

Designing a Custom Antenna

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1 Abstract

Designing your own antennas may seem to be a daunting task. It involves understanding antenna design and learning how to use an EM Simulation Software. With all of the design components required for the EEC 134 Senior Design Radar Project, for some teams it was an easy decision to rely on what was commercially available and purchase pre-made antennas. However, if done correctly, using a custom designed antenna will allow more flexibility in your design, save money, and you will have the excitement of seeing your design working in real life. I encountered many bumps in the road to designing a custom made antenna, and this application note will outline tips and lessons I learned to help future teams navigate their way through designing their own antennas.

2 Picking the Correct Antenna Type

The bandwidth of the antenna will determine the biasing needed for the VCO. Having a wider bandwidth is desirable because that will improve the resolution of the radar system.

$$R = \frac{c}{2BW}$$

It is important to design for acceptable resolution because that will determine the radar system's ability to distinguish between two or more targets in the same vicinity at different ranges. Most of the commercially available antennas designed at 2.4 GHz have good performance at 2.4 GHz, but are relatively narrow band compared to what you can design on your own. Picking the correct antenna type is paramount in the success of your radar system, and it will save you time in the design and testing phases. Below of a list of antenna design options with their estimated bandwidth capabilities.

Type	FBW
Dipole	0.08
Patch	0.03
Horn	1.694
Spiral	1.805

Table 1: Common Antenna Types and their Bandwidth Capabilities [1]

The next step in picking the right antenna type is to look at the specifications of the radar system and what is easily available to you for fabrication. I had taken the Antenna design and RF/Microwave courses and was most familiar with microstripline and patch antennas.

However, in Table 1, it can be seen that patch antennas have the lowest fractional bandwidth, so it is not ideal for the design. Unfortunately, I stubbornly still tried to tweak the conventional patch antenna into something that would work using an array of a novel design. I will go more into detail about how this was a bad decision in the "Understand the Limits of the Device" section.

Playing to my strength in microstripline and patch antennas, and realizing that weight was a component of the final grade calculation, I chose to stick with an antenna design using microstripline. It was especially beneficial because I could order samples (free!) of Rogers board [2] and use the drilling machine in Prof. Leo's lab for fabrication.

The final antenna design I decided on was the Vivaldi Antenna. It had all the same material properties I liked in a patch antenna, and it had a theoretically unlimited bandwidth capability, which made for an easy design. Table 2 lists a collection of possible wideband antenna types that you can do research on and decide if it is right for your radar system.

Type	Experimental BW at 2.4 GHz
Vivaldi	470 MHz, theo unlimited [3]
Inverted F	250 MHz [4]
Slot	120 MHz [5]
Bow Tie	1100 MHz [6]
Yagi Patch	100 MHz [7]

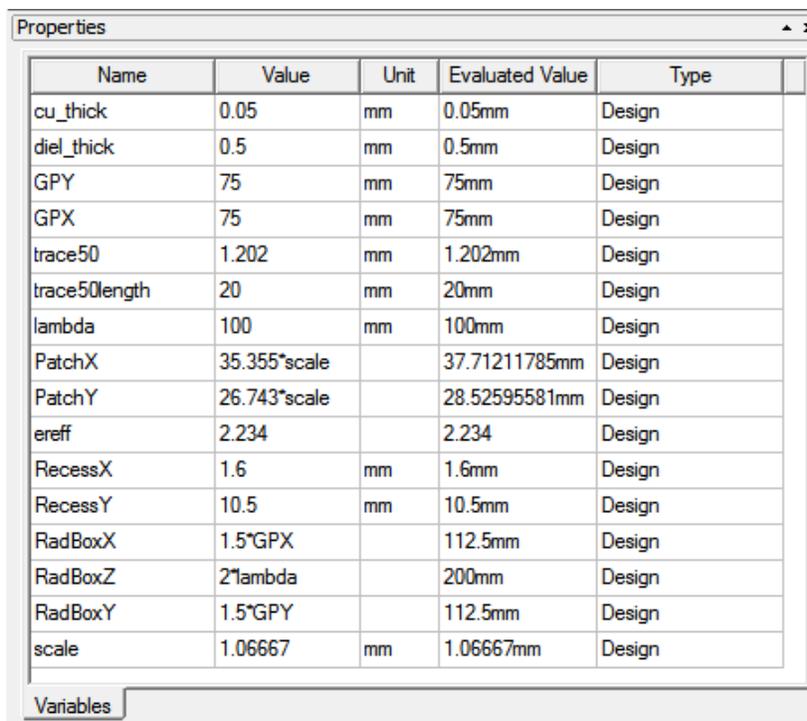
Table 2: Possible Microstrip Antenna Types and their Bandwidth Capabilities [1]

