

LOW-PROFILE EMBEDDED ULTRA-WIDEBAND ANTENNAS FOR PORTABLE DEVICES

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ABSTRACT

This paper addresses the need for low-profile, ultra-wideband (UWB) antenna designs, which are required for laptop and other portable devices. By slotting the vertical ground plane close to the radiator of the antenna and modifying the feeding structure, a low-profile antenna is capable of providing well-matched bandwidth and accepted gain over UWB band. The design is validated by measurement in terms of impedance bandwidth, radiation patterns and gain.

1. INTRODUCTION

Recently, the wireless systems based on ultra-wideband (UWB) technology have been proposed to increase data rate for indoor, short-range, low-power wireless communications or localization systems as a next generation wireless communication technology. The UWB wireless systems may transmit and receive signals with more than 100% bandwidth (3.1GHz – 10.6 GHz) and very low emission limits of EIRP (equivalent isotropic radiated power) levels <-41.3 dBm/MHz. The requirement for UWB antennas should include high efficiency, broad impedance matching, horizontally omni-directional radiation, and small size in order to integrate UWB wireless systems into portable devices such as laptop computers.

Furthermore, the latest trend is to build these wireless systems into portable devices through various interfaces. For embedded solutions the antennas are required to reside with the devices such as the laptop computer itself, underneath the plastic, composite or metals covers. This maintains the computer physical outline without any affix, and also reduces the possibility of accidental breakage. However, one has to suffer from the degraded performance of embedded antennas. The embedded

antennas usually do not perform as well as external ones due to greatly reduced space required for optimal designs, being partially hidden within semi-conducting or conducting materials and the proximity effect of metallic cover and/or LCD (Liquid Crystal Display) panel. To achieve acceptable performance of embedded antennas, the commonly used method is to keep the antenna away from any metal component of a laptop computer. Depending on the design of laptop computers and type of antennas, the distance between the antenna and metal components should be as large as possible.

In existing UWB solutions, the antennas are installed outside of the devices for RF links or testing. Typically, broadband antenna designs require even more space than relatively narrow band or multi-band designs such as used in WLAN. This additional space constraint becomes a bottleneck in embedded UWB antenna design. Usually, the available thickness is less than 2 mm, and the height is less than 10 mm for the antenna part, depending upon the types of laptop covers. The planar antennas are extensively investigated and used [1-4]. However, the antennas are too bulky to be embedded into a portable device, like a laptop computer.

To reduce the height of an antenna, the inverted-L or F antennas are often employed. However, it is difficult to use the inverted-L or F antennas to cover the whole UWB bandwidth due to their narrowband features although they can achieve multi-band performance with additional resonators. Recently, with development of periodic-structure techniques, such as frequency selective surface (FSS), electromagnetic band-gap (EBG), the concept of artificial magnetic conductor (AMC) has been proposed. The AMC can be produced by printing metallic arrays on grounded dielectric slabs so that it fully reflects the incident waves with zero reflection phase. However, the reflection characteristics

of these surfaces mimic a magnetic conductor over a set of discrete frequencies with inherent narrow bandwidth. The bandwidth is determined by the geometrical configurations, dielectric constant, and thickness. The tunable technique has been used to broaden the bandwidth of AMCs [5-7]. The other drawback is the size of the AMC because of its periodic structure although some approaches have been proposed for the reduction in the size [8-10]. The thickness of AMC related antennas is an issue for laptop applications as well.

This paper proposes a novel concept to aim at low-profile broadband antennas for UWB applications. The performance of the proposed UWB antenna is achieved by slotting the vertical ground plane under the radiating element of the antenna to reduce the required height for the UWB band and introducing an additional feed point in the horizontal direction with an extended vertical ground plane. The notches on the vertical ground plane are normal to radiating element of the antenna. The additional feed point horizontally introduced is to decrease the antenna impedance to that of the RF cable to achieve an impedance match. Its performance in the UWB band features acceptable gain, omni-directional radiation in horizontal planes within $\pm 30^\circ$ elevation angles with a single feed point and fits within the small space available in most laptop computers. It also covers the 5 GHz WLAN band well.

2. ANTENNA DESIGN AND RESULTS

Figure 1 shows the proposed UWB antenna. Basically it comprises a ground plane with vertical and horizontal parts, a radiator fed by an RF cable, and a piece of a thin dielectric slab PCB supporting the radiator.

