Analysis of Performance and Radiation Regulation Compliance on a Miniature Ka Band Antenna

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***Abstract*—With the advancements in 5G, 5G-advanced, and 6G technologies, and an increasing number of satellite constellations, there is a greater demand for ground terminals to support non-terrestrial network (NTN) services, particularly earth stations on mobile platforms (ESOMP). For such ESOMPs to achieve global connectivity, low-cost, compact, and power-efficient user terminals are required. This paper analyzes the radiation performance and compliance of small Ka band satcom receiving antennas with European Telecommunications Standards Institute (ETSI) radiation standards.**

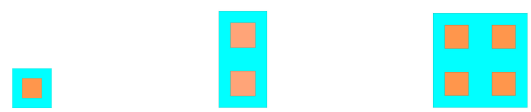
I. Introduction

The integration of non-terrestrial networks (NTN) and terrestrial networks (TN), as well as the growing demand for connectivity, necessitate the development of user terminals with highly directed and steerable beams capable of tracking the satellites if the user and satellite move relative to one another. Though user terminals for connection to NTN already exist, they are still bulky and have a high SWaP-C (size, weight, power consumption, and cost). Terminals with a low SWaP-C are needed in order to have a wider market reach and be suitable to be installed also on small platforms such as electrical vertical take-off and landing vehicles (eVTOLs) and unmanned aerial vehicles (UAV). Additionally, to ensure coexistence and optimal spectrum usage in these expanding communication networks, standardization organizations such as the European Telecommunication Standard Institute (ETSI), the International Telecommunication Union (ITU), and the Federal Communications Commission (FCC) propose radiation regulations for earth stations operating at various frequencies to aid in the reduction of terminal radiation emission and interference to and from neighbouring networks. Thus, this paper investigates the usability of small terminals (with reduced footprints) in the satcom scenario, as well as the limitations, such as regulatory compliance, that arise in such price-driven sub-optimal designs.

Exemplarily, we will analyze small arrays with very small aperture size ($\approx$ 6 cm, to well fit into small antenna footprints on mobile platforms) at Ka band frequencies (20 GHz reception case). Sub-array techniques with various levels of clustering will be evaluated in terms of performance and ETSI regulation compliance. The paper is organized as follows: the details on the analysis performed along with the obtained results are described in Section II. The conclusions are drawn in Section III.

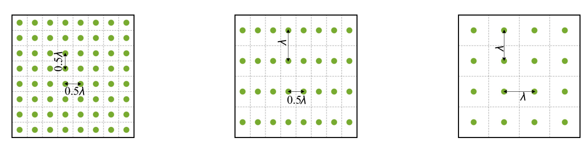
II. Analysis

This paper investigates antenna arrays with a very small aperture size (4λ or $\approx$6 cm) that can potentially be employed on user platforms with restricted installation area, such as drones or eVTOLs. The analysis was performed on three terminal antennas of same aperture (rectangular) size with varied clustering levels, by arranging the blocks in Fig. 1 in a rectangular lattice with body center position according to Fig. 2.



(a) (b) (c)

Fig. 1. Building blocks of terminal antennas (a) T1 (no clustering), (b) T2 (2-element clustering), and (c) T3 (4-element clustering).



(a) (b) (c)

Fig. 2. Body center positions of building blocks in (a) T1, (b) T2, and (c) T3.

The regulatory gain pattern mask (M) shown in Fig. 3 was obtained from the ETSI specifications given in [1] and [2], which defines the maximum antenna gain of each co-polarized component in any direction from the antenna's main beam axis.

The LHCP directivity (one of the co-polarized components), D, of the three terminals and the mask were calculated analytically in a $\{\theta, \phi\}$ grid space with 1° resolution. The directivity pattern for each analysis case was found by iteratively altering the complex excitations delivered to the elements using genetic algorithm, with the goal of increasing directivity along the desired steering direction (θ_0, ϕ_0) while remaining compliant

TABLE I
OBTAINED PERFORMANCE AND NON-COMPLIANCE LEVEL AFTER OPTIMIZATION.

(θ_0, ϕ_0) [deg]	**D_m [dB]**			**$\Delta\theta$, $\Delta\phi$ [deg]**			**NC (L1, L2, L3)[%]**		
	T1	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**
(0, 0)	21.4	20.8	22.7	2, 1	2, -1	0, 0	(0, 0, 0)	(9.8, 0, 0)	(9.9, 0, 0)
(30, 0)	20.8	20.8	20.1	-1, -1	0, -4	-6, 0	(2.3, 0, 0)	(4.9, 0, 0)	(15, 2.6, 1.8)
(60, 0)	17.4	18.8	11.4	-7, 2	-8, 1	-15, 0	(13.7, 0, 0)	(8.8, 0, 0)	(11.1, 10.1, 7)
(30, 45)	21.3	20.9	20.4	0, -2	-3, -5	-5, 0	(2.2, 0, 0)	(9.8, 2.3, 0.7)	(13.1, 5.1, 0.6)
(60, 45)	17.7	15.3	11.5	-6, 0	-6, -3	-10, 0	(8.9, 0, 0)	(9.8, 2.3, 1.7)	(15.2, 8.6, 1.5)

