From Concept to Antenna

How I design antennas for my devices.

Armando Rodrigues

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Myself climbing an antenna truss tower back in my college days.

Antenna design is a fascinating intersection of engineering and creativity. As an RF Engineer working on wireless automotive technologies, I have often found myself marveling at the ingenuity of a well-designed antenna. From enabling seamless connectivity in smartphones to ensuring reliable communication in spacecraft, antennas are the silent heroes of modern technology. In this article, I’ll take you through the journey of designing antennas — from the initial concept to the final product — sharing insights, methods, and tools that have shaped my approach.

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My first ever self-made antenna: an 8-element Yagi-Uda antenna designed for analog video transmission. You can see I used very cheap materials for this project. But it did work perfectly anyway!

Why antenna design matters

The role of the antenna in any wireless communication system cannot be overstated. But, since RF is commonly seen as black magic for most electronics hobbyists, it is quite often overlooked. Antenna design directly impacts the size, aesthetics, cost, and battery life of devices. For example, a compact, highly efficient antenna can enable smaller devices with longer battery life, while a poorly designed one might increase device size and require excessive power for transmission, reducing battery life. This is why antenna design is critical at the concept stage. Instead of slamming a random antenna in your projects, you should always aim to select an antenna with the necessary characteristics in terms of gain, radiation pattern, efficiency, etc… Or design your own antenna if you are up to the challenge!

Selecting the right antenna type

Choosing the right antenna type is the first major decision in the design process. This choice depends on several factors, such as the operating frequency, the environment in which the device will function, and the desired radiation pattern.

For instance, monopole antennas, such as the ones shown below, might be ideal for compact devices that require omnidirectional coverage, while a patch antenna is better suited for applications needing a low-profile design and directional radiation pattern. Loop antennas are great for compact, low-frequency applications, whereas Yagi antennas, such as the one I showed earlier, excel in high-gain, point-to-point communications.

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Different types of antennas based on the classic quarter-wave monopole.

Understanding the trade-offs is key. Higher gain antennas offer better range but are almost inevitably more directional, making them less effective in environments requiring wide coverage. Balancing these requirements ensures the selected antenna aligns with the overall device objectives.

If you don’t know where to start you can consider the following list to spark some Google searches:

Whip Monopole Antenna

Advantages: Compact, omnidirectional, easy to deploy, and low-cost. Does not need a concrete ground plane to work (usually the device it is attached to functions as a ground plane).

Trade-offs: Limited bandwidth, ground plane quality can impact efficient operation.

Helical Antenna

Advantages: Supports circular and linear polarization (depending on the spacing between turns), offers moderate gain, and has a wide bandwidth.

Trade-offs: Usually presents lower radiation efficiency when compared to typical monopoles.

Patch Antenna

Advantages: Low profile, lightweight, and suitable for integration into PCBs or planar structures.

Trade-offs: Narrow bandwidth, lower efficiency, hard to tune.

Yagi-Uda Antenna

Advantages: High directional gain, excellent for long-distance communication and relatively simple design.

Trade-offs: Requires precise alignment and can be bulky for low-frequency use.

Printed Circular Monopole Antenna

Advantages: Wide bandwidth, compact size, and easy to fabricate on PCB.

Trade-offs: Lower efficiency compared to larger designs and can be sensitive to substrate material.

Planar Inverted-F Antenna (PIFA)

Advantages: Compact, low-profile, highly suitable for mobile and embedded devices.

Trade-offs: Narrow bandwidth, limited gain, and requires precise impedance matching.

Dipole Antenna

Advantages: Simple, robust design, omnidirectional in the horizontal plane, and easy to construct.

Trade-offs: Moderate size for low frequencies and less directional control.

Parabolic Dish Antenna

Advantages: Extremely high gain, highly directional, ideal for satellite and long-distance communication.

Trade-offs: Expensive, large, and requires precise mechanical alignment.

Horn Antenna

Advantages: High gain, excellent for high-frequency applications, and easy impedance matching.

Trade-offs: Bulky and expensive, primarily used for specialized purposes like radar and satellite communication.

Loop Antenna

Advantages: Compact, suitable for low-frequency applications, and robust against detuning.

Trade-offs: Low efficiency, low gain, and not ideal for high-frequency applications.

Understanding how the antenna works

An antenna isn’t just a piece of metal — it’s a finely tuned component that must resonate at specific frequencies to perform optimally. To design an effective antenna, you need to understand the principles of resonance, impedance matching, and polarization. You also need to understand how the physical characteristics of the antenna topology correlate with these important parameters. Usually, these relations between antenna topology and fundamental parameters (for example antenna length and operating frequency) are not linear, making the design and tuning process quite challenging.

Below you can see how the different physical aspects of a PIFA design affect its fundamental parameters such as bandwidth and input impedance.

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Main tuning parameter of a planar inverted-F antenna.

Refining the antenna: The cheap way

Prototyping antennas on a budget involves clever use of tools and resources. A good starting point is simulation software, which allows you to model and test antenna designs virtually. Open-source tools like NEC or free versions of commercial software can provide valuable insights.

Once a design shows promise in simulations, physical prototyping can begin. Using inexpensive materials like copper tape or PCB boards, you can create functional prototypes to test in real-world scenarios. Simple tools like vector network analyzers (VNAs) can measure parameters like return loss and impedance, ensuring the design performs as expected. Nowadays it is not hard to find cheap VNAs in AliExpress or similar websites that, although clearly not machines of precision, can still handle any hobbyist project.

Iterative refinement is key at this stage. Small adjustments to dimensions, spacing, or materials can have significant impacts on performance. This approach keeps costs low while allowing for substantial design improvements.

Refining the antenna: The expensive way

For more advanced designs or when budgets allow, high-end tools and facilities can take antenna refinement to the next level. Professional-grade simulation software, such as CST Microwave Studio or ANSYS HFSS, provides highly accurate modelling, including 3D electromagnetic interactions.

Access to anechoic chambers allows precise testing of radiation patterns, gain, and efficiency in a controlled environment. High-quality fabrication methods, like photolithography for PCB antennas or CNC machining for metal elements, ensure prototypes closely match design specifications.

While these methods are costly, they’re invaluable for achieving top-tier performance, particularly in demanding applications like automotive or aerospace systems where I work. These investments are obviously meant for companies, not hobbyists.

Conclusion

Antenna design is a blend of science, creativity, and practicality. From understanding the basics of resonance and impedance to selecting the right type and refining the design, each step requires careful consideration and iteration. Whether working on a tight budget or with state-of-the-art tools, the goal remains the same: to create an antenna that performs optimally and has the right characteristics. More gain or bandwidth is not necessarily better, the characteristics your project needs are the ones you should always aim for.

Antenna

Rf

Engineering