A Cavity-backed Slot Antenna with High Upper Hemisphere Efficiency for Sewer Sensor Network

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***Abstract*—A wireless sewer sensor network has been widespread to monitor combined sewer overflow (CSO) causing human health and environmental hazards. To enable the wireless interconnection between sensor nodes, a radiator needs to be embedded into a manhole cover with sufficient mechanical strength. In addition, the high efficiency in upper hemisphere is essential for successful communication to above-ground sensor nodes. In order to meet these requirements, a full wavelength slot antenna embedded in a shallow cavity inside a cast-iron manhole cover is designed. An electromagnetic analysis is conducted to verify the antenna design. Simulation and measurement show a good agreement. The result shows 2.5dB higher total radiated power in three-dimensional upper hemisphere, compared to a half wavelength slot on the same substrate without a cavity.**

I. INTRODUCTION

Currently, many metropolitan cities and local communities in the United States suffer from the Combined Sewer Overflow (CSO) [1]. In the condition of heavy rainfall or storm, a sewer system is easy to be overloaded and the untreated sewer from home and industry flows to the natural water resources, causing significant hazard on natural waterways and human health. A city-wide wireless sewer sensor network has been built to dynamically monitor and control the level, velocity, and contamination of sewage in South Bend, IN [2].

In order to enable the sensor network, an antenna needs to be robust, low-cost, low-profile, and easy to be integrated on a manhole cover. Furthermore, as the nearby base station node is above ground, the antenna efficiency in upper hemisphere is critical for successful implementation. Various manhole cover antennas for above-ground communication have been studied [3]-[5]. A vertical quarter wavelength antenna with a disk reflector was investigated in [3]. A thick slot antenna was designed by machining a cast-iron manhole cover. However, the feed line and connector were corroded due to moisture and toxic gases [4]. In our previous work, a woven fiberglass composite was designed and fabricated as a RF transparent material for a manhole cover and it was verified with a half wavelength slot antenna underneath the composite [5]. In [6], dipole, patch, Yagi-Uda, and slot antenna were designed and compared to each other in a real sensor network.

A cavity-backed antenna can be advantageous to improve the antenna efficiency toward upper hemisphere since it reflects the downward propagating wave toward above ground. One way to achieve this is to create a cavity that is a quarter wavelength long under a radiator. A crossed slot antenna in a shallow cavity was reported in [7] where the quarter wavelength cavity is split into two and placed in parallel to the slot. In this paper, a slot antenna is designed on FR4 substrate and is placed on a shallow rectangular cavity for high upper hemisphere performance. Mechanical stability is provided with sandwich structure that consists of a form core and two FR4 substrates inside the cavity.

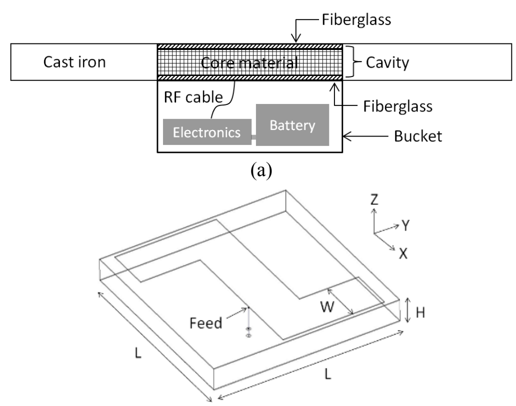
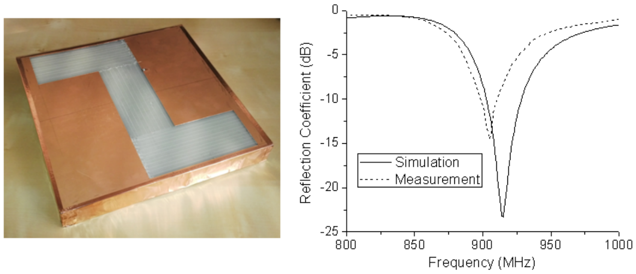


Fig. 1. Proposed shallow cavity-backed slot antenna in a manhole cover. (a) a manhole cover including an integrated antenna, and (b) 3D view of a slot antenna in a rectangular cavity

II. SLOT ANTENNA DESIGN

Fig. 1 shows a cavity-backed slot antenna integrated in a cast-iron manhole cover where a rectangular hole for the cavity is machined. The antenna is centered in the cover with radius of 37cm. To mechanically support traffic, the antenna is embedded into a sandwich structure. A high strength form is used as a core material while two fiberglass plates have been internally mounted on the top and bottom of the cavity. Underneath the cover, a packaging bucket contains RF transceiver, sensor circuitry, and battery. The bucket is typically made of a metal for electrical shielding and hermetic packaging. We found that the previous magnetic-fed slot antenna is detuned with the metal bucket due to the cavity-mode field distribution. In addition, the circuitry and RF cables are often re-arranged after maintenance. To overcome these challenges, a cavity-backed slot is beneficial to prevent the effect of the underneath electronics or shielding metal bucket. To excite the slot, a coaxial cable passes through the cavity and



(a) (b)

Fig. 2. (a) Fabricated antenna and (b) reflection coefficient

is attached to the top surface of the cavity. The configuration of the proposed antenna is shown in Fig. 1(b). The length (*L*) of the square cavity is 22cm. The height (*H*) of the cavity including the internal sandwich structure is 2.54cm which is almost three times less than a quarter wavelength at 915MHz of operating frequency.

