Design and performance of the unitary element

The radiating part of the antenna system is a 2×2 element square antenna array. Unitary element is not crucial for our demonstration. A truncated printed patch antenna has been chosen as unitary element, its geometry is described in Fig. 1. Patch element and ground plane are printed on a 1.6mm FR4 substrate (ε_r=4.7, $tan\delta$=0.025). Patch element is placed to h=10mm upon the ground plane patch and truncated corner sides is respectively L_{patch}= 132mm and a= 20.6mm. A metallic ring (r_{ring}=4mm) is added in order to compensate inductive part brought by connector central conductor. Others dimensions are L_{ground} = 200mm, x_o = 66mm and y_o =37mm.

Reflection coefficient (S_{11}) depicted in Fig. 2 shows an impedance Z^i_a = (72+2j)Ω very close to desired value. Radiating properties illustrated in Fig. 3 are also in accordance with expectations as realized gain is G=7.8dBi, half power beamwidth $\Delta\theta$=74°, front to back ratio better than -17dB, and finally axial ratio in broadside direction is inferior to 3dB on 14MHz including UHF RFID band.

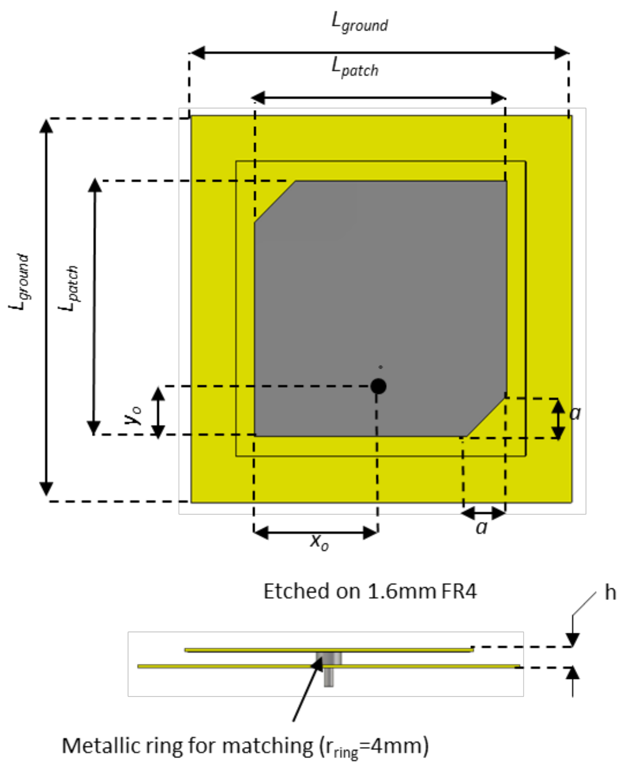

Fig. 1. Geometry of the truncated patch antenna

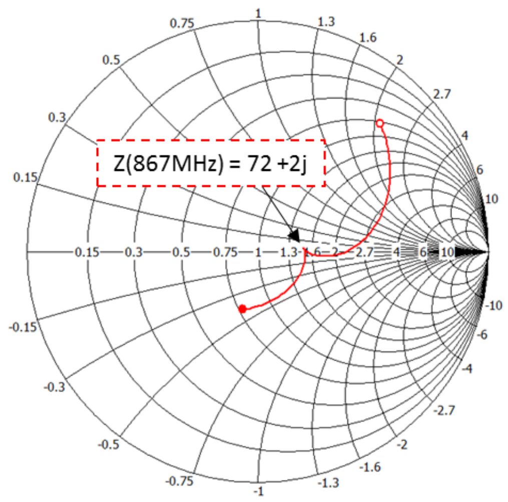

