A Fragmented Aperture-Coupled Microstrip Antenna

[*]Naftali Herscovici[1], James Ginn[2], Tony Donisi[3], and Boris Tomasic[4]

[1] Air Force Research Laboratory, Sensors Directorate, Hanscom AFB, Bedford MA
[2]University of Central Florida, Orlando FL
[3]Ansoft Corporation, Pittsburgh, PA
[4] Air Force Research Laboratory, Sensors Directorate, Hanscom AFB, Bedford MA

ABSTRACT

This paper summarizes an effort to obtain a wideband aperture-coupled fragmented microstrip antenna. The antenna is modeled as a 2.5D structure, and is optimized using a Genetic Algorithm (GA). The realistic physical feed, a microstrip-fed slot, is also included in the optimization process.

1. INTRODUCTION

The concept of fragmented aperture antennas is well-known [1-4] and has been dealt with for quite a while. In order to optimize this class of antennas, many different types of optimization algorithms were used. The complexity of these optimization schemes require some compromise, typically related to the modeling of the feed mechanism. Unfortunately, to simplify the optimization, ideal sources such as "Voltage Gap" or “Elementary Current Sources" were imposed, rather than realistic feed structures. This approximation, while having some value in understanding of the characteristics of the radiating structure, often generates results that are highly unrealistic and sometimes misleading.

In this paper, an attempt is made to incorporate a *realistic feeding mechanism* in the analysis and optimization of a fragmented microstrip antenna. The aperture-coupled microstrip feeding mechanism is chosen for a number of reasons:

1. No reflective ground-plane (at least $\lambda/4$ separation from radiating aperture) required
2. Additional degrees of freedom introduced by the slot and the stub associated with the feeding line
3. In an array environment, fed by a corporate feed network, the spurious radiation does not interfere with the forward hemisphere radiation
4. The multilayer structure does not include vias and is easy to manufacture

The paper presents the results of this optimization for the *single element in free space*; future work will address the case of the *radiating element embedded in an infinite array*. The design methodology of the antenna is similar to the one described in [5,6]. The optimization process consists of dividing the microstrip patch area into a number of cells, where each cell may or may not be metalized. A specific layout is defined by a binary string of “zeros” and “ones”, where “0” = non-metallization, and “1” = metallization. The initial binary string is chosen at random and translated into an initial layout which is subsequently analyzed by a numerical electromagnetic solver (Ansoft's Designer Nexxim package (Ver. 4). The results are delivered back to the GA optimizer which calculates the fitness of each binary string based on a predefined goal function. Using tournament selection, mating occurs between selected parents with uniform crossover and no additional mutation. A new population ready for testing is formed comprising the best parent from the previous generation and the children generated from mating. This iterative process continues until satisfactory results are obtained or convergence occurs. A typical run of the optimizer takes about 8 hours on a 64 bit computer running Windows

978-1-4244-2042-1/08/$25.00 ©2008 IEEE

XP. The population size is 5 and the number of iterations is 300. The GA goal function (to be minimized) is defined as the bandwidth over which VSWR is less than 2:1. The radiating element layer thickness, the slot length and the feeding microstrip line stub length are also included in the optimization. While this technique has been widely used in the past [5,6], in this case the cells are defined a priori to overlap, in order to avoid impractical one-point metallization cell contacts.

2. RADIATING ELEMENT

The geometry of the antenna is shown in Figures 1 and 2. It consists of two substrate layers: radiating and feeding layers. The fragmented metallization is printed on the top of the radiating layer. The slot is etched on the ground plane separating the two layers and is fed by a microstrip feed line as also shown in Figure 2b.

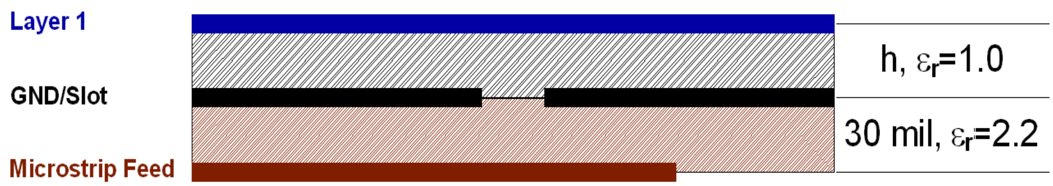


Figure 1 - The Radiating element layer stack geometry

For a fixed 2D square area of 30 x 30 mm the fragmented microstrip metallization layer is divided into 18×18 cells, as shown in Figure 2a. The layout is symmetric with respect to both x- and y-axes to generate well-behaved patterns. The slot is located on the x-axis and centered with respect to the y-axis (Figure 2b). The microstrip feed line is parallel to y-axis and ends with an open-ended stub similar to that described in [7] and [8].