3 Designing in HFSS

If you already know how to use HFSS, the EM simulation software needed to design your antenna, fantastic! If not, a decent user guide can be found here. <http://anlage.umd.edu/HFSSv10UserGuide.pdf>

3.1 Tips for Parametrization

Perhaps the most important tip I will provide in this app note, besides picking the right antenna initially, is to create variables that you can easily parametrize and optimize later on in your design. The initial, and-calculated values will not be your final design, and multiple iterations will be simulated. It is suggested to build variables off fixed data items, like wavelength, as seen in Figure 1.



The screenshot shows a 'Properties' dialog box with a table of variables. The table has five columns: Name, Value, Unit, Evaluated Value, and Type. The variables listed are: cu_thick (0.05 mm, 0.05mm), diel_thick (0.5 mm, 0.5mm), GPY (75 mm, 75mm), GPX (75 mm, 75mm), trace50 (1.202 mm, 1.202mm), trace50length (20 mm, 20mm), lambda (100 mm, 100mm), PatchX (35.355*scale, 37.71211785mm), PatchY (26.743*scale, 28.52595581mm), er_eff (2.234, 2.234), RecessX (1.6 mm, 1.6mm), RecessY (10.5 mm, 10.5mm), RadBoxX (1.5*GPX, 112.5mm), RadBoxZ (2*lambda, 200mm), RadBoxY (1.5*GPY, 112.5mm), and scale (1.06667 mm, 1.06667mm). A 'Variables' tab is visible at the bottom left of the dialog box.

Name	Value	Unit	Evaluated Value	Type
cu_thick	0.05	mm	0.05mm	Design
diel_thick	0.5	mm	0.5mm	Design
GPY	75	mm	75mm	Design
GPX	75	mm	75mm	Design
trace50	1.202	mm	1.202mm	Design
trace50length	20	mm	20mm	Design
lambda	100	mm	100mm	Design
PatchX	35.355*scale		37.71211785mm	Design
PatchY	26.743*scale		28.52595581mm	Design
er_eff	2.234		2.234	Design
RecessX	1.6	mm	1.6mm	Design
RecessY	10.5	mm	10.5mm	Design
RadBoxX	1.5*GPX		112.5mm	Design
RadBoxZ	2*lambda		200mm	Design
RadBoxY	1.5*GPY		112.5mm	Design
scale	1.06667	mm	1.06667mm	Design

Figure 1: Variable Parametrization in HFSS

3.2 Tips for Optimization

It may be desirable to optimize a parameter by sweeping a range of values for a specific variable. This will help narrow down an optimal value and save time. The simulation time will increase, for you will be essentially performing multiple simulations at one time, but it is convenient to "set it and forget it" and come back to see the results. The figure below shows how to optimize a variable for determining the best value.

