Improvement of Communication Reliability of Small UAV by a Tapered Stacked Antenna

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ABSTRACT—This letter proposes a tapered stacked microstrip antenna for application in small unmanned aerial vehicles (UAVs), which has advantages in mountainous terrains. With its tapered structure and increased bandwidth designed to operate at the resonance frequency of 2.4 GHz, the proposed antenna improves directivity, accuracy, and precision of small UAVs. The test flight results show the proposed tapered antenna has a three times higher impedance capability of 350 MHz based on VSWR<2. The transmission pattern is also more reliable than that of previous antenna designs.

Keywords—Small unmanned aerial vehicle, microstrip patch antenna, stacked, tapered.

I. Introduction

Research into small unmanned aerial vehicles (UAVs) began in early 1990 with the presentation for the concept of a micro-system by RAND Corporation in the USA and with the development of the Micro Flyer by MIT Lincoln Laboratory. Interest in its potential applications has increased and serious research into possible applications has been avidly pursued since 1997 by the Defense Advanced Research Projects Agency, USA.

The conventional microstrip antennas mounted on small unmanned aerial vehicles can transmit only visual signals due to limited bandwidth [1]. This limitation causes frequent plane crashes. With just visual signals received, a ground-based pilot cannot control a UAV's flight accurately enough to avoid crashes because essential data such as location, altitude, direction, and flying speed are not provided. For this reason, fully-automated unmanned airplanes are not reliable enough to replace piloted airplanes. The microstrip antennas have advantages such as small size, light weight, low fabrication cost, ease of design, and integratablity with a semiconductor device, and they are diverse in structure [2]-[4]. However, as a two-way antenna, a microstrip antenna has a limitation of low radiation efficiency and a narrow bandwidth of approximately 1 to 2% [5].

To overcome these limitations, we propose a tapered stacked microstrip patch antenna which is suitable for installation in aircraft. The antenna is operated with not only high conformation across wide resonance frequency but also high gain and circular polarization. Moreover, the high directional characteristic of the antenna generated by its narrow beam-width is one of its significant advantages [6], [7].

II. Small UAV Communication System

1. Analysis of Microstrip Patch Antenna

For the resonance, a practical patch width and length are given by

$$W = \frac{1}{2f_r\sqrt{\varepsilon_0\mu_0}}\sqrt{\frac{2}{\varepsilon_r+1}}, \quad L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_0\mu_0}} - 2\Delta L,$$

The resonance frequency f_r of a rectangular microstrip patch antenna with patch length L is given by

$$f_r = \frac{c}{2\sqrt{\varepsilon_{reff}}\,(L+2\Delta L)}.$$

The return-loss coefficient S_{11} of the microstrip patch antenna is calculated from

$$S_{11} = \frac{F[V_1^{ref(t)}]}{F[V_1^{inc(t)}]},$$

where $V_1^{ref(t)}$ and $V_1^{inc(t)}$ are the reflected and the forward (input) voltages, respectively, and $F[\cdot]$, the Fourier transform.

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When a microwave radio link is set up, the received power at the receiver is

$$P_r = P_t \frac{G_t G_r \lambda^2}{(4\pi R)^2},$$

where P and G stand for power and gain of antennas; the subscripts t and r represent transmit and receive antennas; and R is the distance between the transmit and receive antennas.

2. Analytical Process of Antenna for Aircraft

Figure 1 shows the significant loss factors which should be considered in practical small UAV communication. The goal of this research is the development of a transmit/receive module which can transmit from micro-size, micro-weight, low-energy embedded aerial antennas to land. The high speed delivery of information depends on customizing the G_t and G_r.

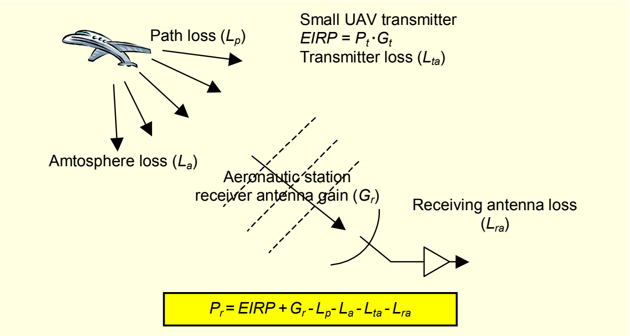

Fig. 1. Concept picture of SUAV communication link.

