Octave Bandwidth Printed Circuit Phased Array Element

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Abstract
A printed-circuit radiating element for wideband phased array antennas is described which provides a well-matched impedance bandwidth of approximately one octave in the array environment. The main benefit compared to existing octave or more bandwidth array elements (e.g. flared notch, tapered slot or Vivaldi antenna) is that this new element can be etched onto panels that lie parallel to the plane of the array, permitting several rows and columns of elements on the same substrate which reduces cost significantly. Also the array thickness is reduced, and the phase center does not move with frequency. The element can provide polarization diversity. A new low-dielectric constant syntactic foam material was also tested and found to be suitable for plated-thru via holes and bonding for microwave printed-circuits.

Introduction

A printed circuit radiating element for wideband phased array antennas is described. As with most phased arrays, periodically spaced elements are phased to scan the beam over a coverage volume. Array directivity and sidelobes are determined mainly by the number of elements, illumination taper, and tolerances. This element is expected to provide the following features never before successfully combined in one phased array:

Table I. Array Features

Octave(2:1) bandwidth with VSWR less than 2:1 at broadside
Low VSWR over ±30° scan cone for octave band
Graceful degradation outside of octave band and at wider scan angles
Low VSWR provides high efficiency: suitable for transmit and/or receive
Multiple rows and columns of elements on same substrate to reduce cost
Triangular lattice and grating lobe spacing minimizes number of elements
Low element density and "tile" layout provide cost savings
Flat profile, compact and portable
Much less than one-quarter wavelength thickness over ground plane
Electronically switched polarization diversity
Phase center location in element does not move with frequency

This array was computer modeled using different electromagnetic simulation software: Ansoft HFSS, Ansoft Designer, and NEC4.1, to verify and refine the design. Measurements were made on an early model [1]. This patented element has similarities to a wide, inverted, folded, crossed dipole. It may find application as a multifunction, multiband, or ultra-wideband (UWB) array.

Element Geometry

Figure 1 shows a 3D view of the element. It has two metalized layers above a metal ground plane. These three metal layers sandwich two dielectric layers (transparent in Fig.1). The ground plane (not shown) lies near the port labels. All these layers are parallel thereby permitting multiple rows and columns of elements to be etched on the same substrate. The upper layer is seen to consist of four metalized quadrangles fed as four arms of a wide crossed dipole. The upper and lower metalized layers are connected to each other using the 12 small vertical plated-thru via holes seen at the extremities of each dipole arm. The lower metalized

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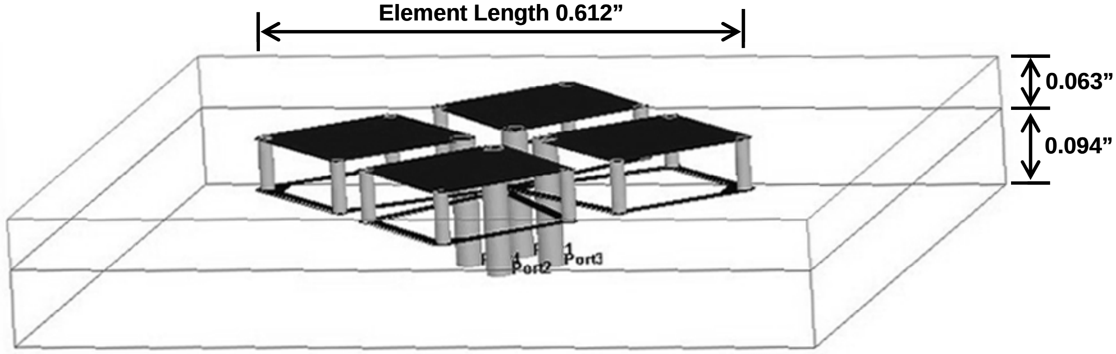

Figure 1. 3D View of One Radiating Element

layer, which is closer to the ground plane, has only the periphery of each quadrangle metalized so there is a hole through each quadrangle, and the four lower quadrangles are connected together at the center. The element is essentially a crossed folded dipole, inverted since its fed from the top layer, and widened.

Four long plated-thru feed vias extend from the ports (at the ground plane) to connect to the innermost corners of the upper layer dipole arms. These four feed vias or probes pass within the perimeter of the lower layer quadrangles without contacting them. These four feed vias are fed as two balanced pairs, and act as balanced transmission lines feeding the radiating elements. In these computer models, the bottom of each of the four feed probes to each element is driven as a 50-ohm coaxial port at the ground plane. In fabrication, the four feed vias would pass down through a single opening in the ground plane and is connected to four stripline, co-planar, or other feed network traces under the ground plane, although that was not tested as yet in hardware. Placing the feed vias closer together (for a low impedance balanced feed line) was found to increase bandwidth, but the spacing between vias must be large enough to allow space for the metalized perimeter traces of the lower layer to join in the center. The main advantage of driving the upper metalized layer instead of the lower layer is ease of fabrication of the feed vias.

