1 | Patch antenna design

1.1 Design Procedure of Patch Antenna

(All formulas from Equation 1.1 to Equation 1.6 is taken from [Balanis, 2005] the formulas from Equation 1.7 to Equation 1.10 is from [Community, 2016])

Before a patch antenna can be designed, it is important to find out on which substrate it should be designed for. This gives some parameter for the height, h and the relative dielectric constant, ϵ_r. Equally important is to determine the frequency for which the patch antenna should work for, f. When these parameters have been determined the actual design can begin. The width is found using Equation 1.1.

$$w = \frac{c}{2f} \cdot \sqrt{\frac{2}{\epsilon_r + 1}} \tag{1.1}$$

Where:

w	is the width of the patch antenna	[m]
c	is the speed of light	$\left[\frac{m}{s}\right]$
f	is the chosen frequency	[Hz]
ϵ_r	is the relative dielectric constant	[1]

Before the length of the patch can be found the effective dielectric constant needs to be found using Equation 1.2.

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \cdot \left(1 + \frac{12h}{w}\right)^{-\frac{1}{2}} \tag{1.2}$$

Where:

ϵ_{eff}	is the effective dielectric constant	[1]
h	is the height of the substrate	[m]

The total length of the patch include both the length of the patch itself but also the electromagnetic extension from the edges. So to find the length of the patch itself can thus be found using Equation 1.3.

$$L_{eff} = L - 2 \cdot \Delta L \tag{1.3}$$

Where:

L_{eff}	is the length of the patch antenna	[m]
L	is the total radiating length of the patch antenna	[m]
ΔL	is the extension of the length from the patch antenna	[m]

The extension of the length is found using Equation 1.4

$$\Delta L = h \cdot 0.412 \frac{(\epsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \cdot 10^{-3} \tag{1.4}$$

The total radiating length is found using Equation 1.5

$$L = \frac{c}{2 \cdot f \cdot \sqrt{\epsilon_{eff}}} \tag{1.5}$$

Now that the physical dimensions of the patch has been found a feed needs to be made. In this case a strip line feed is chosen. Since the equipment including cables and connectors are 50 ohm this will be the desired match. The impedance in the patch varies from edge through the patch and to the other edge with 0 ohm in the center and $\approx$ 240 ohm at the edge. The desired feed point is then found using Equation 1.6.

$$y_0 = \frac{\arccos\left(\sqrt{\frac{R_{in}(y=0)}{R_{in}(y=y_0)}}\right) \cdot L}{\pi} \tag{1.6}$$

Where:

y_0	is the insert feed point	[m]

The gap between the feed line and the patch has through simulations been shown to decrease performance, meaning the smaller the gap the better the performance. The gap is chosen to 0.25 mm as a minimum production width.

The feed line needs to matched to 50 ohm also, this is done by adjusting the width of the feed line. The width can be found using Equation 1.7 to Equation 1.10.

$$Z_0 = \frac{\eta_0}{2\pi\sqrt{2}\sqrt{\epsilon_r + 1}} \cdot \ln\left(1 + 4 \cdot \left(\frac{h}{w_{eff}}\right) \cdot (X_1 + X_2)\right) \tag{1.7}$$

Where:

Z_0	is the desired impedance	[Ω]
η_0	is the free space impedance = 120 π	[Ω]

w_{eff}	can be found in Equation 1.8	[m]
X_1	can be found in Equation 1.9	[1]
X_2	can be found in Equation 1.10	[1]

$$w_{eff} = w_f + \left(\frac{t}{\pi}\right) \cdot \ln\left(\frac{4\mathrm{e}}{\sqrt{\left(\frac{t}{h}\right)^2 + \left(\frac{t}{w_f\pi + 1.1t\pi}\right)^2}}\right) \cdot \frac{\epsilon_r + 1}{2 \cdot \epsilon_r} \tag{1.8}$$

Where:

w_f	is the width of the feed line	[m]
t	is the thickness of the feed line	[m]
e	is Eulars number ≈ 2.718	[1]

$$X_1 = 4 \cdot \left(\frac{14\epsilon_r + 8}{11\epsilon_r}\right) \cdot \left(\frac{h}{w_{eff}}\right) \tag{1.9}$$

