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Magneto-electric dipole antenna as a transceive element in a phased array

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Abstract. We propose a transceive element of a phased array antenna for satellite communications systems operating in K_u frequency band. The proposed element based on a magneto-electric dipole antenna. A substrate-integrated waveguide and a cruciform slit of a special shape are used as a feeding element. We aim to drive the circular polarization at two sub-bands simultaneously. We performed electromagnetic simulations and optimization of the single element and applied array factor to evaluate beam steering, directivity and cross-polarization. The antenna elements were optimized using 8 criteria to obtain acceptable S-parameters and ellipticity. As a results, we obtain satisfactory cross-polarization for R_x-band of <−20 dB. For T_x-band we obtained value <−14.2 dB for oblique beam position and of −20.1 dB for normal beam position. The developed geometry meets the requirements of manufacturing on printed circuit boards. The results obtained indicate the prospects of using such broadband transceive elements in phased arrays.

Keywords: Magneto-electric dipole, Antenna, Phased Array, Sequential Feeding, SIW waveguide_

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Магнитоэлектрический диполь в качестве приемопередающего элемента в фазированной антенной решетке

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Аннотация. В данной работе рассматривается приемопередающий элемент фазированной антенной решетки для систем спутниковой связи, работающих в Ku диапазоне частот. Предлагаемый элемент основан на магнитоэлектрической дипольной антенне. В качестве питающего элемента используются встроенный в подложку волновод и крестообразная щель специальной формы. Целью работы является управление круговой поляризацией в двух поддиапазонах одновременно. Были проведены электромагнитное моделирование и оптимизация одиночного элемента, а также применен фактор массива для оценки направления луча, направленности и кроссполяризации. Элементы антенны были оптимизированы по 8 критериям для получения приемлемых S-параметров и коэффициента эллиптичности. В результате была получена достаточно хорошая кросс-поляризация для R_x-диапазона <−20 дБ. Для T_x-диапазона мы получили значение <−14,2 дБ для наклонного положения луча и −0,1 дБ для нормального положения луча. Разработанная топология на печатной плате соответствует производственным требованиям. Полученные результаты указывают на перспективность использования таких широкополосных приемопередающих элементов в фазированных решетках.

Ключевые слова: магнитоэлекрический диполь, антенна, фазированная антенная решетка, последовательная запитка, SIW-волновод

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Introduction

Modern satellite communications systems require developing compact and planar phased array antennas operating in K_u band. Such an antenna should have possibilities of fast electronical beam steering in azimuthal or/and elevations planes. Such an array can be implemented as two dual-polarized sub-arrays for R_x and T_x bands [1–3] or one combined linear polarized transceive array [4]. Combined transmit-receive phased arrays antennas for K_u are challenging to implement because an antenna element should work in a broad band. To implement an array with the desired properties one can, use magneto-electric dipole (MED) [5–7]. Such a MED has been known for some time and has managed to gain popularity due to its wide operating band (up to ~30% [8]), high directivity [9] and relatively simple geometry [10]. Its performance is based on constructive interference of near electromagnetic fields of a magnetic dipole (effective current frame) and an electric dipole (two poles with different potentials) [11].

We have allocated the R_x (left-handed circular polarization (CP): 10.95-11.7 GHz) and T_x (right-handed CP: 14–14.25 GHz) bands and designed MED geometry in order for both of these bands to be covered. Since the original Γ-shaped feeding element is extremely difficult to implement for modern mass production, such a phased array would greatly lose in performance. This is why we decided to use sequential laminated waveguide or substrate integrated waveguide (SIW) feeding [12]. Although sequential feeding causes frequency beam steering, it is quite stable when operating at the single frequency.

Another challenge is to develop a broadband array element operating in circular polarization at both band simultaneously [13]. In such arrays it is difficult to maintain acceptable level of ellipticity and cross-polarization for R_x and T_x bands. In this work we propose and perform electromagnetic simulation and optimization of such a broad-band MED element for phased arrays in K_u band.

