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Conformal Antenna Array Design on a Missile Platform

Applications, ranging from communications to radar and even medical devices, depend on antenna arrays. Hand calculations successfully facilitate the construction of stand-alone arrays; however, what happens when the mounting platform becomes a part of the radiating system? Basic analytic techniques cannot easily account for obstructions created by aircraft engines, re-radiation from wings, irregular ground planes of cars or the curvature of a missile.

Antennas and antenna arrays targeted toward vehicular applications, often further complicate the design process with additional restrictions. Aircraft, in particular, require consideration of aerodynamic effects and the impact on radar scattering caused by the integration of external systems. As a result, designers tend to incorporate conformal antenna elements that cannot be realized through basic antenna theory.

These applications require 3D simulations to ensure that the final design meets all requirements, before physical prototyping or manufacturing can begin. This application note demonstrates the process of adding an electrically steerable, conformal antenna array to the body of a high speed missile. A specified surface area on a generic missile body and a set of design goals has been provided to illustrate the challenges of designing the array; however, this example does not represent any actual missile or antenna system in production.

PROJECT GOALS

The design goals of the conformal missile array include an operating frequency of 2.4 GHz, with a main beam gain greater than 10 dBi and sidelobe levels at least 20 dB down from the peak gain. The array must scan from broadside of the missile up to a 45° forward tilt toward the nose of the projectile. The missile is 2.3 m long and 24 cm in diameter. The array will be located on the cylindrical body of the vehicle, cannot interfere with the control surfaces and must fit within a 1 m by 10 cm footprint. For this application note, the commercial software package XF7 will be used to generate the simulated results.

ARRAY ELEMENT DESIGN

The first step of the process is to choose and design a single array element. The aerodynamics of the missile will be extremely sensitive to any perturbation to the surface, so a

Kyle Labowski, Christopher Penney and James F. Stack, Jr.
Remcom Inc., State College, PA

TABLE I PATCH PARAMETER EVOLUTION		
Antenna	**Feed Offset (mm)**	**Patch Diameter (mm)**
Patch Antenna (Initial)	4.982	44
Patch Antenna (Final)	7.5	44.5
Bent Patch Antenna	7.5	45.25

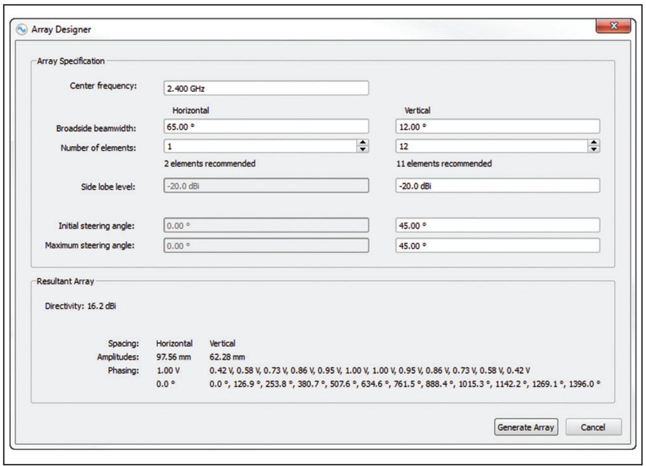

Fig. 1 Inputs to the array designer tool.

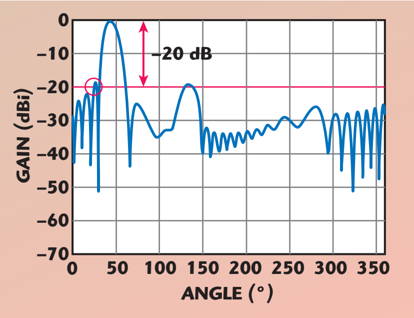

Fig. 2 Simulated antenna gain vs. angle.

planar conformal antenna is required. A circular patch antenna is chosen for this example. Several books, Balanis[1] for example, provide detailed design processes for the patch. Following the analytic design, a brief tuning process ensues. A parametric investigation of the feed location produces an antenna with an excellent return loss of 20 dB and a peak gain of 7.5 dBi at 2.4 GHz.