3. Optimized Small UAV Antenna Design

The proposed microstrip antenna can achieve wideband characteristics using two stacked patches. Figure 2 shows the structure of the antenna. The basic patch (the lower one), designed with the resonance frequency of the basic antenna's frame, expands the bandwidth by making the radiator pattern stacked. The parasitic patch (the upper one) expands the bandwidth by adjusting its height. The size of parasitic patch is important because it has an effect on the height, size, and location of the basic patch.

The lower and upper patch sizes of the proposed antenna are related to its resonance frequency: for the upper and lower patches to achieve the desired resonance so that wideband transmission can occur, the height should be about half the length. Figure 3 shows photos of the fabricated antenna and small UAV.

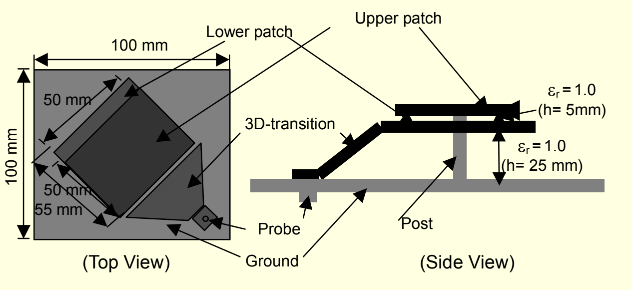

Fig. 2. Optimized structure of antenna.

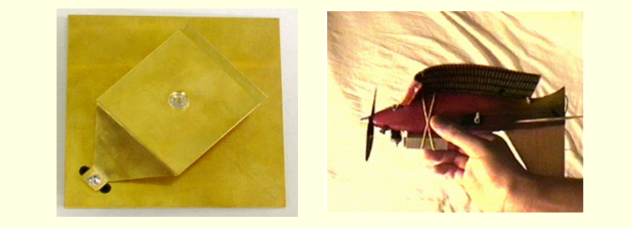

Fig. 3. Photos of proposed antenna and small UAV.

III. Measurement Result

The performance results of the two types of antennas were measured using Ansoft's High Frequency Structure Simulation (HFSS). The 2.4 GHz fractional bandwidth of the proposed antenna was calculated to be about 6.8%, and this is a gain three times higher than that of the existing single microstrip patch antenna.

In antenna patterns, one of the most important characteristics is directivity. Directivity is a parameter which determines whether the antenna's radiation is focused and in which direction. At 2.4 GHz, the directivity performance of the proposed antenna is outstanding (see Fig. 5).

The aviation experiment had several purposes. First it was an overall hardware endurance test. We tested the possibility of land-based control using the tapered stacked antenna design, and gained other aviation data. We compared images, altitude, and the transmitting and receiving of data with real flight tests. The central aim was to test the tapered stacked antenna's potential for use in a remote control system.

Figure 7 compares pictures which were taken on a flight with an embedded single antenna and others which were taken

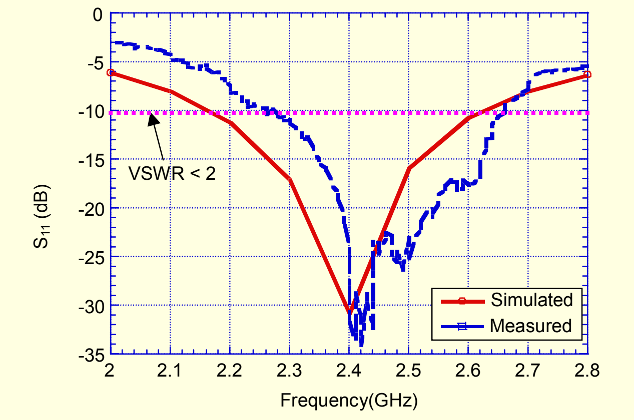

Fig. 4. Reflection loss of proposed antenna with fractional bandwidth of 6.8%.

