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Shared Aperture Dual S- and X-band Antenna for Nano-Satellite Applications

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***Abstract*—This paper presents the simulated performance of a dual S- and X-band shared aperture antenna design. The antenna is 82 by 82 mm and it has a total height of $\leq$ 4 mm. This size allows the antenna to fit within the parameters of a nano-satellite unit structure. The antenna is right hand circularly polarized in both bands. The Antenna is tuned to a S-band frequency range from 2.025 to 2.075 GHz and a X-band frequency range from 7.75 to 8.75 GHz. The design has a Realized right hand circularly polarized gain of $\geq$ 6 dB in the S-band and $\geq$ 12 dB in the X-band. The impedance bandwidth is very wide as it exceeds the selected frequency ranges. The cross-coupling is below -25 dB in the S-band and below -30 dB in the selected X-band frequency range.**

***Index Terms*—Antenna design, Dual-band, S-band, X-band, Circular Polarisation, Simulation.**

I. Introduction

In recent years the demand for nano-satellites has increased. Nano-satellites are smaller and cheaper compared to traditional satellites. The cheaper price of the smaller satellites allows for new potential applications and use cases. When designing a small nano-satellite the weight and size of the satellite are design parameters of great importance. The satellite should be kept as small and as lightweight as possible. For most satellite missions the satellite has to communicate with a ground station on earth. This communication link needs to be reliable and to have a sufficient data rate. The Satellite-Earth communication link could be established by using S-band frequencies for the communication uplink and X-band frequencies for the communication downlink. This allows for a high data rate from the satellite to the ground station whilst still maintaining a slower data link from the ground station to the satellite. To realize a connection as described two antennas could be used, one for each frequency band. However, it would be very beneficial if one antenna could be designed to cover both the selected S- and X-band frequencies. Dual frequency antennas have been widely reported in the literature [3], [4], [5], [6]. However, the reposting on dual S-and X-band antennas and high frequency-ratio antennas are lacking both details and the relevant performance evaluations.

The purpose of this paper is to supply a detailed description of an expanded version of the dual S- and X-and antenna structure presented in [1], [2]. Additionally, a detailed performance evaluation of the presented antenna structure will be presented.

II. Antenna Structure

Fig. 1 and Fig. 2 show two pictures of the CST Simulation model of the proposed antenna structure. Fig. 1 shows the antenna model with the substrate layers hidden. Fig. 2 shows the antenna structure with the feeding network highlighted. Fig. 3 shows a cross section cut of the proposed antenna structure. Tab. I summarizes the dimensions of the proposed antenna design.

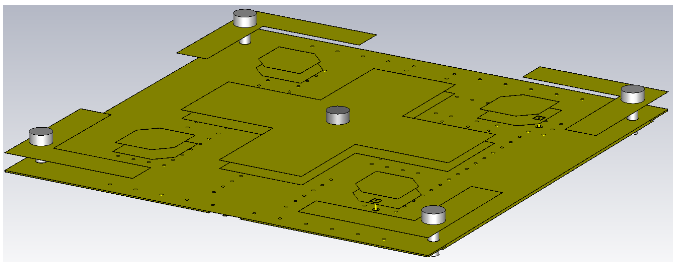

Fig. 1. Model of the proposed antenna structure with the substrate hidden.

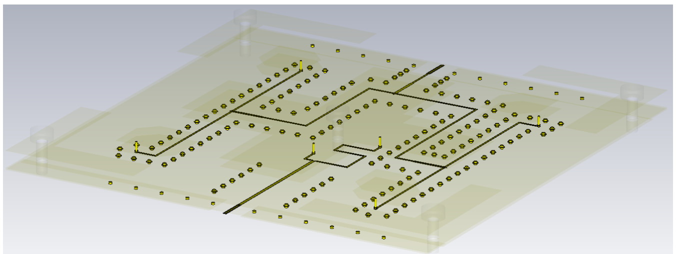

Fig. 2. Model of the proposed antenna structure with the feed network highlighted.

