Optimization of Pixelated Antennas

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***Abstract*— The Computer Aided Design of antennas requires a number of design trades to balance antenna performance and simulation efficiency. For a pixelated antenna, one critical trade to be made is the pixel size of the antenna- the minimum step size with which the antenna design can be manipulated. Using a smaller pixel size leads to a higher resolution design that can achieve performance closer to the theoretical limits; however, the pixel size is also related to the amount of time required to optimize the antenna. An optimal value exists for the pixel size based on electrical size and desired frequency of operation.**

I. Fragmented Aperture Overview

The Fragmented Aperture [1] and the Agile Aperture Antennas [2] are techniques that both pixelate the antenna surface(s). Since the antennas resulting from these designs are not based on a canonical structure (such as a dipole or a spiral), the design process is more open ended and optimization is more time consuming. These drawbacks are balanced by a flexibility that can provide antenna performance not possible with canonical designs. These include extremely wide bandwidths [3], designs optimized for conformal applications [4], and even custom radiation patterns [5].

In this paper, the pixels referenced above are pieces of metal that can be set or cleared similar to a bitmap description on an antenna. Fig. 1 and Fig. 2 show different sized pixels for a 4 GHz antenna. Smaller pixels provide more flexibility for the antenna design but also increase the design time: the 8 mm pixel design has 225 bits of variability while the 4 mm pixel has 900. As a comparison, an equivalent dipole design on a similar substrate would be 4 and 5 bits, respectively, and the final design could be estimated with a simple equation.

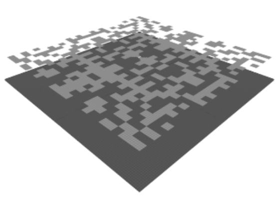

Fig. 1. 4mm pixels on a 12cm square antenna.

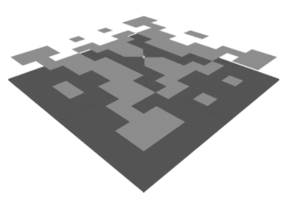

Fig. 2. 8mm pixels on a 12cm square antenna.

II. Pixels as Basis Functions

When designing an antenna using an optimizer, a basis is selected either implicitly or explicitly. Understanding one's basis is important because it sets the complexity required for the design and bounds the performance possible. For example, the basis for a dipole is the length and width of the wires and provides for a specific type of narrowband radiation; the basis for a spiral is the number of turns, the flare rate for the inner and outer radii, and the distance between the feed points. The spiral has more degrees of freedom, adding complexity to get capability. A more flexible basis should always provide more performance for the added complexity.

These choices are important not only for the Fragmented Aperture Antenna, but also for the Agile Aperture Antenna. The Fragmented Aperture Antenna is a fixed pattern made of copper. The Agile Aperture Antenna is designed with metal pads connected with RF switches (Fig. 3) that enable dynamic changes in performance. The performance available to an Agile Aperture Antenna is limited in part by the requirement for the electronics [6], since the metal squares that hide the electronics are fixed scattering elements on the aperture and are not parameters that can be removed during optimization. Therefore, the Fragmented Aperture will generally realize a more efficient design for a fixed beam, while Agile Apertures trade efficiency for the ability to change beams dynamically.

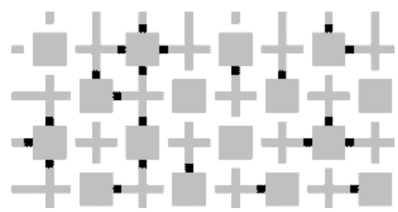

Fig. 3. Pixelated Agile Aperture Antenna- fixed metal is grey, closed swiches are black, open switches are white.

III. Resolution Impacting Performance

When an antenna is designed with a fixed pixel resolution for different frequencies, a "breakpoint' is found where the performance no longer matches the ideal aperture gain limit (1). For the Fragmented Aperture antenna with 1mm pixels, this occurs just above 6.5GHz (Fig. 4). Different pixel sizes will result in different breakpoint frequencies since the breakpoint is a function of the electrical size of the pixel (Fig. 5). While the overall size of the antenna affects the ideal aperture gain limit, it does not strongly affect the frequency breakpoint- increasing antenna size can increase gain but will not change the efficiency.

$$G_{ideal} = 4\pi * Area/\lambda^2 \qquad (1)$$

Resolution is a function of the electrical size of the pixel, and it follows that the breakpoint should scale with size. However, the resolution is set in three-dimensional space, and therefore it should not be expected to track the breakpoint frequency linearly. It has been found that (2) provides a useful prediction tool for the breakpoint frequency for a given antenna

