Fully Collapsible Lightweight Dipole Antennas

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***Abstract*—Flexible, deployable phased arrays enable novel and diverse applications but necessitate similarly flexible radiators. Here we present a light and flexible 10GHz dipole antenna, which is co-cured to a glass-fiber composite and suited for flexible phased arrays. The antennas are designed to dynamically conform to new array shapes and be flexible enough to fold completely flat and pop back up upon deployment. We employ a pop-up dipole with a capacitive fingers feed for impedance matching that is highly robust against manufacturing errors. Upon deployment, the antennas exhibit a -10 dB-bandwidth >1.5 GHz and >110° half-power beam width single lobe pattern suitable for beamforming.**

I. INTRODUCTION

No component's function in modern microwave systems is more tightly coupled to geometry than an antenna's. This presents electromagnetic, mechanical, and materials challenges in designing lightweight antennas that change form-factor during stowage and deployment. Lightweight deployable antennas that can unroll, unfold, or inflate to a functional physical configuration are emerging in many applications [1][2][3]. For example, some space systems require large deployable apertures that can be carried to orbit in a compact fairing volume. Such systems demand antennas that can be stowed in one configuration and self-deploy upon unfolding in space.

This work presents a fully collapsible, mechanically robust 10 GHz dipole radiator. Each radiator weighs only 47 mg, can self-deploy, and has low sensitivity to manufacturing variation. The design is suited for large scale, lightweight, deployable, and flexible arrays for wireless power transfer, communications, and sensing.

II. MECHANICAL DESIGN

The deployable dipole antenna is shown in Fig. 1. Collapsibility and compatiblity with large-scale, lightweight arrays drive the shape, materials, and manufacturing process. The antenna is made from a single 25μm-sheet of polyimide with etched copper on both sides. Polyimide, rather than traditional rigid substrates, allows for the flexibility needed for collapsibility and self-deployment. To provide the desired shape after deployment, the polyimide sheet is combined with a glass fiber composite frame that has been cured into the "J" shape seen in Fig. 2a. The composite is a 3-ply stack of Isola 1067 glass fiber impregnated with Patz-F4 resin, layered in a $45°/90°/45°$ configuration.

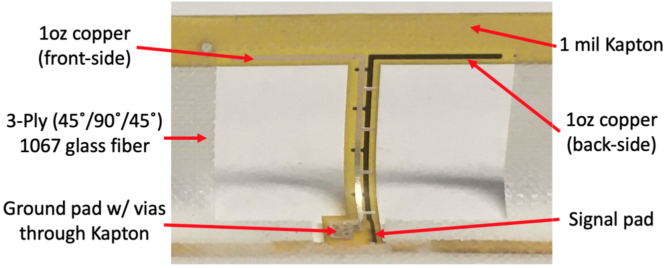

Fig. 1: Collapsible dipole antenna in its operational configuration with labels

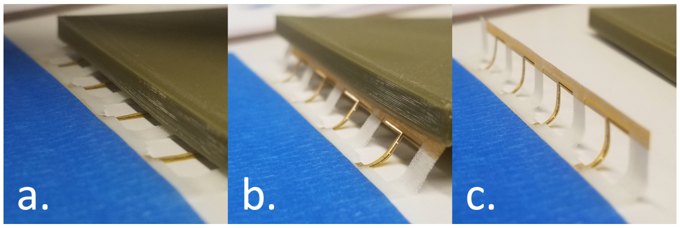

Fig. 2: Antenna collapsibility: a. Collapsed, flat configuration. b. Intermediate state during redeployment. c. Operational configuration

To ensure a robust mechanical connection between the polyimide circuit sheet and the glass fiber frame, these subcomponents are co-cured. To do this, we place the flexible polyimide circuit sheet on top of the un-cured composite layers, place the entire stack into a silicone mold, and cure [1] in an autoclave. Co-curing offers a number of advantages. Aligning the antenna sheet and fiber when flat - and then placing into the shaped silicone mold for co-curing- is simpler and more accurate than attempting to align the flexible sheet after curing the glass fiber into a non-planar shape. Co-curing also eliminates the need for additional adhesive and an application step, as the fiber is already impregnated with epoxy. Moreover, this process is highly scalable and lends itself to bulk manufacturing of antennas from large sheets of glass fiber and polyimide circuit sheets. Cutouts in the glass fiber and polyimide reduce weight and increase collapsibility, as demonstrated in the sequence of images in Fig. 2.

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[1] Curing is done at 120°C and 80 psi for 2 hours.

