The benefits of 3D printed antennas in connected lighting systems

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Abstract

In recent years connected lighting systems used in enabling intelligent buildings integrate sensors, controls, and wireless technology, namely radios to communicate with one another. In such connected lighting systems, antenna is an important component for enabling reliable data transfer between lighting fixtures and the central control system. The antennas are usually placed inside the light fixture enclosure. In this study, communication signal attenuation due to different obstructions within and outside the light fixture was investigated. Then it shown that signal strength can be improved by placing the antenna outside the fixture enclosure. With 3D printing becoming a promising technology for manufacturing components for solid-state lighting fixtures, the authors of this paper investigated the feasibility of making 3D-printed antennas for connected lighting systems.

1. Introduction

Lighting applications have increasingly utilized LED light fixtures due to their low energy consumption and reduced maintenance requirements. Today, users are looking for additional benefits beyond energy savings that can improve the experience and well-being of occupants and facilitate convenient building maintenance strategies for building managers.[1] In recent years, connected lighting systems that integrate sensor-based control technology with wireless communication technology have become popular [1,2]. As part of such connected systems, antennas are crucial for the effective transfer of data between lighting fixtures and the central control unit employed by the building management system. Connected lighting systems commonly use wireless protocols such as Wi-Fi, ZigBee, and Bluetooth that operate in the frequency range of 2.4 GHz to communicate among their sensors, fixtures, and central control unit.

Uninterrupted connectivity ensures the reliability of the wireless communication system. Antennas commonly used in such light fixtures are usually mounted on the circuit board together with the driver circuit, which is buried inside the fixture within an enclosure surrounding the overall fixture components. Generally, these enclosures are used to conceal from the external environment for architectural reasons. As a result, the wireless module and the antenna are covered by multiple layers of fixture sub-assemblies, and obstructions, which partly absorb or reflect wireless signals and lower the system's reliability.[3] During this study, we investigate the possibility of 3D printing antennas placed on the outside of the fixture as a technique to improve signal strength (Figure 1).

Lately, additive manufacturing, commonly known as 3D printing, of light fixtures has captured the attention of lighting system producers.[4] Researchers and manufacturers have been exploring 3D-printed electronics, including antennas.[5-7] Such technology introduces the possibility of printed antennas on the exterior surface of a light fixture. Therefore, the objective of this study was to conduct an experimental study to investigate the feasibility of 3D-printed antennas and assess their potential to enhance signal strength. A literature search revealed that 3D-printed antennas could be developed by either 3D printing the antenna's dielectric substrate and developing the conductive layer using coatings [5,8,9] or by fabricating

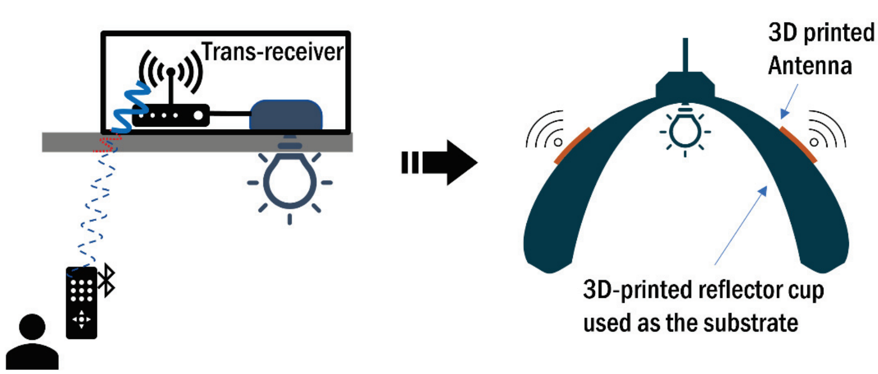

Figure 1. Introducing 3D printed antenna on fixture surfaces

both dielectric and conductive layers using 3D printing processes.[10-12] We initially developed a microstrip patch antenna with 3D-printed substrates with conductive copper foil patches and later used 3D printing to fabricate both the substrate and conductive antenna patch.

