Hindawi
International Journal of Antennas and Propagation
Volume 2017, Article ID 1304359, 8 pages
https://doi.org/10.1155/2017/1304359

Research Article

Dual Polarized Dual Fed Vivaldi Antenna for Cellular Base Station Operating at 1.7–2.7 GHz

Marko Sonkki,[1] Sami Myllymäki,[2] Jussi Putaala,[2] Eero Heikkinen,[3] Tomi Haapala,[3] Harri Posti,[1] and Heli Jantunen[2]

[1] *Centre for Wireless Communications (CWC), University of Oulu, Oulu, Finland*
[2] *Microelectronics Research Unit, University of Oulu, Oulu, Finland*
[3] *Nokia Networks, Oulu, Finland*

Correspondence should be addressed to Sami Myllymäki; sami.myllymaki@oulu.fi

Received 14 February 2017; Accepted 30 April 2017; Published 23 May 2017

Academic Editor: Seong-Youp Suh

Copyright © 2017 Marko Sonkki et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The paper presents a novel dual polarized dual fed Vivaldi antenna structure for 1.7–2.7 GHz cellular bands. The radiating element is designed for a base station antenna array with high antenna performance criteria. One radiating element contains two parallel dual fed Vivaldi antennas for one polarization with 65 mm separation. Both Vivaldi antennas for one polarization are excited symmetrically. This means that the amplitudes for both antennas are equal, and the phase difference is zero. The orthogonal polarization is implemented in the same way. The dual polarized dual fed Vivaldi is positioned 15 mm ahead from the reflector to improve directivity. The antenna is designed for −14 dB impedance bandwidth (1.7–2.7 GHz) with better than 25 dB isolation between the antenna ports. The measured total efficiency is better than −0.625 dB (87%) and the antenna presents a flat, approximately 8.5 dB, gain in the direction of boresight over the operating bandwidth whose characteristics promote it among the best antennas in the field. Additionally, the measured cross polarization discrimination (XPD) is between 15 and 30 dB and the 3 dB beamwidth varies between 68° and 75° depending on the studied frequency.

1. Introduction

Recently an active antenna system (AAS) has been proposed as a technology concept for cellular base stations [1] and it has received much attention from the industrial perspective [2–4]. Traditionally, in base station antenna arrays, the radiating elements are linearly oriented along a vertical line, and the array is fed with the fixed power ratio and relative phase with a limited number of beams in the elevation angle. In the AAS, the radiation pattern is dynamically and electrically adjusted in the elevation and azimuth angels. The AAS is interesting from the mobile communications point of view as it offers capacity enhancement, improved network availability, and especially higher energy efficiency for the future wireless communications demands with 3D beam forming capability [5].

Active antennas can create and adjust beams inside the mobile base station cell by changing the relative signal phase and amplitude of every radiating element. The beam forming can be based on either constructive interference that amplifies the beam in a given direction or a destructive interference that focuses the beam precisely. These can be applied for both transmitted and received beams independently. Beam forming enables a variety of operations according to the users, different diversity techniques, carrier frequencies, radio systems and multiple cells, and even multiple operators [2–4].

The requirements and hence the technology of antennas for AAS base stations largely depends on the application considered. Outdoor mobile communications need well controlled patterns and high power handling and environmental demands like variable weather conditions. Single antenna element performance plays an important role in AAS in terms of properties such as *good impedance matching, high isolation between adjacent antenna elements, low mutual coupling between orthogonal polarizations, and high total efficiency*. For commercial and competition reasons these technical properties should be designed and manufactured with *low costs*.

Currently available vertical micro strip patch arrays [6] or dipoles [7] can be used for interleaving different frequency bands in the AAS usage. Other types of wideband antenna elements for base stations can be found in [8–11]. Polarization diversity is typically used with dual polarized antenna elements with high isolation between the polarizations [7–15]. Complete antenna arrays can be found in [16–19]. State-of-the-art comparison of currently studied antenna radiators is collected in Table 1, where the studied antenna structure can be found in column one.