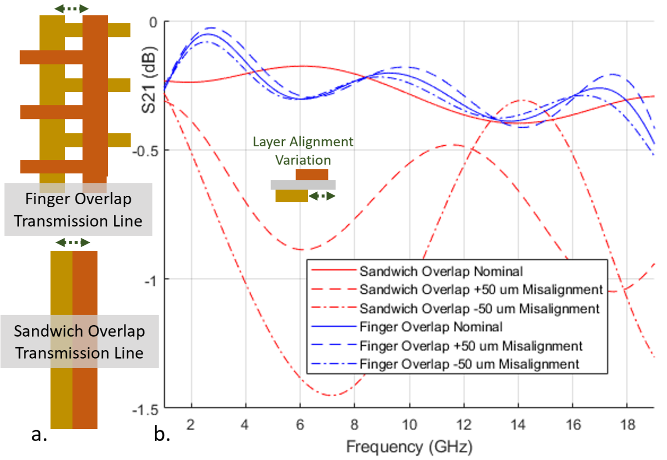

Fig. 3: a. Sandwich and finger overlap feed transmission line designs b. FDTD simulation of s-parameters of the two transmission line designs. $\pm 50\mu m$ alignment error is added from the nominal design dimensions.

III. ELECTROMAGNETIC DESIGN

The presented antenna can be split into three subcomponents: circuit board contact, a feed transmission line, and the radiating arms. The antenna is driven by a single-ended transmission line from a PCB, with one pad connecting to the transmission line ground (also the radiator ground plane) and the other pad connecting to the transmission line signal trace. The feed transmission line, which rises in a "J" shape from the board, is critical to proper functioning of the antenna as it must accomplish single-ended to differential conversion (balun) and impedance matching between the 50Ω transmission line on the PCB and the dipole arms. To achieve a near 50Ω impedance on the thin and narrow polyimide substrate of the feed, the design relies on distributed capacitance formed by overlapping copper on opposite sides of the polyimide. The simplest way to achieve this capacitance is using a "edge overlapping sandwich" design as depicted in Fig. 3a. However, the relative position of etched copper on either side of the polyimide is subject to significant manufacturing variation and, thus, capacitance variation. High manufacturing sensitivity is undesirable, thus motivating use of the finger overlapping design we developed for this work. Fig. 3 illustrates the difference between the sandwich and finger overlap transmission lines. By using fingers to achieve the necessary distributed capacitance for the feed transmission lines, the effect of $\pm 50\mu m$ alignment errors from manufacturing on $|S_{21}|$ is reduced from >1.2 dB to <0.2 dB.

IV. ANTENNA PERFORMANCE

To evaluate the performance of the pop-up dipole, a prototype 1-by-8 antenna array was created and characterized. Measurements are compared to FDTD simulations of the antenna array. Input matching for the 4th antenna, while the other antennas are terminated to 50Ω, is presented in Fig. 4. The simulated and measured gain patterns are presented in Fig. 5. The measured and simulated broadside gain is 5.3 dBi. Both measured and simulated patterns exhibit slight lobe splitting along the array axis. The antenna demonstrates a -10 dB bandwidth of approximately 1.5 GHz and a half-power beam width close to 110° in both the Phi = 0° and Phi = 90° cuts.

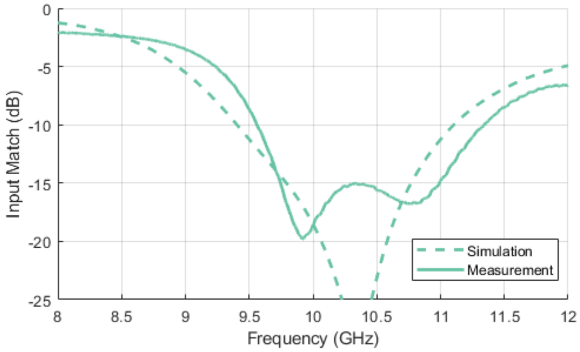

Fig. 4: Simulated and measured antenna input match.

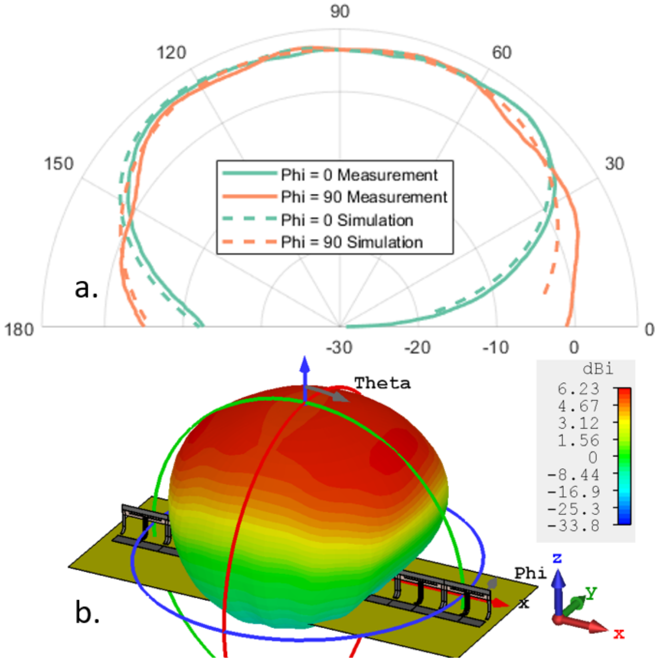

Fig. 5: a. Simulated and measured, collapsible pop-up dipole element patterns. b. Simulated 3d pattern with scale and axis

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