Figure 2 shows the detailed geometry of the proposed antenna. The radiator etched on the side of a rectangular dielectric slab with dimensions of $H \times W$. The dimension W mainly controls the lower edge frequency f_{lower} of the band. The dimension H to some degree also affects f_{lower} . The larger the W or H is, the lower the lower edge frequency f_{lower} is. The radiator is fed by two strips of dimensions of $L1 \times S1$ and $L2 \times S2$ at horizontal and vertical bottoms of radiator at the distance of $d1$ and $d2$. The location of the feed point also affects the impedance match. The strips are excited by a coaxial RF cable at the junction. Due to the wide bottom of the rectangular planar radiator, a broadband impedance transformer is

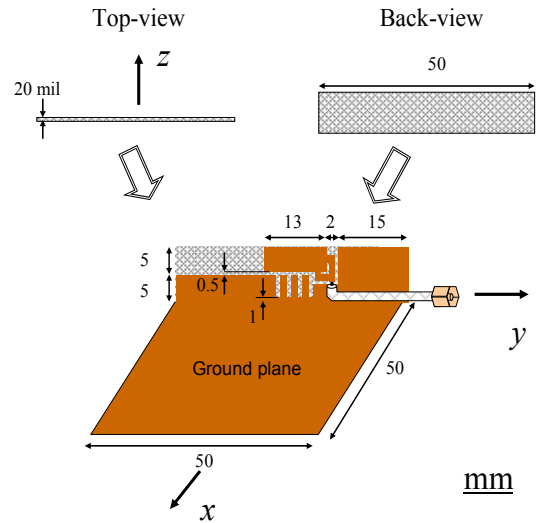


Figure 1 Geometry of the proposed antenna

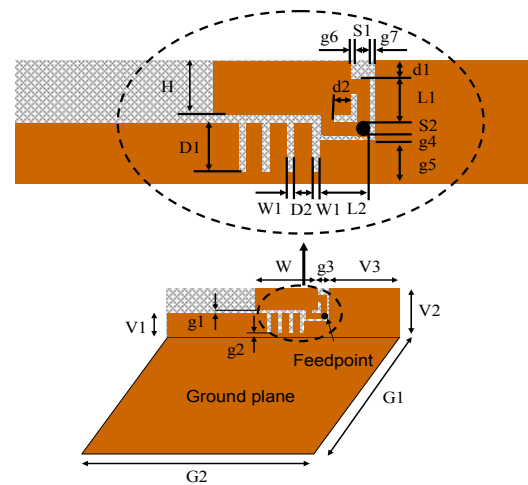


Figure 2 Detailed geometry of the proposed antenna

created. The feed strips are between the radiator and ground plane with the gaps of $g4$, $g6$, and $g7$. The smaller gaps are good for impedance matching. To meet the low profile requirement for laptop computer applications, the height H of the antenna must be reduced. This results in the higher f_{lower} than the original. To maintain the same f_{lower} as the original, the vertical portion of ground plane is notched. Exactly speaking, the vertical portion right under the radiator is notched by the slots of dimensions of $D1 \times W1$ with uniform separation

of D2. The width W1 of the notch is determined by the higher edge frequency, and should be much smaller than the higher edge operating wavelength within the band. The D1 greatly affects the radiation efficiency because the notches change the current distribution on the vertical ground plane, which is out-of-phase against the currents on the radiator as shown in Figure 3 of the simulation results. The notches cause the out-of-phase currents on radiator and vertical ground plane to be a greater distance ($g1+D1$) away. The larger the distance ($g1+D1$) is, the smaller the cancellation of the radiation from the two currents is, which improves the radiation efficiency. To avoid the strong horizontal out-of-phase currents on the ground plane, the separation D2 should be smaller than the operating wavelength of the higher edge frequency. So, the introduction of the notches is the key to lower the height of the antenna. In principle, the selection of dimensions of D1, D2, and W1 should ensure that no out-of-phase horizontal induced current exists in the notches region.