HFSS Electromagnetic Computer Model

The array was modeled on a computer using HFSS software, for an infinite array environment. A baseline configuration is described here, although other cases were also modeled. The frequencies modeled were 4-16 GHz, but the design was found to be scalable to other frequencies with minor changes. The elements were driven for circular polarization. The inter-element spacing in the array was 0.707”, which is one wavelength in air at 16.7 GHz. An equilateral triangular lattice was used. To avoid grating lobes when scanning over a conical scan region, this allows ±23° scan up to 12 GHz, ±31° scan up to 11 GHz, and ±59° scan up to 9 GHz (mid-band). The element length and width is 0.612”. The total element thickness is 0.156” over the ground plane, which is 0.12 free-space wavelengths at 9 GHz. A PTFE dielectric (duroid: $\varepsilon_r = 2.2$) or Teflon ($\varepsilon_r = 2.1$) was modeled between the upper and lower metalized layers. A syntactic foam layer (Hytac 36T with $\varepsilon_r = 1.5$) was modeled to fill the space between the lower metalized layer and the ground plane. The thickness of the dielectric layers was constrained to a multiple of 1/32” since those are most readily available commercially. The feed vias have diameter of 0.03125”, with 0.102” center-to-center spacing between opposite vias. Also, via hole probe diameters are normally at least 0.2 times the substrate thickness, so that constraint was observed in this computer model.

Figure 2 shows the computed reflection coefficient (Γ) for the element in an infinite array scanned to broadside. The element’s S-parameters computed by HFSS were phased for circular polarization and summed to get Γ in the infinite array environment. Γ at each of the four ports of an element are plotted, it is seen to be low at most frequencies over the octave from 5 to 13 GHz. Figure 3 shows the same case but with dielectric removed where it is not needed to support the metallization, this dielectric could be removed with a router. It is seen that Γ has been reduced below -11 dB (1.8:1 VSWR) from 6 to 13 GHz.

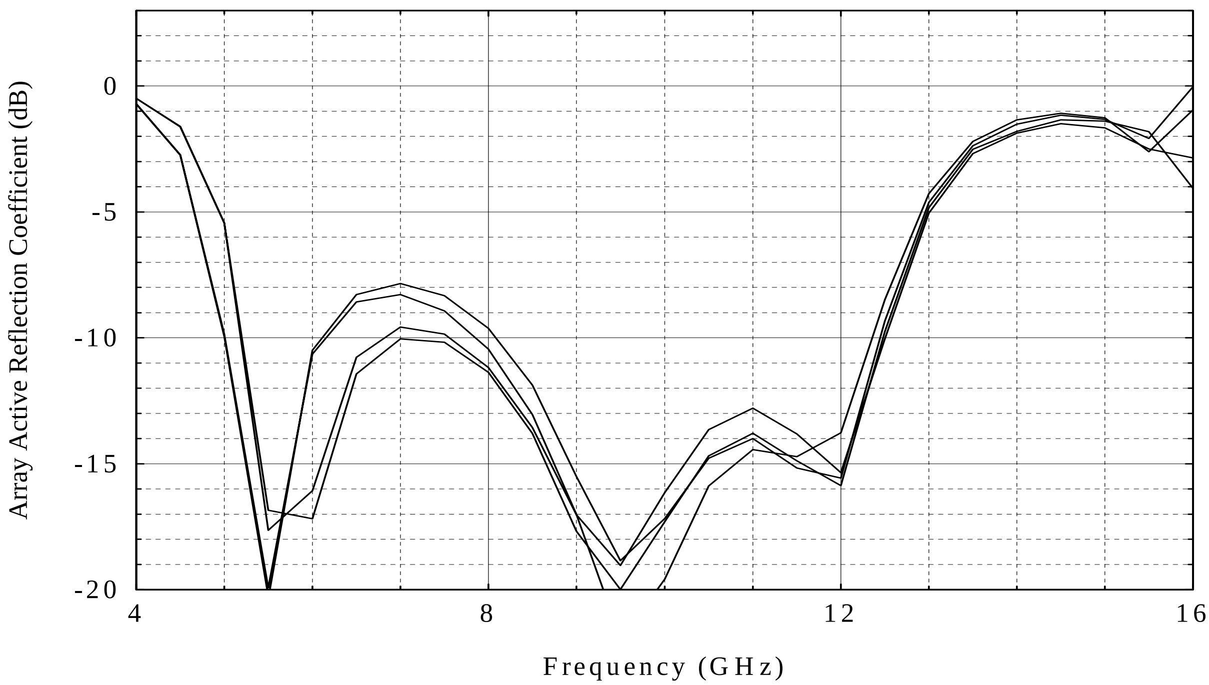

Figure 2. Reflection Coefficient for Broadside Infinite Array, Computed with HFSS. Circular Polarization.

