

Millimeter-wave antenna with adjustable polarisation

Citation for published version (APA):

Akkermans, J. A. G., & Herben, M. H. A. J. (2008). Millimeter-wave antenna with adjustable polarisation. *IEEE Antennas and Wireless Propagation Letters*, 7, 539-542. <https://doi.org/10.1109/LAWP.2008.2002943>

DOI:

[10.1109/LAWP.2008.2002943](https://doi.org/10.1109/LAWP.2008.2002943)

Document status and date:

Published: 01/01/2008

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Millimeter-Wave Antenna With Adjustable Polarization

Johannes A. G. Akkermans and Matti H. A. J. Herben

Abstract—A millimeter-wave antenna is presented that has an adjustable polarization. The polarization can be controlled by the input signal of the antenna and therefore no separate RF switch is needed. A completely planar feed network has been designed that employs branch-line couplers that allow to vary polarization depending on the input signal. The antenna has been realized and the concept of polarization diversity is demonstrated. Measurement results are in agreement with simulated results and validate the performance of the antenna.

Index Terms—Antenna feeds, millimeter wave antennas, polarization.

I. INTRODUCTION

TRANSCEIVERS that operate in the millimeter-wave frequency range have the ability to transmit data rates of gigabits per second over a short range. Especially the 60 GHz frequency band is very suited for the next generation of high-speed wireless links [1]. An important application is the data synchronization of portable devices, which relies on short-range line-of-sight conditions. Here, polarization mismatch between the antennas of the transceivers should be avoided.

For lower frequencies, the use of polarization diversity is presented in [2], where a broadband aperture coupled patch antenna is designed with a separate feed line and coupling slot for each polarization. Circular polarization diversity is presented in [3] that uses switchable slots to select a particular circular polarization. In the millimeter-wave frequency range, similar work is presented in [4], that also proposes to use switchable slots to obtain polarization diversity. A dual-polarized antenna is proposed in [5]. However, the realization of the antenna feed is not discussed in this work.

Here, we present an antenna design for the millimeter-wave frequency range which has an adjustable polarization that can be controlled by the radio-frequency (RF) chip of the transceiver. The planar feed network is designed such that no separate RF switch is needed. The polarization of the antenna can be controlled by exciting the odd mode and/or the even mode of the antenna feed. To realize this behavior, branch-line couplers are used. This is explained in Section II. Measurement results are presented in Section III.

Manuscript received June 30, 2008. First published July 29, 2008; current version published December 30, 2008.

The authors are with the Radiocommunication group at Eindhoven, University of Technology, Eindhoven 5600 MB, The Netherlands (e-mail: j.a.g.akkermans@tue.nl; m.h.a.j.herben@tue.nl).

Color versions of one or more of the figures in this paper are available online at <http://ieeexplore.ieee.org>.

Digital Object Identifier 10.1109/LAWP.2008.2002943

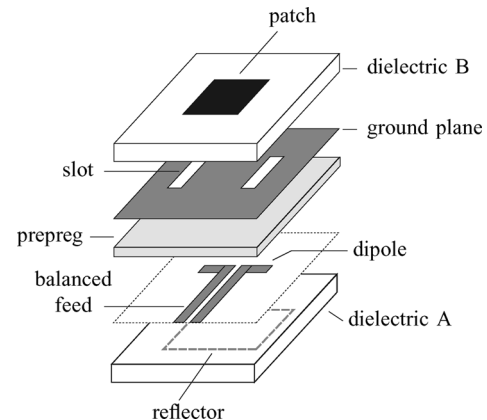


Fig. 1. Geometry of the balanced-fed aperture-coupled patch with reflector element.

II. ANTENNA DESIGN

The antenna design is based on the balanced-fed aperture-coupled patch (BFACP) antenna (see [6], Fig. 1), that operates in the 60 GHz frequency band. This antenna has a balanced feed and uses two apertures (slots) to couple to the patch. Both the slots and the patch can be made resonant in the band of operation to increase the bandwidth. The back radiation that is caused by the resonant slots is effectively cancelled by the reflector element. The use of two separate slots improves the efficiency of the antenna since it reduces the surface-wave excitation in the dielectric layers. The antenna has a bandwidth of 10–15% and an accompanying radiation efficiency that is larger than 80% [6].