Fig. 2. Patch antenna reflection coefficient (S_{11}) – Simulated results

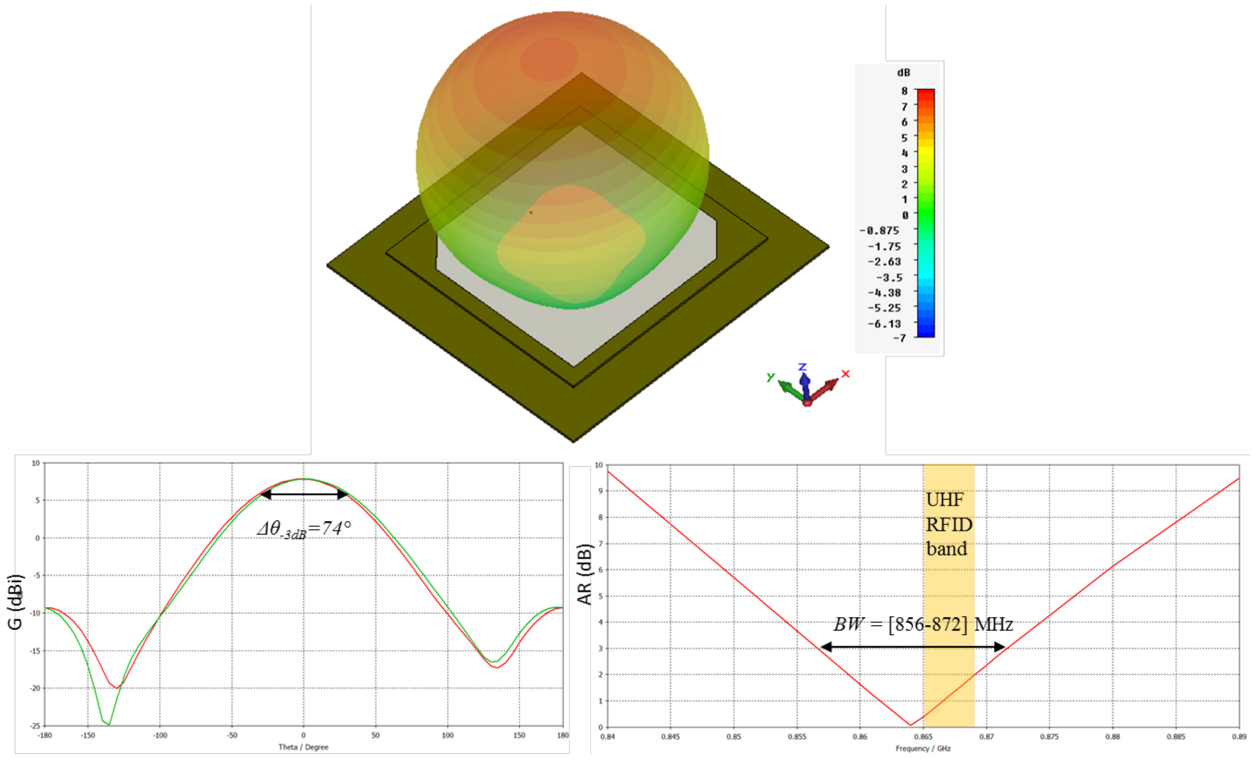

Fig. 3. Radiated properties of designed patch antenna – Simulated results

Design and performance of the feed network

The beam forming network is represented in Fig. 4. The main feed line connected to the RFID reader is separated in four branches to feed the four unitary antennas. Reflective switches are used to excite or not each of the four antennas. Such architecture enables one to feed unitary elements separately or to combine several elements.

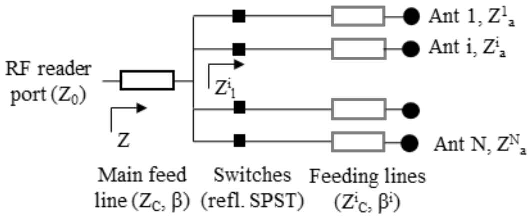

Fig. 4. Proposed beamforming feed network architecture

The impedance loading the RF reader port depends on the number of excited antennas. If only one antenna is fed, the input impedance at RF reader port is given by

$$Z = Z_C.\frac{Z_L^i + jZ_C.\tan(\beta l)}{Z_C + jZ_L^i.\tan(\beta l)} \tag{8}$$

With $$Z_L^i = Z_C^i.\frac{Z_a^i + jZ_C^i.\tan(\beta^i l^i)}{Z_C^i + jZ_a^i.\tan(\beta^i l^i)} \tag{9}$$

Z_C, β and l denote the characteristic impedance, propagation constant, and length of the main feed line, respectively. Z^i_C, β^i and l^i refer to similar quantities for each of the four antenna feed line (i=1 to 4), Z^i_a, is the input impedance of the i^{th} antenna.