It is noticeable that such an element, with the proper manufacture of feeding SIW and cruciform slits, provides circular polarizations depending on the direction of the feeding, and the suggested array is capable of electrical beam steering in the presence of phase shifters.

Methods

Full-wave electromagnetic simulation was performed using finite-element method (FEM)-based solver and far field approximation to compute S-parameters and radiation patterns. The geometry of MED and its geometrical parameters are shown in Fig. 1. The MED was implemented on Rogers RO3003 substrate (ε_r = 3, tgδ = 0.001) from embedded material library. All traces were modeled using lossy copper of 36 μm in thickness. Arms of MED were connected to the upper ground plate using vias. In this upper ground plate, we modeled a slot in the SIW to feed the MED. This SIW waveguide was implemented between upper and lower ground planes that are interconnected using vias. The space between these planes was filed also by Rogers RO3003 substrate. The structure was driven by two emitting waveguide ports 1 and 2, whereas 3 and 4 are receiving ports.

The parameters of the MED, SIW and feeding slot were optimized using trust region algorithm. We used 8 optimization criteria such as minimization of reflection coefficient S_{11} and transmission coefficient S_{21}. In addition, we computed axial ratio and minimized ellipticity at six frequency points that are the borders and the middle of R_x and T_x bands. After this minimization,

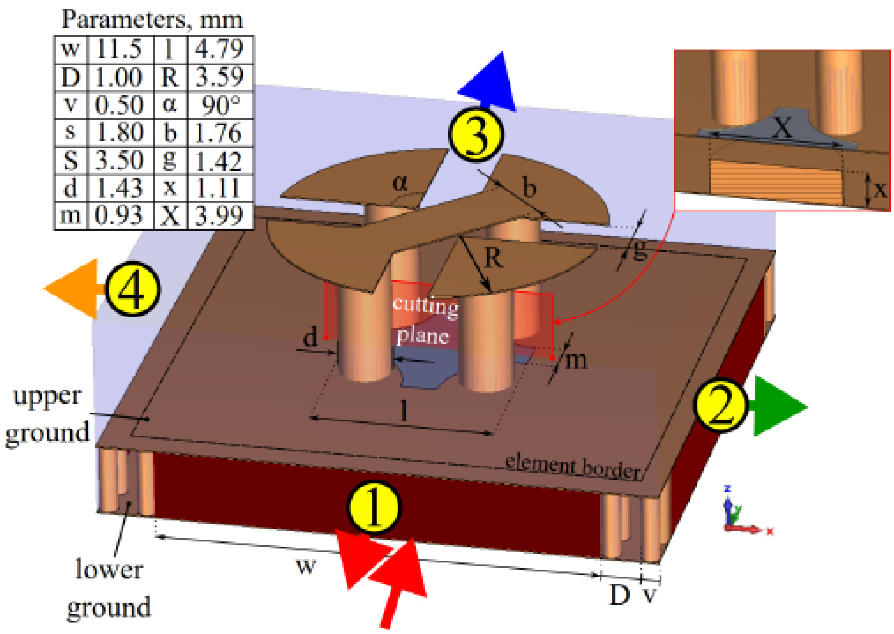


Fig. 1. Suggested geometry of MED and its parameters

the array factor was employed to obtain the far field lattice sum. The array period was 13mm in both x/y directions. This period was optimized to avoid strong sidelobes at T_x band for oblique beam positions. The number of elements was set to 32 in both directions to obtain desired directivity and beam width. We show the results for three beam positions: 0°, +15°, +30° at the central frequency for each band (11.325 and 14.125 GHz). For each beam position we estimated directivity, ellipticity, cross-polarization, −3dB beam width and sidelobe level.