Having achieved acceptable performance with the flat patch, the next level of complication is introduced. XF7's CAD modeling tools bend the patch, substrate and ground plane to match the curvature of the missile body. XF7's conformal meshing tool allows the software to precisely capture the effects of this bend during simulation. The bend causes the operating frequency to shift slightly higher than desired to about 2.45 GHz; however, a quick parameter sweep finds an increased patch diameter that returns the operating frequency to the desired point. ***Table 1*** demonstrates the evolution of the patch parameters from the initial analytic design to the curved implementation.

ARRAY DESIGN

For the next step, a script from Remcom's XTend Script Library synthesizes an array design, based on the specified performance criteria. The script employs a Fourier transform technique to determine the appropriate amplitude and phasing of each array element and applies a modified Taylor distribution to the amplitudes to better control the sidelobes. As shown in ***Figure 1***, the inputs to the tool are the center frequency of 2.4 GHz, the horizontal beamwidth of 65°, the vertical beamwidth of 12° and the desired sidelobe suppression of 20 dB down from the peak. A maximum electrical downtilt of 45° is also entered. The script-based GUI recommends the minimum number of elements required in each dimension to meet the specifications and provides an estimated directivity of the proposed array.

The script suggests a 2 × 11 element array; however, the limited space on the missile body only accommodates a single column of antenna elements. The user opts for an initial design, using a 1 × 12 array of the circular patch elements and the script prepares the project using the calculated spacing, phases and amplitudes. The modified project uses parameterized spacing and amplitudes to expedite possible future parametric investigations or optimization. The element phasing is defined as a function of electrical downtilt to provide control over beam steering.

As with any simple analytic process, the Fourier transform technique includes certain assumptions. This approach assumes the radiation emanates from a uniformly illuminated aperture, which fails to account for the non-uniform field produced by the actual antenna elements. It also neglects fringe effects from the ground plane, substrate and edge of the antenna. As a result, it is expected that the initial array design may fail to meet some requirements and the initial flat design simulation results, shown in ***Figure 2***, indeed demonstrate a slightly high sidelobe level.

XF7 provides multiple approaches to address this issue. A parameter sweep or optimization could be used to refine the array parameters in order to improve performance; however, a simpler option is to repeat the array design process with stricter criteria. The designer is run again with a tighter restriction of –34 dB sidelobe suppression. Following this process, the flat array greatly exceeds the target performance criteria as evidenced by comparing the blue and green plots shown in the revised radiation pattern of ***Figure 3***.

Having verified the array performance with the simple planar element, the user now applies the array definition to the previously tuned curved elements. The red plot in Figure 3 indicates that the curvature negligibly affects overall array performance, so no further tuning is required at this stage. The array is found to have a peak gain of nearly 14 dBi with sidelobe levels that exceed the original specifications.

FINAL VALIDATION

The user integrates the curved array with the missile body in order to validate the overall design. As expected, the presence of the missile body does change the performance of the array and the final shape of the gain pattern; however, the resulting pattern still meets the design criteria. The final system exhibits greater than 14 dBi gain. Sidelobe suppression exceeds 32 dB as seen in the magenta plot of Figure 3. Altogether, the design requires no fur-

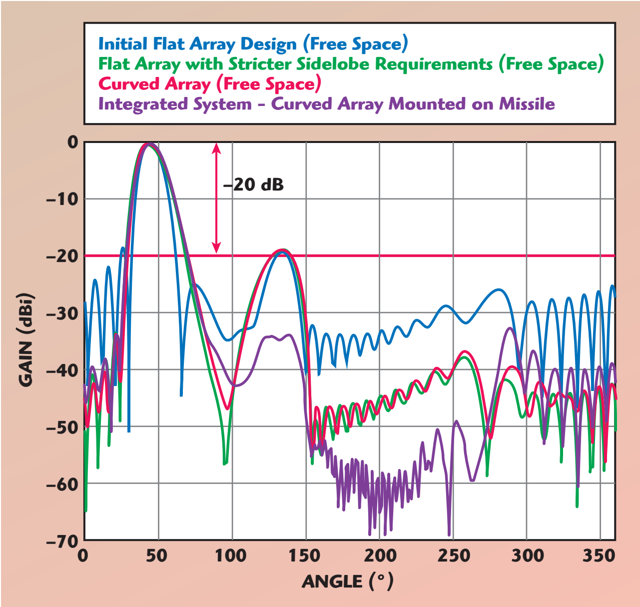

Fig. 3 Optimized simulated antenna gain vs. angle.

