# Beam-Shaping of Planar Array Antennas Using Integrated Attenuators

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**Abstract**

The use of planar integrated attenuators to shape the beam of a planar array antenna is investigated on a lightweight organic polymer ideal for satellite applications. The entire array is fabricated using a single type of liquid crystal polymer (LCP), reducing the cost of fabrication and simplifying the integration of the attenuators. A fabricated prototype was designed, fabricated, and measured revealing a sidelobe reduction of 12dB compared with a similar antenna using a uniform amplitude distribution, or an overall sidelobe level of –25dB. The 3dB beamwidth of the binomial array was measured to be 31 degrees, an increase of 3 degrees over the uniform amplitude case.

## Introduction

Array antennas are used extensively in remote sensing applications, where a highly directive beam is needed to scan a particular area of interest on the surface or atmosphere of the earth. The tropical rainfall measuring mission (TRMM), a precipitation radar that operates at 14 and 35 GHz, is one such application [1]. Traditionally, parabolic reflector elements are used for this task in order to provide the necessary directivity specifications. These large and bulky antennas increase project costs and become impractical for inherently small and lightweight platforms such as satellites. Attempts to use other antenna types, such as microstrip fed patches, need to overcome several performance obstacles in order to achieve high directivity, low sidelobe level, desired beam shape, steering capabilities, and low loss.

Basic antenna theory reveals that a uniformly-fed array consisting of equally-spaced identical radiating elements operating at maximum efficiency results in a radiation pattern with sidelobe level of –13.2dB. This is undesirable for a remote sensing application that is dependent on measurements at a precise location in space. In this situation, sidelobe radiation translates into unwanted noise and reduces the signal to noise ratio of the radar system before any signal processing is even attempted. For this reason, the sidelobe level of the array should be minimized, a specification achieved through the use of amplitude tapering of individual elements [2].

In this work, the applicability of planar attenuators in the beam-shaping of a planar array antenna for rain precipitation at 14 GHz is investigated and demonstrated through a fabricated prototype [3]. The array module has been developed for deployment on a lightweight satellite platform. Even though common approaches for low sidelobe arrays implement a Chebyshev or n-Taylor amplitude distribution, a binomial planar array antenna is presented here, serving as a proof of concept prototype as well as to facilitate measurement results and potential integration faults detection. The antenna is compared with a prototype 14GHz array with uniform amplitude distribution. Furthermore, RF-MEMS switches can be integrated with such systems in order to enable on-demand beam-forming of large electronically-scanned arrays with respect to mission requirements. This agility enables benefits for modern radar systems by permitting deliberate alterations in antenna performance to accommodate potential changes in mission. In addition to the above, the integration of the entire structure is accomplished using a single organic lightweight material, thus simplifying the fabrication and packaging process.

## Antenna Design and Performance

For our research purposes, aperture-coupled microstrip patch antenna (ACMPA) elements were chosen, due to their small size, high front-to-back ratio, and ideal topology for low cost circuit board-style fabrication. Shown in Figure 1, the ground plane is placed between the radiating elements and the feed network, effectively isolating the radiation pattern from interference caused by RF signals in the remainder of the circuit. The radiating patches are placed on the top layer of the circuit, with a 10mil separation from the ground plane in order to increase the array bandwidth.

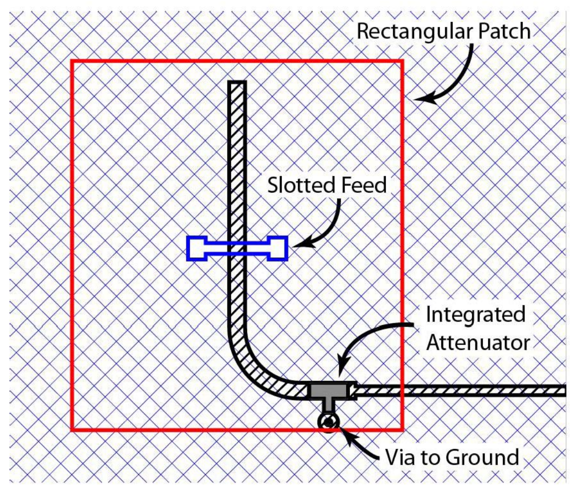


Figure 1. Layout of an aperture coupled microstrip patch antenna element.

