

Array of folded patches

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Tchebyshev array factor design

The design parameters for the array are:

Parameter	Value
# elements	$2N + 1 = 5$
Mean lobe/side lobe ratio	$R = 120 \cong 41.58 \text{ dB}$
Frequency	$f = 2.1 \text{ GHz}$

It's been specifically required to find the optimal inter-element spacing so that the minimum of the beamwidth will be reached:

$$d_{opt} \rightsquigarrow \min\{BW_{fn}\}$$

$$d_{opt} = \lambda \left[1 - \frac{\arccos\left(\frac{1}{\gamma}\right)}{\pi} \right] \quad (1)$$

$$\gamma = \cosh \left[\frac{1}{2N} \ln \left(R + \sqrt{R^2 - 1} \right) \right]$$

where $\lambda = \frac{c}{f}$ is the frequency in the free-space. In this case, $d_{opt} \in \left(\frac{\lambda}{2}, \lambda \right]$, which means that The coefficients a and b related to the Tchebyshev polynomial approximation for the array will be chosen by following the $d_{opt} \in \left(\frac{\lambda}{2}, \lambda \right]$ condition:

$$T_2[x = a + b \cos u] = C_0 + 2C_1 \cos u + C_2 \cos 2u = (2a^2 + b^2 - 1) + 4ab \cos u + b^2 \cos 2u \quad (2)$$

Once the amplitude current feed coefficients are computed (C_n , $n = \overline{0, 2}$), the tapering efficiency can be calculated:

$$\eta_T = \frac{1}{2N + 1} \frac{|C_0 + 2C_1 + C_2|^2}{C_0^2 + 2C_1^2 + C_2^2} \quad (3)$$

Let's consider two cases of uniform spacing array and:

$$\text{Uniform Amplitude (UA)} \quad || \quad \text{Non-uniform Amplitude (NUA, Tchebyshev)} \quad (4)$$

The comparison will show how

$$BW_{fn}^{[UA]} < BW_{fn}^{[NUA]}$$

$$BW_{fn}^{[NUA]} = 2 \frac{180}{\pi} \left[\frac{\pi}{2} - \arccos \left(\frac{\arccos \left(\frac{\cos \left(\frac{\pi}{2N} - a \right)}{b} \right)}{k_0 d} \right) \right] \quad (5)$$

$$BW_{fn}^{[UA]} = \frac{2\lambda}{Nd} \frac{180}{\pi}$$

Parameter	Value		
Feed coefficients [A]	C_0 41.2	$C_1 = C_{-1}$ 29.8	$C_2 = C_{-2}$ 9.6
Normalized feed coefficients to C_{\max}	C_0^* 1.000	$C_1^* = C_{-1}^*$ 0.7215	$C_2^* = C_{-2}^*$ 0.2336
Tapering efficiency	$\eta_T = 79\%$		
Beamwidth	Tchebyshev 50.6°	Uniform 34.8°	

Now, discussing the results is mandatory:

Max/min feed ratio Even if this is the design of a Non-Uniform Amplitude Array, the less the ratio $r_{\max/\min} = \frac{C_{\max}}{C_{\min}}$ is, the more efficient distribution of current is reached. In this particular design:

$$r_{\max/\min} \cong 4.39 \quad (6)$$

meaning that if a damage of the element with the C_{\max} level of feed occurs, most part of the efficiency will be lost. In any case, the tapering efficiency shows how it will not be possible to take advantage of 21 % of the array in an ideal situation, remembering that this design model can be discerned by the real circumstance in terms of the Tchebyshev error [Balanis].

