Arrow Patch-Slot Antenna for 5G Lower Frequency Band Communications

Yuhao Feng [1]
yuhaofeng@mymail.mines.edu

Yiming Chen [1]
yimingchen@mymail.mines.edu

Atef Z. Elsherbeni [1, 2, *]
aelsherb@mines.edu

Khalid Alharbi[2]
khalharbi@kau.edu.sa

[1] Department of Electrical Engineering
Colorado School of Mines
Golden, CO 80401 USA

[2] Department of Electrical and Computer Engineering
King Abdulaziz University
Jeddah, 21589, Saudi Arabia

***Abstract*—**A compact size arrow shaped patch in a rectangular slot antenna is designed for 5G communications in the lower 3 to 6 GHz band. The antenna element is fed through a coplanar waveguide with partial ground plane for better impedance matching with 50 Ohms across the entire band. The maximum gain of a single element is 3.8 dB at 3.7 GHz, while for linear arrays of 5 and 15 elements with uniform excitation the maximum gains are 10.9 dB and 16 dB, respectively. The 5 and 15 elements arrays provide scanning range with no significant degradation of the main beam up to 30˚ and 45˚, respectively. The properties of this antenna element makes it suitable for 5G wireless mobile devices and miniaturized base stations antenna arrays.

Keywords*—5G antenna, compact size, FDTD, wide-band.*

I. INTRODUCTION

In recent years, the establishment of the fifth-generation communication systems (5G) are getting more and more attentions [1], in which the antenna working as the wireless signal receiver and transmitter are facing the challenges of updating systematically due to the new licensed frequency band for 5G. The 5G frequency announced by the FCC in 2018 has the sub-6 bands like 3.55-3.7 GHz band and 3.7-4.2 GHz band, and higher frequency bands as 24.25-24.45 GHz band, 24.75-25.25 GHz band, 27.5-28.35 GHz, 37-38.6 GHz, etc. [2]. Initially, 5G antenna designs are mainly focus on the sub-6 bands due to the lower cost and lower manufacturing accuracy requirements. However, the wide-ranging bands at the sub-6 range are enforcing the need for antennas covering these bands in a configurable mechanism. Reconfigurable antennas are usually consisting of other circuit elements that introduces losses and complications to the design [3]. An alternative approach is to design an antenna that support the entire sub-6 GHz band with miniaturization and low cost in mind [4].

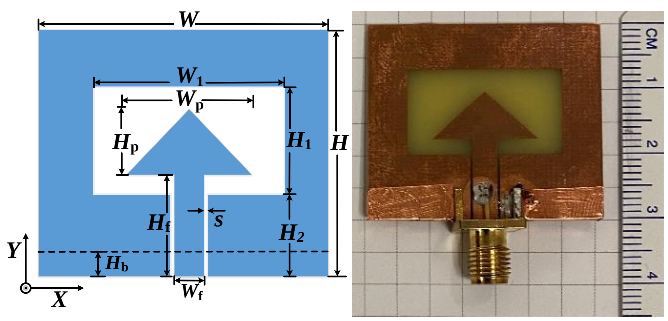
In order to achieve a compact size antenna working at different bands within the 3 to 6 GHz range using single feeding port, an arrow-like patch/slot type antenna with partially grounded coplanar waveguide (CPW) feed is considered. CPW feeding configuration has several advantages such as low profile, low cost, and broader bandwidth relative to traditional microstrip line configuration [5].

*Adjunct Professor, Department of Elec. & Computer Eng., King Abdulaziz University, Jeddah, Saudi Arabia

The finite difference time domain (FDTD) method is used for the current design simulation [6] and the numerical results for one element antenna is compared with the corresponding measured results of a fabricated prototype and simulated results using commercially available Ansys High Frequency Structure Simulator (HFSS). A linear array with 30˚ and 45˚ scanned beams are also simulated to show the future capabilities of this element in array configurations.

II. ANTENNA DESIGN & STRUCTURE

The top view of the proposed antenna element is shown in Fig. 1 along with the fabricated prototype using an FR4 substrate, with thickness of 1.6 mm, relative permittivity of 4.4, and loss tangent of 0.02. The footprint size of this antenna is 35 (W) × 30 (H) mm^2, which are 0.43λ × 0.37λ at 3.7 GHz. The dash line in Fig. 1 (a) represents a partial metal ground plane at the bottom side of the substrate with dimensions of 35 (W) × 3 (H_b) mm^2. The above dimensions are optimized using the full wave simulation software CEMS [8] which is based on the FDTD method [6], but running on GPU. The other dimensions of the antenna element in millimeters are: W = 35, H = 30, W_1 = 23, H_1 = 13, H_2 = 10, Wp = 15.6, H_p = 7.2, W_f = 3.6, H_f = 12.4, s = 0.4, H_b = 3. Fig. 1 (b) presents the fabricated single element.



(a) (b)

Fig. 1. (a) The proposed arrow shaped patch/slot antenna element. (b) Fabricated prototype element.

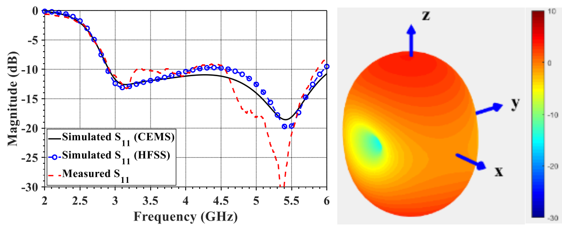
To demonstrate the potential of this element in building a phased array base station antenna with miniaturized size and wide-band capabilities, a 5-elements and a 15-elements linear arrays were also simulated and sample results are presented. This design provides a good potential of multi-input and multi-output (MIMO) antenna designs for 5G applications.