The BFACP antenna can be extended to support dual polarization or circular polarization by adding two more slots (Fig. 2). In this way, the advantages of the linearly polarized antenna are maintained while the flexibility of polarization diversity is added. However, the design of the feed network becomes more involved. The antenna now has four slots and opposite slots need to be excited simultaneously. Therefore, it becomes complicated to design a feed network on a single metal layer. One could use more metal layers to design the feed network, but then the use of vias is required (see Fig. 2). Especially at millimeter-wave frequencies, the use of vias should be avoided since they introduce mismatch and additional losses. Therefore, an alternative feed network is designed that uses a single metal layer and that supports polarization diversity.

The feed of the antenna is a coupled microstrip line that supports two propagating modes, i.e., the odd and even mode. Both modes are used in the feed network in a way that each mode excites a specific polarization. The coupled microstrip line is split

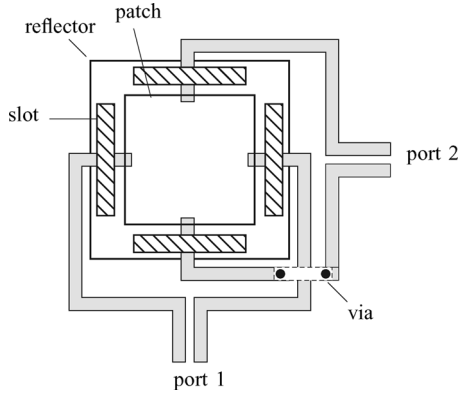


Fig. 2. Top view of the dual-polarized BFACP antenna with two separate feed networks.

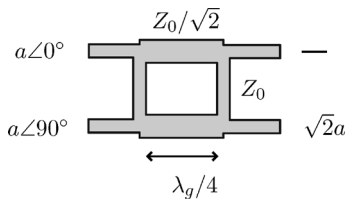


Fig. 3. Layout of a branch-line coupler.

into two separate microstrip lines that are fed to branch-line couplers (Fig. 3) [7]. A branch-line coupler has two inputs and two outputs. The output signals can be controlled by the phase and amplitude of the input signals. When the input signals have a phase difference of 90 degrees and equal amplitude, only one output is active while the other output is isolated. This property is employed to obtain polarization selectivity. In this setup, an RF source is needed that is able to generate both an even-mode and an odd-mode signal simultaneously.

The feed network of the polarization diversity antenna with branch-line couplers is shown in Fig. 4. It consists of two branch-line couplers that select which slots of the patch antenna are excited. The feed-line length from branch-line coupler to slot should be the same for opposite slots. If the antenna is operated in the even mode (Fig. 4), one linear polarization is active while the other linear polarization is active in the odd mode (Fig. 5).

The far-field of the antenna can be related to the mode excitation as

$$\begin{aligned} E_\nu &\sim \Re\{a^{\text{even}}e^{j\omega t}\} \\ E_\tau &\sim \Re\{a^{\text{odd}}e^{j\omega t}\} \end{aligned} \quad (1)$$

where E_ν is the ν -directed far-field at broadside (z -direction), E_τ is the τ -directed field at broadside, a^{even} is the amplitude of the even mode, a^{odd} is the amplitude of the odd mode, ω is the radial frequency and t is the time variable.