To understand signal attenuation caused by different enclosure materials commonly used in light fixtures, we initially conducted a study using a Bluetooth test module. Then, we examined whether the signal strength increases when an antenna is placed outside a fixture as opposed to being buried inside it. The results of our experiment have been used to discuss Bluetooth signal attenuation due to obstructions. As a solution, we investigated the feasibility of 3D-printed antennas and assessed their potential to enhance signal strength.

2. Methodology

2.1 Signal strength attenuation due to different obstruction materials

In this study the effect of obstruction materials on signal strength was investigated. The experiment used a BLE Pioneer baseboard preloaded with a CY8CKIT-142 PSoC 4 BLE module as the peripheral transmitter and a CY5677-CySmart BLE 4.2 USB dongle as the signal receiver. Signal strength values were measured using the receiver, and the results for three conditions were used to estimate attenuation due to two different materials and compared them to the no obstruction condition.

As illustrated in figure 2, the first condition was chosen as the control condition, which measured the signal strength without any obstruction between the BLE antenna module

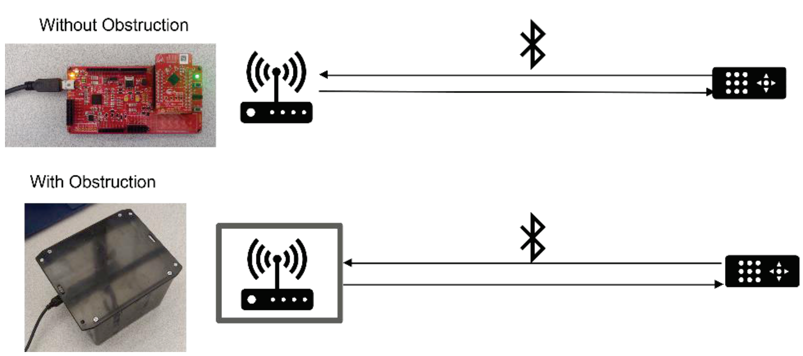

Figure 2. Experimental setup to measure signal attenuation due to different obstructions

(CY8CKIT-142) and the signal receiver. Out of the two obstructive environments, the first condition covered the BLE antenna and circuit with a plastic enclosure. The purpose of the experiment was to determine the attenuation due to commonly used plastic enclosures in lighting fixtures. The second condition tested the signal strength with a metal enclosure box that concealed the BLE antenna and circuit.

The investigation was further extended to determine whether the signal strength increases when an antenna is on the outside of a fixture as opposed to the antenna being inside the fixture. In this experimental setup, a Cypress CY8CKIT-142 PSoC 4 BLE module with an ARM CortexM0 CPU (32bit 48 MHz) was used with a Bluetooth 4.2 transceiver. Experiments were conducted in two scenarios: one with the antenna in the open, and the other with the antenna folded inside the metal box. The metal box was used to simulate a fixture enclosure when the antenna and radio were placed inside the light fixture.

2.2 Designing 3D printed antennas

Next, a 3D-printed antenna module was e printed on the outer surface of the fixture. A literature survey helped identifying the most appropriate antenna type that can be attached to the outer surface of a luminaire. An initial search revealed that the microstrip patch antenna is one of the most promising candidates for the target application and manufacturing method.[5] Past literature showed that 3D-printed substrates with conductive copper patches could be used to develop antennas for different applications. [5,8,9]

