Comparison of Indoor Wireless Signal Propagation Between Ground Plane Booster and Omni-Directional Patch Antenna

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Abstract. “Antenna-less” ground plane boosters maximize the contribution of wireless device ground planes to their radiating systems [1]. They have the potential to simplify wireless/mobile application design as replacements to customized, dedicated radiating antennas. Their multi-band capability and standardized low packaging profile lend to seamless printed circuit board (PCB) integration. The miniaturized, surface mount (SMD), commercial off-the-shelf (COTS) components may be a solution for the challenges of increasing frequency bands, reducing antenna space, improving wireless system performance, multiple and evolving wireless communication standards, and design and manufacturing efficiency. As wireless Internet of Things (IOT) applications and 5G mobile technology demand and enable ubiquitous, higher speed, and more reliable mobile communications, antenna system design becomes an even more challenging and critical engineering task. This study presents a comparison of RF signal strength received by a conventional, omni-directional patch antenna and an “antenna-less” ground plane booster inside of a dense, suburban building.

1. Introduction

This paper compares the wireless signal propagation of a ground plane booster and omni-directional patch antenna in a college campus-building environment. Wireless signal penetration is evaluated inside of a six-floor University building representing a medium dense radio frequency (RF) environment.

Antenna design solutions for wireless devices have historically been customized, complex, and costly. Microwave engineers have been focused on controlling radio waves through a variety of active and passive devices, such as amplifiers, oscillators, active tuners, etc. to accommodate increasing numbers of frequency bands. Antenna engineers have been focused on optimizing radio waves through complex geometries to accommodate shrinking antenna space [1].

Antenna-less technology looks to reduce and simplify the mechanical engineering related to antenna geometry from the antenna design process and replace it with the simpler task of designing a matching network for wireless devices with typically between three and seven passive components that can tailor nearly any frequency response between 698 MHz and 2690 MHz.

2. Background

2.1. Antennas

Antennas are transducers that convert electromagnetic signals propagated through free space at the
speed of light to radio frequency (RF) alternating current. The role they fulfill is required in any wireless system, and they have traditionally been the principal radiating element used in wireless systems.

Antennas for most contemporary wireless devices are structurally complex, with irregular metal patches, and finite dielectric surfaces [2]. Their characteristics can also be affected by the geometries of mounting structures. The increasing demand for versatile and compact wireless devices has uncovered the need to reduce the space allocated for antennas. Physical space limitations pose a performance challenge for wireless device antenna designers, who typically rely heavily on geometric solutions to design antennas systems capable of multi-band operation. Conventional techniques to enable multi-band operation often involve shaping the geometry of different types of antennas [3], which makes designs more complex and difficult to integrate.

Wireless device antenna designs are usually complex and device-specific. Conventional wireless devices typically contain resonant, multi-band antenna devices able to operate in several frequency ranges to meet their need for a radiating system. Internal antennas, such as patch and monopole antennas, are the most common designs for wireless handsets [4]. Overall, antenna design engineers balance the competing mechanical and electromagnetic priorities of matching shape and size with the inside of the device they are enclosed in and delivering the required radiation performance.

2.2. “Antenna-less” Ground Plane Boosters

Virtually every wireless device employs a metallic ground plane to provide a zero-voltage reference to device electronics and buffer electromagnetic interference [4]. Ground planes have been widely used as important complementary factors in the radiation process [1] for some time, but not as primary radiators until recently. Electromagnetic analysis of the ground plane began to be recognized as a worthwhile subject on its own in the early 2000s, when several studies showed that proper excitation of an efficient mode of the ground plane as the principal means to obtain good radiation is viable [6]. Ground plane radiation is gaining significance and relevance due to several studies that demonstrate its strong contribution to radiation properties. Recent antenna research and design efforts explore ways to exploit ground plane radiation potential.

“Antenna-less” ground plane boosters are non-resonant, reactive devices that excite an efficient mode of the ground plane [3]. The booster balances the ground plane so that full RF current is strategically injected onto the conducting layer, which supports multiple radiating characteristic modes and enables multiple wavelengths to be radiated from the ground layer simultaneously. In this way, the standard SMD antenna booster causes the device ground plane to become the sole radiating element of the system [1], eliminating the need for a customized antenna design because the device is “antenna-less.”

