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Designing a Stacked Three-Element Parasitic Superdirective Antenna

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Abstract—In this paper we investigate designing a stacked three-element antenna arrays for UHF band. The array is based on miniaturized printed half-loop antenna integrated in a PCB of $8 \times 8\text{cm}^2$. To study the inter-element distance effect on the antenna performance (directivity, input impedance and radiation efficiency), a parametric analysis is performed. The obtained results show that for small distances high directivities can be achieved in the case of the fully driven element. However, to transform this array to a parasitic (loaded) one, negative resistances are required and neglecting these resistances significantly decrease the antenna directivity. The results are validated via measurements.

Keywords—Superdirectivity, parasitic-element, directivity, radiation efficiency

I. INTRODUCTION

Superdirective antenna arrays satisfy both the miniaturization- and high directivity- criteria required in most of the modern wireless applications. Since the first practical validation of such arrays by Altshuler et al [1], a considerable research was done in this domain. In analogy to Yagi antenna, early works were based on wire-type antennas [2]-[5]. Recent works are based on printed antennas (due to their attractive characteristics) [6]-[10]. In this paper, we investigate designing a stacked three-element parasitic superdirective antenna array. The main tradeoffs between the antenna directivity, efficiency, and dimensions are detailed.¹

II. PROPOSED ANTENNA DESIGN

The design methodology of superdirective antenna arrays detailed in [10] was used to develop a three-element array. The unit-element used in this array is a miniaturized half-loop antenna printed on a 0.8mm-thick Rogers RO4003 substrate and integrated in a PCB of $8 \times 8\text{cm}^2$. It has a simulated (ANSYS HFSS [11]) resonance frequency around 864MHz . The antenna size factor is $ka = 1$, where $k = 2\pi/\lambda$ and a is the radius of the smallest sphere enclosing the antenna. The antenna has a directivity of 2.4dBi and radiation efficiency of 89.4% . The proposed antenna geometry is shown in Fig. 1(a). The inter-element distance d_1 is varied from 0.69cm to 6cm to investigate its effect on the antenna input reflection coefficient (Fig. 1(b)), maximum directivity (Fig. 1(c)) and radiation efficiency (Fig. 1(d)). For very small distances the antenna resonance is shifted to 926MHz . As the distance increases this resonance approaches the one of the unit-element. As for

the maximum directivity, we see that starting from an inter-element distance of $d_1 = 3.5\text{cm}$ interesting directivities can be attained in the case of the fully-driven array. However, in the case of the parasitic array, some negative resistances are required, and neglecting these resistances significantly decreases the attained directivity. As for the parasitic array radiation efficiency, it increases when the inter-element distance exceed $3\text{cm}(0.1\lambda)$.

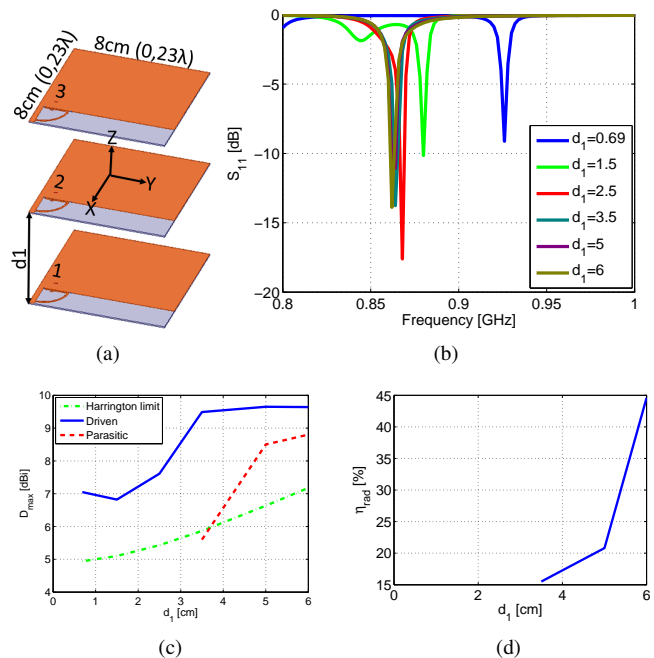


Fig. 1. Proposed array simulated parameters as a function of the inter-element distance. (a) Array geometry, (b) input reflection coefficient magnitude in dB, (c) total directivity and (d) radiation efficiency.

