Chapter

Introductory Chapter: Introduction to Array Pattern Optimization

Khalil H. Sayidmarie and Jafar Ramadhan Mohammed

Array antennas offer versatile and flexible solutions to the requirement for desired radiation patterns. The total field of the array can be controlled by five array parameters that are the main design parameters [1]. These are: the geometrical layout of the array elements and their spacings, the excitation amplitude and phase of the individual elements, and finally the pattern of the individual elements. These factors have been utilized by many array synthesis techniques that use either analytical or numerical approaches. These techniques have been extensively studied and are well documented [2, 3]. This chapter aims at presenting recent techniques that aim to improve and optimize the radiation pattern of array antennas.

While most of the array pattern synthesis approaches deal with all of the elements of the array antenna, the techniques presented in Chapter 2 offer easier solutions as only a limited number of the elements need to have their magnitudes and phases adjusted. Such approaches reduce the cost and complexity of the optimization process and achieve the desired radiation patterns by modifying the excitations of a small number of elements. Toward achieving this goal, earlier techniques that were based on simple analytical procedures have utilized only two or four elements at the side of the array to reduce the sidelobe level [4–9]. These simple analytical approaches have demonstrated the feasibility of the techniques in finding the proper excitations of the side elements. The same idea was developed to the case of planar arrays where much larger number of elements is used and much less number of controllable elements was required. Thus, it would be more economical if only the side elements are made controllable for the improvement of the array pattern [10]. The deployment of the side elements was also found applicable to improve the sum and difference patterns [11]. Some other effective methods based on either controlling the steer angle in a certain sub-array configuration or even sharing the element excitations at the tail of the array were also used to generate an improved sum and difference patterns in the tracking antenna arrays [12, 13]. The use of the side elements for obtaining a wide-angle null in the radiation pattern was presented in [14, 15]. Other approaches have utilized few elements at the center of the array to achieve better adaptive responses [16]. The side element idea was also deployed for the synthesis of asymmetrical radiation pattern where it is desirable to highly reduce the sidelobe on one side of the main beam while tolerating a higher sidelobes on the other side [17].

While simple analytical approaches give better insight into the mechanism of the antenna pattern improvement, global numerical optimization methods have been proved to give better performance and optimum results [18–20] than those analytical approaches. In order to show the superiority and the power of the global optimization methods that were presented in [18–20] among the analytical approaches that were presented in [10, 15], the nonsymmetric array is considered as an example. For this case, the mathematical equation of the array factor with two variable parameters on each side of the array cannot be solved analytically using the method introduced in [15], since it is a function of four unknown parameters, that is, two different attenuators and two different phase shifters. However, this case can be efficiently solved, and optimal values of the unknown parameters in the array factor can be easily found using any global optimization algorithm such as genetic algorithm or particle swarm optimization (PSO) as it was shown in [18–20]. On the other hand, the analytical approaches [10, 15] were able to solve this case only under the assumption of symmetric array and by assuming a proper value of the required phase shifter and then find the value of unknown parameter of the required amplitude excitation. However, the symmetric array is not a general case especially in practice.

Most of the designs dealing with array antennas, as those described in Chapter 2, are concerned with the radiation pattern in the farfield region at a constant distance or equivalently across the surface of a sphere. In some applications, the designed array antenna is required to supply field or power density distribution of certain characteristics across a plane surface. This goal can be approached through one of the synthesis techniques. The problem of antenna array synthesis for radiation pattern defined on a planar surface is examined in Chapter 3. In this situation, the distance from the array to the planar surface cannot be assumed constant, and thus the 1/r decay factor effect cannot be neglected. One example of such case is an antenna array that is mechanically tilted and a pattern defined in terms of Cartesian coordinates, as in the electronic toll collection (ETC) scenario [21]. In this application, the plane surface is parallel to and just above the ground, while the transmitting and receiving antennas are a few meters above the ground. Chapter 3 presents two possible approaches to this issue [22, 23]. The first one aims at the precise synthesis of the pattern in the case both a constant power bounded area and a sidelobe suppression region are defined and the required element excitations need to be found. In the second approach, the coverage area is stretched toward the travel length (without considering a precise definition of the communication area). This is to increase the available identification time with an iterative methodology. The chapter presents an antenna prototype which was fabricated and experimentally tested to confirm the validity of the approach [24].