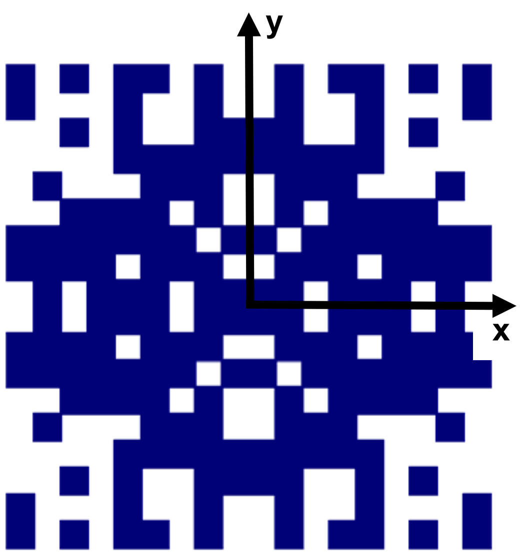


Figure 2a - The layout of the optimized fragmented aperture

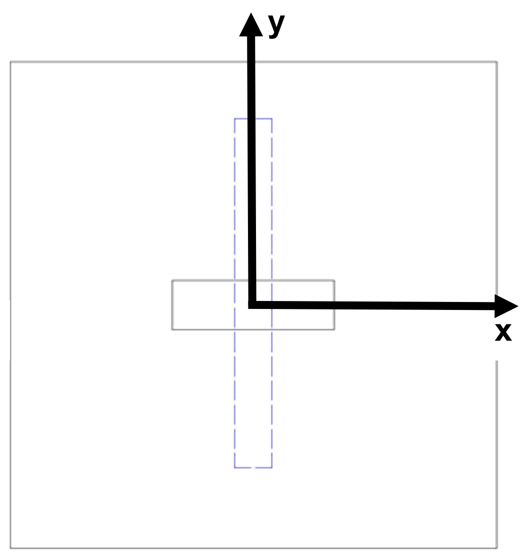


Figure 2b - The feeding layer layout

3. OPTIMIZATION RESULTS - SINGLE ELEMENT IN FREE SPACE

As mentioned above, the goal function is defined as the bandwidth over which the VSWR of the antenna is less than 2:1. The thickness and relative permittivity of the feeding substrate are fixed, while the slot dimensions, the stub length and the top substrate thickness are variables in the optimization process. The relative permittivity of the top substrate is 1.

Figure 3 shows the return loss of the optimized antenna while Figure 4 shows the gain and directivity in the broadside direction. As shown in Figure 5, the cross polarization in the principal planes is extremely low (below -40 dB). Note the similarity between the E- and H-plane patterns which indicates that the element can provide very good axial ratio (CP) over a wide angular sector.

As in any aperture-coupled radiating elements, the front-to-back radiation ratio is somewhat of a concern. However, solutions proposed in the past for this problem still have to be investigated to assess their impact on the broadband capabilities of this element.

For the *single element in free space*, and for this set of fixed parameters, the best calculated bandwidth achieved is better than 38%. The size of the optimized antenna in wavelengths is given in Table I.