The feed network is a corporate architecture implemented in microstrip, and is placed 4mils below the ground plane, with the slotted aperture in the ground plane used to feed the radiating element. In the corporate architecture, the impedance of T-junctions are matched using quarter wave transformers to bring parallel combinations of transmission lines to the standard 50Ω. The array itself is arranged in a 4x4 orientation with each patch spaced λ/2 apart as seen in Figure

2. In this configuration, the array pattern will indeed contain sidelobes for consideration.

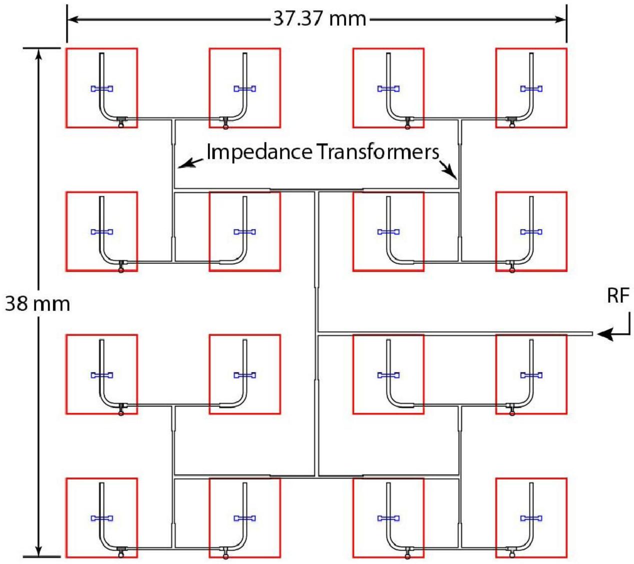

Figure 2. Layout of the complete 4x4 antenna array.

The attenuators are incorporated in the same layer as the feed, approximately 500um before each antenna element. Three different amplitude values are implemented and used to distribute power to the individual elements according to Figure 3. Full power is delivered to the central elements and applied with a short length of transmission line, in effect providing the elements with 0dB attenuation. One third of that power is supplied to the edge elements. This power level is achieved by placing a 4.77dB attenuator in the feed path. Similarly, the corner elements are given one ninth of the full power by way of a 9.54dB attenuator.

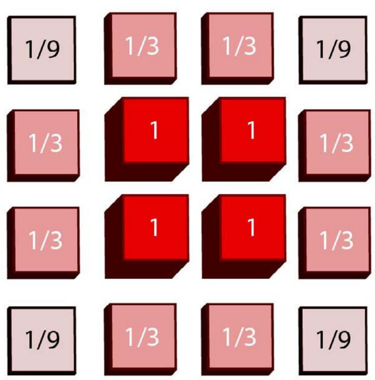

Figure 3. Normalized 2-D amplitude distribution of the fabricated 4x4 antenna array.

The attenuators were created by modifying a simple T-network. Table 1 shows the resistor values needed to achieve the necessary attenuation levels while maintaining a 50Ω match. These resistances were then translated into the dimensions required by the distinct integrated resistors. Finally, the small conductive area connecting the distinct resistors was removed to form a more compact attenuator, as shown in Figure 4. The attenuator was optimized using a numerical field solver to minimize the area and phase shift, resulting in a maximally compact solution with good performance across the operating bandwidth of the antenna as shown in Figure 5.

Table 1. Attenuator Resistor Values

| | 4.77dB Attenuator (1/3 Power) | 9.54dB Attenuator (1/9 Power) |
|---|---|---|
| $R_s$ | 13.4 Ω | 25 Ω |
| $R_p$ | 86.6 Ω | 37.5 Ω |

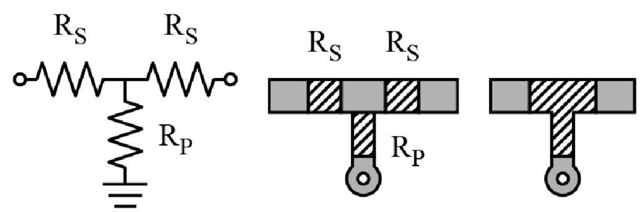

Figure 4. Integrated attenuator development from schematic to the final layout implanted in this work.