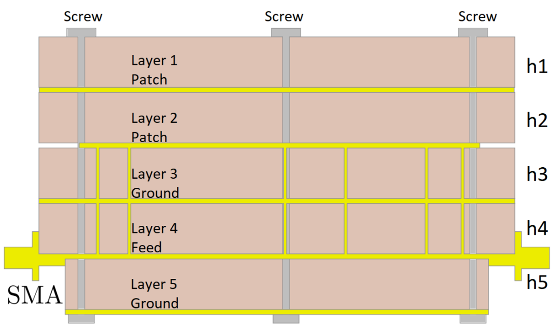

Fig. 3. Cross-section of the antenna stack-up.

The proposed antenna structure is a stacked antenna structure with four stacked circular polarized X-band antenna elements and one stacked cross shaped S-band patch antenna element. Additionally, the structure includes five mounting screws and a feeding network. Feeding probes are used to excite the lower patch antenna elements.

For the cross shaped S-band antenna circular polarisation is achieved by exciting two perpendicular legs of the lower cross with a 90° phase difference. Two opposite corners of the X-band patches are trimmed such that the X-band patches also achieve circular polarisation.

The length of the upper and lower cross shaped S-band patches are tuned to slightly offset frequencies. This gives a multi resonant return-loss frequency response, which results in a wider impedance bandwidth. For the X-band patch antenna elements, a good impedance match is achieved by cutting a capacitive rectangular slot on the patch around the feeding point.

The feed network consists of strip lines and T-junction power dividers with quarter-wave transformers. The feed network has four power divisions, one for the S-band antenna elements and three for the X-band antenna elements.

The antenna has a five layer structure. Below layer 5 and between layer 3 and 4 are the two ground layers. The feed network is encapsulated between the ground layers as it is located between layers 4 and 5. The driven patches are between the substrate of layers 2 and 3. The parasitic patches and the side shields are located between layers 1 and 2.

Tab. I shows the dimensions of the proposed antenna design.

TABLE I
THE DIMENSIONS OF THE PROPOSED ANTENNA DESIGN.

Parameter	*S-band*	*X-band*
Substrate Type	RT5880	
Substrate Height (h_1, h_4, h_5)	0.254 mm	
Substrate Height (h_2, h_3)	1.575 mm	
Feed Line Height	0.035 mm	
Board size	82 mm	
Ground side shield length	25 mm	
Ground side shield width	6.0 mm	
Feed line Width 50 Ω	0.32 mm	
Feed line Width 35 Ω	0.49 mm	
Quarter wave transformer length	25.0 mm	5.8 mm
Untrimmed Patch Length Top	52.1 mm	9.86 mm
Untrimmed Patch Width Top	16.0 mm	9.86 mm
Patch Corner Trim Top	-	4.07 mm
Untrimmed Patch Length Bottom	51.8 mm	10.49 mm
Untrimmed Patch Width Bottom	16.0 mm	10.49 mm
Patch Corner Trim Bottom	-	4.05 mm
Feeding point (Distance from center)	8.20 mm	3.80 mm
Feed Pin diameter	0.35 mm	0.35 mm
Ground Cut out Radius	0.60 mm	0.60 mm
Solder Pad radius	0.30 mm	0.30 mm
Feeding cut inner diameter	-	1.4 mm
Feeding cut outer diameter	-	1.6 mm
Antenna separation	-	45 mm

III. Simulation Results

Fig. 4 shows the simulated S-band S-parameters of the proposed antenna structure. The antenna has a 85 MHz Impedance bandwidth from 2.010 GHz to 2.095 GHz. Additionally the cross-coupling is below −25 dB in the full simulation range.

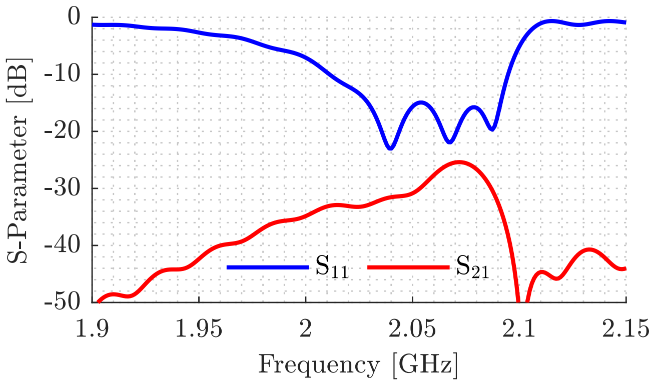

Fig. 4. Simulated S-band S-parameters for the proposed antenna design.

