Antenna system design and integration for 5G mmWave handset

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***Abstract*—Design challenges of the millimeter-wave (mmWave) antenna array in mobile handsets for the 5th generation (5G) communication are discussed in this paper, which includes wideband array design, dual-polarized array design, and phone integration issues. Based on the analysis, state of art solutions are also reviewed and discussed.**

Keywords—5G; mmWave; mobile handset; antenna array

I. Introduction

The mmWave spectrum has become a critical component for the 5G cellular network since large and contiguous frequency resources are available for wideband communications. Currently, the spectrum between 24 GHz to 52 GHz has been identified as the frequency range 2 (FR2) in the 3rd generation partnership project (3GPP) specification. Utilizing such a high spectrum requires dedicated antenna systems for both base station (BS) and user equipment (UE). Due to the higher propagation loss in mmWave, antenna arrays with high gain and beam steering capability are needed on both BS and UE [2]. Consequently, the current 3GPP radio frequency (RF) requirements on handheld mobile devices are derived based on antenna arrays with four elements [1]. Therefore, designing and integrating mmWave antenna arrays become a particularly critical and challenging task for 5G handheld mobile devices.

The antenna array for 5G mmWave mobile handsets needs to operate over a wide bandwidth and support dual-polarized operation. Besides, the integration of an antenna system into a mobile handset is also challenging in such a high frequency due to the complicated electromagnetic environment. For the research work, the mobile antenna systems in sub-6 GHz have been studied intensively in the past decades, but works on the mmWave antenna array for the mobile handset application has emerged for recent years [2]-[7]. In this paper, an overview of key design issues in mmWave antenna arrays for mobile handset application is provided, and some related state of art works is given. Future works for mmWave antenna design in mobile handsets will also be provided at the end of the paper.

II. Antenna Array for 5G mmWave Mobile Handsets

A. Wideband Antenna Array Design

An antenna array that can operate over a wideband does require not only a wide impedance bandwidth of antenna element but also the stability of element radiation pattern over the frequencies. Besides, the frequency depends on the array factor that also needs to be resolved through an optimized array topology. Mobile antenna systems in sub-6 GHz usually generate wide bandwidth by exciting multiple modes on the radiation elements. However, due to the usage of the beam steering array, the multiple modes method will be more challenging to be used since it may lead to different radiation patterns at different frequencies. A stable radiation pattern over the operation bands becomes critical and leads to a more challenge design for wideband antennas.

On the other hand, The mmWave spectrum spread over a large frequency range. Therefore, the array factor for a phased array can change dramatically over the frequency. Such a variation will lead to a frequency variant beam direction. In some specific scenarios, e.g., inter-band carrier aggregation (CA) over two frequency bands with significant frequency separation, it could also limit the deployment of the cellular systems [8].

One way to overcome the issues mentioned above is to use a beam switch antenna system than the phased array (see Fig. 1). Different from a conventional phased array, the proposed beam switch antenna system realizes the beam steering feature by switch among multiple high directional antenna elements. The advantage of the proposed array can be concluded:

- The beam switch antenna system does not require any phase shifter in the array but only a simple switch, which benefits for increasing the array efficiency.
- The beam switch antenna system does not require inter-element distance. Therefore, the impact of the frequency depends on the array factor can be resolved. Also, it can offer much more flexibility in terms of integration.

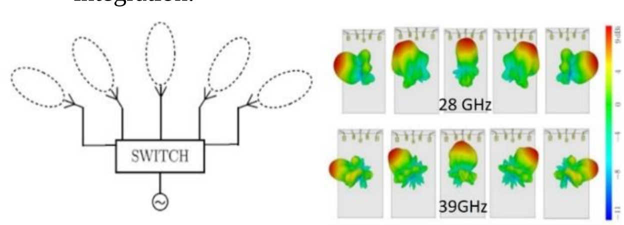

Fig. 1. The array topology of a beam switch array and radiation patterns at 28 GHz and 39 GHz (figure from [3]).

