Broadband Dolph-Chebyshev Array Synthesized by Slow-Wave Transmission Line

Mei Li, Ming-Chun Tang, Da Yi
College of Communication Engineering
Chongqing University
Chongqing, 400044, China
{li.mei, tangmingchun, yida_cqu}@cqu.edu.cn

Richard W. Ziolkowski
Global Big Data Technologies Centre
University of Technology Sydney
Ultimo NSW 2007, Australia
richard.ziolkowski@uts.edu.au

***Abstract*—A broadband, low sidelobe level (SLL), microstrip array excited with a Dolph-Chebyshev distribution that is implemented with a periodic-stub loaded slow-wave transmission line (SW-TL) feed network is presented. The desired Dolph-Chebyshev excitation of the uniformly spaced microstrip array is achieved simply by modulating the widths of the stubs along the SW-TL feed network. Simulated results demonstrate that the array is low profile, 0.023λ_0 in height, has a broad fractional bandwidth, 10.18%, and exhibits SLLs as low as -30dB.**

Keywords—Antenna array, broad bandwidth, Dolph-Chebyshev excitation, low sidelobe levels.

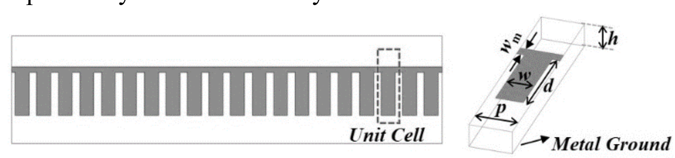
I. Introduction

Antenna arrays with low sidelobe performance are highly desired in many radar, wireless communication and radio frequency identification device (RFID) systems that operate in heavy clutter and jamming environments [1]-[3]. In order to obtain an antenna array with a particular sidelobe level (SLL), various synthesis schemes, e.g., Dolph-Chebyshev [4], Taylor [5], and binomial [6] methods, have been adopted to achieve the required tapered excitation distributions to feed the radiating elements of the antenna array. In general, corporate (parallel) and series feeds are two kinds of popular excitation networks [7]-[9]. Among them, the series-fed arrays cascade all of the antenna elements along one direction. This leads to a more compact feed network and high radiation efficiency, but at the cost of less design flexibility and larger array lengths. Slow-wave transmission lines (SW-TLs) facilitate the miniaturization of the associated electric components [10].

A low sidelobe Dolph-Chebyshev array is synthesized in this work with a periodic-stub loaded SW-TL. The SW-TL is implemented to achieve a series-fed network with Dolph-Chebyshev excitation distributions. The simulation results demonstrate that the antenna array is compact, being 3.2λ_0 × 0.6λ_0 in size, and has the outstanding advantages of low SLLs, below -30dB; a low profile, 0.023λ_0 in height; and a broad fractional bandwidth, 10.18%.

II. Antenna Array Design

The configuration of the periodic-stub loaded SW-TL is depicted in Fig. 1. It is one-sided with a period p = 2.5mm and is printed on the upper surface of a grounded Arlon AD450 substrate with relative dielectric constant ε_r = 4.5 and a thickness h = 1.524 mm. The width of the microstrip line is w_m, and the width and height of each stub is w and d, respectively, as illustrated in Fig. 1(b). The other unit cell parameters have the optimized values w_m = 0.64 mm, and d = 5.0 mm. The width of the stubs, w, can be modified to modulate the characteristic impedance of the SW-TL while maintaining its propagation constant (waveguide wavelength). This feature has great significance in the synthesis of the desired, broadside radiating Dolph-Chebyshev excited array.