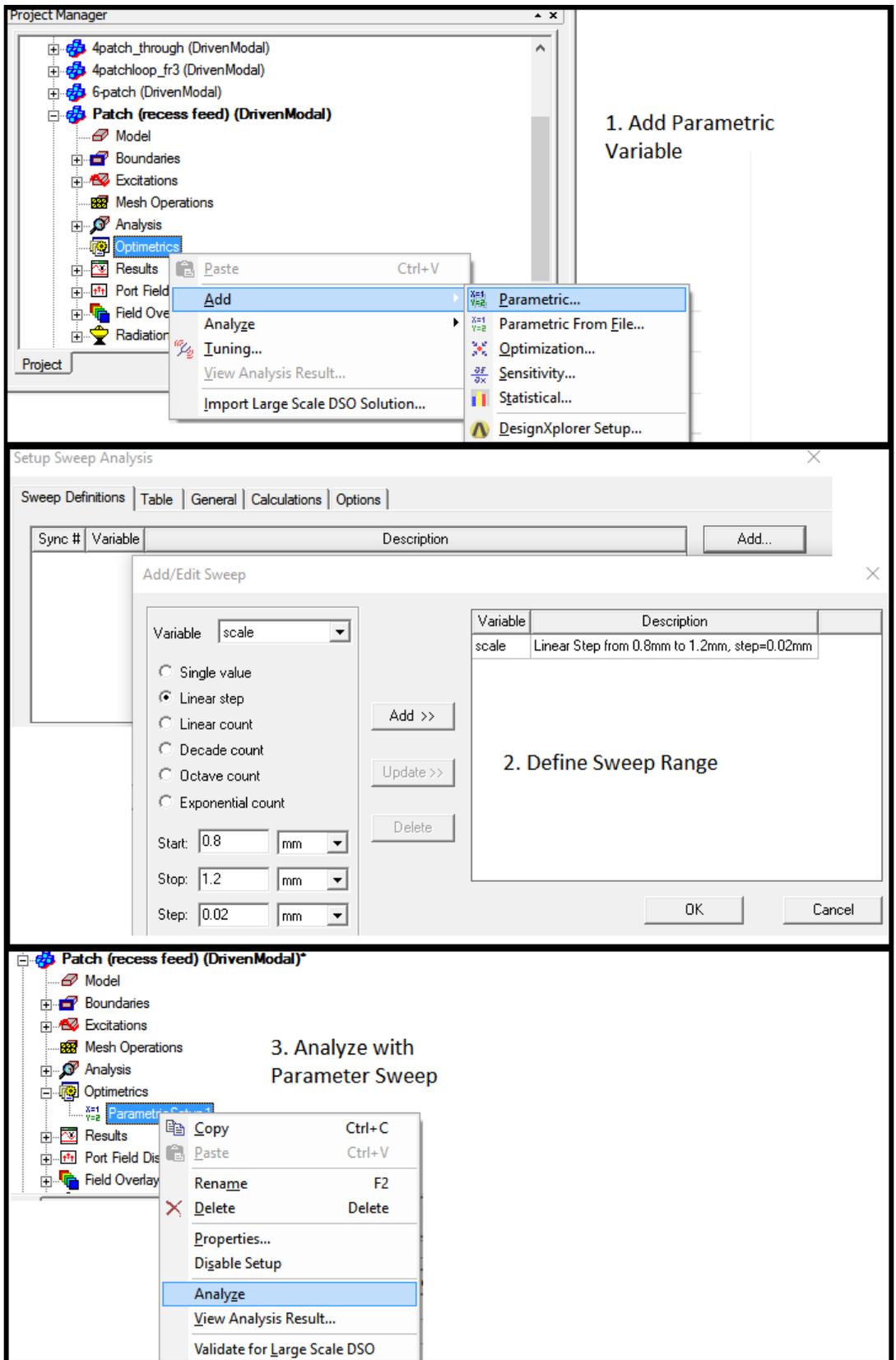


Figure 2: Optimization in HFSS

Once you have your parameters optimized, you can be confident you have pushed your design to its full potential. If you are still not satisfied, you may have chosen the incorrect design and need to revisit your options laid out in section 2.

4 Lessons Learned

This section describes where I made mistakes, techniques I picked up along the way, and what I would do differently if given a second chance to start over.

4.1 Understand the Limits of the Device

Out of the gate, I was set on designing a patch antenna. I was comfortable with them and they were easy to draw in HFSS and I did not even research other options. Our team wanted at least a 200 MHz bandwidth to achieve a decent resolution and I ignored the fact that patch antennas are inherently narrow band. I tried to push the patch antenna to its limits, and even started adding novel designs to it. Don't do this. I spent maybe 4 weeks running optimizations and redesigning. I wasted a lot of time trying to make a patch antenna wideband, which it is not. Lesson learned here is to understand the limits of the device.