The excitation of the even and odd mode simultaneously results in the excitation of the two port lines with a specific amplitude and phase-difference. These excitations are

$$\begin{aligned} s_1 &= \Re\{(a^{\text{even}} + a^{\text{odd}})e^{j\omega t}\} \\ s_2 &= \Re\{(a^{\text{even}} - a^{\text{odd}})e^{j\omega t}\}. \end{aligned} \quad (2)$$

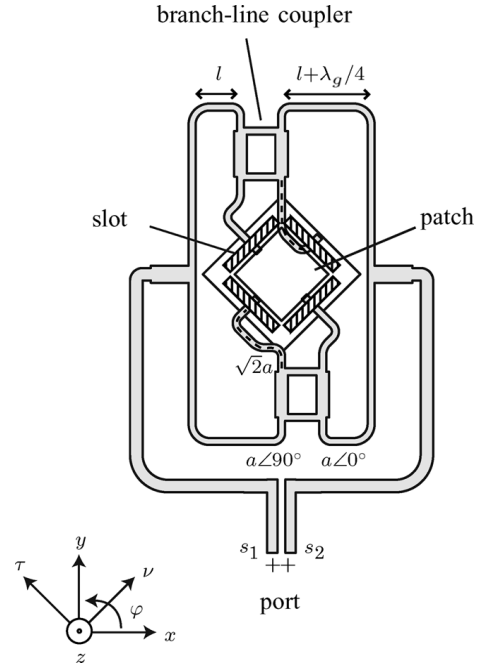


Fig. 4. Top view of the dual-polarized BFACP antenna with branch-line couplers in even-mode operation. The dashed lines indicate the active feed lines.

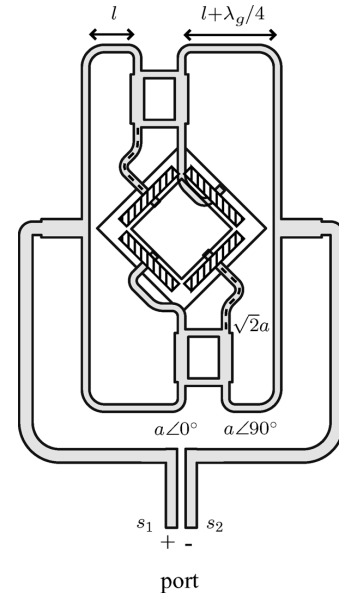


Fig. 5. Top view of the dual-polarized BFACP antenna with branch-line couplers in odd-mode operation. The dashed lines indicate the active feed lines.

An arbitrary linear polarization can be realized by exciting both modes in phase simultaneously. Circular or elliptical polarization can be obtained when both modes are excited with a phase difference of 90 degrees. Some examples for the relation between mode excitation and polarization are listed in Table I.

III. MEASUREMENT RESULTS

To demonstrate the ability of the antenna to change polarization, two versions have been made. One with odd-mode excitation and one with even-mode excitation. RF probes are used to connect to the antenna. Therefore, a transition from coplanar

TABLE I
 RELATION BETWEEN MODE EXCITATION AND POLARIZATION

even mode	odd mode	s_1	s_2	polarization
$a\angle 0^\circ$	0	$s\angle 0^\circ$	$s\angle 0^\circ$	linear, $\varphi = 45^\circ$
0	$a\angle 0^\circ$	$s\angle 0^\circ$	$s\angle 180^\circ$	linear, $\varphi = 135^\circ$
$a\angle 0^\circ$	$a\angle 0^\circ$	$2s$	0	linear, $\varphi = 90^\circ$
$a\angle 0^\circ$	$a\angle 90^\circ$	$s\angle 0^\circ$	$s\angle 90^\circ$	right-hand circular
$a\angle 90^\circ$	$a\angle 0^\circ$	$s\angle 90^\circ$	$s\angle 0^\circ$	left-hand circular