The most common way to implement two orthogonal polarizations with Vivaldi antennas is to place them orthogonally along the outer edge of each element [20–22]. Another way to implement a wideband dual polarized antenna is to orientate two Vivaldi antennas into a cross-shape with respect to the antenna center where a galvanic contact is avoided by a small longitudinal gap between antenna elements [23–25]. Dual fed Vivaldi antennas do not exist.

This letter presents a dual polarized dual fed Vivaldi antenna for 1.7–2.7 GHz frequency band keeping in mind the AAS concept for mobile base stations. The antenna is designed with two parallel dual fed radiating elements for both polarizations to increase the overall aperture of the antenna, and, thus, to increase the directivity. The antenna presents the measured −14 dB impedance matching and isolation between the antenna ports better than 25 dB over the operating bandwidth with good radiating properties. The performance is compared with the existing antenna types. Section 2 describes the radiating element and the implementation, Section 3 describes simulation results, and Section 4 describes measurement results. Finally, the conclusions are given in Section 5.

2. Radiating Element

Figure 1(a) presents a dual polarized antenna structure on Rogers RO4003C laminate containing two pairs of orthogonally oriented dual fed Vivaldi radiators located on rectangular form. The separation of radiators for one polarization is 65 mm (~$\lambda/2$ wavelength) at 2.38 GHz center frequency. The tapered opening of Vivaldi is elliptical (a = 23 mm, b = 33 mm) as can be seen in Figure 1. The idea of using two symmetrical Vivaldi antennas for one polarization is to increase the aperture of the radiating element.

The width of a radiator is 61 mm and height is 46 mm, and the distance from the reflector is 15 mm. The size of the radiator is 125 mm × 240 mm and it is so called floating structure fed by a symmetrical feeding network (Figure 1(b)). The size of the reflector was optimized for low ground currents and high antenna efficiency and, on the other hand, not too high relative distance to adjacent subarray at 2.7 GHz that would increase grating lopes in the antenna array. The floating reflector here means that the antenna and the reflector are not in the same ground potential. Symmetrical feeding is implemented by using a strip line to separate the feed from the reflector. As it can be noticed, from the back of both Vivaldi antennas, an area with the radius of r = 10 mm of conducting material is taken out. This is done to reduce the coupling of the radiated field to the reflector.

The connection between the symmetrical feed network and Vivaldi radiator is done with a coaxial transmission line maintaining a 50 Ω characteristic impedance. The coaxial feed line also neglects the effect of feedthrough in the reflector by minimizing the coupling of the field. The measured prototype antenna is presented in Figure 1(e) with the reflector dimensions.

In the following sections, CST Microwave studio was used to perform the antenna simulations, HP 8510C VNA was used for impedance matching measurements, and Satimo Starlab was used to measure the radiation properties of the antenna.

3. Simulation Results

Simulated impedance matching of the dual polarized dual fed Vivaldi radiator is presented in Figure 2. Both polarizations (Ports 1 and 2) were simulated from 1.5 to 3 GHz and the results exhibited better than −14 dB impedance matching over the 1.7 GHz–2.7 GHz band with the mutual coupling lower than −27 dB between antennas of Ports 1 and 2. Port length of 1 and 2 is different (two-layer feed) that causes different matching response. Simulated total efficiency is shown in the same figure and it presents better than −0.2 dB (95%) over the 1.7 GHz–2.7 GHz band. This can be considered good for base station application.

The simulated theta and phi polarization components of the dual polarized dual fed Vivaldi are presented in Figure 4. The XPD results calculated from the figure are 38 dB for theta and 25 dB for phi polarization components at 1.7 GHz. At 2.7 GHz the XPD for the theta component is 18 dB and it is 28 dB for phi, respectively. The variation of XPD is 18–42 dB over the frequency range.

4. Measurement Results

Measured impedance matching of the dual polarized dual fed Vivaldi radiator is presented in Figure 3. Port 1 presents better than −13 dB impedance matching, whereas Port 2 shows better than −17 dB impedance matching over the 1.7 GHz–2.7 GHz band. The mutual coupling between the Ports 1 and 2 is below −25 dB. Discrete ports were used in simulation whereas realization was made by connectors and thus the matching is different. Additionally, the measured total efficiency was better than −0.625 dB (87%) over the band for both ports.