Choosing $Z_C = Z^i_C = Z^i_a$ leads to $|Z| = |Z^i_a|$. As RF reader port is fixed to Z_0, the matching condition is straightforward: $Z_C = Z^i_C = Z^i_a = Z_0$. This matching condition is much more complex if more than one antenna is fed at a time. In this paper, we only consider cases where one or two branches (n= {1, 2}) are connected simultaneously. Considering $Z^i_C = Z^i_a$, the impedance Z loading the RF reader port is given by

$$Z = Z_a^i \text{ for } n=1 \quad \text{and} \quad Z = Z_a^i / 2 \text{ for } n=2 \tag{10}$$

The best compromise to match both configurations with the same circuit is to choose $Z^i_a = Z_0.\sqrt{2}$. In this case, the reflection coefficient $|\Gamma_0|$ becomes

$$|\Gamma_0| = \frac{Z - Z_0}{Z + Z_0^*} = \left|\frac{\sqrt{2}-1}{\sqrt{2}+1}\right| \text{ for } n=\{1,2\} \tag{11}$$

where Z^*_0 is the complex conjugate of Z_0.

- Feed network design and simulation results

The geometry of the feed network is represented in Fig. 5. As in our case, the RF reader port impedance is Z_0=50 ohms, we set Z^i_C = Z^i_a = 70 Ω. All microstrip lines are etched on a FR4 substrate (ε_r = 4.6, tan δ = 0.025, h=0.8mm) and their widths are w_1 = 1.3mm and w_2 = 0.7mm. Dielectric and ohmic losses are included in the numerical models.

As a first approach, switches are modelled as short (resp. open) circuit for ON (resp. OFF) states. Two switches configurations have been considered, namely {ON – OFF – OFF – OFF} and {ON – OFF – ON – OFF} and Z^i_a = 70 Ω loads are connected on each antenna output. For first configuration, results are $|S_{11}|_{1ON}$ = -15.9dB and $|S_{21}|_{1ON}$ = - 0.3dB and for the second $|S_{11}|2_{ON}$ = -13.7dB and $|S_{21}|_{2ON}$ = $|S_{41}|_{2ON}$ = - 3.3dB. Isolation is better than -40dB with non-excited outputs. Theory and simulation results are in good accordance.

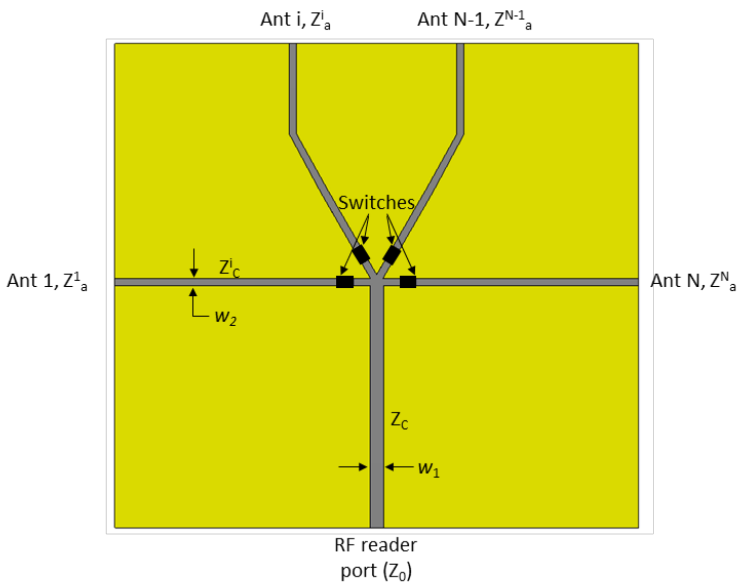

Fig. 5. Microstrip feed network geometry on printed technology