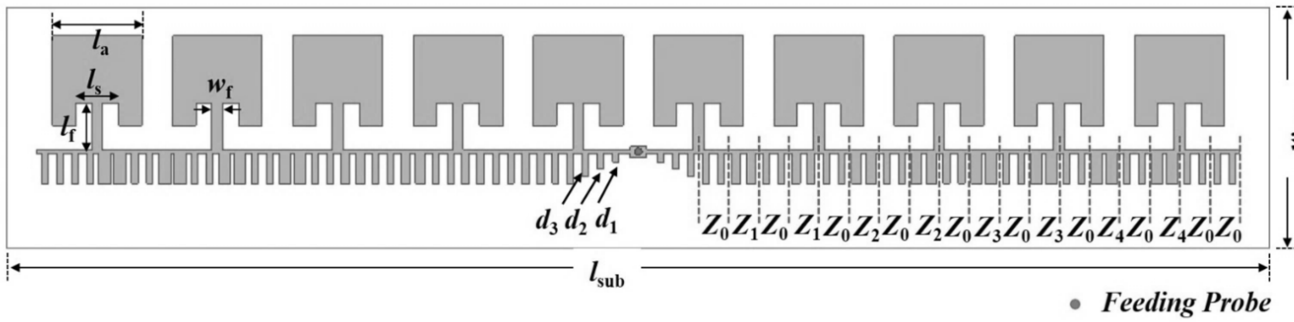
(a) (b)

Fig. 1. Periodic-stub loaded SW-TL. (a) Top view. (b) Unit cell geometry.

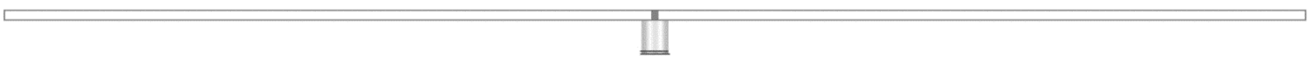
TABLE I
Stub Width w for a Specified Characteristic Impedance Z_0

Z_0 (Ω)	40	37.5	34.9	32.1	31.0
w (mm)	1.06	1.31	1.56	1.83	1.93

The configuration of the Dolph-Chebyshev antenna array is illustrated in Fig. 2. Its 10 radiating elements are in the form of inset microstrip-line-fed square patches. The inter-element (center-to-center) spacing of any two adjacent radiating elements is set to 20.0 mm, the desired guiding wavelength λ_g. Consequently, all of the elements are excited in-phase. With the periodicity of the SW-TL, p = 2.5 mm, there are 8 periods attained within two adjacent elements. Two periods form a quarter-wavelength transformer. The characteristic impedance Z_0 of this array is then determined to be 40-Ω. Setting Z_0 = 40-Ω, the impedance ratios Z_i/Z_0 (i =1, 2, 3, 4) are specified according to −30dB Dolph-Chebyshev current distributions [3]. The requisite stub widths to obtain the desired Dolph-Chebyshev excitation distribution are determined by the Z_i values. All of the final values are summarized in Table I. The array is center-fed with a 50-Ω SMA connector with its inner conductor connected to the microstrip line and its outer conductor connected to the ground. A transition region composed of gradient-height stubs is introduced to ensure good matching between the microstrip line and the quarter-wavelength SW-TL sections as shown in Fig. 2.



(a)



(b)

Fig. 2. Configuration of the SW-TL-based Dolph-Chebyshev excited array. (a) Top view. (b) Side view. Matching is attained with gradient stubs of height d_1-d_3 with d_1= 1.4, d_2= 2.6, and d_3 = 3.8. Other design parameters: l_a = 14.9, l_s = 7.2, lf = 7.7, w_f = 1.8, l_{sub} = 210, and w_{sub} = 40. All dimensions are in millimeters (mm).

The radiation performance was simulated with ANSYS/ANSOFT HFSS. The simulated $|S_{11}|$ curve of the proposed antenna is plotted in Fig. 3. It shows that the -10 dB impedance bandwidth ranges from 4.38 to 4.85 GHz. The corresponding fractal bandwidth (FBW) is 10.18%.

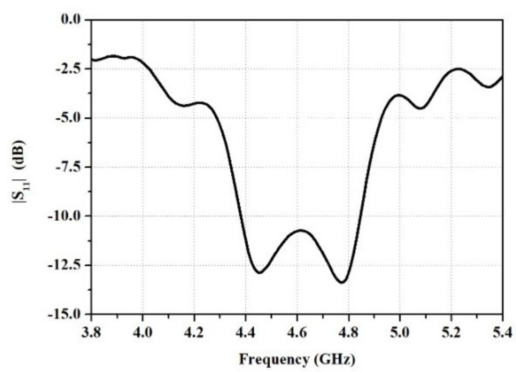


Fig. 3. Simulated reflection coefficients of the SW-TL-based Dolph-Chebyshev excited array.