Measured total gain in the boresight direction ($\theta = 0^{\circ}$) is presented in Figure 5. As it can be observed, the gain is rather flat over the frequency range varying between 7.75 and 9.2 dBi. Notice that the simulated main polarization in Figure 4 is comparable to maximum gain as the antennas are linearly polarized.

The measured XPD of the dual polarized dual fed Vivaldi is presented in Figure 5. As it can be observed, the XPD varies between 15 and 30 dB and correlates well with the simulated ones.

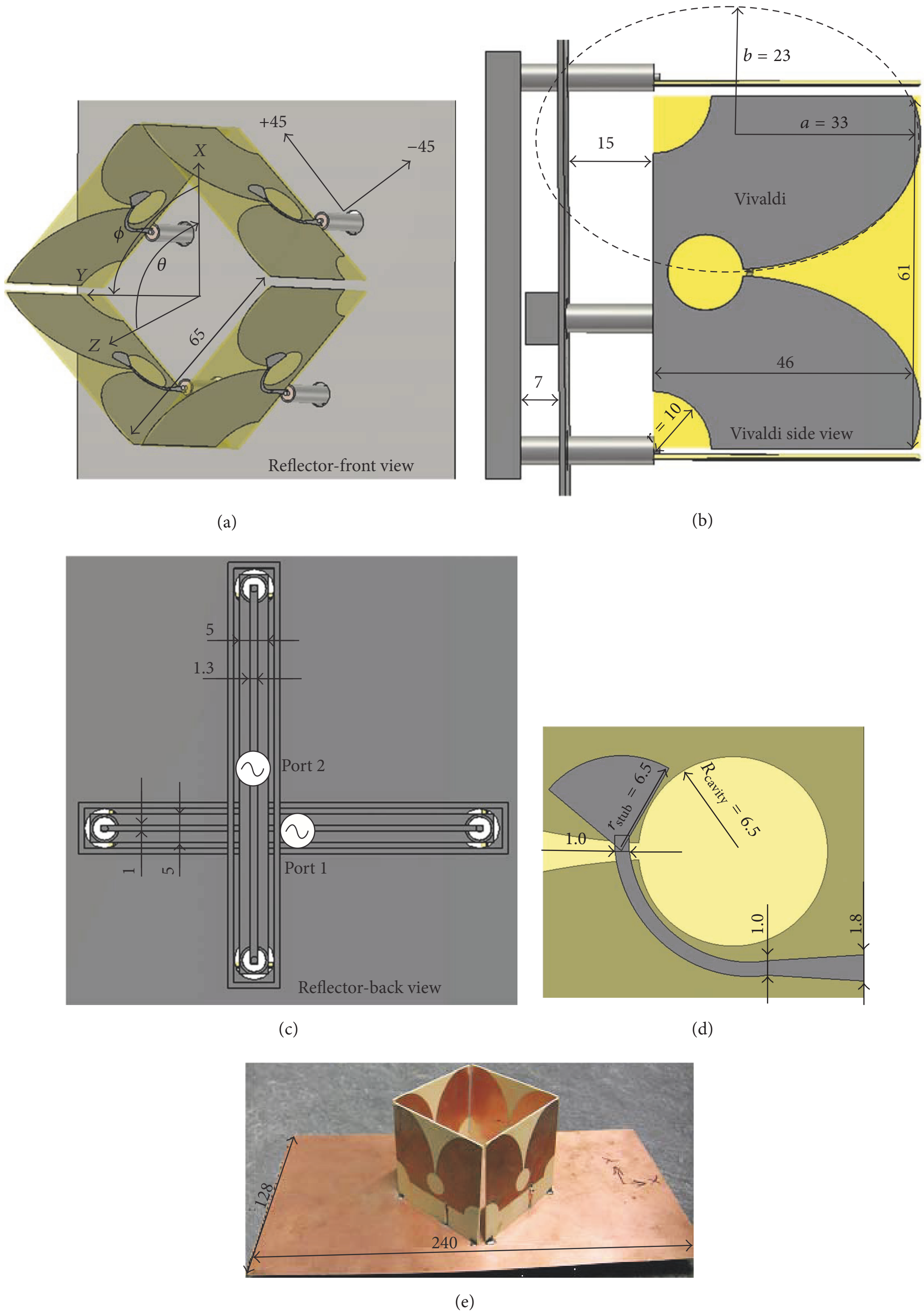

Figure 1: The simulation model of one radiator. (a) Dual polarized radiator structure with the coordinate system (b) and radiator structure with dimensions. The figure is presented in XZ-cut with respect to $\phi = 45^{\circ}$ in