CmWave to MmWave Reconfigurable Antenna for 5G Applications

Jinqun Ge and Guoan Wang
Department of Electrical Engineering
University of South Carolina
Columbia, USA
jinqun@email.sc.edu, gwang@cec.sc.edu

***Abstract*—This paper presents a reconfigurable antenna with tunable operating frequency from mmwave band (e.g., 28GHz) to microwave frequency band (e.g., 6GHz and below). The antenna consists of multiple individual antenna elements at mmwave frequency connected with Microelectromechanical Systems (MEMS) based switches. Considering the location, dimension, and number of MEMS switches, this paper thoroughly studies their effects on the performance of individual antenna elements and entire array. A 3x3 antenna array has been implemented to demonstrate frequency tunability from 6GHz to 28 GHz with good performance. Better frequency reconfigurability can be achieved with more optimized antenna elements and switches.**

Keywords—reconfigurable; cm wave; mm wave; MEMS; 5G

I. Introduction

With the increase in the number of wireless communication standards and developments of systems, especially in the case of multiple input and multiple output (MIMO) systems, modern wireless communications and radar systems are demanded miniature in size, and they are required operating at multiple-frequency bands to provide the enhanced and multifunctional performances [1]. Taking mobile devices as an example, it is highly desirable to roam seamlessly across geographic boundaries, accommodating different protocols and frequencies of use as required. The implementation of multi-band RF and microwave antenna topology has become feasible that incorporates multiple cellular modes as well as Bluetooth, Wi-Fi and other functionalities. This generally implies that the designers use a number of antenna duplicated for each band, with the associated penalties of increased size, weight and cost. However, board area is very limited due to the device convergence trend, transceivers with tunable circuits (e.g. antennas, match networks, duplexers, couplers) provide multi-standard/multi-function, reduction in cost and size, improved battery life, better performance, and increased manufacturability.

The implementation of multi-band RF and microwave circuit topology has become a hot topic [2]. Reconfigurable antenna has been widely studied [3]. The reconfigurability can be done on the operating frequency, bandwidth, and antenna polarizations. Various switches technologies such as RF MEMS, PIN diodes and FET have been employed to provide reconfigurable frequency performance. RF MEMS switches have both high switch performance (e.g., isolation and insertion loss) and consume low to zero power to reduce overall system power requirements when compared with PIN diodes or FETs, leading to the commercially development in multiple applications [4].

This work is supported by the National Science Foundation under grant 1910853

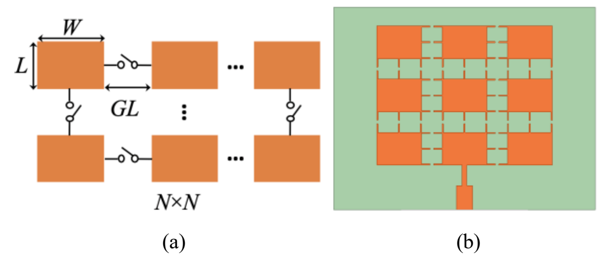

Fig. 1. (a) *N*×*N* phased-array antenna with physical switches. (b) ANSYS HFSS simulation of a 3x3 patch phased-array antenna on a FR4 substrate.

In this paper, a MEMS switches enabled frequency reconfigurable antenna is proposed with a wide tunable operating frequency from mmwave band to cmwave band. The configurations of antenna elements are investigated and optimized for superior performance at frequency above 28 GHz. And connections and locations of MEMS switches have been fully investigated achieving frequency reconfigurability and improved electromagnetic (EM) performance at 6GHz and below. A design guideline is provided to achieve an *N*×*N* antenna array for specific frequency tuning applications.

II. Structure Design

From the antenna design theory, the operating frequency of antenna is proportionally dependent on the physical dimension of the design, thus the frequency of the antenna is reconfigurable by connecting smaller antenna elements with switches to form a large antenna element as shown in Fig. 1. Individual patch antenna element (*L*=2.7mm, *W*=3.7mm) at mmwave frequency is first designed on a FR4 substrate (ε_r=4.4, tanδ=0.002, thickness=0.5mm) with the operating frequency of 32GHz. A massive MIMO array is then formed with the separation of *GL* and the elements are connected with three narrow interconnects and MEMS switches.

In order to achieve good EM performance for both individual and connected patch elements, effect of the gap between the adjacent elements are first investigated in Fig. 2 (a). *GL*=1.7mm is chosen to minimize the effects on the individual patch antenna generated by the surrounded elements. Taking

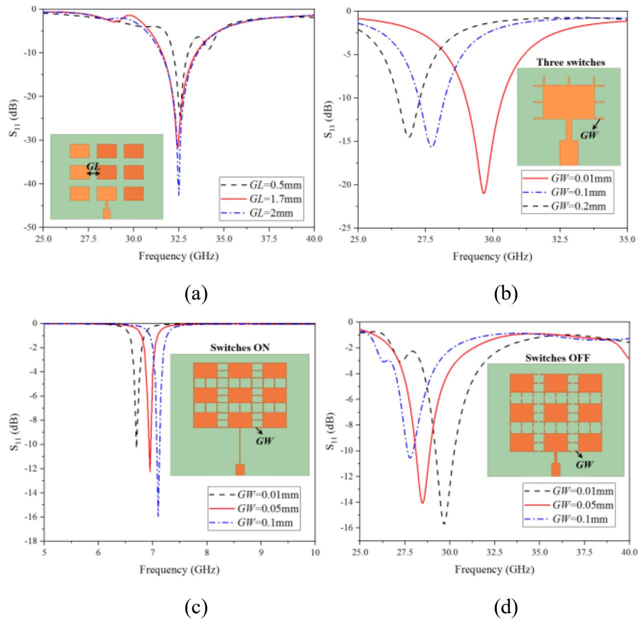

Fig. 2. Preliminary results of antenna performance for (a) single patch antenna with various gap, (b) single antenna element with multiple narrow interconnects /switches, and antenna array with multiple switches (c) ON and (d) OFF.