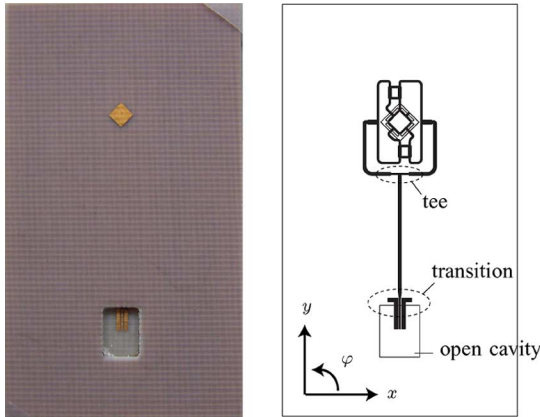
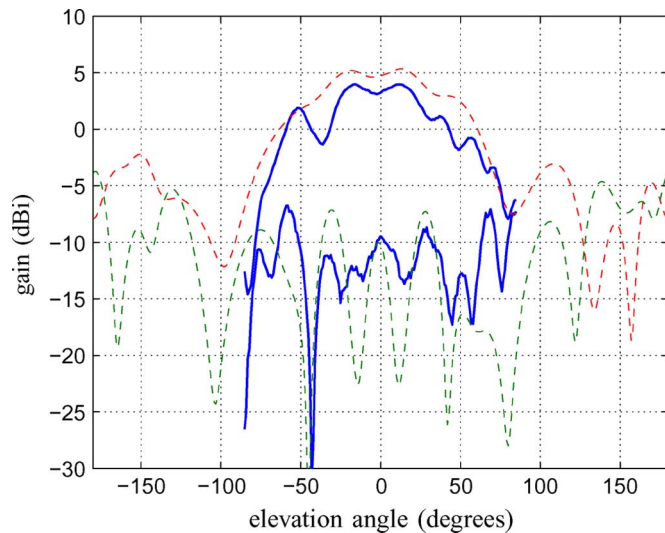
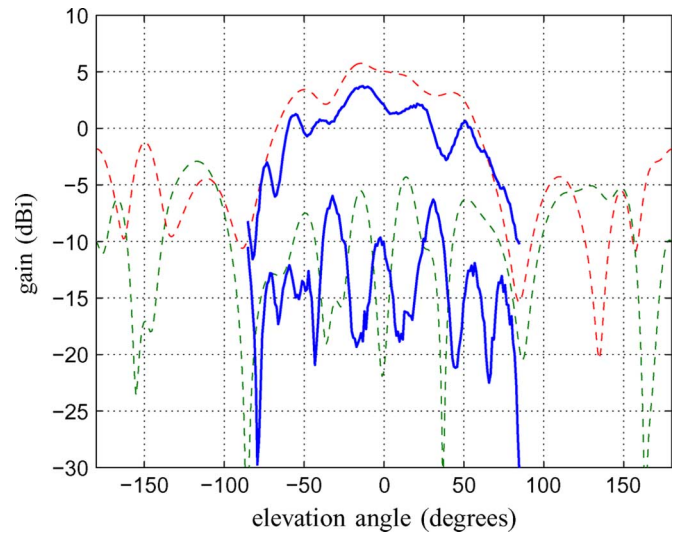


Fig. 6. Dual-polarized antenna with even-mode excitation. Photograph (left), layout feed network (right).


 Fig. 7. Co- and cross-polarized radiation pattern of dual-polarized antenna with even-mode excitation. Linear polarization, $\varphi = 45^\circ$, frequency $f = 60$ GHz. Measurement (solid), simulation (dashed).

waveguide (CPW) to microstrip (MS) is designed as well [8]. An open cavity is realized to be able to land the RF probe directly on the CPW feed. The feed network for the even-mode excitation is shown in Fig. 6.

A tee is used to split the MS line into the two branches of the balanced feed. The position of this tee is adjusted to select odd-mode or even-mode excitation. If the center of the tee is aligned with the center of the patch, the two outgoing microstrip lines of the tee are in phase and the antenna is excited similar to the even-mode excitation of Fig. 4. If the center of the tee is placed $\lambda_g/4$ out of the center-line, the effective phase difference between the two outgoing microstrip lines is 180 degrees, which


 Fig. 8. Co- and cross-polarized radiation pattern of dual-polarized antenna with odd-mode excitation. Linear polarization, $\varphi = 135^\circ$, frequency $f = 60$ GHz. Measurement (solid), simulation (dashed).

is similar to the odd-mode excitation of Fig. 5. In this way, the even-mode and odd-mode excitations of the coupled microstrip line are emulated.

