ground penetrating radars and wall imaging systems restricted in the frequency spectra 3.1GHz-10.6GHz or below 960MHz, and automotive radar systems restricted in the frequency spectra above 24.075GHz [6]. Initial communications applications are further restricted to tethered operations indoor, or to lower out-of-band emissions, outdoor handheld uses. Although a UWB antenna was defined by FCC as an antenna with a fractional bandwidth greater than or equal to 0.2 or with a UWB bandwidth greater than or equal to 0.5GHz, it will be beneficial to take the typically widest frequency spectra of most UWB devices, i.e. 1.99GHz-10.6GHz, into consideration. In this scenario, the UWB antenna will demand the fractional bandwidth of 1.37 $(= 2 \times (10.6 - 1.99)/(10.6 + 1.99))$ with its centre frequency at 6.30GHz $(= (10.6 + 1.99)/2)$. Alternatively, the frequency spectra of 8.61GHz $(= 10.6 - 1.99)$ will be bounded by the upper and lower -10dB emission points.

III. THEORY AND METHODOLOGY

The antennas in wireless communications devices can typically be divided into two categories according to their appearances, namely external antennas and internal antennas. The external antennas consist of the conventional whip (e.g. $\lambda/4$, $3\lambda/8$, $\lambda/2$ end-fed and $\lambda/2$ centre-fed), helix (e.g. $\lambda/4$ and "stubby"), and whip-helix antennas (e.g. $\lambda/4$ retractable two-in-one, $3\lambda/8$ retractable two-in-one, and retractable-base helix), which are mounted outside the communications devices; while the internal antennas are those that can be installed inside the devices, such as microstrip patch antennas (MPAs) and loop antennas. MPAs are getting more and more important in the wireless applications where external antennas are undesirable, due to their small size, light weight, low profile, mechanical robustness, frequency agility, broadside patterns, low cost and conformance. They offer several advantages compared to conventional external antennas in some characteristics, such as mechanically robust, less easily broken off, less sensitive to the terminal geometry, appearance aesthetic, cost-saving, power-saving, and size miniaturising. To satisfy different practical applications, they are critically designed for single-frequency, dual-frequency (dual-band), multi-frequency and even wideband operation, which leads to a tougher experience.

Bandwidth enhancement, size miniaturisation, gain and radiation pattern optimisation are essential considerations for designing high-performance compact MPAs in practical applications. There have been dozens of designs and variations proposed for bandwidth improvement of individual patch elements. It is possible to categorise them into three canonical approaches: a) Impedance matching, b) Multiple resonance, and c) Effective permittivity reduction. The feeding or coupling mechanisms for MPAs can be classified as co-planar coupling (like gap-coupling and stripline-direct-feed), coaxial feed, and electromagnetic feed (like aperture-feed and pin-connector-feed) [7]-[9]. They are not just for coupling either full or partial energy to individual radiating elements, but also for the controlled distribution of the transferred electromagnetic energy to a linear or planar element arrays. Impedance matching is also essential to maximise antenna performance between the feed and the antenna.

To satisfy severe constraints on physical configuration of the wireless devices, miniaturisation or compactness is needed for MPAs [10]-[12]. It has frequently been accomplished by loading, which takes various

techniques, i.e., a) Use of substrates with high permittivity, b) Use of circuiting posts or shorting-pins, c) Modification of basic patch shapes, and d) Combination of the above.

To develop a UWB antenna operating in the frequency spectra 1.99GHz-10.6GHz by simply introducing the microstrip patch type, it is more than challenging to date. A new antenna design is needed to serve this purpose. In this paper, the methodology realising the desired broadband operation for the UWB devices is to obtain multiple resonances at the lower spectrum end by applying a specifically loaded square microstrip patch element, and expand the bandwidth at the upper spectrum end by introducing an additional single monopole element. Both the microstrip patch and monopole elements are properly integrated and commonly probed to optimise the impedance matching over the whole frequency spectra. Furthermore, a low-permittivity Styrofoam substrate (relative permittivity $\epsilon_r \approx 1.07$) and three shorting-posts are implemented to both enhance the operation bandwidth and reduce the overall dimensions of the microstrip patch element. In this design, a commercial-off-the-shelf software package Ansoft Ensemble (Ver. 8.0), which is theoretically based on method of moments (MoM), is implemented to predict the impedance behaviour and radiation characteristics of the proposed UWB antenna.

IV. RESULTS AND DISCUSSIONS

The proposed UWB antenna configuration is shown in Fig. 1. It is composed of a square copper patch, three shorting-posts, part of Styrofoam substrate, a monopole, a copper ground plane and a SMA coaxial probe-feed.