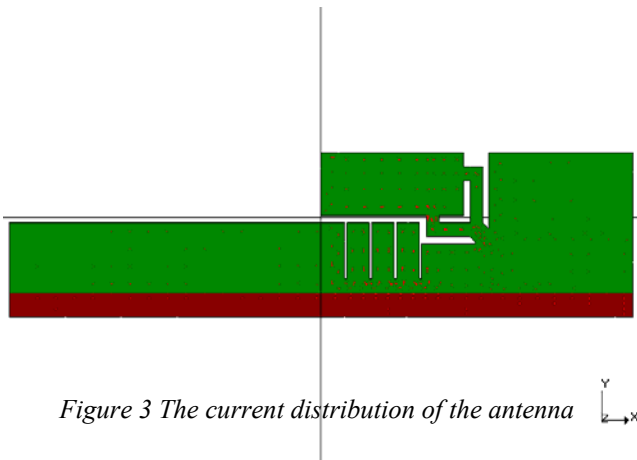


Figure 3 The current distribution of the antenna

There are two vertical ground plane regions. The first with the notches has the dimensions of V1. When antennas are installed in the display, this part is below the surface of the LCD (liquid crystal display) panel. The lossy LCD panel blocks the radiation from this part and lowers the radiation efficiency greatly. The second with the dimensions of V2×V3 significantly affects the impedance match. It should be close to the vertical bottom of the radiator. The horizontal portion is necessary for alleviating the effect of installation environment (metal cover and display) on the impedance matching. This part should be electrically connected to the cover or/and LCD panel. The RF cable should be

reliably connected to the ground plane but orientation is not a concern.

Figure 3 shows the electric current distribution simulated by IE3D on the ground plane and radiator. From the current distribution, it is seen that the currents right under the radiator (horizontal portion) where the currents are horizontally polarized, is vertically polarized due to the notches. The out-of-phase horizontal current concentrates on the bottom of the notched vertical ground plane. This reduces the loss due to induced currents on the vertical ground plane and lossy metal cover rim.

As an example, though the design may be implemented in a number of other materials, the antenna was etched onto a 10 mm ×50 mm ×20 mil 25N Arlon PCB slab with dielectric constant $\epsilon_r=3.38$ and 0.0025 loss tangent at 10 GHz. In this implementation the ground plane surface is in good contact with the metal cover and RF cable outer conductor. The antenna is installed at the top of the cover as shown in Figure 4. The bent rim of the cover has a height of 12 mm (inside) and a slant of $\sim 10^\circ$. A 12 cm long RF feed cable is installed along the rim of the display cover. The minimum distance between the rim of the LCD panel and the bottom of the antenna is about 3 mm. The thickness of the LCD panel is about 5 mm. The top of the antenna is 2 mm below the edge of the cover rim.

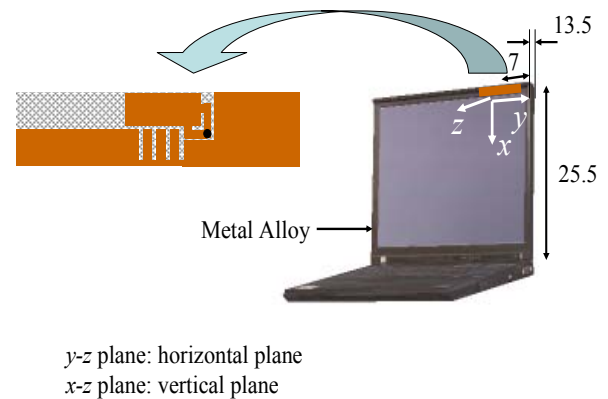


Figure 4 The location of the antenna implementation in a ThinkPad laptop

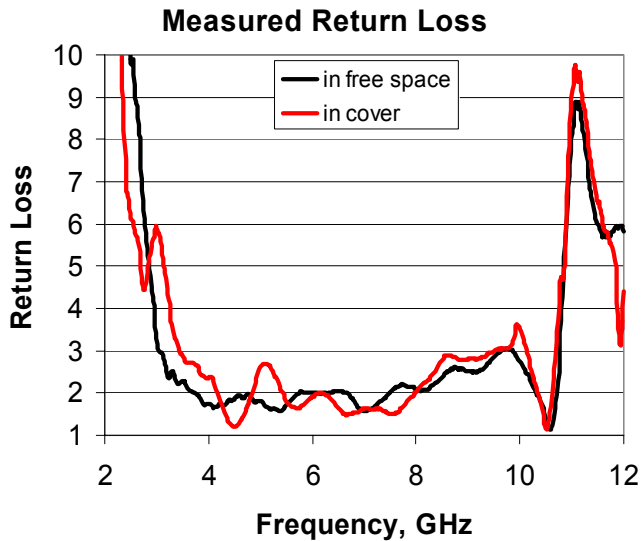


Figure 5 Comparison of measured SWR for the antenna implemented in free space and in a ThinkPad laptop