XY-cut. (c) The symmetrical feed network to divide the signal of one polarization. The figure is presented in XY-cut with respect to $\phi = 45^{\circ}$. (d) Microstripline feed with the stub and the cavity dimensions and (e) the prototype antenna. Dimensions are in mm and all the figures are not in the same scale.

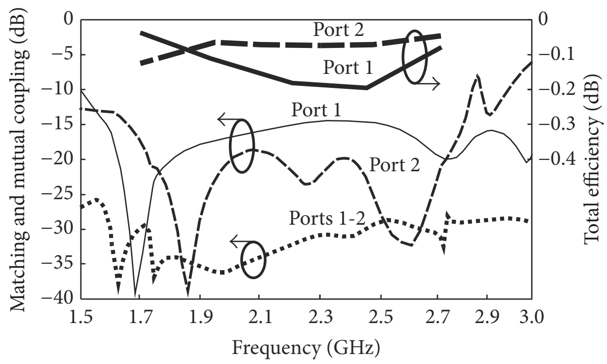

Figure 2: Simulated impedance matching, mutual coupling between the antenna ports, and total efficiency as a function of frequency.

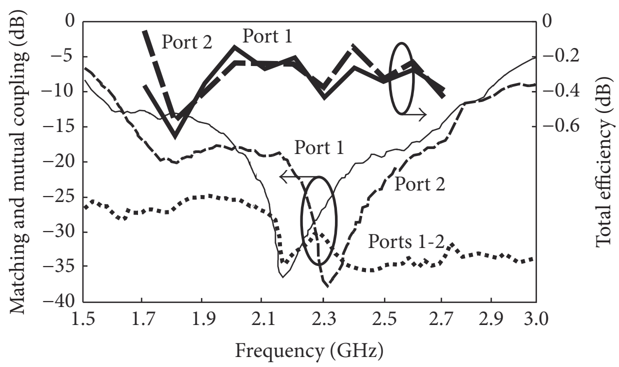

Figure 3: Measured impedance matching, mutual coupling between antenna feed ports, and total efficiency as a function of frequency.

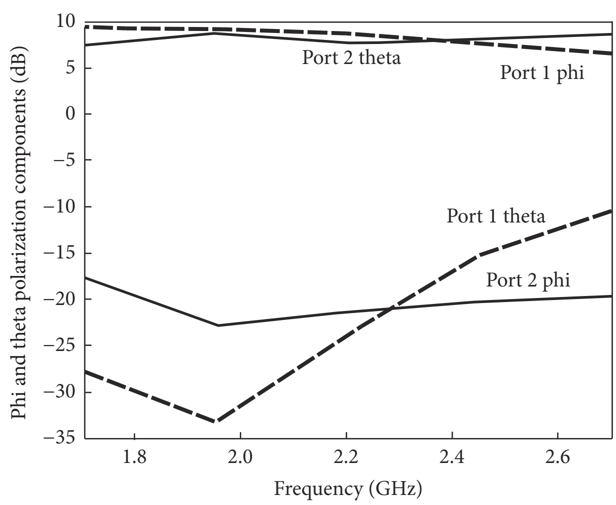

Figure 4: Simulated theta and phi polarization components as a function of frequency.

