Design of mm-wave Phased Array in Mobile Terminal for 5G Mobile System

Ming Cai, Congcong He, Xiaoqiang Li, and Guangli Yang
The Key Lab of Specialty Fiber Optics and Optical Access Network
Shanghai University, Shanghai, China

Abstract— In this paper, the study of the mm-Wave phased array in mobile terminal for the fifth generation (5G) mobile communication system is proposed. The design methodologies are presented based on the concept of coupled oscillator arrays, making the phased array without the need of conventional phase shifter and complex feeding network.

The operating band of the proposed phased array is in 21 GHz–22 GHz, which is one of the candidate bands for 5G cellular. The design of tunable coupling networks can achieve the desired scanning beam by tuning the phase gradient states of adjacent oscillator elements. The overall array is low cost and low profile, which is suitable for 5G mobile system.

1. INTRODUCTION

In current cellular bands (< 6 GHz), the spectrum resource is scarce. In recent year, a number of research institutions and experts have begun to focus on the millimeter-wave (mm-Wave) frequency. Employing mm-Wave to wireless communication has attracted global attention [1]. Applying mm-Wave frequency to mobile system requires many novel techniques at the hardware level. For mobile terminal, considering the characteristics of complicated inner working environment causes a number of constraints, there are: size, cost, and efficiency. Therefore, how to realize a compact and efficient beam steering antenna is a significant part in the whole 5G mobile communication system.

In [2], proposed a novel, low profile 28GHz phased array for the 5G cellular handset devices in the first time. The whole system consists of 16-element mesh-grid patch antenna array and RF circuit utilizing 16 6-bit phase shifters based on RF beamforming architecture. As we see, desire to be serviced by mm-Wave commercial products have brought some constraints that could make conventional phased array more expensive. Detailly, phase shifter is a key component on RF beamforming. However, a number of factors influence the utilization of phase shifter, such as phase shift states, high insert losses in high frequency and cost.

In two decades, coupled oscillator arrays (COAs) have been demonstrated for beam steering application without the need of phase shifters, due to the advantages of the capability of continuous beam-scanning and light, low cost circuitry. In this paper, we propose a novel design including antenna array and RF circuit for the 5G mobile communication system.

2. PRINCIPLE OF OPERATION

For an equal-spaced one-dimensional array, illustrated in the Figure 1, the relationship between phase gradient $\Delta\theta$ and scan angle ϕ is described by Equation (1).

$$\Delta\theta = \frac{2\pi d}{\lambda}\sin\phi \tag{1}$$

where d is the spacing between adjacent elements and λ is the wavelength. We consider the coupling effects of neighboring element, especially on the coupling phases rather than the coupling strengths in coupled systems. In other words, we can make the desired scanning angle through manipulation of the coupling phases [3]. In [3], Equation (2) is described as the phase dynamics model of N coupled oscillators.

$$\omega = \omega_0 + k_{j+1,j}\sin(\theta_j + \phi_{j+1,j}) - k_{j-1,j}\sin(\theta_{j-1} + \phi_{j-1,j}) \tag{2}$$

for $j = 1, \ldots, N$, where $\phi_{j+1,j}$ is the coupling phase between oscillators $j+1$ and j. The coupling amplitudes $k_{j+1,j}$ are assumed to be equal. For the purpose of beam steering, the phase gradient states of the nearest-neighbor element oscillator are adjustable control parameters of beam steering.

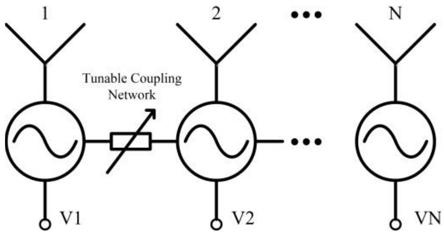

Figure 1: 1-D coupled oscillator arrays with tunable coupling network.

3. ANTENNA ARRAY DESIGN

Yagi-Uda antenna is suitable for many millimeter wave applications considering the advantages of high gain, high efficiency, low cost and ease of fabrication. In our work, the phased array is composed of eight planar Yagi-Uda antennas. The microstrip-fed 3-element Yagi-Uda antenna utilizes one drive dipole built on the both side of substrate and two forward directors elements on the top plane. The microstrip ground is employed as a reflector. The element antenna with the size of $10 * 30\,\text{mm}^2$ is built on Tly-5 substrate with a thickness of 0.254 mm, ε_r dielectric constant 2.2 and $\tan\delta$ loss tangent 0.0009. Detailed geometry is illustrated in Figure 2. The impedance bandwidth ($S_{11} < -10\,\text{dB}$) is about 2.3 GHz (from 20.5 GHz to 22.8 GHz).