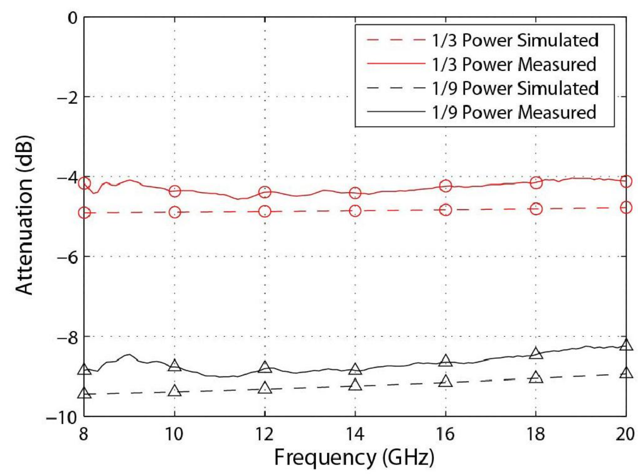

Figure 5. Measured attenuator performance from 8-20GHz. The broadband constant response can be observed.

**Fabrication and Integration**

Fabrication of the array prototype is a complex task that involves careful alignment at every step on a flexible organic material that can be difficult to work with. Liquid Crystal Polymer (LCP) is the organic material chosen as the substrate because it is lightweight, flexible, and resistant to radiation; properties that make it ideal for satellite applications [4]. It is also ideal for RF packaging and multilayer integration because when melted into its liquid crystal state, it will form strong bonds with other LCP layers, creating a single uniform dielectric. LCP is available commercially in standard 4mil sheets along with 1 and 2-mil varieties of low melt LCP used as bonding layers. The stack-up for the array is shown in Figure 6.

Fabrication begins with cutting several identical pieces of LCP with a $CO_2$ laser. The cutouts make each layer an identical size as well as provide alignment marks for each layer. Two types of alignment marks are used. Pinhole alignment marks are used in the corners of each puck to align multiple distinct layers, while cross marks along the edges are used to align the features with respect to the layer itself. It is also convenient for front to back alignment required for the feed network and ground apertures.

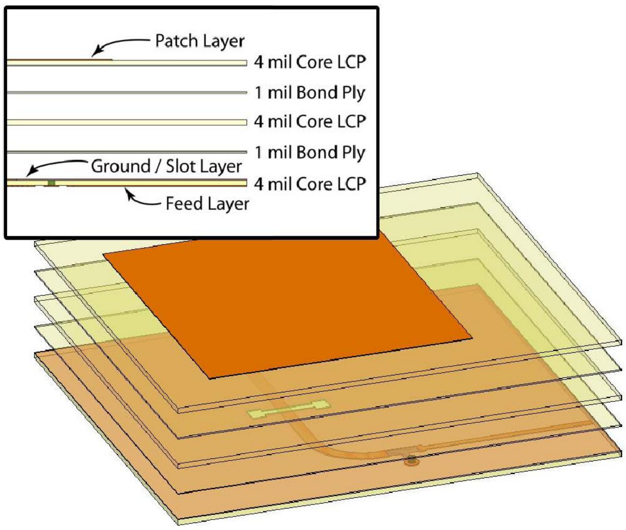


Figure 6. Antenna layer stack-up with all dielectric and metallization layers shown.

This step is followed by laminating a resistor foil to a core layer of 4mil LCP, which will form the feed layer along with the integrated resistors used for the attenuators. Foils were chosen as the resistor integration method for their low cost and compatibility with the bonding process of LCP [5]. After lamination, the feed network, resistors, and calibration structures can be formed using a two-step photolithographic etch process. The first step etches through both the copper and resistor, forming most of the trace structures. The second step selectively removes portions of the remaining copper and leaves the resistor intact. This forms the resistors used for the attenuators, completing the feed layer.

The T-network configuration of the attenuators requires a ground connection for the shunted resistor. This interconnect is achieved through a via from the feed layer to the ground layer. Vias were ablated through the LCP using a 248nm KrF Excimer laser capable of creating holes on the order of tens of microns in diameter. A 1:1 ratio was chosen for the via height to diameter in order to produce the most reliable results, giving the vias a 100μm diameter. The Excimer laser will not ablate the copper foil, which provides a convenient stop layer for the laser drilling as well as necessitates the formation of the feed layer as the first step. Ablation of the LCP leaves a black carbon residue around each drill site that is easily removed with a brief $O_2$ plasma etch.