Fig. 5 shows the simulated X-band S-parameters of the proposed antenna structure. The antenna has a very wide impedance bandwidth from 6.75 GHz to 9.15 GHz. The cross-coupling is below −30 dB in the desired frequency range from 8.00 GHz to 8.50 GHz.

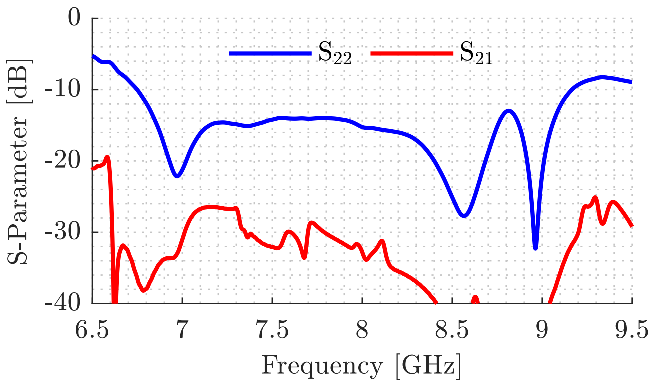

Fig. 5. Simulated X-band S-parameters for the proposed antenna design.

Fig. 6 shows the simulated radiation pattern of the S-band antenna port. The proposed antenna achieves a realized right hand circularly polarized gain of 6.55 dB at 2.05 GHz.

Fig. 7 shows the simulate X-band radiation pattern. The proposed antenna is simulated to have a realized right hand circularly polarized gain on 12.5 dB at a frequency of 8.30 GHz.

The large separation distance of 45 mm (approximately $1.25 \cdot \lambda$) between the X-band patch antenna elements do cause the X-band antenna to have noticeable side lobes. Side lobes are undesired, however, it is a necessary compromise for this design topology.

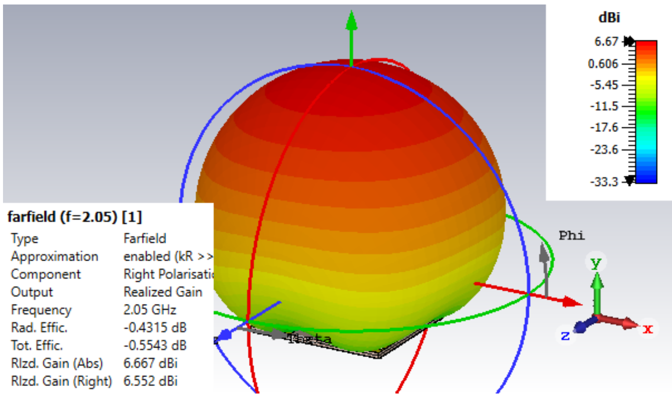

Fig. 6. S-band radiation pattern at 2.05 GHz.

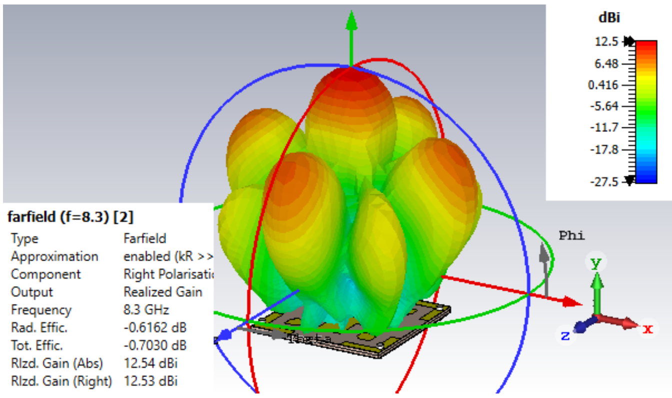

Fig. 7. X-band radiation pattern 8.30 GHz.

