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:

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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 $= 120\,\pi$ | [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]

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

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]

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

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

2 | Monopole design

Bibliography

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

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