4.2 Keep a Record of Results and Design

It is paramount to keep a record of previous results and the original design with your variables. If you try different designs, or have multiple people working on the antenna, this will save a lot of time redoing work and understanding the layout of the design file. Below are examples of good record keeping:

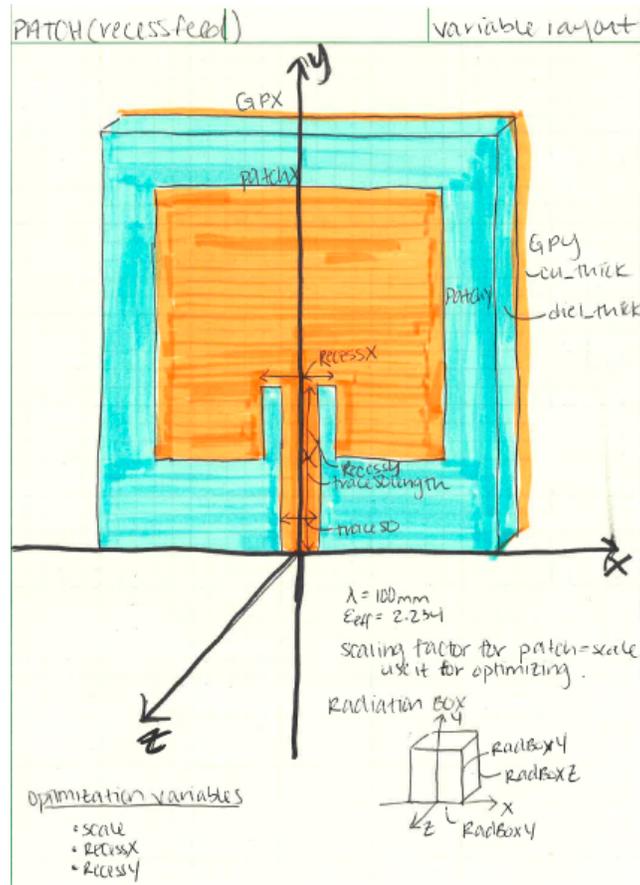


Figure 3: Design Layout

OPTIMIZATION RECORD

<u>VARIABLE</u>	<u>FROM</u>	<u>ID</u>	<u>STEP</u>	<u>BEST RESULT</u>
scale	0.8	1.2	0.2	1.0
scale	0.9, 0.8	1.02	0.01	1.00
scale	1.05	1.07	0.001	1.0060 ✓
recessX	1.5	2.0	0.1	1.6
recessX	1.55	1.65	0.01	1.6 ✓
recessY	9	12	0.25	10.5
recessY	10.3	10.7	0.1	10.5
recessY	10.49	10.51	0.01	10.5 ✓

Figure 4: Optimization Trials

4.3 Analyzing the Result for Accuracy

HFSS does a fantastic job of simulating the EM response of the antenna design, but it will only do what you tell it to. Below is a list of helpful checkpoints if you feel you hit a wall and don't understand what went wrong:

CheckPoint	Reason
J, Surface Currents	Is the current going where you want? Is it cancelling out other currents?
Mesh	HFSS segments the antenna into tetrahedral mesh elements to solve for the solution. If there are not enough tetrahedral sections, your solution may be invalid.
Excitation Line	Is it actually touching both conductors? Rotate the view to double check.
Substrate Symmetry	Having an asymmetrical antenna will change your design. Make sure the top and side dielectric boundaries are even.

Table 3: Common Simulation Check Points

References

- [1] Bevelacqua, Pete. "Bandwidth." Antenna-Theory.com - Bandwidth
- [2] "RO3000 ©Laminates" Rogers Corporation
- [3] Wu, Feng T., Guang F. Zhang, Xue L. Yuang, and Nai C. Yuang. "Research on ultra-wideband planar Vivaldi antenna array." Microwave and Optical Technology Letter. Wiley Subscription Services, Inc. A Wiley Company, 24 July 2006.
- [4] Andersen, Audun. "Small Size 2.4 GHz PCB antenna." Application Note AN043, Texas Instruments Incorporated, 2008.
- [5] Yun Liu, Zhenyi Niu, Xiaojun Wang. "Design of dual-band H-shaped Slot Antenna for 2.4 and 5 GHz Wireless Communication." 2009 International Conference on Microwave Technology and Computational Electromagnetics, pages 95-97.
- [6] W.S. Yeoh, K.L. Wong, and W.S.T. Rowe. "Wideband Miniaturized Half Bowtie Printed Dipole Antenna With Integrated Balun for Wireless Applications." 2011 IEEE Transactions on Antennas and Propagation, Vol. 59, NO. 1, page 339-342.
- [7] "WiFi Antenna — 14 Element WiFi Yagi Antenna." RadioLabs, Inc.