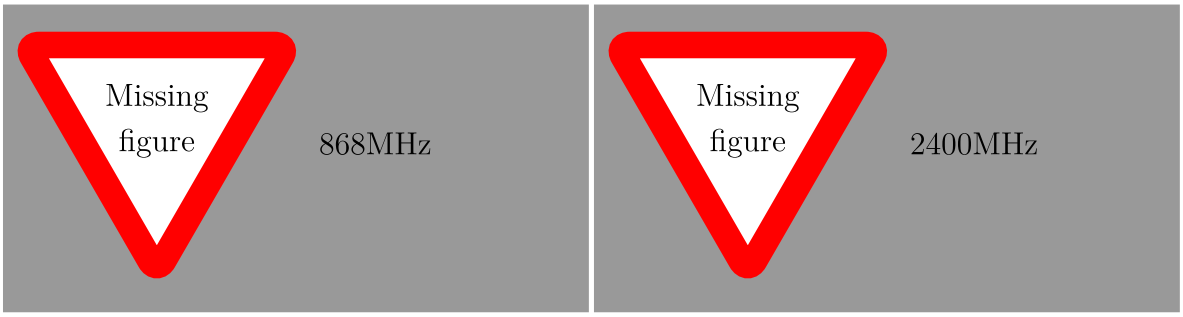
$$X_2 = \sqrt{X_1^2 + \left(\frac{\epsilon_r + 1}{2 \cdot \epsilon_r}\right) \cdot \pi^2} \tag{1.10}$$

1.2 Dimensions of Patch Antennas

The patch antennas have been designed for a FR4 board with a height of 1.6 mm and a copper thickness of 35 µm.

	868MHz	**2.4GHz**	**Unit**
Width	105.7	38.2	mm
Length	82.7	29.6	mm
Feedpoint	29.5	10.9	mm
Feed Width	3.06	3.06	mm

Table 1.1: Calculated parameters



(a) Designed patch for 868 MHz

(b) Designed patch for 2.4 GHz

Figure 1.1: The manufactored patch antennas

1.3 Measured Performance

The antennas have been tested in Satimo Starlab see Figure 1.2. The radiation pattern can be seen on ??, and gain for vertical and horizontal polarization can be seen in ??.

Figure 1.2: Satimo starlab

2 | Monopole design

A monopole antenna is the most simple antenna, as it is a wire, where the signal generator is connected at one end and nothing a the other end. It is normally place atop of a ground plane. The radiation pattern is the same as a dipole antenna with a larger ground plane, which is a doughnut shape, where there is less to none radiation directly above and below the antenna, while the strength of the radiation gets better, the more horizontal the direction gets. But if the ground plane is not large enough, the doughnut shape, will be tilted more upwards.

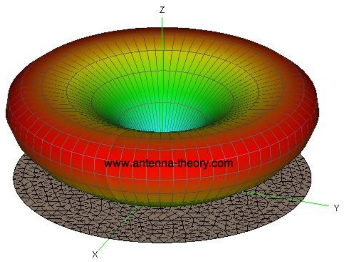


Figure 2.1: Satimo starlab

The frequency of the monopole antenna is determined by the length of the antenna, like the dipole antenna. The antenna needs a length equal to a forth of the wavelength of the wanted frequency, which is equal to half the size of a dipole antenna, with same frequency. With this length, it will have a input impedances on $(36.5 + 21.25j)\Omega$.

$$L = \frac{\lambda}{4} \tag{2.1}$$

Where:

L	is the length of the antenna	[m]
λ	is the wavelength of the wanted frequency	[m]

Bibliography

Balanis, C. A. (2005). *Antenna Theory Analysis and Design*. John Wiley and Sons, INC., 3 edition. ISBN: 0-471-66782-X.

Community, E. E. E. (2016). Microstrip Impedance. https://www.eeweb.com/toolbox/microstrip-impedance.