The antennas are realized in printed circuit-board (PCB) technology. Teflon-based dielectric material is chosen with a relative dielectric constant of 2.17 and a loss tangent of 0.002. A low dielectric constant improves the bandwidth and radiation efficiency of the antenna. The thickness of dielectric A and B (see Fig. 1) is $254 \mu\text{m}$. The thickness of the prepreg (adhesive) layer equals $112 \mu\text{m}$. This thickness is suited for the design of the feed network, since it allows for properly dimensioned transmission lines. The prepreg material has a relative dielectric constant of 2.6 and a loss tangent of 0.004. The antenna is designed with in-house developed method-of-moments (MoM) software and CST Microwave Studio [9]. The in-house software is a planar MoM code that is used to analyze the radiation efficiency of the antenna element itself, as presented in [6]. CST Microwave Studio is used to analyze the antenna including the complete feed network and the edge effects of the dielectric.

A far-field measurement setup has been built, that is tailored to the measurement of millimeter-wave antennas [8]. The radiation pattern of the antenna is measured in the $\varphi = 0^\circ$ plane (see Fig. 6). The co- and cross-polarization is simulated and measured for both antenna excitations (Figs. 7, 8). These simulations have been performed with CST Microwave Studio, and include the scattered radiation at the edges of the dielectric. It is observed that the antennas radiate a field with an orthogonal linear polarization. The measured gain is 1–2 dB lower than the simulated gain, which indicates that the dielectric and the feed network introduces some additional losses that are not accounted for in the simulation. In practice, the losses in the feed network can be reduced by designing a more compact feed network that is connected directly to a RF chip. The measured cross-polarization suppression level in the forward direction is 10–15 dB, which demonstrates that the antenna is able to select one specific linear polarization.

IV. CONCLUSION

A millimeter-wave antenna has been presented that has an adjustable polarization. The polarization can be controlled by the excitation signal of the antenna and therefore no separate RF switch is needed. A feed network has been designed that employs branch-line couplers that allow to vary polarization depending on the input signal. The antenna has been realized and the concept of polarization diversity is demonstrated. Measurement results are in good agreement with simulated results and validate the performance of the antenna.

REFERENCES

- [1] P. Smulders, "Exploiting the 60 GHz band for local wireless multi-media access: Prospects and future directions," *IEEE Commun. Mag.*, vol. 40, pp. 140–147, Jan. 2002.
- [2] S. Gao, L. Li, M. Leong, and T. S. Yeo, "A broadband dual-polarized microstrip patch antenna," *IEEE Trans. Antennas Propag.*, vol. 51, no. 4, pp. 898–900, Apr. 2003.
- [3] F. Yang and Y. Rahmat-Samii, "A reconfigurable patch antenna using switchable slots for polarization diversity," *IEEE Microw. Wireless Compon. Lett.*, vol. 12, no. 3, pp. 96–98, Mar. 2002.
- [4] K. Hettak, G. Delisle, G. Morin, and M. Stubbs, "A novel reconfigurable single-feed CPW coupled patch antenna topology with switchable polarization," in *Proc. Antennas Propagation Int. Symp.*, Jun. 2007, pp. 5199–5202.
- [5] G. Chattopadhyay and J. Zmuidzinas, "A dual-polarized slot antenna for millimeter waves," *IEEE Trans. Antennas Propag.*, vol. 46, no. 5, pp. 736–737, May 1998.
- [6] J. Akkermans, M. van Beurden, and M. Herben, "Design of a millimeter-wave balanced-fed aperture-coupled patch antenna," presented at the EuCAP 2006, ESA SP626, Nice, France, Nov. 2006.
- [7] D. Pozar, *Microwave Engineering*. New York: Wiley, 2004.
- [8] J. Akkermans, R. van Dijk, and M. Herben, "Millimeter-wave antenna measurement," in *Proc. Eur. Microw. Conf.*, München, Germany, Oct. 2007, pp. 83–86.
- [9] CST Microwave Studio [Online]. Available: <http://www.cst.com>