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Antenna design for a massive multiple input environmental sensor network☆

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ABSTRACT

This article describes the design and simulation of a pair of antennas on a small PCB with minimal coupling for a massive multiple input sensor network. The two antennas are planar inverted-F antennas (PIFA) that are fed with microstrip feed lines. The critical design factors are minimizing mass while creating ISM band and GPS L1 band antennas and developing data transmission schemes for maximum usage of all communication channels. The designed board is a 60 mm diameter, 0.6 mm thick circular FR4 board that weighs approximately 5 g.

1. Introduction

Currently, atmospheric researchers rely heavily on remote sensing technologies such as satellites to predict the weather; however, there is a tremendous need for additional in-situ measurements to improve weather models and create more accurate forecasts. Current in-situ measurements for hurricane reconnaissance primarily rely on devices known as dropsondes. The dropsondes have a terminal velocity of 11 m/s at sea level, and approximately 21 m/s at a 12 km altitude [1]. For more quiescent conditions, weather balloons carrying radiosondes [2] are launched around the globe every day to measure the properties of the atmosphere. This article showcases the antenna design and application of a novel type of atmospheric sensor which our group is developing as an alternative to these devices.

The devices will be part of a new atmospheric monitoring system known as GlobalSense [3]. The system features an ensemble of disposable airborne drifters, called environmental motes or eMotes, as can be seen in Fig. 1, that will be carried by wind currents much like naturally occurring dandelion or maple seeds. The GlobalSense system innovation is based on the continuing trend for ubiquitous sensing [4,5], also known as the Internet-of-Things [6,7], where extremely large numbers of disposable, low-cost electronic devices measure various parameters and communicate that data in different formats and frequencies for various applications.

Once deployed from balloons or aircraft, eMotes will transmit low power signals in one of the industrial, scientific, and medical (ISM) radio bands to avoid expensive licensing requirements. The fixed or mobile receiver platforms will contain hardware and software to gather and process sensor and other data from multiple eMotes within range and store or retransmit the information to other locations. The GlobalSense system has been designed to support up to 50,000 eMotes operating simultaneously.

The GlobalSense system could benefit a wide range of applications with sensitivity to atmospheric conditions including but certainly not limited to energy, transportation, agriculture, construction, insurance, and tourism. The initial focus is on improving weather analysis and forecasting by greatly expanding the time and space density of critical weather parameters such as temperature, pressure, wind velocity, and humidity throughout as much of the relevant atmospheric volume as possible.

With the appropriate chemical sensors integrated on eMote platforms, the GlobalSense system could monitor air quality and greenhouse gases such as carbon dioxide and methane for global climate change initiatives [8,9]. Even broader applications involve measuring parameters of interest for surveillance, reconnaissance, and related applications. The modular and interoperable system design makes it relatively straightforward to integrate other sensors that have the appropriate specifications.

The current prototype eMotes have a mass around 7 g with a terminal velocity <5 m/s which provides greater dwell time in the atmosphere than typical environmental sensors. The final design goals are an eMote mass ≤1 g and a terminal velocity on the order of 1 m/s.

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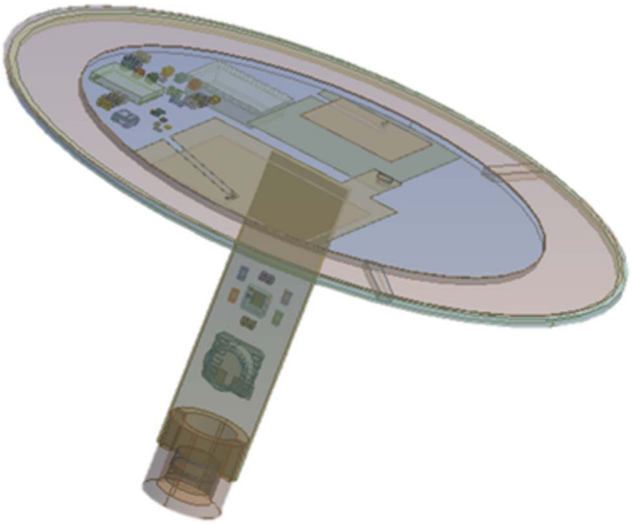

Fig. 1. CAD model of the eMote.

Given such low mass and an aerodynamic shape, eMotes can remain airborne and take measurements for hours or longer depending on atmospheric conditions and release altitude. The innovative eMote design creates an energy-efficient, long range, low power sensing device.

The eMote is designed as a cap and stem system. The antennas, along with the microcontroller and GPS receiver, are integrated into the cap along with the prerequisite passive components. The sensors are integrated into the stem with the batteries attached to the end of the stem opposite the cap. The sensors will be used to measure ambient temperature, relative humidity, pressure, and velocity. The stem board which contains the sensors will communicate using inter-integrated circuit (I^2C) communication protocol, allowing different versions of the stem to be interchanged and permitting more sensing options.