Fig. 8 shows the S-band realized right hand circularly polarized gain of the broadside direction. The 6 dB gain requirement is satisfied in a 50 MHz range from 2.025 GHz to 2.075 GHz.

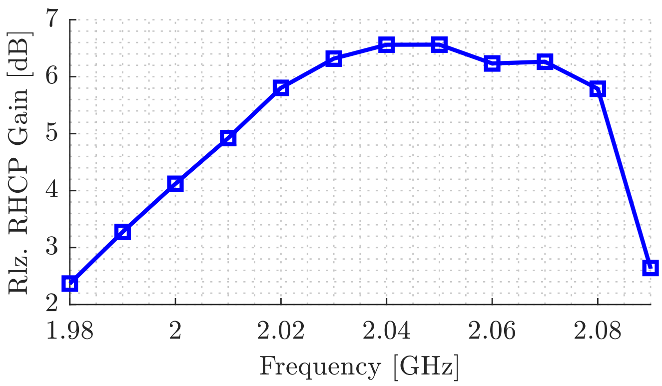

Fig. 8. S-band realized right hand circularly polarized gain of the broadside direction.

Fig. 9 shows the X-band realized right hand circularly polarized gain of the broadside direction. The gain requirement of 12 dB is satisfied in the frequency range from 7.75 GHz to 8.75 GHz

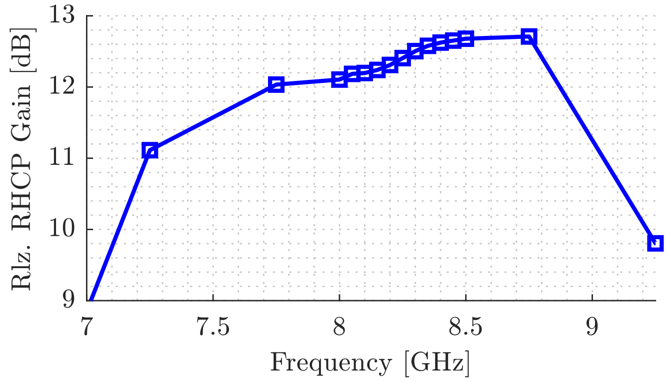

Fig. 9. X-band realized right hand circularly polarized gain of the broadside direction.

Fig. 10 shows the S-band $\phi = 90°$ and $\theta = 90°$ slices of the antenna radiation pattern. Both slides are for a frequency of 2.05 GHz. The half power beam width is 84°.

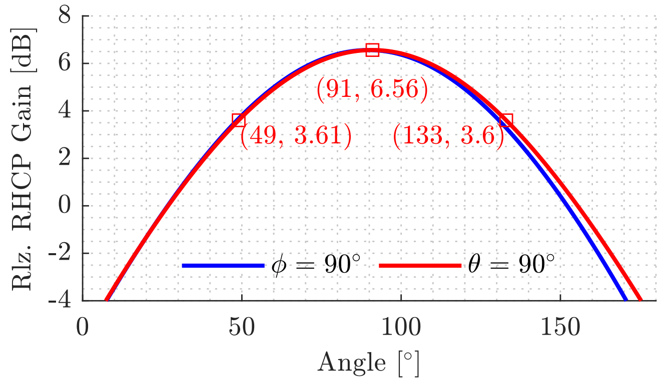

Fig. 10. Radiation pattern slice of the S-band part of the antenna at 2.05 GHz.

Fig. 11 shows the X-band $\phi = 90°$ and $\theta = 90°$ slices of the antenna radiation pattern. Both slides are for a frequency of 8.25 GHz. The half power beam width is 21°. The peak to side lobe level is 4.41 dB.