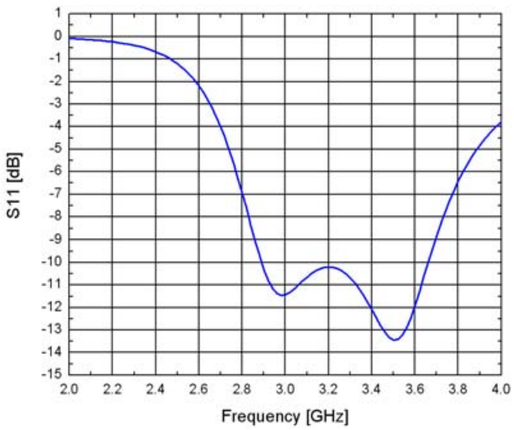


Figure 3 - The antenna return loss

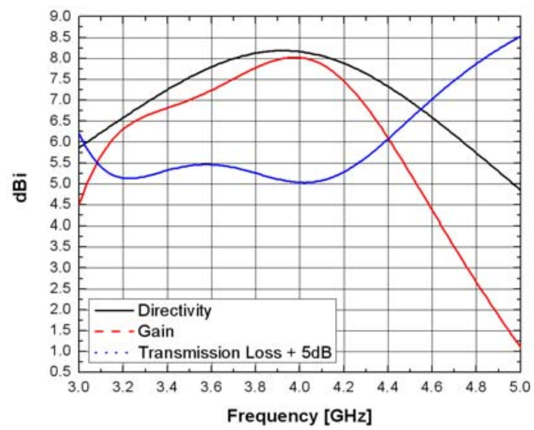
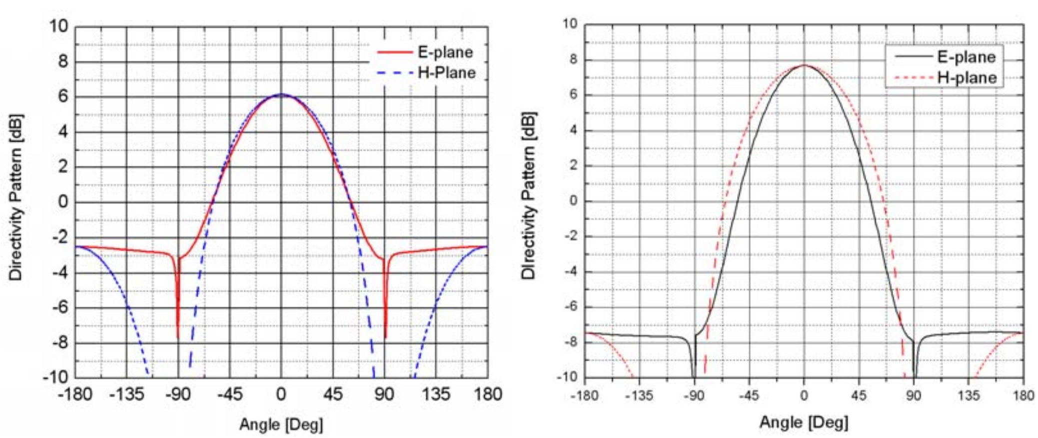


Figure 4 - The Antenna gain and directivity



a. b.

Figure 5 - Simulated Radiation patterns
a. Radiation Patterns at 3.08GHz,
b. Radiation Patterns at 4.27GHz

Table I - Dimensions of the Optimized Antenna

Frequency [GHz]	Wavelength [cm]	X_Dim,Y_Dim [λ]	Z_Dim [λ]
3.08 (F_{low})	9.74	0.31	0.10
4.27 (F_{High})	7.03	0.43	0.14

4. CONCLUSIONS

A method for the synthesis of an aperture-coupled fragmented microstrip antenna was demonstrated. The results obtained for this first design iteration show the potential of this antenna for low-profile, wide-band applications. Additional configurations will be investigated in the future including their behavior in the array environment. A radiating element was designed to operate over more than 38% bandwidth, with VSWR<2:1.

REFERENCES

[1] James Geoffrey Maloney, Morris Philip Kesler, Paul H. Harms, Glenn Stanley Smith US 6,323,809 B1 - fragmented aperture antennas and broadband antenna ground planes.
[2] James C. Maloney and all - Switched Fragmented Aperture Antennas, *IEEE AP-S International Symposiu*m, Salt Lake City, UT, July 2000, p310-313.
[3] B. Thors, H. Steyskal, H. Holter, "Broad-Band Fragmented Aperture Phased Array Element Design Using Genetic Algorithm", IEEE Trans. AP, Oct. 2005.
[4] H. Steyskal, D. Hanna, "Design Aspects of Fragmented Patch Elements for Phased Arrays", IEEE Antenna and Propagation Society International Symposium, Honolulu, Hawaii, June 2007.
[5] J. Michael Johnson and Yahya Rahmat Samii, "Genetic Algorithms and of Methods of Moments (GO/MOM): A Novel Integration for Antenna Design", IEEE Antenna and Propagation Society International Symposium", Montreal 1997, pp.1664-1667.
[6] Naftali Herscovici, Manuel Fuentes Osorio and Custódio Peixeiro, “Miniaturization of Microstrip Rectangular Patches using Genetic Algorithms”, *IEEE AP-S International Symposiu*m, Boston, MA, July 2001.
[7] N. Herscovici and D.M. Pozar, "Full-Wave Analysis of Aperture-Coupled Microstrip Lines", IEEE Transactions on Microwave Theory and Techniques, vol. 39, July, 1991 pp.1108-1114.
[8] D. M. Pozar, “A Reciprocity Method of Analysis for Printed Slot and Slot Coupled Microstrip Antennas”, IEEE Trans. Antennas and Propagation, vol. AP-34, pp. 1439-1446, December 1986.