Figure 6 presents measured radiation patterns at YZ-cut ($\phi = 90^\circ$, $\theta = 0^\circ$) at 1700 MHz, 2200 MHz, and 2700 MHz. It can be observed that the 3 dB beamwidths are 70°, 68°, and 75°, respectively. Electrical results are comparable with antennas [9, 13, 15] and the antenna complexity will decide the choice order for economic manufacturing. Antenna array concepts at [16–19, 24, 25] can be straightforwardly applied with the studied structure. Presented dual polarized dual fed Vivaldi antenna has wideband, well matched, high isolated, and high total efficiency structure with flat gain response when compared to other antennas in Table 1. Antenna array performance was simulated and presented in Figure 7 as eight-element linear array such as [8]. As it can be observed, the grating lobes are arising at 2.2 GHz in ± 90 deg and at 2.7 GHz in ± 60 deg. The maximum gain in boresight is around 18 dB as sidelobe levels are around 15 dB below the maximum gain.

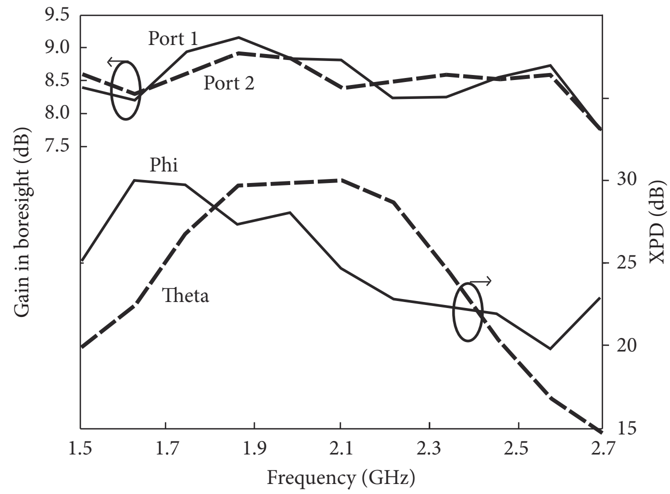

Figure 5: Measured total gain and XPD in boresight as a function of frequency.