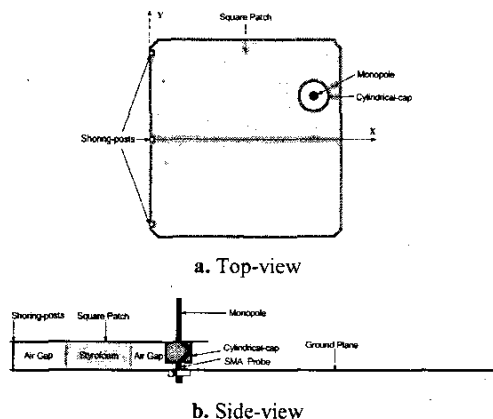


Fig. 1. Configuration of the proposed UWB antenna

The shorting-posts are symmetrically placed at one edge of the square patch, with the central one fixed in the edge centre. Between the patch and the ground plane are part of Styrofoam substrate and air gaps. The monopole is vertically integrated into the square patch at the feeding location. The coaxial feeding cable is placed far away from the shorted edge on the patch. The inner conductor, i.e. probe, of the coaxial cable is connected to the square patch through a small opening in the ground plane. The outer conductor of the coaxial cable is directly connected to the ground plane. A cylindrical-cap with a larger diameter than that of the probe is inserted between the probe and square patch for the impedance matching optimisation. The planar dimensions of the antenna are less than 40mm×40mm, while the minimum and maximum heights of the antenna are 6.5mm and 15.5mm, respectively. The antenna is installed at one end of the ground plane, whose dimensions are about 40mm×100mm.

Fig. 2 presents the simulated and measured results of the return loss or forward reflection for the proposed UWB antenna. Four significant resonant frequencies are observed, namely 2.9GHz, 3.6GHz, 4.6GHz, and 8.0GHz. The first three resonances are mainly related to the shorted square patch, while the highest one is resulted from the monopole element. Due to the loading effect from the square patch, the resonant wavelength of the monopole shifts slightly from its quarter-wavelength. The useable frequency spectra with -10dB emission points are from 1.5GHz to 10.7GHz. This stands for a fractional bandwidth of about 1.5, which covers the widest UWB frequency band requirement of 1.99GHz-10.6GHz, as proposed by the latest FCC Part15 specifications. The center frequency of the proposed antenna is located at 6.1GHz. It should be noted that this resultant frequency bandwidth also satisfies the frequency bands of other wireless applications, such as PCS, GSM1800/1900, Bluetooth, WLAN, and 3G IMT-2000, etc.

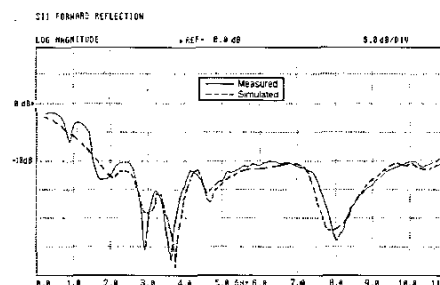


Fig. 2. Return loss of the proposed UWB antenna

The measured maximum input gain of the proposed antenna within the frequency spectrum of interest is shown in Fig. 3. The peak antenna gain is 4.3dBi, and the gain variations less than 2.1dBi are observed. The overall gains are greater than that of an ideal half-wave dipole, which is typically 2.15dBi. The typical far-field radiation patterns at the centre frequency of 6.1GHz, in both the E-plane ($\Phi = 0^\circ$) and H-plane ($\Phi = 90^\circ$), are presented in Fig. 4. Both E_θ and E_ϕ have semi-omnidirectional patterns in the E- and H-planes. A mild null in the E-plane of E_ϕ is noted, which may be related to the unsymmetrical structure of this UWB antenna. It should also be noted that, exhibiting a low specific absorption ratio (SAR) value and good performance even beside the human body, this antenna could be easily shielded to reduce possible interaction with the human body.

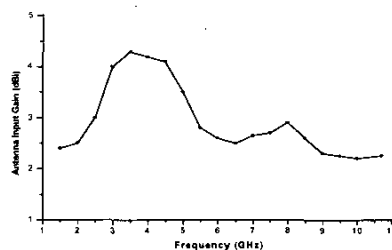


Fig. 3. Measured input gain of the proposed antenna

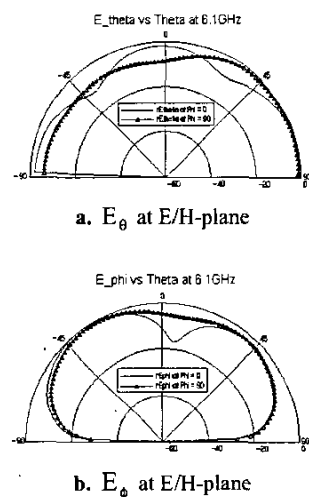


Fig. 4. Radiation patterns of the proposed UWB antenna at its center frequency

V. CONCLUSIONS

A small and compact microstrip-monopole-integrated antenna suitable for the UWB devices has been presented and analyzed. By combining two different antenna types and introducing a common probe-feed, the antenna features the fractional bandwidth of 1.5 with its centre frequency at 6.1GHz and exhibits the planar dimensions less than 40mm×40mm. It satisfies the UWB frequency band requirements as proposed by the latest FCC Part15 specifications and can be easily integrated into a conventional PCB.

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