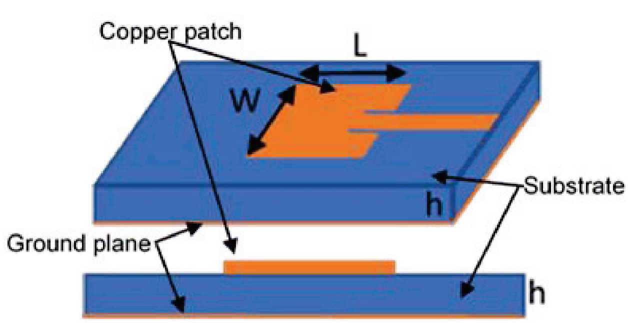

Figure 4. Antenna Schematic diagram

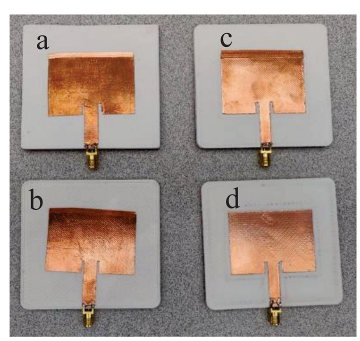

Figure 3. Antennas with 3D printed substrates
Fig. a & b – Substrates without inset
Fig. c & d – Substrates with inset

Based on patch antenna theory,[13] a microstrip patch antenna was designed and optimized using the CST Studio Suite®, a commercial antenna design software. Employing the optimized antenna dimensions given in the figure 3, initially, the antenna was 3D printed on a substrate using the fused deposition modeling (FDM) method with polylactic acid (PLA) polymer material (Figure 4). In this phase, two batches of substrates were printed, one with an inset that houses the metal foil and one without the inset and the foil attached to the top. The copper foil is used to create the conductive patch with optimized dimensions obtained from the simulation.

Then the study was extended to investigate antenna performances with 3D printed conductive antenna patches. To compare different methods for making the antenna assembly, the following four designs were used.

i. FR4 substrate with copper foil conductive antenna patch. (Figure 5a)

ii. FR4 substrate with 3D-printed conductive antenna patch. (Figure 5b)

iii. 3D-printed substrate with copper foil conductive antenna patch. (Figure 6a)

iv. 3D-printed substrate with 3D-printed conductive antenna patch. (Figure 6b)

To operate within the 2.4GHz frequency range, all four antenna designs were optimized based on substrate characteristics. Antennas with 3D printed substrates were printed using the using FDM method with PLA material. Two antennas involved in 3D printing conductive antenna patches printed using an electronic trace printer, Voltera V-One, with Perky Pegasus conductive ink. After printing the antennas onto the substrates, SMA connectors were attached to power up antennas to test signal strength with a NanoVna V2 Vector Network Analyzer (VNA).

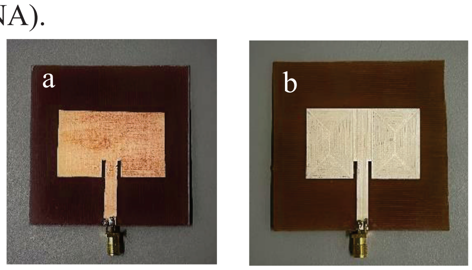

Figure 5. Antennas with FR4 substrates
Fig. 5a copper foil antenna patch
Fig. 5b 3D printed antenna patch

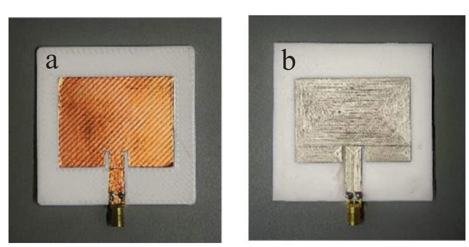

Figure 6. Antennas with 3D printed substrates
Fig. 6a copper foil antenna patch
Fig. 6b 3D printed antenna patch

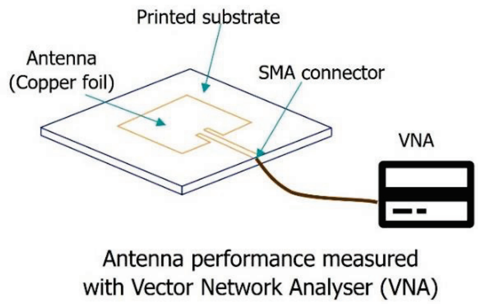

Figure 5. Antenna performance measurement setup

3. Results

3.1 Signal strength attenuation due to obstructions.

Using the CY8CKIT-142 PSoC 4 BLE module as a transmitter and CySmart BLE 4.2 USB dongle as a receiver, the signal strength in RSSI values were recorded for conditions without any obstruction and two other conditions using the different obstructive environments. Figure 8 illustrates the signal strength of different obstruction environments at different distances.