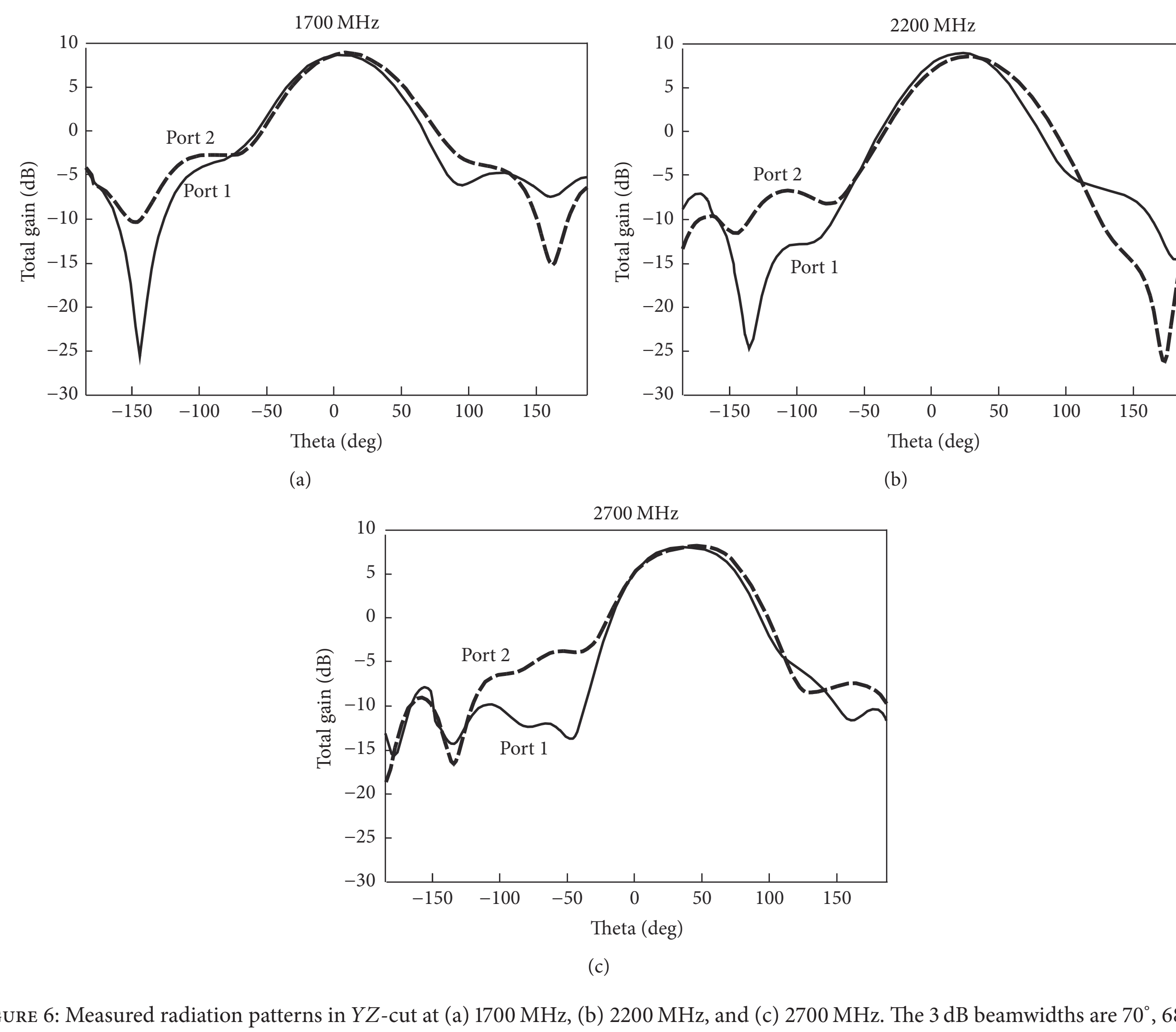

Figure 6: Measured radiation patterns in YZ-cut at (a) 1700 MHz, (b) 2200 MHz, and (c) 2700 MHz. The 3 dB beamwidths are 70°, 68°, and 75°, respectively.

Table 1: Reference antenna.

	Polarized Vivaldi (this study)	Dual polarized omnidirectional [7]	Dual polarized patch [8]	Folded dipoles [9]	Inverted L [10]	Unidirectional antenna [11]	Fed by L- and M-probe [12]	Magnetodielectric dipole [13]	Four-point antenna [14]	Dual polarized square loop [15]	Dual polarized Vivaldi [16]	Dual polarized Vivaldi [24]	Dual polarized Vivaldi [25]
Polarization	*Dual*	Dual	Dual	Dual	Linear	Linear	Dual	Dual	Dual	Dual	Dual	Dual	Dual
Frequency range [MHz]	*1700–2700*	1700–2200	1700–2730	1650–2850	1914–2219	1850–2890	1710–2690	1690–2830	805–2190	1710–2690	1000–4500	3100–10600	680–7300
Relative BW [%]	*45*	25	47	53	15	44	45	50	92	45	127	109	166
Return loss [dB]	*>14*	>10	>10	>15	>10	>14	>9.5	>14	>9.5	>15.5	>10	>10	>10
Mutual coupling [dB]	*<−25*	<−40	<−30	<−30	—	—	<−26	<−30	—	<−32	—	<−25	<−30
XPD in boresight [dB]	*15–30*	20	40	30	—	27	25	21	18–27	20	—	20	20
Gain [dBi]	*7.75...9.2*	8	9.3...10	7.5...9	5.5...7	7.5...8.2	4.9...9.6	7.6...9.3	8...9	8.0...8.8	—	4...7	4...11
Radiator dimensions $W \times L \times H$ [mm]	*63 × 63 × 63*	88 × 88 × 27	58 × 58 × 28	60 × 60 × 42	68 × 17 × 0	60 × 77 × 30	50 × 90 × 19	59 × 59 × 34	114 × 114 × 64	50 × 50 × 37	23 × 23 × 69	35 × 35 × 103	220 × 220 × 240
Reflector $W \times L$ [mm]	*128 × 240*	120 × 120	160 × 160	130 × 130	40 × 110	120 × 120	100 × 100	110 × 110	—	145 × 300	—	—	—