A full-wave analysis is conducted with Ansoft High Frequency Structure Simulator (HFSS). The slot is designed on 0.8mm-thick FR4 substrate with the same size of the cavity. The slot length is determined by the operating frequency which is the center frequency of ISM (Industrial Scientific and Medical) band at 900MHz. Herein, this slot length is set to be 35cm long which is almost a full wavelength at the design frequency. To accommodate the long slot on the top surface of the cavity, the slot is bent to increase its physical length, resulting in a shape of "Z". The slot width (*W*) is adjusted to 5cm for impedance matching. The feed location is 4cm and 2.6cm off from the center of the cavity in x and y axis, respectively. The fabricated antenna is shown in Fig. 2(a).

III. RESULT

The antenna is characterized at an anechoic chamber. Reflection coefficient of the antenna is measured with a network analyzer (Agilent E5071C). The resonance frequency is observed at 908MHz with 28MHz of -6dB bandwidth which is wide enough to cover the ISM band, as shown in Fig. 2(b). The 7MHz of frequency shift occurs because of fabrication tolerance. Fig. 3 shows omni-directional pattern in the plane of $\varphi=0^o$, which is desirable for multipath fading environment in a city. This allows for a crew to open and replace the manhole cover in an arbitrary direction after maintenance. Similarly, another omni-directional pattern is also observed above $\theta=\pm 90^o$ in the plane of $\varphi=90^o$, as shown in Fig. 4. The total antenna efficiency and gain measured are -0.9dB and 4.5dBi, respectively. Fig. 5 shows two examples of comparison between cavity-backed and without-cavity slot antenna on the same substrate. The total efficiency of the proposed antenna shows -2.6dB at $-90^o \le \theta \le 90^o$ which is 2.5dB higher than a half wavelength bidirectional slot antenna.

IV. CONCLUSION

A slot antenna in a shallow cavity is designed and measured for above-ground radiation. The simulation and measurement show that the proposed antenna is efficient because most energy radiates toward upper hemisphere. Therefore, it is promising that this antenna can be a strong candidate for a wireless sewer sensor network.

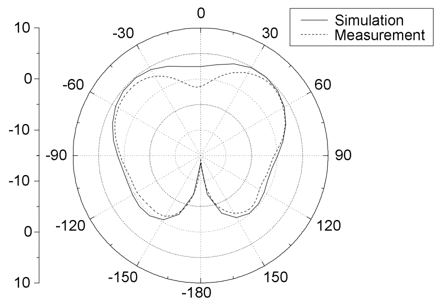


Fig. 3. Radiation Pattern in $\varphi=0^o$ plane

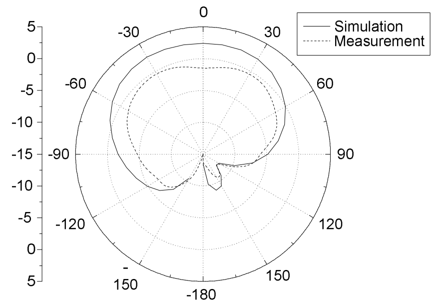
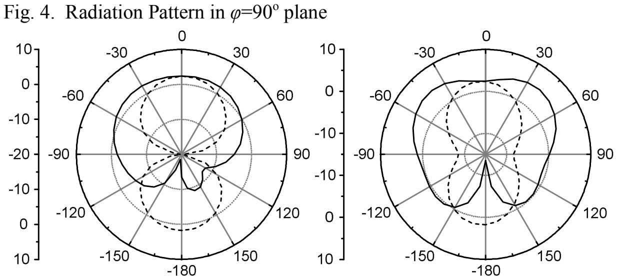


Fig. 4. Radiation Pattern in $\varphi=90^o$ plane



(a) $\varphi=90^o$ plane (b) $\varphi=0^o$ plane

Fig. 5. Comparison of simulated cavity-backed (solid) and without-cavity (dashed) slot antenna.

REFERENCES

[1] U.S. Environmental Protection Agency; Report to Congress: Impacts and Control of CSOs and SSOs, Washington, D.C.

[2] L. Montestruque and M. D. Lemmon, "CSOnet: a metropolitan scale wireless sensor-actuator network," *International workshop on mobile device and urban sensing* (MODUS), 2008.

[3] S. Mizushina, A. Adachi, and T. Watanabe, "Radiation from an antenna in manhole," *Asia-Pacific Microwave Conference*, pp. 2052-2055, 2006.

[4] J. F. Mastarone and W. J. Chappell, "Urban sensor networking using thick slots in manhole covers," *IEEE Antennas and Propagation Symposium*, pp. 779-782, July 2006.

[5] S. Jeong, C.-L. Yang, J. R. Courter, S.-I. Kim, R. B. Pipes, and W. J. Chappell, "Multilayer composite for below ground embedded sensor networking," *IEEE Aantennas and Propagation Symposium*, pp. 1-4, 2008.

[6] S. Jeong and W. J. Chappell, "Adaptive composite antennas for a city-wide sensor network," *IET Microwaves, Antennas & Propagation*, vol. 4, pp. 1916-1926, 2010.

[7] C. A. Lindberg, "A shallow-cavity UHF crossed-slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 17, no. 5, pp. 558-563, 1969.