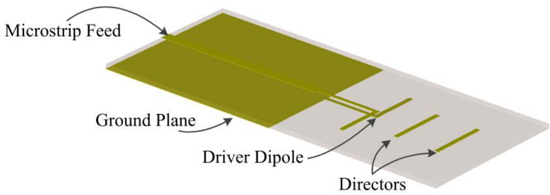

Figure 2: Geometry of the proposed antenna.

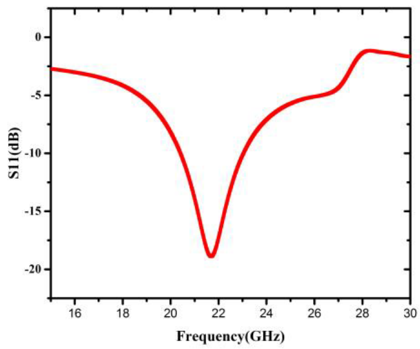

Figure 3: Simulated reflection coefficient (S_{11}) of the proposed element antenna.

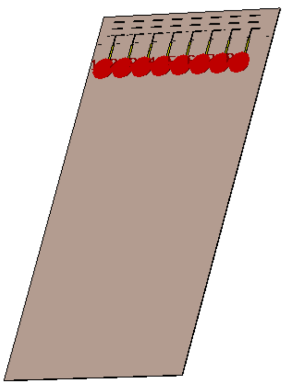

Figure 4: Geometry of the proposed antenna array for 5G mobile terminal.

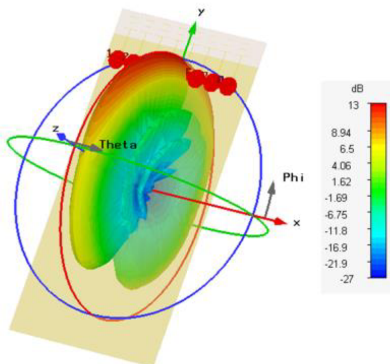

Figure 5: Simulation result of radiating pattern of the proposed antenna array for 5G mobile terminal.

The geometry of the proposed eight-element antenna array is presented in Figure 4. The overall antennas lying in a row are in the top edge of the handset with $65 * 130\,\text{mm}^2$. The spacing between antenna elements is almost a half free-space wavelength at 21 GHz. The antenna array has been designed and simulated. The simulated radiation patterns of the proposed antenna which excite by equal amplitude and phase is illustrated in Figure 5.

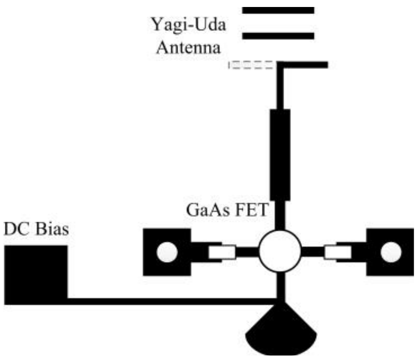

Figure 6: Layout of the active element antenna without tunable coupling network.

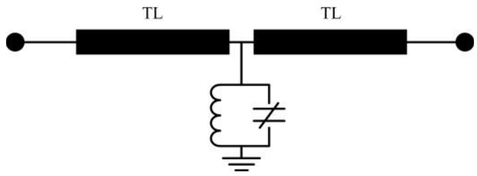

Figure 7: Schematic of tunable coupling network.

4. COUPLED OSCILLATOR ARRAY DESIGN

The overall design of COAs composes of two parts: an array of negative oscillators shown in Figure 6 using as the source of a phased array, and tunable coupling network. The proposed coupling network consists of two microstrip transmission lines (TLs) and parallel resonant circuit making a phase shift. Figure 7 presents the schematic of tunable coupled network. Above and under of resonant frequency of interest, the overall parallel resonant circuit appears capacitive and inductive, causing a phase shift. By using variable capacitor can generate several phase gradient states.

5. CONCLUSIONS

In this paper, the study of the mm-Wave phased array in mobile terminal for the fifth generation (5G) mobile communication system is presented. A method utilizing the concept of COAs to realize a phased array antenna without the need of phase shifters is designed. In the future, additional research focuses on the physical implementation of the antenna array and RF circuit.

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