The work presented in [3] demonstrates the idea with an array composed of yagi-like elements. Each element can cover from 24 GHz to 40 GHz. A single-pole, four throw (SP4T) switch used in this study only causes 1.6 dB insertion loss at 28 GHz, which is much lower compare to mainstream phase shifters. The radiation pattern of each antenna element at 28 GHz and 39 GHz are shown in Fig. 2: Stable radiation patterns can be observed over such a significant frequency separation, which can provide extraordinary and flexibility when the handset needs to operate over a wide bandwidth or in CA mode.

B. Dual polarized Antenna Array Design

Another essential aspect of the 5G mmWave antenna array is to support the dual-polarized operation. Since the wireless channel naturally is sparser in higher frequency, and the utilizing of beamforming also reduces the number of the multipaths; higher rank communications over two orthogonal polarizations become more critical than in sub 6 GHz. Designing an end-fire dual-polarized antenna in mmWave is particularly challenging.

The end-fire antenna system usually shows better spherical coverage than boresight [8] and thus is feasible for mobile handset applications. However, the thin thickness of the mobile printed circuit board (PCB) places difficulties in designing the polarization vertical to the PCB plane (name as the vertical polarization here). The work in [4] shows one method to resolve this issue. The proposed design has a PCB thickness with only 1.5 mm (see Fig. 2). The vertical polarization is generated by a substrate integrated waveguide (SIW) antenna. The bandwidth of the SIW is extended by adding a two-layers matching strip. Meanwhile, the top layer of the matching stripes can be used as the horizontally polarized antenna. The total footprint of the dual-polarized antenna is compact, and the bandwidth can reach at least 2 GHz at 28 GHz for both polarizations.

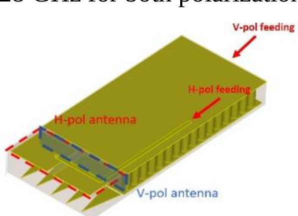

Fig. 2. Dual polarized antenna design in [4] for 5G mmWave mobile handset application.

III. ARRAY INTEGRATION FOR 5G MMWAVE MOBILE HANDSETS

Due to the complicated electromagnetic environment in mobile handsets, the antenna performance can change dramatically due to the integration. High dielectric materials and metal structures that are near to the antenna array can cause an unignorable impact on the antenna radiation performance. For example, the metal frame of a mobile phone can block the horizontally polarized radiation towards the end-fire direction. In [5], a pair of parasitic elements are placed between the mmWave antenna and the metal frame, which couple the energy from the metal frame and re-radiates towards the end-fire direction (see Fig. 3). In [6], a different approach to reducing the metal frame blockage is introduced. A group of embedded slots is etched on the metal frame, which is coupling-fed by the mmWave array and operates as a secondary array. With such a slots array, a higher gain can be obtained, and thus less active element from the mmWave antenna module is needed.

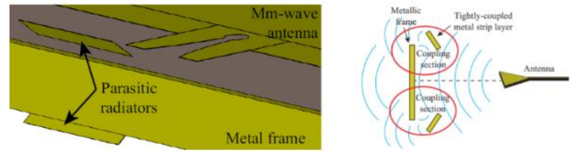

Fig. 3. The structure of the parasitic radiator (figure from [5]), and the principle of parasitic radiators.

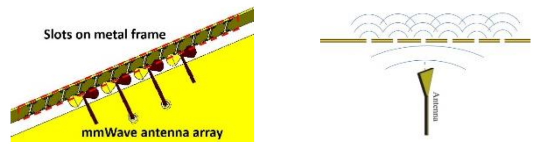

Fig. 4. The structure of the embedded slots on the metal frame to reduce the metal frame blockage in [6] and increase the array gain, and the principle of slots arrays on the metal frame.

IV. CONCLUSION

In this paper, the design and integration challenges on mmWave antenna array for 5G mobile handset is introduced. It has identified that the antenna array design to support the wideband and dual-polarized operation is important. A beam switch antenna system is presented to overcome the drawbacks of the phased array when it is operating over a broad bandwidth. Meanwhile, the integration of the array system into a mobile device is also critical. Two methods to overcome the metal frame blockage on mmWave antenna radiation are introduced. The integration over other phone components, for example, the back cover effect, needs further study.

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