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Printed-dipole End-fire Array for mm-Wave Applications

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***Abstract*—A novel curved printed-dipole element in an end-fire array for mm-Wave communication is presented. The curved dipole element is printed on both sides of a RO5880 substrate of 0.5mm thickness. The proposed antenna operates in the frequency bands n257, n258, and n261 (22.79 GHz - 29.7 GHz) and the 4-element array has a peak gain of 8.85 dBi.**

***Index Terms*—antennas, end-fire array, printed dipole,mm-Wave.**

I. Introduction

Over the past few years, interest in millimetre Wave bands (mm-Wave) has grown significantly due to the increased bandwidth and spatial capacity. The improved capacity allows service operators to provide multi-gigabit per second (Gbps) data rates to end users which mitigates low data rate issues in dense internet traffic scenarios [1]. Recent studies suggest consideration of mm-Wave as a strong candidate for mobile communications [2].

There are few dipole antenna designs reported for phased arrays and end-fire arrays in the mm-Wave bands. In [3], a 60° angled dipole is introduced with an element gain of 2.6 dBi. The element was used to create a 1×8 linear phased array with a peak gain of 9.9 dBi. In [4], a similarly angled dipole is used to create a series-fed end-fire array (8×1) with a peak gain of 10.8 dBi while the single antenna element gain is 3.8 dBi. A planar end-fire array with a coupled feed was proposed with an element gain of 3.1 dBi and an array gain of 5.5 dBi [5]. In [6], a multilayer end-fire Vivaldi antenna array was reported with a peak gain of 8.3 dBi, for the frequency range of 27.5-28.5 GHz. An antenna in package was reported with end-fire properties and a gain of 6 dBi for the frequency band of 26.6-29.5GHz [7]. There is also a multilayer design reported [8] with an endfire radiation pattern providing a simulated peak gain of 5.5 dBi for the element and 12 dBi for the 1×8 array.

In this paper, a novel curved printed dipole element and antenna array is proposed. The measured peak gain for the single element is 6.41 dBi with the impedance bandwidth from 24.7 GHz to 29.3 GHz. The array also has a high gain of 8.85 dBi and broad impedance bandwidth of more than 7 GHz (fractional bandwidth of 26.6 %) for $S_{11} \leq$ -10 dB from 22.79-29.7GHz.

CST microwave studio suite was used to model the array. The array has a small footprint of only 60 mm × 35 mm (5.24 λ_o × 2.65λ_o), as well as a low-cost, low-profile, and easy manufacturability.

II. Single-element design and measurements

A. Design development motivation

Reported designs show element gains of 2.4 dBi to 5.5 dBi for printed dipoles in endfire arrays [3]-[7]. Because mm-Wave frequencies suffer from high propagation and dielectric losses, most designers prefer to use thinner substrates (0.1-0.3mm) but this creates difficulty in fabrication and handling, especially if the design is printed on both sides of the substrate. Designers also use multilayer layer designs to meet thinner substrate requirements. So, a high gain element on a 2-layer substrate is a contemporary requirement for mm-Wave communication.

B. Antenna design

Fig. 1 presents the layout of a curved-dipole antenna. The laminate used is RO5880 with ε_r = 2.2, tan δ = 0.0009, substrate thickness of 0.5 mm, and conductor thickness of 0.035 mm. The antenna consists of two identical curved dipoles, one on the top side and the other one on the bottom side of the substrate.

The curved dipole provides a directional radiation pattern in the ZY plane at (ϕ= 90°) while maintaining a fan beam pattern in the elevation ZX plane at (ϕ= 90°). The microstrip feed line is used to feed the antenna. The abrupt feed line connected to the wide ground plane helps to achieve a better front-to-back ratio and also acts as a reflector to provide a unidirectional dipole pattern.

Fig. 2 shows the fabricated antenna element. The end launch SMA was used for the measurements.

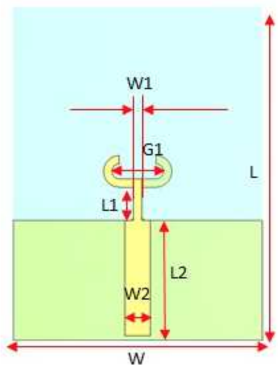
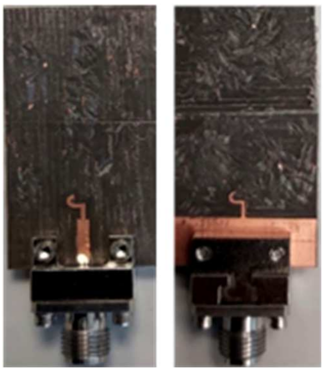


Fig. 1. Single-element design with dimensions



a) Front view b) Rear view

Fig. 2. Fabricated single-element photo (a) Front view (b) Rear view.

The antenna element was designed for end-fire radiation pattern. This high gain element was designed to incorporate the mm-Wave bands n257,261 and n258. Table. I show the design parameters for the single element and antenna array.

