### 12-to-1 Bandwidth All-Metal Vivaldi Array Element

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#### Introduction

The notch element is a classic example of a wideband antenna that functions very well as a stand-alone radiator and also as an element in wideband phased arrays [1, 2]. Also known as a Vivaldi Aerial or tapered-slot antenna, the Vivaldi has seen perhaps the most widespread use in ultra-high bandwidth applications (> 3:1 Bandwidth) of any type of element due to it's robustness in design and range of manufacturability. Part of its popularity stems from the ease with which inexpensive printed-circuit board manufacturing can be used to create large arrays. It is also popular in high-power radar applications as well as ultra-wideband military applications, where all-metal designs are typically preferred. In this paper, a 12:1 bandwidth all-metal Vivaldi array element design is presented that can be easily machined from metal sheets and fed via standard SMA coax connectors. No soldering is required and assembly is simple and modular.

### Description

The constraints under which this element was designed included: (1) it should be all metal, (2) there should be no soldering required for assembly, (3) it should be fed via a standard SMA connector inserted directly/straight into the back of the element, (4) achieve a target bandwidth of at least 8:1, (5) dual-polarized, (6) assembly should be modular to make it simple to swap array components. What follows is the design achieved subject to these guidelines.

For fabrication and weight considerations, 6061 Aluminum was chosen as the base material for construction. Wire-EDM cutting technology was used to shape the elements from the base metal stock. In order to support a standard SMA connector with a typical outer diameter of 0.162", common <sup>1</sup>/4"-thick Aluminum sheet stock was used. In the proprietary feed design of the element, a 0.162" diameter hole is drilled in the back of the element, through which a standard bulkhead-type SMA connector is simply inserted and either pressed or bolted in place without the need for soldering. The elements are structurally much thicker than common embodiments of tapered-slot designs – approximately 1/3 of the array cell size, or 1/3 as thick as they are wide. This is done primarily for two reasons: (1) such that it is possible to create a cylindrical hole large enough for a coax line that can feed in directly (straight) from the back and (2) it pushes the undesirable resonant frequency associated with the cavities formed by the element lattice arrangement well-above the highest frequency of operation.

The cavity of the slot-line open is flush with the backplane of the element. Because the cavity is a resonant structure whose presence can have an ill effect on the bandwidth of the radiator, it has been designed and positioned is such a way that any resonances associated with the cavity fall above the highest operational frequency. In order to feed the coax straight through the rear the element, it is necessary to bend the slot such that it turns 90 degrees perpendicular to the direction of radiation. In part, this is difficult to do because of the cramped space within the element cell. To compensate, the slot must be meandered which has been observed to cancel some of the cross-polarization interference occurring from the field asymmetry introduced by turning the slot. In the final design, the element is roughly  $\lambda/2$  wide,  $5/32\lambda$  thick, and  $3\lambda$  long at the high end of the frequency range. The designed frequency range is roughly 725MHz-8.7GHz.

For the linear array, sub-arrays are formed in modular groups of 8 elements. A 32element array is formed from four sub-arrays fit into a test fixture as shown in Figure 1a. The 8x8 core of dual-polarized elements shown in Figure 1b is also cut using the same wire-EDM technology. This core is intended as a modular part of a larger array structure, but has undergone rudimentary performance testing here.

## Results

The linear and dual-polarized elements have been designed and fully characterized using infinite-by-finite and infinite-by-infinite simulations performed with proprietary in-house and commercial FEM-based simulation tools. At the time of submission, several preliminary vector network analyzer measurement sets have been taken on the 32-element linear array and also the dual-polarized 8x8 array core.