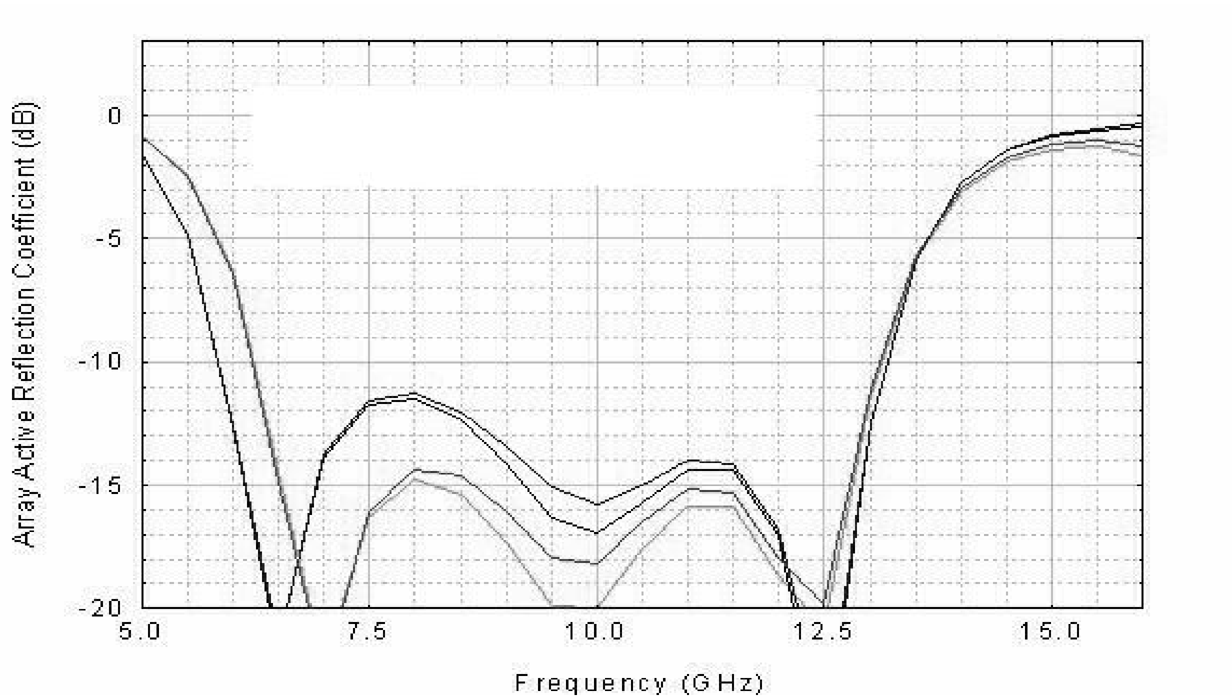

Figure 3. Same Case as Previous Figure but with Some Dielectric Removed Between Elements

This geometry was optimized for broadside in HFSS. The reflection coefficient with scan was not computed due to time limitations, although element patterns were computed and they were smoothly varying with no notches. An earlier UHF version of the array found good scan performance over a ±30° scan cone [1]. There was general agreement between the HFSS and Ansoft Designer computer models regarding the frequency band of best performance (lowest Γ), although not the magnitude of Γ. The HFSS results are shown here because HFSS is probably the more accurate of the two. Also, for the infinite array model, HFSS took less computer run time than Designer.

A superstrate layer over the antenna was also tried in the computer models, it would provide protection from weather, and was found to also improve the element feed impedance match if the superstrate has a very low dielectric constant such as $\varepsilon_r = 1.4$ or less. The superstrate does not need any etching or vias. The best superstrate thickness was about lambda/4 at the top of the band.

Syntactic Foam Spacer with Plated-Thru Via Holes

The modeling showed that reducing the dielectric constant of the substrates improved the reflection coefficient. Therefore, a manufacturing innovation included in the HFSS model was the use of syntactic foam with plated-through vias. Syntactic foam has a low dielectric constant, for example HYTAC-36T has dielectric constant of 1.5 which was used in the computer model as the spacer layer between the lower metalized layer and the ground plane. Lab tests made by a microwave printed circuit fabricator (MCN Corp in Lowell, MA) found that plated through via holes could be successfully made in HYTAC-36T, which had never before been attempted. MCN also thinks the bonding could be accomplished. The maximum temperature that HYTAC-36T can be exposed to is 350 °F, although it could probably go up to 380 °F for less than 2 hrs, and possibly even higher for only 20-30 min which is all the time required for bonding. Bonding agents do exist which need only 375° to 400°F.

UHF Measurements and Computer Models

Measurements were done on an earlier version of the antenna. A 7-element array was tested in the UHF band for VSWR, gain, and radiation pattern, and those test results were published [1]. Those measurements, as well as earlier NEC4.1 computer models, demonstrated over one octave (71%) bandwidth for the center element over a full 30 degree scan cone. The element was patented [2] based on that modeling, which also found that polarization diversity over a wide bandwidth could be obtained by phasing the feed probes. The tested UHF array used coax to feed the lower metalized layer, and used air-loaded elements (etched on a Hexcell sandwich) and hence was more expensive to manufacture and assemble. A subsequent patent [3], and the more recent HFSS modeling described above for printed-circuit fabrication, would make the array more affordable than the previously published and tested configuration.

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