Results

S-parameters computed in EM simulations are shown in Fig. 2. In this plot we also denote R_x and T_x bands as blue and pink zones. Here S_{11} and S_{22} are the reflection coefficients, S_{21} and S_{41} are the port isolation coefficients, and S_{31} is the directional coupling or SIW waveguide characteristics [12]. Such parameters as S_{12}, S_{32} and S_{42} are not shown because they are identical to S_{21}, S_{41} and S_{31}. As it can be observed, we obtained the worst value of S_{11} coefficient in in the lower R_x band of −17.9 dB whereas worst value S_{22} coefficient in the upper T_x band of −16.8 dB. The port isolation S_{21} and S_{41} are −16.3 dB and −13.7 dB respectively for the R_x band, whereas −17.4 dB and -25.2 dB for the T_x band. The directional coupling S_{31} is −0.61 dB and -0.68 dB for the R_x and T_x band respectively. It is important to note that this directional coupling has to be toughly optimized depending on the number of elements in the full array to maintain desired magnitude distribution.

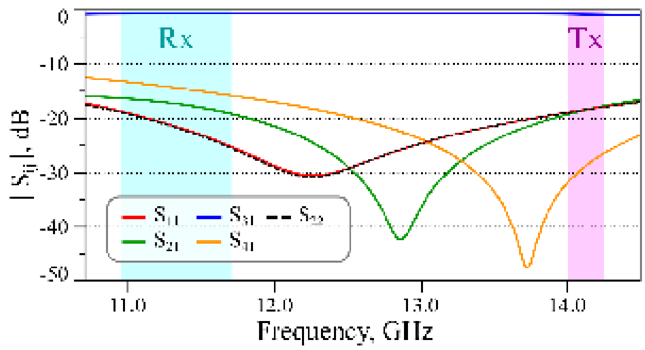
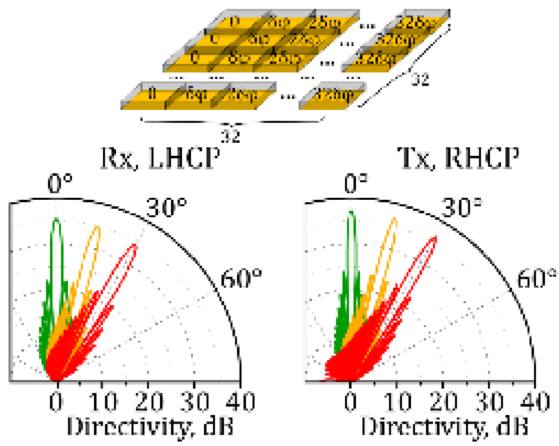


Fig. 2. Simulated S-parameters (dB) in the range from 10.7 GHz to 14.5 GHz



SLL, dB	Dir, dB	$\delta\varphi$, deg.	w_{-3dB}, deg.	CP, dB
-13.3	35.3	0	3.2	-23.4
-13.1	34.8	45.7	3.3	-24.1
-12.7	34.3	88.5	3.7	-20.9

SLL, dB	Dir, dB	$\delta\varphi$, deg.	w_{-3dB}, deg.	CP, dB
-13.3	37.1	0	2.6	-20.1
-13.1	36.7	57.0	2.7	-18.2
-12.8	36.1	111	3.0	-14.2

Fig. 3. Directivity patterns of the suggested MED at frequencies of 11.325 GHz and 14.125 GHz for three beam positions: normal, 15° and 30°

The directivity patterns and antenna array evaluation are shown in Fig. 3. In this figure we show left-handed CP for R_x band, and right-handed CP for T_x band. It is important to note that we succeeded to optimize the ellipticity for the central frequency, where it equals to 1.17 dB for the 0°, 1.15 dB for 15° and 1.59 dB for 30°. It is observed that optimized antenna provided low level of ellipticity in R_x band that lead to cross polarization level below −20 dB for all beam positions. For T_x band the ellipticity becomes to 1.72 dB for the 0°, 2.05 dB for 15° and 3.3 dB for 30°, and therefore cross polarization comes to −20.1 dB for 0°, whereas it drops to −18.2 and −14.2 dB for oblique beams. Nevertheless, minimization of cross polarization is a common problem [13, and requires thorough optimization of the array [14].