TABLE II **SIMULATION TIME FOR DIFFERENT GPU**	
Hardware	***Run Time (H:MM:SS)***
Intel Core i7 CPU (2.8 GHz); 8 threads	3:13:00
Nvidia Tesla C2070 GPU; 1 GPU	0:29:40
Nvidia Tesla C2070 GPU; 2 GPUs	0:14:10
Nvidia Tesla C2070 GPU; 4 GPUs	0:08:50
Nvidia Tesla C2070 GPU; 6 GPUs	0:07:20

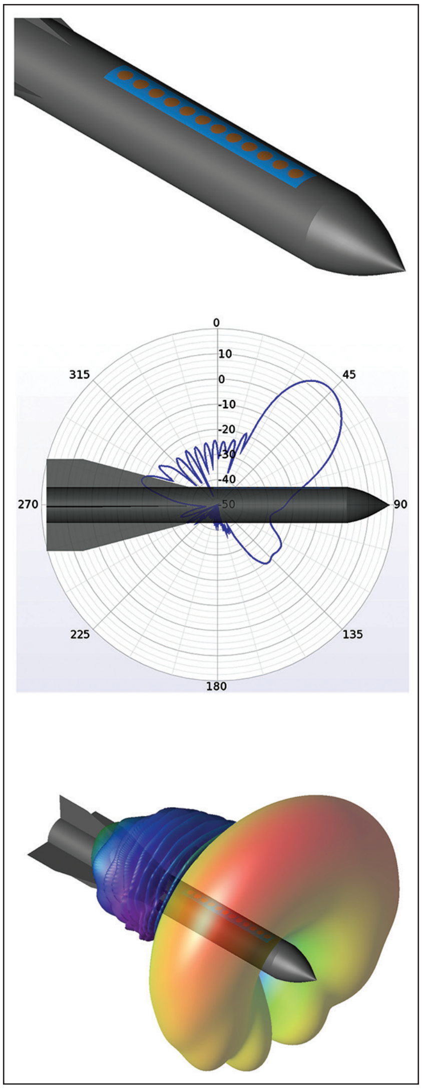

Fig. 4 Completed array on the missile body and two gain patterns.

ther adjustments. ***Figure 4*** displays multiple views of the completed system including a close-up view of the completed array on the missile body and two gain patterns. For these plots, the electrical downtilt parameter has been set for the full 45° forward tilt.

HARDWARE AND SIMULATION TIMES

The iterative nature of the design process often threatens to consume an unacceptable amount of time. This application note required numerous simulations to progress from the analytically designed patch through the initial array design to the final integrated system. In a real production environment, the number of simulations can easily increase by orders of magnitude. Antenna designs are often treated almost as an afterthought and antennas are expected to fit within ever decreasing volumes in order to make room for other system components. The evolution of the overall system generally translates to significantly modified requirements for the antenna subsystem.

The entire design and workflow of XF7 helps address the challenges of working within an iterative process; however, XF7's GPU acceleration offers the most easily measured time savings. It tremendously improves EM simulation performance by leveraging the power of CUDA capable GPUs from NVIDIA. For example, the fully-integrated system in this example requires approximately 1.5 GB of RAM for simulation. An eight core Intel core i7 CPU needs over three hours to complete this work. However, the same simulation can be completed in just over seven minutes, using multiple GPUs. See ***Table 2*** for more detailed timing information.

CONCLUSION

This application note focused on the design of a conformal array on the surface of a missile. The initial circular patch design chosen provided a good start for developing the curved array, due to the minimal impact that bending had on the return loss and gain of the antenna. The array synthesis tool rapidly provided a good design, with only slight adjustment needed to reach the required sidelobe levels. The final design was easily integrated into the full missile platform and simulated with good results, completing the final step in the process. It was also shown that a complex 3D simulation including multiple array elements with curved surfaces that could take several hours was completed within a few minutes. Applying these techniques together can help increase productivity, while increasing the fidelity of the design, all before physical prototyping has begun. ■

Reference

1. C.A. Balanis, *Antenna Theory*, 3rd edition, John Wiley & Sons Inc., Hoboken, NJ, 2005.

REMCOM®

Remcom Inc.
Tel: 814-861-1299
SALES@REMCOM.COM
WWW.REMCOM.COM