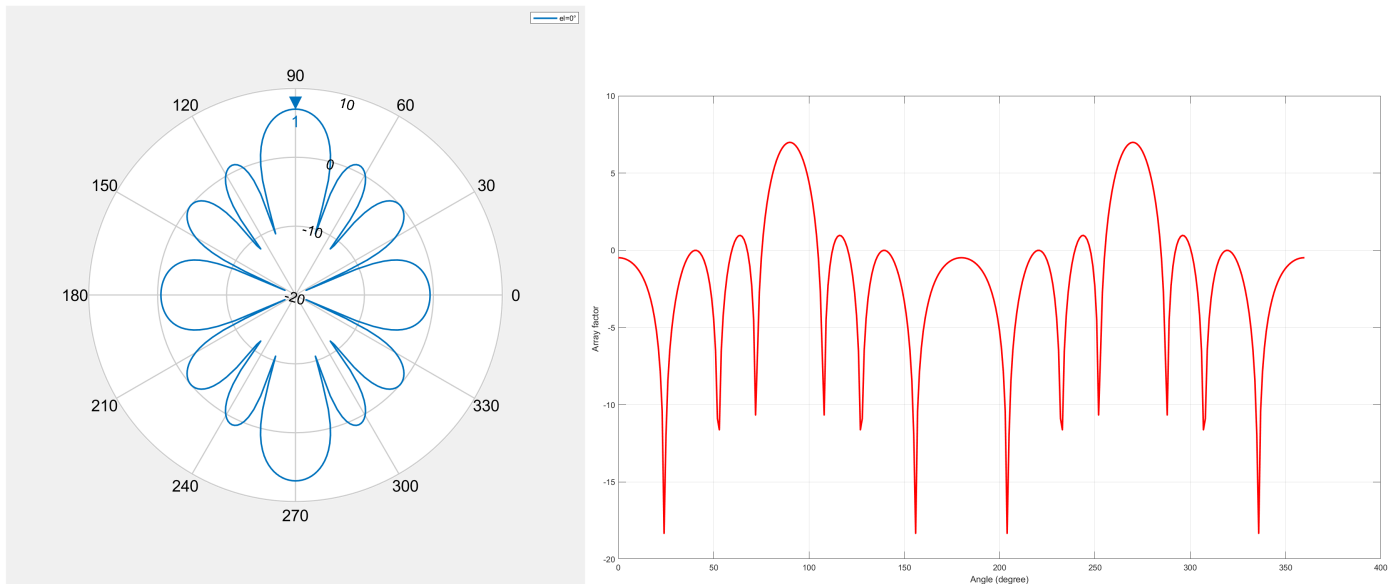


Figure 1: Array factor polar (left) and rectangular (right) diagrams

Rectangular folded patch design

Mesh density refinement

A FR4 substrate thickness of $h_{sub} = 0.8 \text{ mm}$ has been selected so it could be considered as a thin one:

$$\lambda_{sub} = 0.0652 \text{ m} \quad \rightsquigarrow \quad \frac{h_{sub}}{\lambda_{sub}} \cong \frac{1}{81}$$

In case of thin substrates ($h/\lambda \leq 1/50$), the **Antenna Toolbox** suggests to mesh the antenna using dielectric in auto mode. The other two available substrate thicknesses (1.0 mm and 1.6 mm) have not been adopted because the **Antenna Toolbox** reference doesn't give any information about accuracy of the results in case of $h_{sub} \in \left(\frac{\lambda}{50}, \frac{\lambda}{10}\right)$.

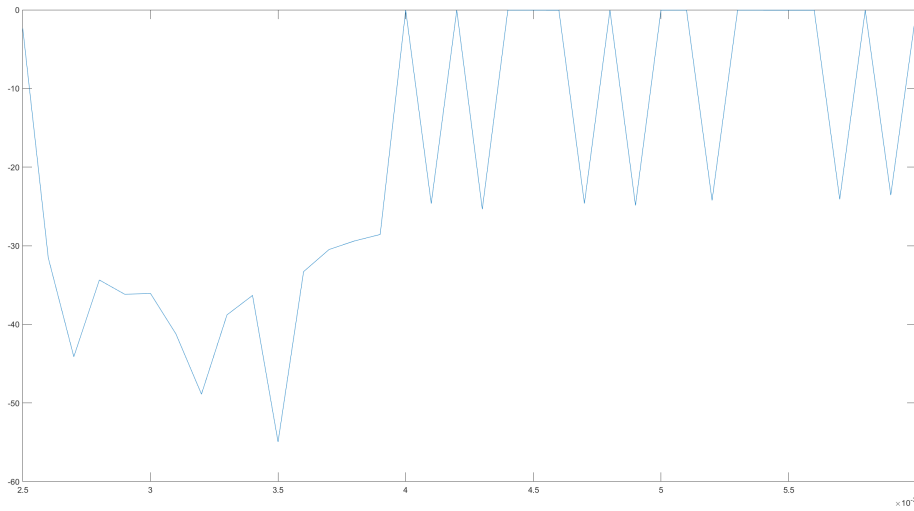


Figure 2: Minimum of the reflection coefficient $\Gamma [dB]$ in the frequency range $2.0 \div 2.2 GHz$ depending on the varying mesh density level