TABLE I. DESIGN PARAMETER LIST

Parameter	*W1*	*G1*	*L1*	*L2*	*W2*
Value (mm)	0.5	3.1	2	6.9	1.55
Parameter	*L*	*W*	*L3*	*L4*	*L5*
Value (mm)	40.7	20	1.60	1.52	16.75
Parameter	*W3*	*d*			
Value (mm)	0.9	7.6			

C. Simulated and Measured results

The coordinate system used to measure the end-fire antenna array is shown in Fig.3. measurements are made in the ZY and ZX planes for antenna element and antenna array. The antenna element dimensions are 40mm×15mm× 0.5mm.

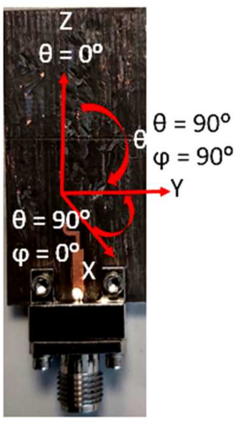


Fig. 3. Measurement coordinate system.

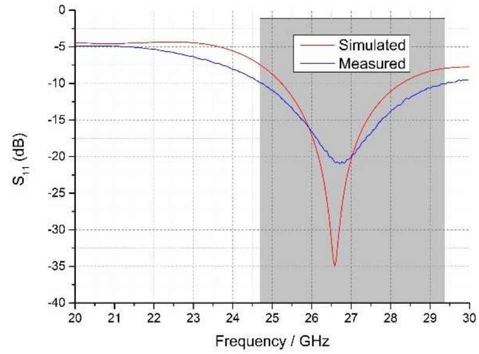


Fig. 4. Simulated and measured S_{11}.

The measured and simulated S_{11} are shown in Fig. 4 with reasonable agreement. The measured S_{11} is ≤ –10 dB from 24.76 GHz to 29.33 GHz.

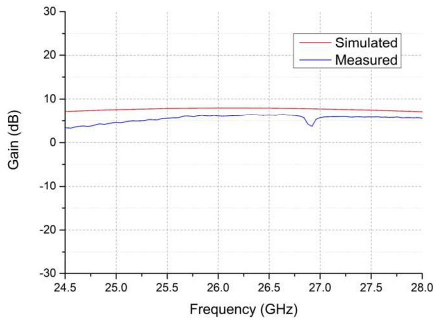


Fig. 5. Simulated and measured gain.

The measured peak gain for the proposed antenna element is 6.41 dBi as shown in Fig. 5. The simulated and measured elevation patterns for ZY and ZX plane for antenna elements are shown in Figs 6 and 7 respectively for the 28 GHz band. They are in reasonable agreement.

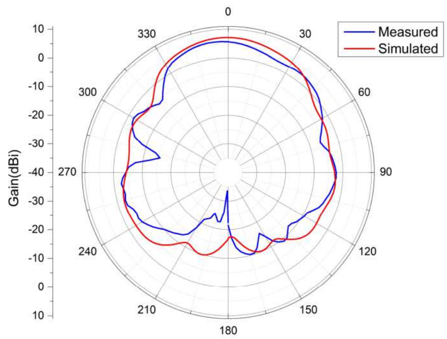


Fig. 6. Simulated and measured elevation (ϕ= 90°) ZY plane patterns.

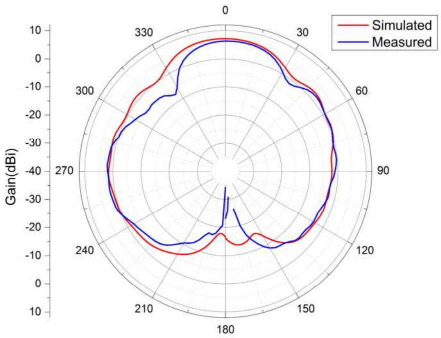


Fig. 7. Simulated and measured (ϕ= 0°) ZX plane patterns.

III. ANTENNA ARRAY DESIGN AND DEVELOPMENT

The novel curved printed-dipole antenna was used to create the end-fire array for mm-Wave communication.

A. Corporate feed design and antenna array development

A 4-element corporate-feed power divider was designed for the array. An inter-element spacing of 7.6 mm was used. The 7.6 mm is 0.68 λ_o at 26.75 GHz as this was the center frequency for the single-element band of operation.

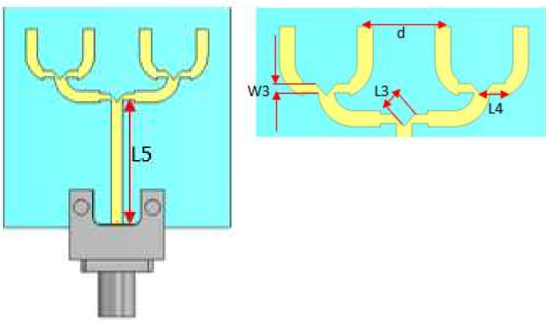


Fig. 8. 4-element corporate power divider.

The equal power divider was optimized to achieve the best impedance matching (S_{11}<−15dB) and minimal insertion loss.

a) Front view b) Rear view

Fig. 9. 1×4 element antenna array design.