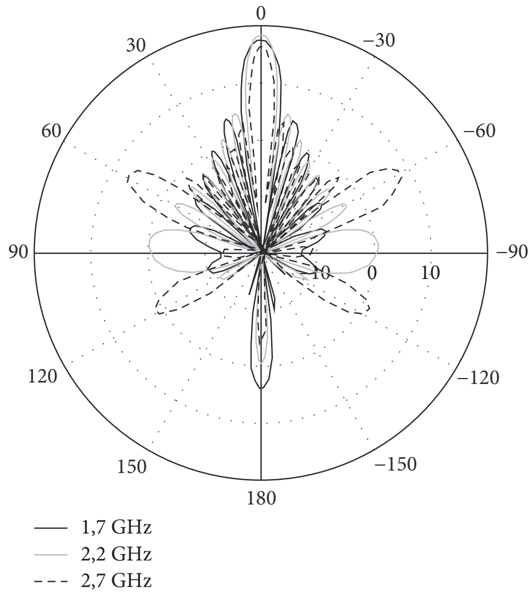

Figure 7: Simulated radiation patterns of eight-element linear array at 1.7, 2.2, and 2.7 GHz with 128 mm element spacing in y-axis. The radiation is presented in phi = 90 deg as a function of theta.

5. Conclusions

The dual polarized dual fed Vivaldi antenna element for 1.7–2.7 GHz frequency band was designed for AAS concept utilized at mobile base stations. Simulated and measured performance exhibited 45% relative impedance bandwidth with return loss better than −14 dB and mutual coupling between antenna ports was better than −25 dB. The antenna gain in the boresight was 7.75–9.2 dBi and the variation between the polarizations was observed to be very small. The total efficiency was −0.625 dB (87%) over the band for both ports. The half power or 3 dB beamwidth was approximately 70° over the antenna operating bandwidth. In conclusion, the antenna performance is sufficient to be utilized in an active antenna system in mobile base stations.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by Finnish Funding Agency for Innovation and Nokia Networks.

References

[1] R. Gabriel and K. A. Steinhauser, "Active antennas for MIMO and beamforming operation," in *Proceedings of the International Workshop on Antenna Technology (iWAT '13)*, pp. 394–397, March 2013.

[2] S. Yrjölä and E. Heikkinen, "Active antenna system enhancement for supporting Licensed Shared Access (LSA) concept," in *Proceedings of the 9th International Conference on Cognitive Radio Oriented Wireless Networks (CROWNCOM '14)*, pp. 291–298, June 2014.

[3] W. Y. Z. Wurong and Z. Rong, "Active antenna system: utilizing the full potential of radio sources in the spatial domain," Huawei Whitepaper, 2012.

[4] K. Linehan and R. Chandrasekaran, "Active antennas: the next step in radio and antenna evolution," October 2011, https://pdfs.semanticscholar.org/277c/bc63d4a2c63d968ee3fb-403b56f88037e836.pdf.

[5] Y. Kishiyama, A. Benjebbour, T. Nakamura, and H. Ishii, "Future steps of LTE-A: evolution toward integration of local area and wide area systems," *IEEE Wireless Communications*, vol. 20, no. 1, pp. 12–18, 2013.

[6] H.-D. Chen, C.-Y. Sim, J.-Y. Wu, and T.-W. Chiu, "Broadband high-gain microstrip array antennas for WiMAX base station," *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 8, pp. 3977–3980, 2012.

[7] X. Quan and R. Li, "A broadband dual-polarized omnidirectional antenna for base stations," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 2, pp. 943–947, 2013.

[8] B. Li, Y.-Z. Yin, W. Hu, Y. Ding, and Y. Zhao, "Wideband dual-polarized patch antenna with low cross polarization and high isolation," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 427–430, 2012.

[9] Y. Cui, R. L. Li, and P. Wang, "A novel broadband planar antenna for 2G/3G/LTE base stations," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 5, pp. 2767–2774, 2013.

[10] M. Taguchi and S. Sato, "Wideband base station antenna composed of ultra low profile inverted L antenna for mobile phone," in *Proceedings of the 2nd IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC '12)*, pp. 902–905, September 2012.

[11] K.-M. Luk and H. Wong, "A new wideband unidirectional antenna element," *International Journal of Microwave and Optical Technology*, vol. 1, no. 1, pp. 35–44, 2006.