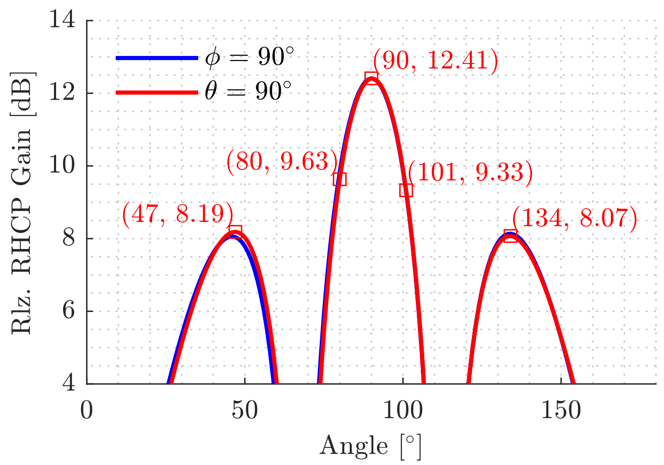

Fig. 11. Radiation pattern slice of the X-band part of the antenna at 8.25 GHz.

Fig. 12 and Fig. 13 show the axial ratio of the two frequency bands. The low axial ratio of the X-band port indicates good circular polarization. The axial ratio of the S-band port is not as low as ideally desired. However, the antenna is optimized to achieve a wide impedance and gain bandwidth, which resulted in a sub-optimal axial ratio.

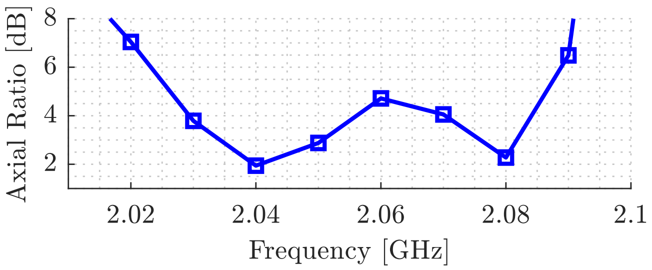

Fig. 12. Axial ratio of the S-band antenna port.

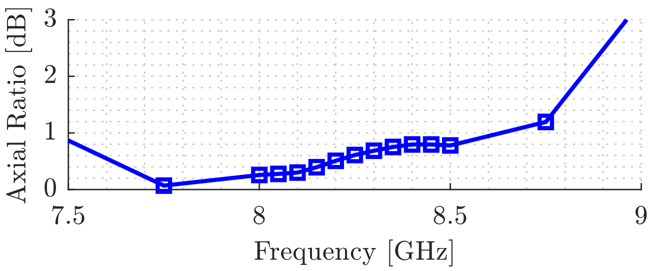

Fig. 13. Axial ratio of the X-band antenna port.

Tab. II shows the simulation performance of the proposed antenna design.

TABLE II
THE PERFORMANCE OF THE PROPOSED ANTENNA DESIGN.

Requirement	Band	Simulated
-10 dB impedance bandwidth	S-Band X-Band	2.010 GHz to 2.095 GHz 6.75 GHz to 9.15 GHz
Gain bandwidth ≥ 6 dB and ≥ 12 dB	S-Band X-Band	2.025 GHz to 2.075 GHz 7.75 GHz to 8.75 GHz
Min. gain (in 40 MHz and 0.5 GHz range)	S-band X-band	6.20 dB 12.1 dB
Half Power beam width	S-Band X-Band	84° 21°
Cross-coupling	S-Band X-Band	≤ -25 dB ≤ -31 dB
Antenna dimensions	-	82 by 82 mm
Antenna height	-	3.947 mm

IV. CONCLUSION

With the satisfactory simulation results, it is concluded that it is possible to design a dual S- and X-band antenna with the desired performance.

The presented antenna design is 82 by 82 mm and it has a total height of ≤ 4 mm. This compact antenna size allows for the antenna to be used with small nano-satellites.

The presented antenna achieves a 50 MHz 6 dB gain bandwidth in the S-band frequency range from 2.025 GHz to 2.075 GHz and a 1 GHz 12 dB gain bandwidth in the X-band frequency range from 7.75 GHz to 8.75 GHz.

The proposed antenna has a 85 MHz S-band impedance bandwidth and X-band impedance bandwidth of 2.4 GHz. The cross-coupling between the two antenna ports are ≤ -25 dB.

The next step would be to fabricate an antenna prototype and measure the antenna performance to validate the simulated performance.

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