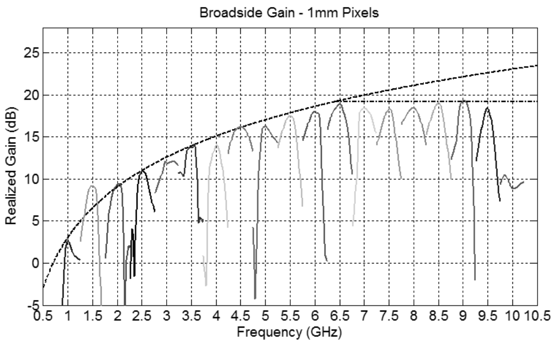

Fig. 4. Breakpoint for a single resolution of Fragmented Aperture Antenna. Each gain curve is a different design at this resolution.

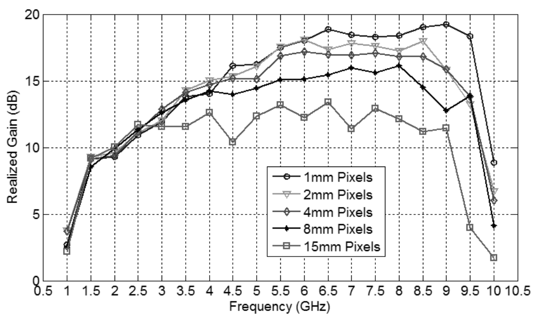

Fig. 5. Realized gain vs frequency plotted for each resolution of simulated fragmented aperture antenna.

design type. The antenna type, the feed and the materials used can influence the Break Frequency Constant, c_{BF}. Fig. 6 shows the relationship between pixel resolution and the break frequency for two antennas types. For Fragmented Aperture Antennas, the Break Frequency Constant is around $0.75 GHz \cdot m^{1/3}$. The Agile Aperture Antenna has a more constrained pixel shape, with the constant around $0.4\ GHz \cdot m^{1/3}$.

$$f_{break} = {c_{BF}} \Big/ {\sqrt[3]{\Delta x_{pixel}}} \qquad (2)$$

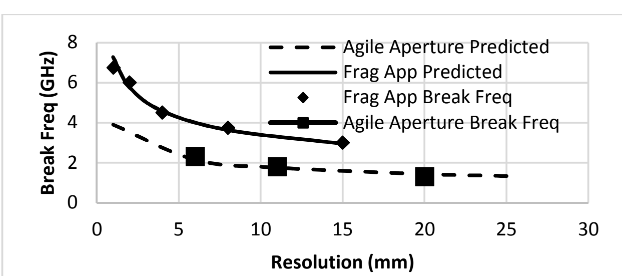

Fig. 6. Break Frequency plotted against antenna resolution for Agile Aperture and Fragmented Aperture antennas. The predictions are plotted based on the simple formula in (2)

IV. Resolution Impacting Convergence

For this paper, all of the simulations were run in a Finite Difference Time Domain (FDTD) code with the same grid size to isolate grid effects on performance, grouping larger numbers of cells to toggle pixels. Typically, grid size would be more tightly coupled to pixel size to improve the runtime since minor changes in simulated performance would be less of a concern.

As with many genetically optimized problems, as the number of bits goes down (with increasing pixel size) the number of evaluations required to achieve convergence is reduced logarithmically (Fig. 7). While not graphed, the improvement in design time is even more pronounced if one allows the cell size to increase with the pixel size (fewer cells in the simulation). For this code, doubling the pixel resolution increases the runtime by a factor of sixteen (x, y, z, and time).

V. Conclusions

The computational effort required to tune a pixelated antenna depends on the resolution with which one can modify the metal. A finer control of the metal pattern improves the ability to tune the antenna. However, too high a resolution can make the design time unnecessarily long, either wasting time or causing convergence to take too long for an optimal solution to be found. The optimal resolution sets the pixel size such that the break frequency is just above the maximum desired frequency. The optimum resolution can be derived from the Breakpoint Frequency Constant for a given type of antenna.

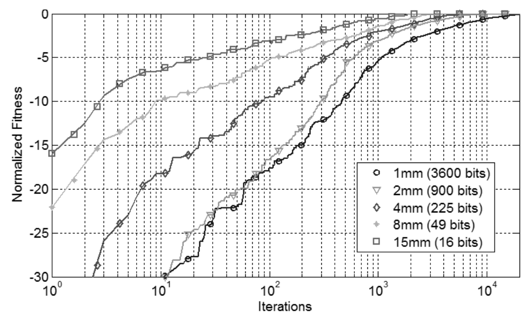

Fig. 7. Normalized Fitness vs Number of Iterations Run

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