An important approach to the design and optimization of array patterns is the beamforming techniques. Here, the array elements are fed through a network that furnishes the phases and magnitudes necessary to obtain the desired radiation pattern. Chapter 4 reviews the worldwide progress in the design of optical beamforming networks that are intended to the next-generation ultra-wideband millimeter-wave phased array antennas [25, 26]. Such approaches are prepared for the incoming 5G wireless systems, which in recent years are under investigation and development of worldwide communication community. Toward this goal, the chapter presents a detailed study for the design concepts below true-time delay photonics beamforming networks based on switchable or continuously tunable control. The NI AWRDE CAD-based simulation experiments are presented in the frequency range of 57–76 GHz on design of two 16-channel photonics beamforming networks using true time delay approach [27]. In the first scheme of the known configuration, each channel includes laser, optical modulator, and 5-bit binary switchable chain of optical delay lines. The second scheme has an optimized configuration based on only 3-bit binary switchable chain of optical delay lines in each channel, all of which are driven by four lasers with wavelength division multiplexing and a common optical modulator. In the result, the novel structurally and cost-efficient configuration of microwave-photonics beamforming network combining wavelength division multiplexing and true time delay techniques is proposed and investigated.

As the applications of the array antenna principles are developing, the number of the required antenna elements is rapidly increasing, as for the case of scanned radars and synthetic imaging radars. In compliance with the development of massive multiple-input multiple-output (MIMO) and beamforming techniques in 5G technology increased antenna elements became of further concern. The integrated antenna, which is composed of multiple antenna elements, will be considered for next generation technologies. Therefore, chapter 5 provides the mathematical and practical explanation of the integrated antenna for the next generation technologies. The integrated antenna array consists of multiple array elements, and the array element has multiple antenna elements. Each antenna element of the integrated antenna has different radiation patterns to increase the spectral efficiency in wireless communication area. This chapter first presents a mathematical expression of the antenna element based on the spherical vector wave modes [28], then the channel models for the integrated antenna, and the antenna array based on the integrated antenna are explained. Second, the chapter provides practical antennas designed based on the integrated antenna approach, and it is verified that the integrated antenna array can be implemented practically [29]. Last, the performance of the integrated antenna array compared to mono-polarization and dual-polarization dipole arrays is compared.

The most recent antenna array technologies such as smart antenna system (SAS) and massive multiple-input multiple-output(MIMO) system are giving a strong and increasing impact relative to 5G wireless communication systems. This is due to the benefits that are obtainable in terms of performance improvements with respect to omnidirectional antennas. A considerable number of theoretical proposals have been presented in this field [30, 31]. However, the most commonly used network simulators do not implement the latest wireless network standards. Consequently, most simulators do not offer the possibility to emulate scenarios in which SAS and massive MIMO system are employed. This aspect heavily affects the quality of the network performance analysis with regard to the next generation wireless communication systems. To overcome this issue, it is possible, for example, to extend the default features offered by one of the most used network simulators such as Omnet++ which provides a very complete suite of network protocols and patterns that can be adapted in order to support the latest antenna array systems. The main goal of Chapter 6 is to illustrate the improvements accomplished in this field, allowing to enhance the basic functionalities of the Omnet++ simulator by implementing the most modern antenna array technologies [32].

Author details

Khalil H. Sayidmarie and Jafar Ramadhan Mohammed*
College of Electronic Engineering, Ninevah University, Mosul, Iraq

*Address all correspondence to: jafarram@yahoo.com

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