Submitted On: August 28, 2020
Accepted On: September 5, 2020

https://doi.org/10.47037/2020.ACES.J.351178

III. Simulated and Measured Results

The major simulation parameters used in CEMS are: dx=0.1, dy=dz=0.2 mm and 50,000 time steps with 10 layers of convolutional perfectly matched layer (CPML) boundary.



(a) (b)

Fig. 2. (a) Antenna element reflection coefficients, and (b) far-field gain pattern at 3.7-GHz.

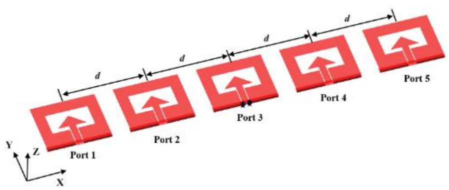
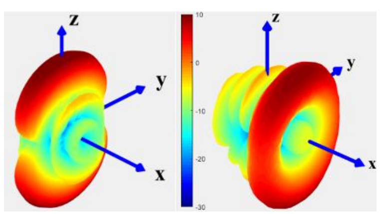


Fig. 3. A 5-elements linear array with size less than 2.65λ.



(a) (b)

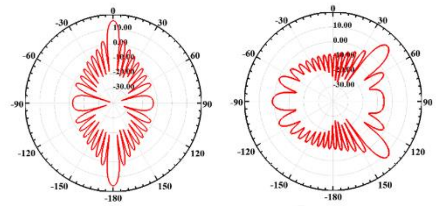
Fig. 4. The 5-elements 3D far-field gain pattern at 3.7 GHz: (a) with uniform excitation; (b) with phase distribution for 30˚ scanned beam.

The comparison between the simulation based on CEMS and HFSS and measured reflection coefficient of a single element antenna yields good agreement from 2.9 GHz to 5.9 GHz as shown in Fig. 2 (a). The measured response covers two of the sub-6 bands for 5G: 3.55-3.7 GHz and 3.7-4.2 GHz. The far-field gain pattern of a single element at 3.7 GHz is shown in Fig. 2 (b) with maximum gain of 3.8 dBi at the broadside (θ=0˚).

Fig. 3 shows the configuration of a 5-elements linear array which supports the operation in the sub-6 bands while maintaining coupling among the elements in the order or less than -20 dB. The 3D gain patterns for this configuration is shown in Fig. 4 for uniform and phased excitation with 0˚ and 30˚ main beam directions, respectively. Similarly, the gain patterns for a 15 elements array are shown in Fig. 5. The gain of 1 element, 5, and 15 elements with uniform and phased excitation for scanning at 30˚ and 45˚ are listed in Table I.

IV. Conclusions

A miniaturized, low-cost design of patch/slot antenna element and the corresponding linear arrays supporting the sub-6 GHz frequency bands for 5G communications is presented. Higher gains and larger scanning range are achieved with the increase of number of elements in the linear array configuration without obvious deterioration in S-parameters or far-field characteristics. Good element to element isolation is observed, and scanning capabilities are predicted for larger number of elements. Future work will include the extension to two-dimensional arrays.



(a) (b)

Fig. 5. Far-field gain pattern of the 15-elements linear array in xz plane at 3.7 GHz with size less than 8.31λ: (a) with uniform excitation; (b) with phase distribution for 45˚ scanned beam.

Table I. Broadside Gain at 3.7GHz

Element Numbers (N)	***Main Beam Direction (degree)***	***Gain (dBi)***
N=1	0	3.8
N=5	0	10.9
N=5	30	9.4
N=15	0	16
N=15	45	12.4

Aknowledgment

This project is partially supported by a gift fund from Futurewei Technology Inc., New Jersey Research Center, Bridgewater, NJ, USA and by ANSYS gift of HFSS license.

References

[1] M. Agiwal, A. Roy, and N. Saxena, "Next generation 5G wireless networks: A comprehensive survey," IEEE Communications Surveys & Tutorials, vol. 18, no. 3, pp. 1617-1655, Aug. 2016.

[2] 5G Americas Spectrum Recommendations for the U.S. (2019, July 25). Retrieved from https://www.5gamericas.org/5g-americas-spectrum-recommendations-for-the-u-s/

[3] A. Zaidi, A. Baghdad, W. A. Awan, Halima, A. Ballouk, and A. Badri, "CPW Fed Wide to Dual Band Frequency Reconfigurable Antenna for 5G Applications," 2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS), Fez, Morocco, pp. 1-3, 2019.

[4] G. Gao, B. Hu, and J. Zhang, "Design of a miniaturization printed circular-slot UWB antenna by the half-cutting method," IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 567-570, May 2013.

[5] Y. Wang, Z. Ying, and G. Yang, "A Compact CPW-fed Wideband Antenna Design for 5G/WLAN Wireless Application," 2017 IEEE International Symposium on Antennas and Propagation Meeting, San Diego, CA, pp. 1775-1776, 2017.

[6] A. Z. Elsherbeni and V. Demir, The Finite-Difference Time-Domain Method for Electromagnetics with MATLAB® Simulations, New Jersey: SciTech Publishing, 2016.

[7] V. Demir and A. Elsherbeni, CEMS: A software package for electromagnetics simulations, Version 4, Oct. 2019.