As shown in Figure 1, a cube-shaped 5 mm × 5mm antenna booster is typically 1/20 to 1/30 of the longest operating wavelength and assimilated into a SMD component.

![Figure 1. Fractus Antenna CUBE mXTEND™ Antenna Booster component: (a) top and (b) bottom](image)
Antenna-less ground plane boosters can reduce device volume by a factor of up to 20. Using impedance matching techniques to design an appropriate matching network, device frequency response is managed through the matching network instead of antenna geometry and structure [1], which is a less expensive, more predictable, simple, and faster process.

3. Methodology

3.1. Devices Under Test

3.2. Fractus Antennas CUBE mXTEND™ (FR01-S4-250) Antenna Booster

3.2.1. Mounted on evaluation board
3.2.2. 824 MHz to 960 MHz and 1710 MHz to 2690 MHz operating frequency bands
3.2.3. Coplanar grounded transmission line integrated into evaluation board
3.2.4. Pulse SPDA24700/2700 swivel blade patch antenna

4. Measurement Instruments

4.1. Agilent Technologies E5071C ENA Vector Network Analyzer
4.2. Agilent Technologies E4440A PSA Spectrum Analyzer
4.3. Agilent Technologies N9310A RF Signal Generator

5. Test Environment

As shown in Fig. 2, McNair Hall is a six-floor concrete-block-brick type building, 50% density of double-pane layered glass window with aluminum frame. Outside wall is 16 inches of masonry (concrete layer: 8 in., isolation layer: 2 in., air layer: 2 in., brick layer: 4 in). Office areas are normally isolated metal framing with 3.5” of gypsum board. The wall in corridors is made of concrete with a thickness of 5 inches. “Previous researchers have provided a rule of thumb for the average signal losses among the common building materials at frequency 900 MHz. However, at 2100 MHz, the average material losses are: Concrete Wall (18 dB), Brick 3.5” (8 dB), Brick 7” (12 dB), Double Pane Glass (9 dB) and Dry Wall (4 dB) [8].”

Figure 2. Antenna test environment at Ronald E. McNair Hall - North Carolina Agricultural and Technical State University

5.1. Test Set-up

The booster antenna and standard patch antenna were directly connected to the Vector Network Analyzer (VNA) to measure the antenna input impedance while the spectrum analyzer was employed to measure over-the-air signal strength in Decibels (dBm) (see Fig. 3 below).
Figure 3. Test set-up for comparing antenna performance

The patch antenna length including radome originally measured 278 mm. In the interest of decreasing the height difference between the patch antenna and the antenna booster, the antenna’s total height was reduced to approximately 140 mm to approximate a cell phone form factor and comparable to the CUBE mXTEND™. See Fig. 4 below.

Figure 4. Patch antenna to compare with CUBE mXTEND™

The CUBE mXTEND™ Antenna Booster evaluation board is shown below in Fig. 5 where an integrated transmission line connects to the spectrum analyzer input port.

Figure 5. Patch antenna to compare with CUBE mXTEND™
6. Appendix A

**Figure A1:** Comparison between patch antenna and antenna booster impedance versus frequency at 850 MHz

**Figure A2:** Comparison between patch antenna and antenna booster impedance versus frequency at 2100 MHz
**Figure A3.** Comparison between the signal strength of the antenna and antenna booster vs. frequency at McNair Hall basement hallway at 850 MHz

**Figure A4:** Comparison between the signal strength of the antenna and antenna booster vs. frequency at McNair Hall basement hallway at 2100 MHz

**Figure A5:** Comparison between the signal strength of the patch antenna and antenna booster vs. frequency at McNair Hall basement elevator at 850 MHz
**Figure A6:** Comparison between the signal strength of the antenna and antenna booster vs. frequency at McNair Hall basement elevator at 2100 MHz

**Figure A7:** Plot showing comparison between the signal strength of the antenna and antenna booster vs. frequency in McNair Hall lobby elevator at 850 MHz

**Figure A8:** Plot showing comparison between the signal strength of the antenna and antenna booster vs. frequency in McNair Hall lobby elevator at 2100 MHz
7. References

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