A prototype of the antenna array for $d_1 = 6\text{cm}(0.17\lambda)$ was fabricated and measured (Fig. 2(a)). In this array, the second element is excited, the first is short-circuited, while the third one is loaded by 8.3nH . Fig. 2(b) shows the antenna input reflection coefficient magnitude in dB. As it can be noticed, the antenna has a simulated/measured resonance at $863/868\text{MHz}$ with a $S_{11} < -10\text{dB}$ bandwidth of $1.7/5\text{MHz}$. The higher losses in the measurement may be attributed to the UFL cable used in measurement. Fig. 2(c) shows the antenna 3D total directivity radiation pattern. The figure shows a directive pattern with a directivity of $8.8/8.5\text{dBi}$ toward z-axis. This directivity is about 1.4dB greater than Harrington's normal directivity limit for an antenna with the same size factor

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($ka = 1.6$) [12]. The HPBW in E (XoZ) and H (YoZ) planes are respectively $72^\circ/73.1^\circ$ and $64^\circ/67.5^\circ$ and FBR is $5.8\text{dB}/4.1\text{dB}$ (Fig. 3). The antenna presents a radiation efficiency of $34.7\%/37\%$. Finally, Fig. 4 shows that the current on the first and third elements are out of phase and they are out of phase compared to the second element. This is the condition for having three-element superdirective arrays with very small spacing.

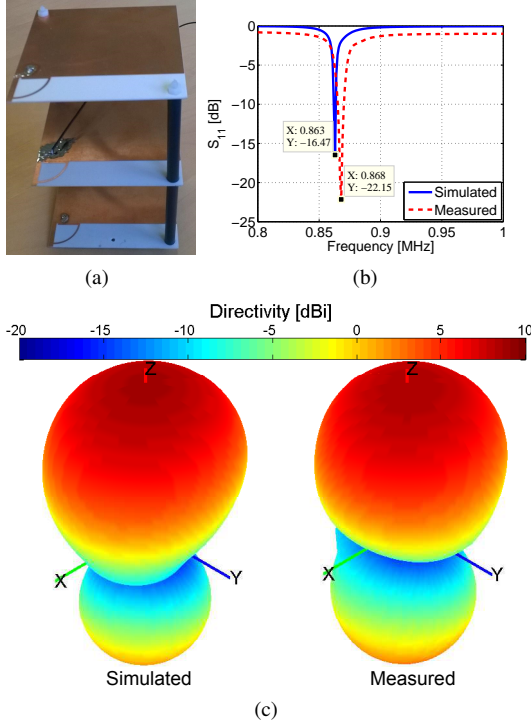


Fig. 2. Three-element array with 6cm spacing simulated and measured parameters. (a) Fabricated prototype, (b) input reflection coefficient magnitude in dB and (c) 3D total directivity radiation pattern.

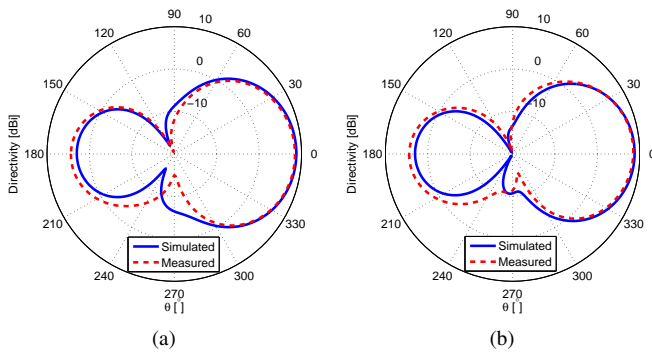


Fig. 3. Three-element array with 6cm spacing simulated and measured parameters 2D total directivity radiation patterns. (a) E-plane, (b) H-plane.

III. CONCLUSION

In this paper, we investigated the design of a three-element stacked parasitic antenna array for UHF band. The tradeoffs between the antenna directivity, radiation efficiency, and dimensions were demonstrated. A prototype was fabricated and measure. The measured results were in a very good agreement with the simulated ones.

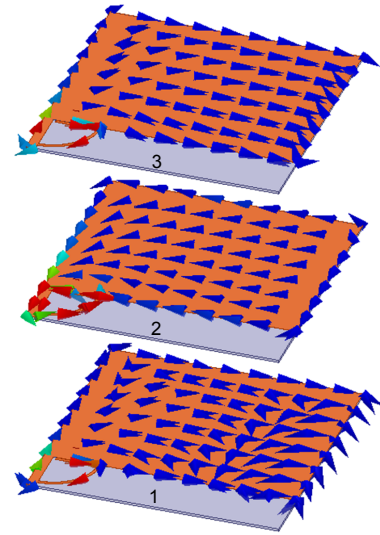


Fig. 4. Three-element array with 6cm spacing simulated surface current distribution.

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