Upon completion of the ablation step, the vias can then be filled using the same process as the ground plane deposition. A thin seed layer of copper is deposited using either sputtering or electroless plating, followed by electroplating to completely fill the vias. The slotted apertures can then be etched using alignment marks created during the initial layer cut. The radiating patches were fabricated on a separate 4-mil piece of LCP in the same manner. With all of the layers complete, the complete stack was bonded together in the order seen in Figure 6, resulting in the complete antenna array shown in Figure 7.

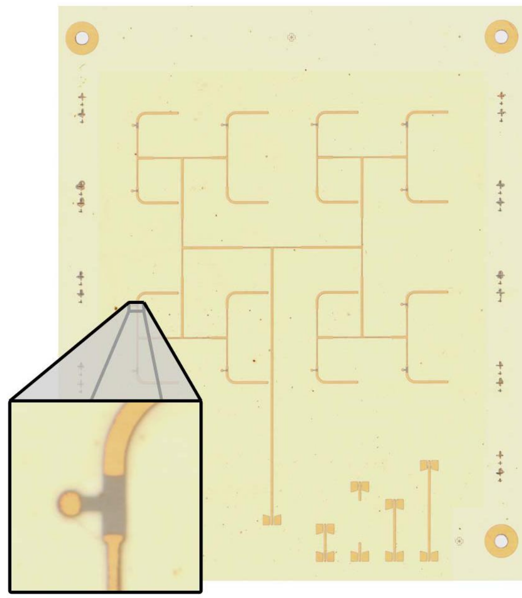

Figure 7. Feed network of the fabricated antenna array. A T-junction attenuator is shown in magnification (inset). The TRL calibration lines can be seen at the bottom right side.

**Experimental Results and Discussion**

In order to demonstrate the effectiveness of the attenuators, a control design was fabricated without the attenuators, delivering equal power to all of the elements. Normalized radiation patterns comparing the two designs can be seen in Figure 8. It can be seen that the beam-shaping attenuators give the array a peak sidelobe level of -25dB, reduced from the uniform case by 12dB at the expense of a slightly larger beamwidth in the main lobe. H-plane results are presented in Figure 8 because it is not susceptible to interference caused by the probe head stage needed to measure the antenna array. The 3dB beamwidth of the binomial array was measured to be 31 degrees, slightly broader than the 28 degree beamwidth that was measured in the uniform array. These results show significant pattern improvements due to the use of attenuators to give the array beam the desired shape.

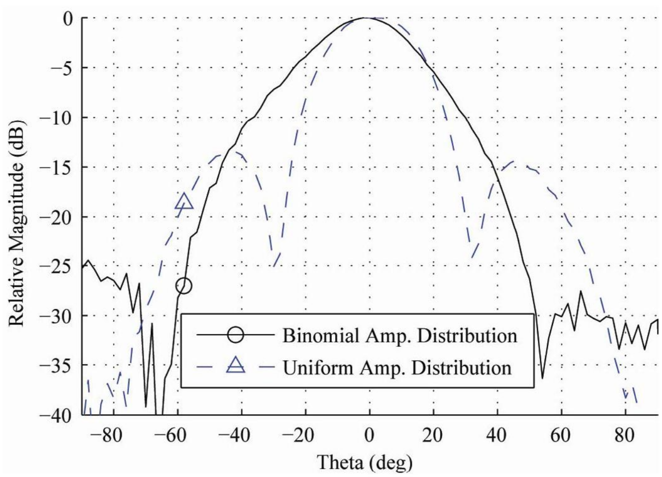

Figure 8. Normalized H-plane co-polarization pattern measurements of the fabricated 4x4 antenna arrays.

**Conclusions**

A binomial array antenna with integrated planar attenuators on a flexible organic substrate for remote sensing applications has been presented. The structure has reduced sidelobe level when compared to a uniform array, effectively increasing the signal to noise ratio at the input of a remote sensing system. Further research includes the integration of MEMS switches in order to increase reconfigurability in the beam-shaping level of the array.


**Acknowledgments**

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