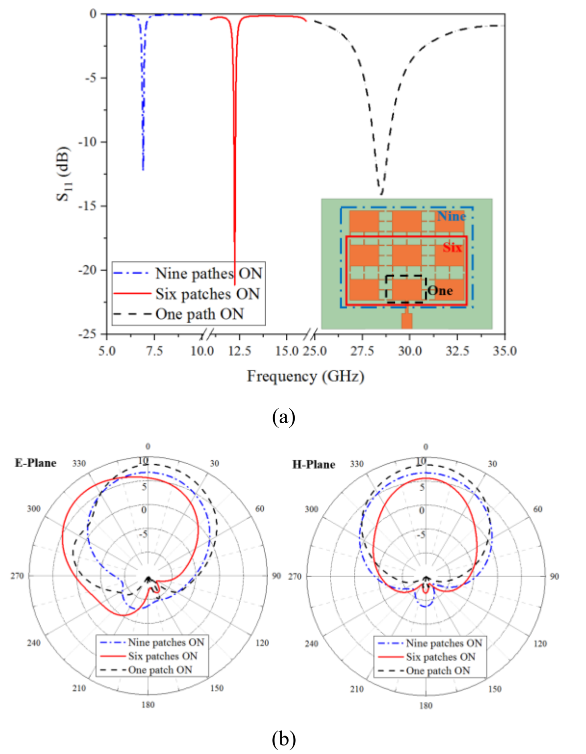

Fig. 3. (a) Frequency reconfigurability demonstration of the proposed antenna. (b) Comparison of the radiation patterns for different operating frequency states.

account of the connection of patch elements, the width of the interconnects/ switches is investigated for a single element, connected elements with switches ON and OFF, respectively. As illustrated in Fig. 2 (b), the increased width of introduced interconnects shifts the operating frequency of a single patch antenna element to lower frequency. This trend is found for connected antenna array in Fig. 2 (c) and (d). In addition, the S_{11} performance are deteriorated with wider interconnects. By maintaining both the frequency shifting and EM performance, the *GW* is chosen as 0.05mm for the final antenna array. When all the switches are OFF, individual antenna is working at 28GHz. When all the switches are ON, the antenna array acts as a patch antenna with a larger dimension, leading to a much low working frequency of 6GHz.

III. Results

To further demonstrate the frequency reconfigurability of the proposed antenna, the antenna array is tuned to three operating frequency states as shown in the insert in Fig. 3 (a). By connecting one, six and nine patch elements with MEMS switches, the operating frequency can be tuned to 28GHz, 12GHz and 6GHz, respectively. The S_{11} of the three working states are all below -10 dB, showing good EM performances.

The radiation patterns of the three working states are also compared in Fig. 3 (b) on both E-plane and H-plane. Where the 28GHz working state (single patch antenna) has the largest gain of 8.1 dB. This is because the feed line used here is the original feed line designed for the single patch antenna, leading to the impedance mismatch for the 12GHz and 6GHz working states.

IV. Conclusion

This paper proposes a frequency reconfigurable antenna with the ability of tuning the antenna operating frequency from mmwave band (e.g., 28GHz) to cmwave frequency band (e.g., 6GHz and below). The effects of the MEMS switch connection and element distribution have been fully investigated in terms of individual and array elements. A 3×3 antenna array is implemented to demonstrate the flexibility of the proposed concept, where three working frequencies of 28GHz, 12GHz and 6GHz are achieved. Each working state has good EM performance with S_{11} lower than -10 dB. This paper provides a study and guideline on the development of high-performance multiple MEMS switches enabled frequency reconfigurable antenna array with wide tunable range.

Acknowledgment

The authors would like to thank the funding support from the National Science Foundation under grant 1910853 and software support from ANSYS corporation.

References

[1] Chen S , Sun S , Wang Y , et al., “A comprehensive survey of TDD-based mobile communication systems from TD-SCDMA 3G to TD-LTE(A) 4G and 5G directions,” China Communications, vol 12, no. 2, pp.40-60, 2015.

[2] Guo D , He K , Zhang Y , et al., “A Multiband Dual-Polarized Omnidirectional Antenna for Indoor Wireless Communication Systems,” IEEE Antennas and Wireless Propagation Letters, vol. 16, no. 99, pp.1-1, 2016.

[3] Guoan Wang, Ramanan Bairavasubramanian, Bo Pan, and John Papapolymerou, “Radiofrequency MEMS-enabled Polarization-Reconfigurable Antenna Arrays on Multilayer Liquid Crystal Polymer,” IET Microwaves, Antennas and Propagations, vol. 5, no.13, pp. 1594-1599, 2011.

[4] Liya Ma, Norhayati Soin, et al., “Comprehensive study on RF-MEMS switchesused for 5G scenatio,” vol. 7, pp. 107506, 2019