Figure 5 compares the measured SWR of the antenna in free space and in the display of a laptop across 2 GHz-12 GHz. In the free space, the antenna has enough 3:1 SWR bandwidth to cover the UWB band (3.1 GHz -10.6 GHz). However, the installation environment causes poor impedance matching at the lower edge frequencies so the bandwidth decreases, although the bandwidth nearly covers the whole UWB band.

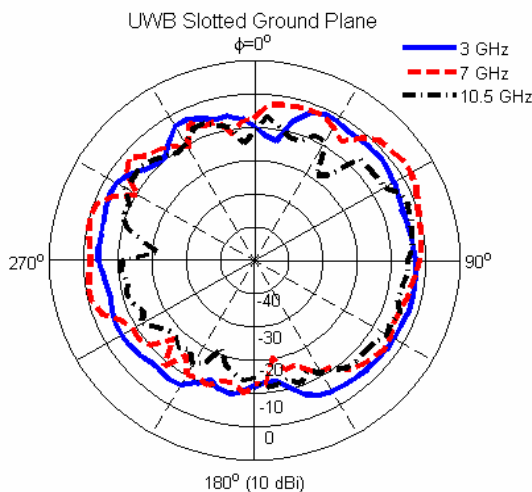


Figure 6 Measured radiation patterns of the antenna installed in the display of the laptop

Figure 6 shows the measured radiation patterns at different frequencies at 3.0 GHz, 7.0 GHz and 10.5 GHz in the horizontal planes, respectively. The radiation patterns do not change too much across the bands. The average and maximum gains at -10, -5, 0, 5, and 10 degree elevation angles are tabulated in Table 1. Due to the measurement system setup, -10 deg refers to 10 deg above the horizontal plane. The laptop effects on the radiation patterns are obvious.

3. CONCLUSION

A new low-profile embeddable UWB antenna has been proposed for UWB applications. By cutting slots from the ground plane right under the radiator the height of the antenna has been reduced. By using double feed points the improved impedance matching has been realized. With the use of a vertical ground plane close to the horizontal bottom of the radiator the impedance matching has maintained stable, i.e. less affected by the environment where the antenna is installed.

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TABLE 1: MEASURED AVERAGE AND PEAK GAIN

Average Gain in dBi																
$\theta, ^\circ$	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
-	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz
10	5.57	4.82	3.02	3.26	3.39	3.02	3.06	3.41	3.37	3.27	2.48	3.19	6.33	4.89	10.38	7.48
-5	4.46	5.24	2.51	2.89	3.86	2.74	2.81	3.50	3.46	3.24	3.05	3.82	6.52	5.45	10.20	7.97
0	4.87	5.29	3.92	3.14	3.76	3.05	3.30	3.84	3.61	3.20	3.48	3.89	6.82	5.22	10.17	8.46
5	5.52	4.94	3.10	3.39	3.91	3.26	3.45	4.08	3.80	3.44	3.61	4.04	7.40	5.46	10.31	8.85
10	4.67	5.29	3.34	3.02	4.05	3.31	3.53	4.15	4.05	3.96	3.48	4.86	7.11	5.94	-9.50	9.03
Peak Gain in dBi																
$\theta, ^\circ$	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
-	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz	GHz
10	1.71	0.40	1.41	1.70	1.91	2.68	3.77	3.15	2.71	0.68	2.95	2.11	1.00	0.01	-4.08	1.04
-5	0.75	1.15	2.58	2.38	0.60	3.90	3.45	2.88	1.95	1.21	2.55	1.72	1.35	0.19	-4.72	1.98
0	1.51	0.89	1.70	2.31	2.05	3.27	3.78	3.18	2.68	1.71	2.22	1.91	1.31	0.30	-4.65	2.18
5	2.15	1.59	2.45	2.12	0.74	3.74	3.40	2.35	2.62	2.25	2.62	2.19	2.32	0.25	-4.72	3.80
10	0.36	0.05	3.03	2.98	1.79	2.93	3.64	2.41	2.77	1.84	3.74	0.55	2.11	0.79	-2.67	2.67