Chapter 6
Microwave and Millimeter-Wave Pyramidal Horn Arrays Design Using Analytical Techniques

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ABSTRACT

This chapter describes the design and modeling of horn-based phased-array antennas using analytical approaches. Phased-array antennas are important devices for 5G wireless technologies since their radiation patterns can be reinforced in the desired direction and provide high directivity, which can be suppressed in the undesired direction. In this chapter, analytical analysis has been used for single horn element design. Various analytical formulations proposed by previous researchers were comprehensively reviewed. Once a single horn element has been designed, N number of horn elements were arranged in a 2D array to become a horn-based phased-array antenna. The universal antenna factor formula was used to model the phased-array antenna. The uncertainty of the antenna factor formula was studied since the formula has not mentioned which type of antenna element is suitable to be implemented. The calculated and simulated gain and radiation patterns for the horn-based phased-array antenna obtained from the analytical formula and commercial EM simulator were compared and analyzed.

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INTRODUCTION

Nowadays, advances in the electronic communication technologies, such as fifth-generation (5G) wireless technologies, are increasing globally. Fifth-generation (5G) wireless technologies specifies new frequency bands to enable higher data throughput for applications like streaming HD video and allow for more network capacity. The operating frequency of 5G applications has been expanded to millimeter-wave (from 24.25 GHz to 95.0 GHz) to meet the needs of 5G applications.

Further improvements in the efficiency of 5G access networks have begun to focus on antenna designs that will be installed on base stations, so-called multi-user MIMO (MU-MIMO) systems or massive antenna systems (LSAS). A general MU-MIMO is a base station (BS) with multiple antennas serving a group of single-antenna users simultaneously, and the multiplexing gain can be shared by all users on the same frequency band. The base station adopts an antenna array as a beamforming antenna, and simultaneously realizes directional signal transmission and reception (full duplex). To change the direction of the array, the beamformer adjusts the phase shift and amplitude of the signal at each antenna element. A change in phase shift alone is sufficient to achieve beam steering in different directions. Additionally, the ability to vary the amplitude optimizes side-lobe suppression. Therefore, the beamforming of each antenna can improve the received power level of the user equipment, reduce the interference to other users, and improve the overall system efficiency. More recently, massive MIMO (large number of antenna elements, N) partially addresses the bandwidth and energy consumption issues.

In this book chapter, a comprehensive analysis of single horn and horn array antennas are carried out and analytical models are used for the design of the horn antennas at 5G New Radio (5G NR) frequency bands. Various analytical models were previously proposed will be reviewed and the accuracy of the formulas will be studied with reference to measurement and simulated results from commercial professional EM simulators. The analytical analysis is particularly useful when used for the initial design of an antenna due to its simplicity and cost-effectiveness. The standard gain horn antenna is the focus of this chapter due to the horn is an antenna capable of achieving high gain up to 25 dB. The horn antenna gain can be further increased by using multiple horn antennas arranged in an array. In addition, the directional beam of the antenna can be controlled by the array antenna.

Normally, after the single horn antenna is designed, the horn array antenna can be further designed by using the linear antenna array factor formula. Since the analytical array factor formula is a general formula for array antenna design (not specific to a particular antenna), then the accuracy of the array factor formula applied to the horn antenna will be compared to the simulated results. The 4×4, 8×8, 16×16, and 18×18 horn array antennas will be studied in terms of gain level, radiation pattern, side-lobe level, and half-power beamwidth. All analytical calculations will be applied into graphical user interfaces (GUI) using MATLAB software.

PYRAMIDAL HORN ANTENNAS

There are several types of horn antennas including pyramidal horn, sectoral horn, circular or conical horn, scalar/exponential horn, corrugated horn, double-ridged horn, and feed horn. However, this chapter focuses more on the pyramidal horn as shown in Figure 1. The simple pyramidal horn antenna is capable of providing wide bandwidth, high directivity, and high gain, G (10 dBi $\leq$ G $\leq$ 25 dBi).