[12] K.-M. Mak, H.-W. Lai, and K.-M. Luk, "Wideband dual polarized antenna fed by L- and M-probe," in *Proceedings of the Asia-Pacific Microwave Conference (APMC '12)*, pp. 1058–1060, December 2012.

[13] M. Li and K.-M. Luk, "A wideband dual-polarized antenna with very low back radiation," in *Proceedings of the 2012 Asia-Pacific Microwave Conference (APMC '12)*, pp. 61–63, December 2012.

[14] S.-Y. Suh, W. Stutzman, W. Davis, A. Waltho, K. Skeba, and J. Schiffer, "A novel low-profile, dual-polarization, multi-band base-station antenna element—the fourpoint antenna," in *Proceedings of the IEEE 60th Vehicular Technology Conference, VTC2004-Fall: Wireless Technologies for Global Security*, vol. 1, pp. 225–229, September 2004.

[15] Z. Bao, Z. Nie, and X. Zong, "A broadband dual-polarization antenna element for wireless communication base station," in *Proceedings of the IEEE Asia-Pacific Conference on Antennas and Propagation (APCAP '12)*, pp. 144–146, August 2012.

[16] T.-H. Chio and D. H. Schaubert, "Parameter study and design of wide-band widescan dual-polarized tapered slot antenna arrays," *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 6, pp. 879–886, 2000.

[17] E. De Lera Acedo, E. García, V. González-Posadas, J. L. Vázquez-Roy, R. Maaskant, and D. Segovia, "Study and design of a differentially-fed tapered slot antenna array," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 1, pp. 68–78, 2010.

[18] D. H. Schaubert, S. Kasturi, A. O. Boryssenko, and W. M. Elsallal, "Vivaldi antenna arrays for wide bandwidth and electronic scanning," in *Proceedings of the 2nd European Conference on Antennas and Propagation (EuCAP '07)*, November 2007.

[19] S. Balling, M. Hein, M. Hennhöfer, G. Sommerkorn, R. Stephan, and R. Thomä, "Broadband dual polarized antenna arrays for mobile communication applications," in *Proceedings of the 33rd European Microwave Conference (EuMC '03)*, pp. 927–930, October 2003.

[20] M. W. Elsallal and J. C. Mather, "An ultra-thin, decade (10:1) Bandwidth, modular BAVA array with low cross-polarization," in *Proceedings of the IEEE International Symposium on Antennas and Propagation and USNC/URSI National Radio Science Meeting (APSURSI '11)*, pp. 1980–1983, July 2011.

[21] C. A. Balanis, *Modern Antenna Handbook*, John Wiley & Sons inc., New York, NY, USA, 2008.

[22] R. W. Kindt and W. R. Pickles, "Ultrawideband all-metal flared-notch array radiator," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 11, pp. 3568–3575, 2010.

[23] J. Zhang, E. C. Fear, and R. H. Johnston, "Cross-Vivaldi antenna for breast tumor detectlon," *Microwave and Optical Technology Letters*, vol. 51, no. 2, pp. 275–280, 2009.

[24] G. Adamiuk, T. Zwick, and W. Wiesbeck, "Compact, dual-polarized UWB-antenna, embedded in a dielectric," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 2, pp. 279–286, 2010.

[25] M. Sonkki, D. Sánchez-Escuderos, V. Hovinen, E. T. Salonen, and M. Ferrando-Bataller, "Wideband dual-polarized cross-shaped Vivaldi antenna," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 6, pp. 2813–2819, 2015.


Journal of Engineering
The Scientific World Journal
International Journal of Rotating Machinery
Journal of Sensors
International Journal of Distributed Sensor Networks
Advances in Civil Engineering
Hindawi
Submit your manuscripts at
https://www.hindawi.com
Journal of Control Science and Engineering
Journal of Robotics
Journal of Electrical and Computer Engineering
Advances in OptoElectronics
VLSI Design
International Journal of Navigation and Observation
Modelling & Simulation in Engineering
International Journal of Aerospace Engineering
International Journal of Chemical Engineering
International Journal of Antennas and Propagation
Active and Passive Electronic Components
Shock and Vibration
Advances in Acoustics and Vibration