The graph is in the figure 8 shows higher RSSI values (higher signal strengths) with no obstruction covers surrounding the BLE module. When the BLE transmitter module is inside the plastic enclosure, RSSI values at a given distance reduce. The setup with the metal obstruction surrounding the BLE transmitter further signal strength reduction at given distances is observed.

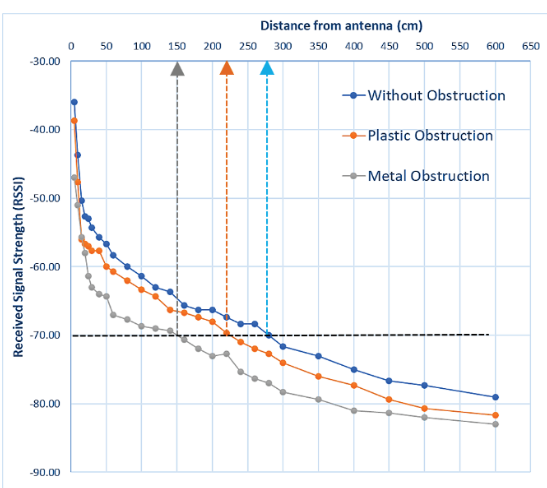

Figure 7. Signal attenuation with different obstruction materials

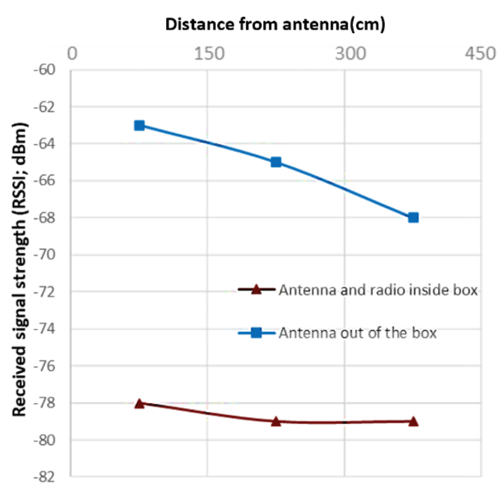

Figure 6. Signal strength with antenna inside and outside the enclosure

Next, an experiment was conducted to determine whether the signal strength increases when an antenna is on the outside of a fixture. Figure 9 illustrates that the signal strength is higher when the antenna is externally mounted than when it is enclosed in the metal box. The results of experiments suggest that having the antenna outside fixture enclosures can reduce signal attenuation, thus increasing system reliability compared to having the antennas and transmitters covered with enclosures.

3.2 Results for 3D printed antennas

After calculating and optimizing the patch antenna dimensions, the CST Studio Suite® was used to simulate the results of the performance of the antenna. Next, with the built patch antenna models, the NanoVna V2 Vector Network Analyzer was used to gather data for all four antenna types. Figure 10 compares the results from the four antennas with the simulation results. The 3D printed antennas achieved minimum return loss values (S11) near 2.4GHz., indicating that the antennas can be used to communicate signals in the 2.4 GHz range. Antennas 2 and 4 have lower return loss compared to antennas 1 and 3 because the copper foils in 2 and 4 are inset within the substrate, resulting in an increased effective dielectric constant.