Fig.9. shows the fabricated 4-element array design. The fabricated antenna dimension is 5.25 $\lambda_o \times 2.6 \lambda_o \times 0.04 \lambda_o$.

B. Simulated and measured results

Fig.10 shows the measured and simulated S_{11}. The measured impedance bandwidth for the antenna array is 7 GHz from 22.75-29.75 GHz for $S_{11} \leq$ -10 dB.

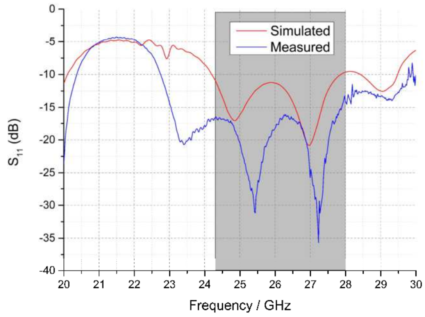


Fig. 10. Simulated and measured S_{11} for the antenna array

Fig.11 shows the measured and simulated gain for the antenna array. The measured peak gain was 8.85 dBi while the simulated peak gain was 10.4 dBi.

Figs.12 and 13 show the ZY and ZX plane patterns for the antenna array, respectively.The measured patterns show a good correlation with the simulated results.

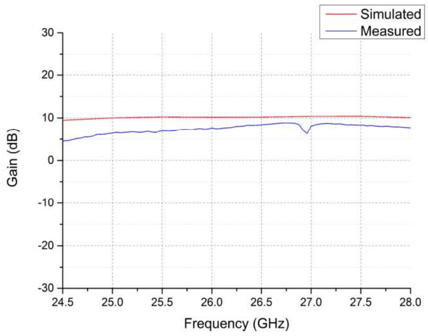


Fig. 11. Simulated and measured peak gain for the array.

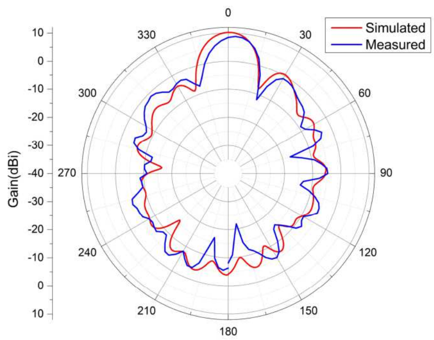


Fig. 12. Simulated and measured (ϕ= 90°) ZY plane pattern.

TABLE II. TABLE OF COMPARISON (*SIMULATED, **MEASURED)

Ref.No	Frequency (GHz)	No. of PCB layers	Array element	Design configuration	Element gain (dBi)	Array gain (dBi)	Substrate/PCB thickness (mm)
[3]**	23.5-51.9	2	8×1	Angled Dipole	3.8	10.9	0.2032
[4]**	21.5-26	2	1×8	Angled Dipole	2.5	9.9	0.381
[5]**	16-40	2	NA	Bowtie dipole	5.5	NA	0.254
[6]**	27.5-28.5	10	1×4	Vivaldi	< 5	8.01	0.79
[7]**	26.4-29.8	3	1×2 (sub-array)	Shorted patch	2	6	0.5
[8]*	27.2-30.7	4	1×8	Dipole	5.5	12	1.53
Proposed Work	**22.7-29.7**	**2**	**1×4**	**Curved Dipole**	**6.41**	**8.85**	**0.5**

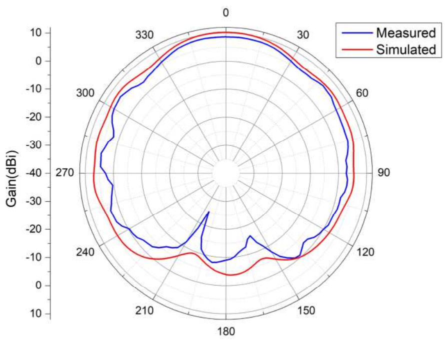


Fig. 13. Simulated and measured elevation (ϕ= 0°) ZX plane pattern.

IV. COMPARISON WITH THE REPORTED ENDFIRE ANTENNAS AND ARRAY

There are several antennas reported to date. Table II. shows the comparison of the proposed antenna with the reported designs.

In comparison, the proposed design has a low profile of (5.25 λ_o × 2.6 λ_o × 0.04 λ_o) with a measured peak gain for the element is 6.41 dBi and 8.85 dBi for the array. The designs [3]-[5] were developed on two-layer PCBs with thicknesses varying from 0.2032 mm to 0.381 mm, whereas designs [6]-[8] used multilayer PCBs with thicknesses of 0.5mm-1.53mm. The proposed design employs a two-layer 0.5mm PCB which is simpler to fabricate compared to multilayer designs.

V. CONCLUSION

In this design, a novel curved printed dipole was used to develop an end-fire array. This array design covers mm-Wave bands within 24.25-29.25 GHz with best-in-class element gain. Furthermore, the compact array has a low-profile, low cost, and is easy to fabricate, making it a viable candidate for future mm-Wave communications.

The proposed antenna element and array are attractive candidates for emerging mm-Wave mobile communication and phased array applications.

VI. ACKNOWLEDGMENT

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