Patch Antenna Design and Miniaturization Techniques
A Qualitative Approach

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Abstract

Hello world!

1 Introduction

Among all of the antennas in use today, perhaps none is as revolutionary as the patch antenna. First envisioned in the 1950's[1], patch antennas were first adopted by the aerospace industry[2], due to their low profile and light weight being essential for spacecraft, missiles, and airplanes. In the 1980's, with the advance of printed circuit technology, patch antennas became far cheaper to manufacture[3], which brought them applications in commercial wireless communication systems. However, these very rudimentary patch antennas were too large to be effectively used in hand held devices. Like all antennas, patch antennas (PAs) radiate most efficiently when their length is one-half of the wavelength they emit [3]. For instance, if one wanted to design a PA which radiated at a frequency of 900 MHz, then, without using any of the miniaturization techniques discussed in this paper, they would need their PA to have a length of around 33 cm, which is too big to be used in many applications.

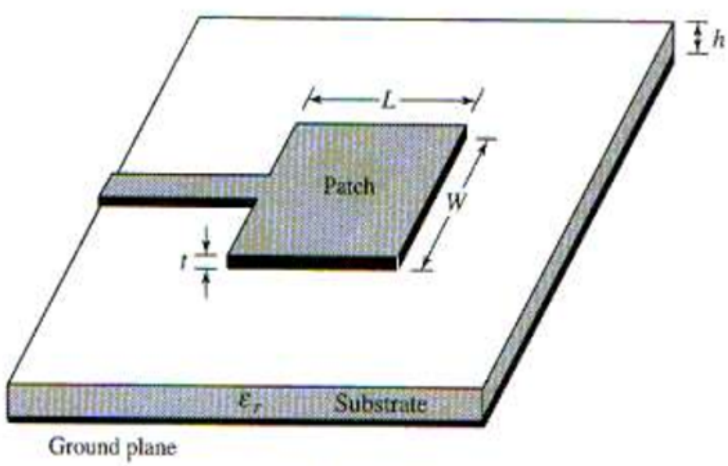

Figure 1: The basic structure of a patch antenna. This particular antenna is being fed with a microstrip. The ground, and the patch are conductors. The substrate is a dielectric. [4]

Besides its large size at lower frequencies, a PA with Figure 1's design would have a narrow frequency band, low efficiency, low power, high Q, poor polarization purity, and spurious feed radiation[2]. Fortunately, significant effort has gone into addressing these limitations, and a variety of design techniques to mitigate these limitations have been created[2]. Furthermore, PAs have also been investigated theoretically, and theories to describe the operating mechanism of most PAs have been created. However, the theories describing PA operation are mathematically dense, and are quite challenging to read. This unapproachability in theory leads to obfuscation on both the theory of PA operation, and research associated with it. One of the most intuitive high level ways of describing antennas is visually. While antenna simulation software does exist, it seems like nobody has used it provide a surface level introduction to patch antennas. This paper intends to do so, using the antenna simulation software known as HFSS, by Ansys. HFSS is a 3D electro-magnetic field simulator, used by RF engineers to design antennas, but it can also be used to visualize the fields in patch antennas, thereby giving an intuitive explanation of why certain antenna designs work, and others don't.

This paper will use HFSS to provide a visual explanation of the radiation mechanism of a basic PA, as well as show some of its properties. Afterwards, the paper will review some methods which have been used to miniaturize PAs. None of the presented methods will be exceptionally novel, however, the methods are actually used in current patch antennas, and the mechanism behind their operation is fascinating in its own right. Since this is a surface level paper, certain concepts will be introduced without adequate in depth explanation. In these cases, the paper will reference other readings for a more in depth explanation.

2 Patch Antenna

2.1 Basic Characteristics

As shown in figure 1, a basic patch antenna consists of a very thin metallic strip (the patch), placed a small fraction of a wavelength above a metallic ground plane. While patches are usually either rectangular or circular[3], numerous other shapes have been investigated[2]. In between the patch, and ground plane, is a dielectric. Dielectrics are electronic insulators which can be polarized by an external electric field.

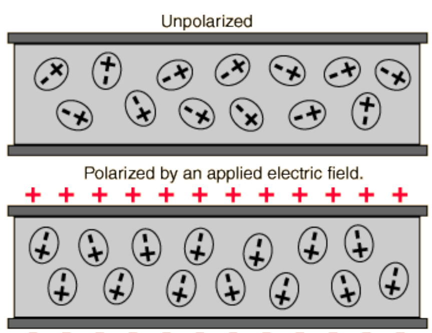

Figure 2: [Uncited, provide a citation here] A dielectric with and without an applied E-field. The dielectric constant ϵ_r (relative permittivity) is a measure of how much the atoms in the dielectric align to the external E-field. Dielectrics with low ϵ_r will polarize less to the external E-field, compared to high ϵ_r dielectrics.