Much existing research with long range, low power sensor networks focuses on the design and optimization of the communication schemes and sensor devices [10–13], but not the antenna design. This article builds upon that research and focuses on the antenna design and implementation of the massive multiple input sensor network. The antenna design followed the typical design method of a literature search followed by simulation. The fabrication and testing of the antenna is currently in progress.

2. Antenna design

The antennas described in this article are based on the planar inverted-F antenna or PIFA. This antenna is a modification of the inverted-L antenna, which is based on the quarter-wave monopole antenna [14]. The PIFA is an ideal candidate for the eMote design as the sum of the length and width are approximately a quarter-wavelength (for the standard case) which makes it an electrically small antenna while still possessing desirable performance characteristics [14,15].

The eMote is designed to have a link margin of 10 dB at a range of 50 km. Therefore, the two antennas will need to be oriented for optimal reception and range with the top of the cap facing upward and the stem perpendicular to the ground. The antennas are oriented so that the main lobe of the ISM band antenna points down and the main lobe of the GPS antenna points up. This orientation could be modified for optimal reception depending on the receiver location.

Fig. 2 shows the antenna board designed in ANSYS HFSS. The smaller patch is the GPS antenna, the larger patch is the ISM antenna, and the large, slotted copper segment is the ground plane. The antenna board is made of FR4 with a relative permittivity of 4.4. The cap is a

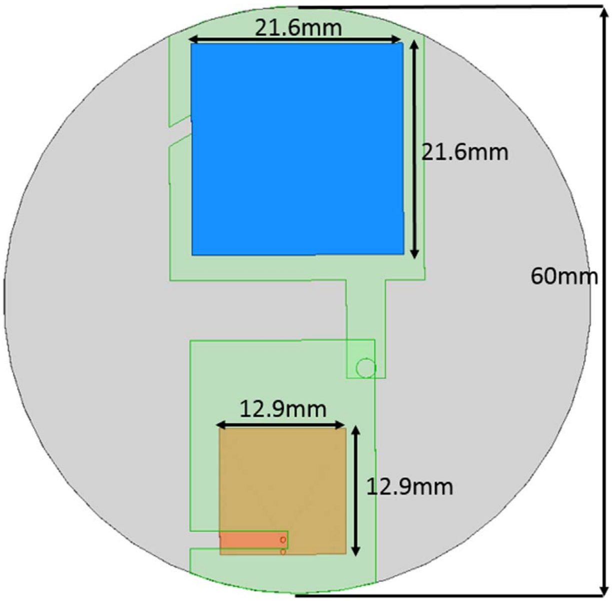

Fig. 2. Antenna board layout in HFSS with dimensions shown.

60 mm diameter circular PCB that is 0.6 mm thick. Similarly, the stem is a 0.6 mm thick 11 mm by 40 mm rectangular PCB with a plastic battery compartment attached to the bottom. The two boards are connected with a four pin header that passes the V+, ground, I^2C clock, and I^2C data lines to the cap board.

A standard, wire-fed PIFA with an air gap between the radiating element and the ground plane has a bandwidth of approximately 4%–12% [16]. When the PIFA is built on a PCB, the bandwidth decreases. Additional decreases in bandwidth are seen when the height of the feed pin shrinks [14], where the height of the feed is determined by the PCB thickness. A major design constraint was the mass of the eMote. A board thickness of 0.6 mm was selected as a trade-off between rigidity and mass.

Unlike a traditional PIFA which is fed through a coax or similar method, these antennas are fed with 50 Ω microstrip lines. The feed lines are terminated at the feed vias which connect to the radiating patch. In order to achieve this design, the ground plane is cut, creating a meandering design. The meandering design allowed the antenna to operate effectively with the reduced board thickness [17] and allowed the antenna size reduction that was desired [18].

3. Antenna performance

The data will be transmitted to the receiver over the 902 to 928 MHz ISM band. To verify the antennas bandwidth, the voltage standing wave ratio (VSWR) is shown in Fig. 3. For the ISM band antenna at the 915 MHz design frequency, the VSWR is 1.14 and the bandwidth is 901 – 927.6 MHz, which is 2.9% of the design frequency. Additionally, the VSWR is less than 2 for the range of 906–922 MHz for the ISM band antenna. For the GPS antenna, the bandwidth is significantly smaller as a percentage of the design frequency. Therefore, for the range of 1.563–1.587 GHz, the VSWR is below 1.5 with a VSWR of 1.15 at the design frequency.

The directivity plots of the two antennas shown in Figs. 4 and 5 demonstrate the appreciable gain. The ISM band antenna's pattern is more isotropic than the GPS antenna's pattern. This characteristic should allow for a more robust communication link in most directions excluding the center null located in the middle of the ground plane. Ideally the center null will face upward away from the receiver if the eMote is falling through the atmosphere as intended. The maximum directivity is approximately 6.5 dB.

The GPS antenna has a more bulbous pattern. This pattern is