Conclusion

We performed EM simulations and optimization of magneto-electric dipoles for combined circular polarized transceiver phased array antenna operating in K_u-band. We obtain acceptable level of cross-polarization for R_x-band of <−20 dB. For T_x-band we obtained value <−14.2 dB for oblique beam position and of −20.1 dB for normal beam position. Proposed and designed MED can be employed in a phased array, which can be used for beam steering in a presence of the phase shifters However, to construct the array period and directional coupling coefficient has to be further optimized.

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REFERENCES

1. **Aljuhani A.H., Kanar T., Zihir S., Rebeiz G.M.,** A Scalable Dual-Polarized 256-Element Ku-Band Phased-Array SATCOM Receiver with ±70° Beam Scanning, IEEE MTT-S Int. Microw. Symp. Dig., (2018) 1203–1206.
2. **Gultepe G., Kanar T., Zihir S., Rebeiz G.M.,** A 1024-Element Ku-Band SATCOM Phased-Array Transmitter with 45-dBW Single-Polarization EIRP, IEEE Trans. Microw. Theory Tech., 69 (9) (2021) 4157–4168.
3. **Aljuhani A.H., Kanar T., Zihir S., Rebeiz G.M.,** A Scalable Dual-Polarized 256-Element Ku-Band SATCOM Phased-Array Transmitter with 36.5 dBW EIRP per Polarization, 2018 48th Eur. Microw. Conf. EuMC. (2018) 938–941.
4. **Kapusuz K.Y., Sen Y., Bulut M., Karadede I., Oguz U.,** Low-profile scalable phased array antenna at Ku-band for mobile satellite communications, IEEE Int. Symp. Phased Array Syst. Technol., Jul. (2016).
5. **Ge L., Luk K.M.,** A wideband magneto-electric dipole antenna, IEEE Trans. Antennas Propag., 60 (11) (2012) 4987–4991.
6. **Ketham R., Althuwayb A.A., Kumar A.,** Low-profile Magneto-electric Dipole Antenna, (2021).
7. **Guo J., Chu Q. X.,** A Dual-Band Nested Ku/Ka Magneto-Electric Dipole Antenna Array with High Isolation, 2022 Int. Conf. Microw. Millim. Wave Technol. ICMMT 2022 - Proc., (2022).
8. **Causse A., Rodriguez K., Bernard L., Sharaiha A., Collardey S.,** Compact Bandwidth Enhanced Cavity-Backed Magneto-Electric Dipole Antenna with Outer Γ-Shaped Probe for GNSS Bands, Sensors. 21 (11) (2021) 3599.
9. **Kakhki M.B., Dadgarpour A., Antoniades M.A., Sebak A.R., Denidni T.A.,** Dual Complementary Source Magneto-Electric Dipole Antenna Loaded with Split Ring Resonators, IEEE Access, 8 (2020) 59351–59361.
10. **Limpiti T., Chantaveerod A., Petchakit, W.,** Design of a magneto-electric dipole antenna for FM radio broadcasting base station antenna implementation, Prog. Electromagn. Res. M, 60 (2017) 75–84.
11. **Li M., Luk K.-M.,** Wideband Magneto-electric Dipole Antennas, Handb. Antenna Technol., (2015) 1–43.
12. **Uchimura H., Takenoshita T., Fujii M.,** Development of a ‘laminated waveguide, IEEE Trans. Microw. Theory Tech., 46 (12) (1998) 2438–2443.

13. **Zeng Q., Xue Z., Ren W., Li W., Yang S.,** A high-gain circular polarization beam scanning transmit array antenna, IET Microwaves, Antennas Propag., 15 (11) (2021) 1519–1528.

14. **Hussain S., Qu S. W., Bu D., Wang X.H., Sharif A.B.,** A meta-surface loaded, low profile 28 GHz phased array antenna," Int. J. RF Microw. Comput. Eng., 32 (1) (2022).

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