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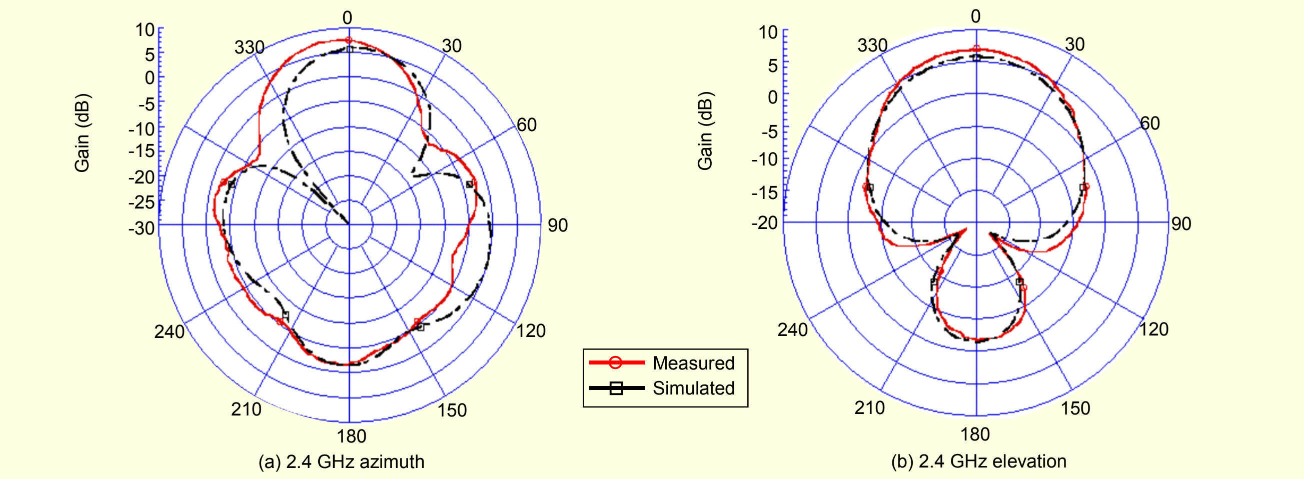

(a) 2.4 GHz azimuth (b) 2.4 GHz elevation

Fig. 5. 2.4 GHz azimuth and elevation patterns measured from the proposed antenna.

Fig. 6. Flying test view.

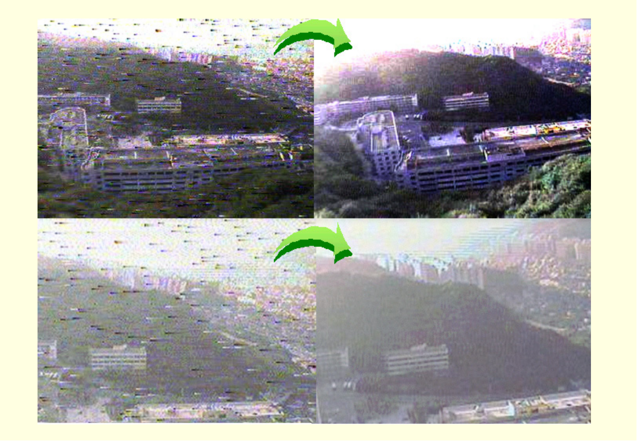

Fig. 7. Comparison of images from two types of antennas.

on a flight in mountain peaks with an embedded tapered stacked microstrip antenna.

IV. Conclusion

In this letter we reported the design and testing by flight experiments of a new tapered stacked microstrip antenna which is suitable for use in small UAVs. Test results were obtained using Ansoft's HFSS, after designing and actually manufacturing, a small and lightweight microstrip patch antenna—built into subminiature unmanned aircraft—suitable to transmit stable visual signals in the 2.4 GHz band in addition to other flight information. The microstrip patch antenna system used in the present unmanned aircraft has advantages in that it has a thin film type structure, and is easy to attach despite the restrictions of the external structure. On the other hand, it had disadvantages in that being narrowband, it has limitations in transmitting or receiving any signals other than visual signals. Test flights showed that precision visual operation was possible due to the proposed antenna's reliable, stable, and continuous transmitting and receiving of signals. Moreover, it was found to be capable of transmitting and receiving additional signals necessary for the operation of airplanes, besides visual signals. Simulations of the microstrip patch antenna showed that resonance was generated at 2.4 GHz, and that the return loss was about –22 dB. Also, each bandwidth is 430 MHz based on the return loss of –10 dB, which is broadband.

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