Numerous dielectric materials are used in PAs. Most of these materials will have dielectric constants in the range of 2.2 to 12[2]. More discussion on the choice of substrate in the antenna will be provided in section 3.

2.2 Radiation Mechanism

The three most popular model used to describe patch antennas are, the transmission line model, the cavity model, and the full wave model[2]. Since the transmission line model gives the best visual insight[2] into patch antenna operation, this model will be used. It should be noted however, that the transmission line model is only valid for rectangular patch antennas, and doesn't give the most accurate results[2]. As a result, the results from both the cavity wave model, and the full wave model will be included. More information on the cavity model can be found here [2].

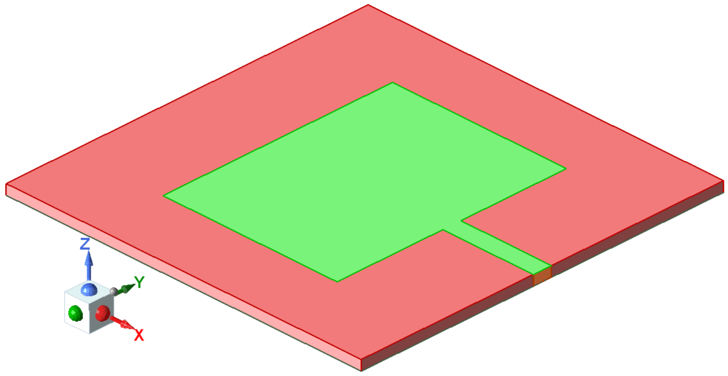

Figure 3: A basic PA designed in HFSS. This particular PA has been designed to radiate at 2.4 GHz. The green material on top is the patch, with the red material being the substrate. The substrate has a relative permittivity (dielectric constant) of 4.4. There is a ground plane beneath the substrate, although it is not visible here. The entire antenna has dimensions 60 mm $\times$ 60 mm $\times$ 1.6 mm, in the x,y,z planes, respectively. The patch itself is 29.4 mm long in the x direction, and 38 mm long in the y direction. The thickness of the patch and ground plane is negligible with respect to the substrate thickness.

Figure 3 depicts a basic microstrip patch antenna (MPA) that is designed to radiate at 2.4 GHz. When an RF signal is applied to this antenna, at a 2.4 GHz frequency, the patch antenna will radiate EM waves. Although the antenna can radiate at other frequencies, it will radiate less efficiently at those frequencies. The frequency at which an antenna radiates most efficiently is known as the *resonant frequency* of the antenna. A more technical definition of the resonant frequency of an antenna is the frequency at which the impedence of an antenna is purely resistive, the frequency at which the capacitive and inductive reactances cancel each other out.

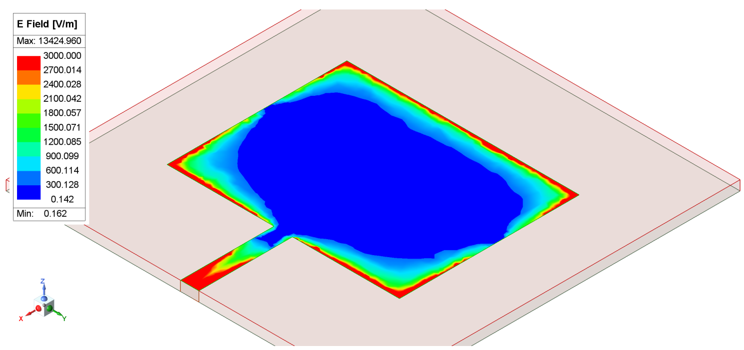

Figure 4: This depicts the same PA from figure 3, with an RF current applied to the patch. The magnitude of the E-field is being shown on the patch, with the RF current applied.

2.3 Properties

3 Substrate Loading

References

[1] H. Gutton and G. Baissinot, "Flat aerial for ultra high frequencies," *French patent*, vol. 703113, 1955.

[2] C. A. Balanis, *Antenna theory: analysis and design*. John wiley & sons, 2016.

[3] M. U. Khan, M. S. Sharawi, and R. Mittra, "Microstrip patch antenna miniaturisation techniques: a review," *IET Microwaves, Antennas & Propagation*, vol. 9, no. 9, pp. 913–922, 2015.

[4] N. Girase, R. Tiwari, A. Sharma, and H. Singh, "Design and simulation of slotted rectangular microstrip patch antenna," *International Journal of Computer Applications*, vol. 103, no. 10, pp. 19–23, 2014.