The simulated realized gain patterns in the H-plane at 4.6 GHz are plotted in Fig. 4. They demonstrate that stable broadside radiation patterns with narrow beamwidths and low sidelobes in the H-plane are realized. Specifically, the simulated realized gain and SLL values are 11.6 and -29.7 dBi at 4.6 GHz, respectively.

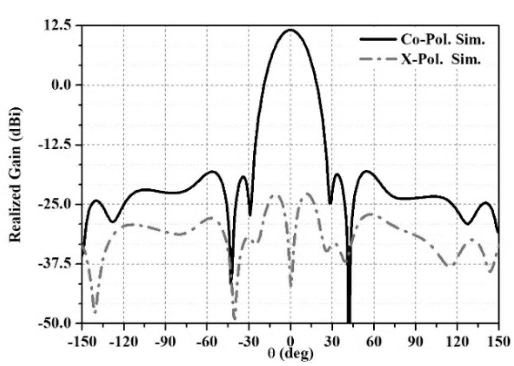


Fig. 4. Simulated realized gain patterns at 4.6GHz.

III. Conclusion

A compact, low sidelobe level Dolph-Chebyshev array fed by a periodic-stub loaded SW-TL was reported. The antenna exhibits a peak realized gain of 11.6 dBi and has compact transverse dimensions: 3.2 $\lambda_0 \times$ 0.6 λ_0. Its SLLs are below -30dB. Other outstanding merits of the prototype array include its broad bandwidth performance, 10.18%, and its low-profile configuration, 0.023λ_0.

Acknowledgment

This work was supported in part by the National Natural Science Foundation of China under Grants 61701052; in part by the Opening Subject of State Key Laboratory of Millimeter Waves, contract number K202004; and in part by the Chongqing Special Project of Technology Innovation and Application Development, contract number cstc2019jscx-msxmX0074.

References

[1] Z. Zaharis, E. Vafiadis, and J. N. Sahalos, “On the design of a dual-band base station wire antenna,” IEEE Antennas Propag. Mag., vol. 42, no. 6, pp. 144-151, Dec. 2000.

[2] G. T. F. de Abreu and R. Kohno, “A modified Dolph–Chebyshev approach for the synthesis of low sidelobe beampatterns with adjustable beamwidth,” IEEE Trans. Antennas Propag., vol. 51, no. 10, pp. 3014-3017, Oct., 2003.

[3] Z. Sun, S.-S. Zhong, X.-R. Tang, and K.-D. Chen, “Low-sidelobe circular-polarized microstrip array for 2.45 GHz RFID readers,” Microw. Opt. Techn. Lett., vol. 50, no. 9, pp. 2235-2237, Sep. 2008.

[4] C. L. Dolph, “A current distribution for broadside arrays which optimizes the relationship between beam width and side-lobe level,” Proc. IRE, vol. 34, no.6, pp. 335–348, Jun., 1946.

[5] T. T. Taylor, “Design of line-source antennas for narrow beamwidth and low side lobes,” IRE Trans. Antennas Propag., vol. AP-3, no. 1, pp. 16–28, Jan, 1955.

[6] J. D. Kraus, *Antennas*. New York, NY, USA: McGraw-Hill, 1988.

[7] T.-S. Horng and N. G. Alexopoulos, “Corporate feed design for microstrip arrays,” IEEE Trans. Antennas Propag., vol. 41, no. 12, pp. 1615-1624, Dec. 1993.

[8] N. E. Stabolidis, “A study of the isolation of two different feed networks for antenna arrays,” IEEE Trans. Broadcasting, vol. 41, no. 2, pp. 83-88, Jun. 1995.

[9] T. Metzler, “Microstrip series arrays,” IEEE Trans. Antennas Propag., vol. AP-29, no. 1, pp. 174-178, Jan. 1981.

[10] W.-S. Chang and C.-Y. Chang, “A high slow-wave factor microstrip structure with simple design formulas and its application to microwave circuit design,” IEEE Trans. Microw. Theory Techn., vol. 60, no. 11, pp. 3376-3383, Nov. 2012.