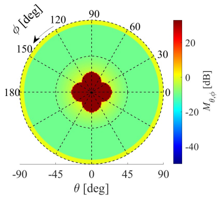
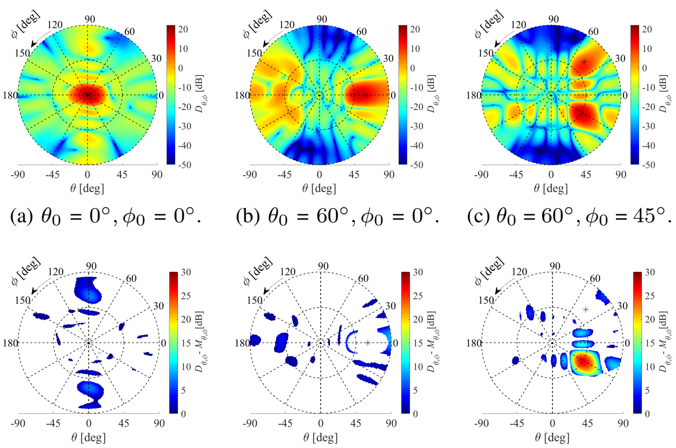


Fig. 3. 3D regulatory mask $M_{\theta,\phi}$ for broadside radiation.

to the mask. The non-compliance (NC) exhibited by the terminals was calculated in 3 levels (L1, L2, and L3) where the low NC level L1 considered the percentage of non-compliant ($D > M$) points with values less than 10 dB, medium NC level L2 considered values ranging from 10 to 20 dB, and high NC level L3 for values greater than 20 dB. After optimization, the computed non-compliance level, maximum total directivity of the array (D_m), and the pointing error ($\Delta\theta$, $\Delta\phi$) are given in Table I. The pointing error was calculated by subtracting θ_0, ϕ_0 from the obtained pointing direction (θ_p, ϕ_p). Due to page limitations, the optimized directivity and non-compliance patterns of only some of the examined cases are shown for T2 in Fig. 4.



(a) $\theta_0 = 0°, \phi_0 = 0°$. (b) $\theta_0 = 60°, \phi_0 = 0°$. (c) $\theta_0 = 60°, \phi_0 = 45°$.

(d) $\theta_0 = 0°, \phi_0 = 0°$. (e) $\theta_0 = 60°, \phi_0 = 0°$. (f) $\theta_0 = 60°, \phi_0 = 45°$.

Fig. 4. Optimized directivity (top) and non-compliance patterns (bottom) of T2 for various steering directions.

A. Observations

To fully satisfy the ETSI mask, the NC values should result in 0, which T1 obtained at broadside steering, but non-compliance was observed to increase at high steering angles. Based on the obtained performance measures, we can state that small arrays have the ability to cater to the needs of satcom connectivity, but they also have limitations (as expected) that must be carefully evaluated. Since T2 and T3 have fewer RF channels, the drop in main lobe gain (impacted by grating lobes), pointing inaccuracy, and non-compliance relative to T1 worsened during high steering angles (except along the axis, where the lattice design is similar to T1). However, the degree of performance loss and non-compliance (high NC in L2 and L3) in T3 is relatively major, owing primarily to the decreased degree of freedom of excitation points. Although the acquired results were anticipated from theoretical knowledge, this work focused on quantifying the performance degradation and non-compliance levels and therefore enhancing the insight into the trade-off space, allowing for proper trade-off designs in future research.

III. CONCLUSION

This paper investigated three array antennas with varied amounts of clustering to reduce the SWaP-C of satellite user terminals and assessed their limits in terms of radiation performance and regulatory compliance. It was observed that a higher level of clustering can reduce the cost and power consumption of terminal antennas, but the antenna's performance degrades as a result. Therefore, as a trade-off between performance and SWaP-C reduction, clustering of two elements (in T2) can be considered a viable approach with fewer RF channels but at same time not compromising much in the radiation performance. The grating lobes were not decreased solely by optimizing the excitations and hence require additional exploration, possibly by the utilization of a non-uniform lattice arrangement to lower them and thereby meet radiation standards in all steering directions.

REFERENCES

[1] *Satellite Earth Stations and Systems (SES); Harmonised Standard for Earth Stations on Mobile Platforms (ESOMP) transmitting towards satellites in geostationary orbit, operating in the 27,5 GHz to 30,0 GHz frequency bands covering the essential requirements of article 3.2 of the Directive 2014/53/EU*, ETSI EN 303 978 V2.1.2, 2016.

[2] *Satellite Earth Stations and Systems (SES); Harmonised Standard for Earth Stations on Mobile Platforms (ESOMP) transmitting towards satellites in non-geostationary orbit, operating in the 27,5 GHz to 29,1 GHz and 29,5 GHz to 30,0 GHz frequency bands covering the essential requirements of article 3.2 of the Directive 2014/53/EU*, ETSI EN 303 979 V2.1.1, 2016.