Next, data for different antenna configurations were collected. Figure 11 shows data for the antennas placed on FR4 substrates. The return loss graph for the data obtained from VNA demonstrates the two antenna patches, one using copper foil (no 3D printing) and one

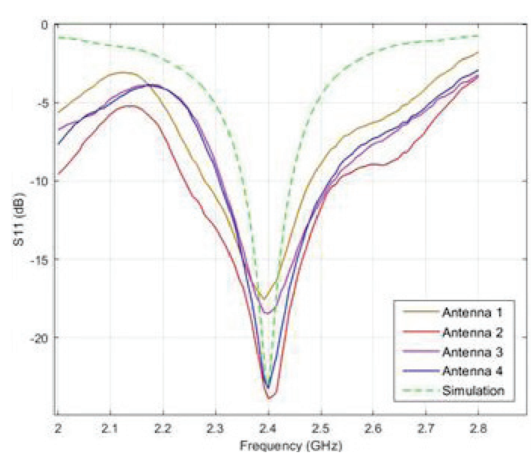

Figure 8 Comparison of return loss values for experimental antenna designs with the simulated results

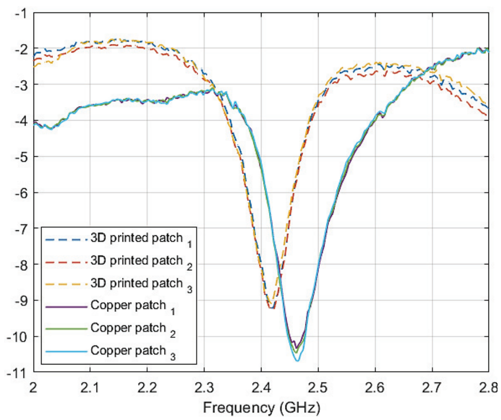

Figure 9 Antennas with FR4 substrates

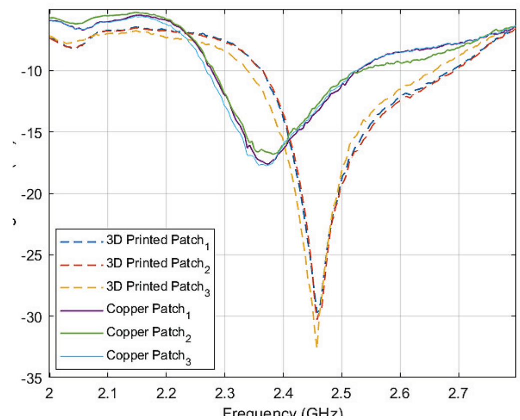

Figure 10 Antennas with 3D printed substrates

3D printed using Voltera V-One electrical trace printer. Return loss frequency plots confirm that both antennas resonate close to 2.4 GHz, and 3D printed patch antenna has lower return losses at 2.4GHz hence better performance with antennas placed on FR4 substrates.

Results from the two antennas printed on 3D printed substrates are given in figure 12. The results indicate that a 3D printed patch antenna on the substrate has lower return losses than a copper foil antenna patch placed on the substrate. However, 3D printed patch antenna demonstrated a resonance frequency shift. The authors suggest this can be rectified with further finetuning the patch antenna dimensions to achieve higher performances at 2.4 GHz. When comparing the two substrates, printed PLA with FR4, it can be observed that with 3D printed substrates, it is possible to achieve lower return losses. This translates to higher antenna performances at the desired frequency.

4. Discussion

In this study, a Bluetooth test module was used to demonstrate how different enclosure materials, typically employed in light fixtures, affect signal strength. The results showed significant signal attenuation due to fixture enclosure. An additional study explored the signal strength when an antenna is on the outside of a fixture compared to being buried inside the fixture. Results showed that the signal strength is significantly higher when the antenna is placed outside the enclosure compared to the internally placed antenna.

This study showed the feasibility of a 3D printing antenna on the external surface of a lighting fixture to improve communication performance. Further, this study explored different methods of making antennas and evaluated their performances. Results showed the possibility of integrating 3D printed antennas onto existing substrate surfaces such as FR4 substrates and the potential for 3D printing complete antenna structures, including the substrate and the conductive patch. In conclusion, this study showed promising results for 3D printing antennas on light fixtures. However, this solution requires understanding the influence of 3D-printing geometries and print materials on resonance frequencies. Therefore, authors suggest future studies to be conducted to investigate on how 3D-printed antenna geometry affects the dielectric property of the printed substrate and thus the antenna's resonance frequency.

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