To validate the array operation, we first evaluate how well the VSWR matches with the infinite design case. It is expected that elements near the center of the array will perform asymptotically similar to the infinite array case. An element near the center of the linear array (number 16 of 32) was chosen for this study. To synthesize the input impedance seen at this element with all elements of the array excited at uniform phase and amplitude (noted as  $\overline{S}$ ), the superposition of 32 measurements are taken (noted as:  $\overline{S}_{16,16} = \sum_{n=1}^{32} S_{n,16}$ ), where  $S_{n,m}$  is the isolated reflection seen at element *n* with element *m* excited, all other ports matched. Note that for this 32-element array, there are 32(32-1)/2 = 496 unique S-Parameter measurements that can be taken to fully characterize the scattering matrix of the array. Once collected, it is possible to synthesize any combination of phase scanning and amplitude weighting [3].

Figure 2 shows the agreement between the synthesized impedance measurement for the  $16^{th}$  element of the array compared with the infinite design case. It can be seen that the impedance of this center element of the array agrees quite well with the infinite design case. A similar measurement set was taken for a central

element of the dual-polarized 8x8 core. For this central element, Figure 3 shows the comparison with this synthesized measurement and the infinite design case. While the agreement is quite good at the high end of the frequency spectrum, it has not fully converged at the low end of the spectrum due to the limited core size. Note that this element requires a two-dimensional lattice to function at the low end of the band. For the same element, Figure 4 shows the comparison between simulations and measurements for several scan angles.

# Discussion

Presented here is a design for an all-metal ultra-wideband antenna element that can achieve bandwidth of 12:1. While the design itself is worth reporting in its own right, this array element was designed as part of a study on low-cost ultrawide bandwidth arrays reported here. For more robust design validations, finite array simulations will also be performed to mimic the set of S-Parameters collected as measured data. For the linear array, it is planned to collect a complete set of S-Parameters. A meaningful sub-set of S-Parameter measurements are to be collected from the dual-polarized core as well. Scheduled for the near future are pattern measurements using a fixed set of static beam formers for several scan angles over roughly 700MHz to 10GHz. A more comprehensive set of simulations and measurements are underway and will be presented at the conference. This work is sponsored by the Office of Naval Research.

# References

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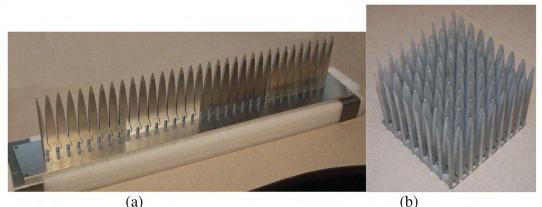


Figure 1. (a) 32-element linear array, (b) dual-polarized 8x8 array

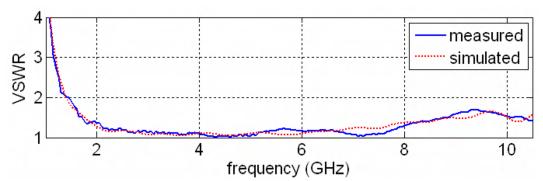


Figure 2. Comparing the measured VSWR of a central array element in the linear array to the infinite design case (broadside operation)

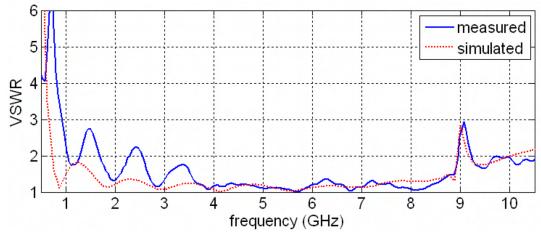


Figure 3. Comparing the measured VSWR of a central array element in the dualpolarized array to the infinite design case (broadside operation)

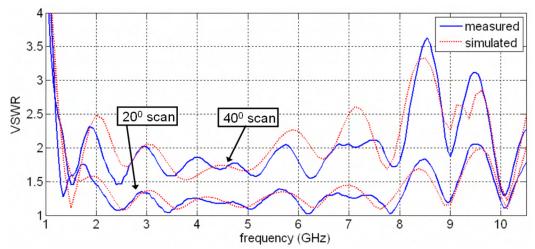


Figure 4. Comparing the measured VSWR of a central array element in the linear array to the infinite design case (several scan angles)