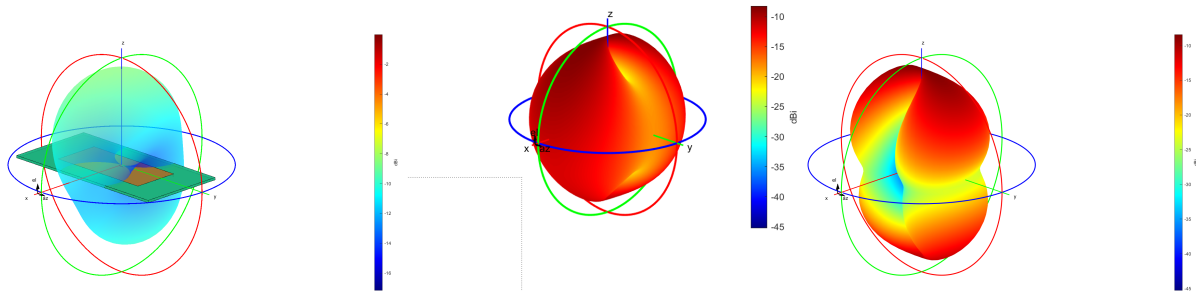


Figure 3: Gain pattern (left), gain pattern with vertical polarization (center) and with the horizontal one (right)

Patch parameters

$$L + W - w_{SC} = \frac{\lambda}{4} + h_{sub} \quad (7)$$

$$W = \frac{\lambda_0}{2} \sqrt{\frac{2}{\epsilon_r + 1}}$$

$$BW_E = 2 \arccos \sqrt{\frac{7.03 \lambda_0^2}{4(3 L_e^2 + h^2) \pi^2}} \quad (8)$$

$$BW_H = 2 \arccos \sqrt{\frac{1}{2 + k_0 W}}$$

$$\ell_{feed} = \frac{L}{\pi} \arccos \sqrt{\frac{R_{in}}{R_r}} \quad (9)$$

Overall array performance evaluation

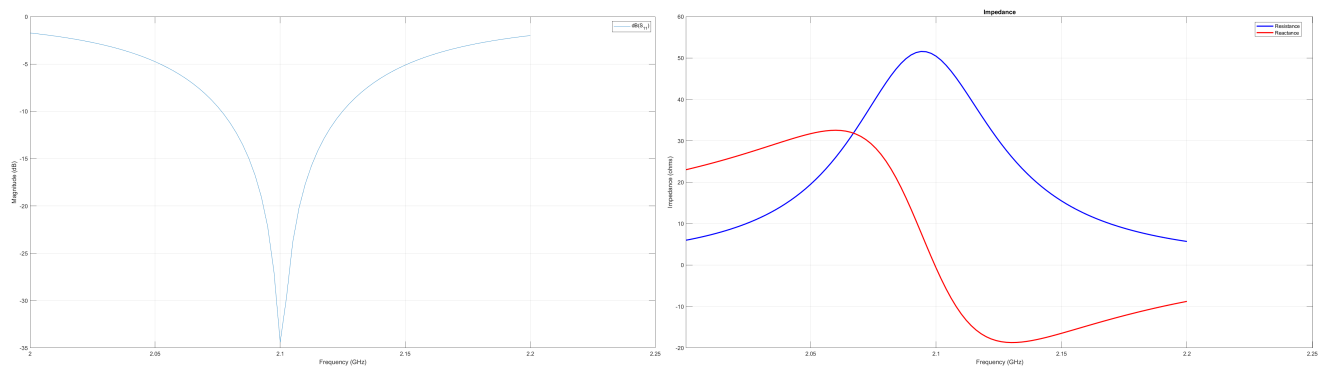


Figure 4: Reflection coefficient (left) and impedances (right) plots depending on $f \in 2.0 \div 2.1 \text{ GHz}$