High performance 60-GHz dielectric rod antenna with dual circular polarization

Citation for published version (APA):

Document status and date:
Published: 01/01/2013

Document Version:
Accepted manuscript including changes made at the peer-review stage

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.

Download date: 09. Jan. 2020
High Performance 60-GHz Dielectric Rod Antenna with Dual Circular Polarization

M.W. Rousstia and M.H.A.J. Herben
Eindhoven University of Technology, The Netherlands
E-mail: {m.w.rousstia, m.h.a.j.herben}@tue.nl

Abstract—In this paper, the design of a high performance dielectric rod antenna is described and validated through measurements. The manufactured 60-GHz dielectric rod antenna has the predicted gain of around 15 dBi and supports dual circular polarization. The lateral dimension of the rod antenna is very small in comparison to its counterparts. The measured port-to-port isolation larger than 20 dB is obtained for the bandwidth of 1.1 GHz. The measured axial ratio (AR) in the bandwidth of interest is below 0.5 dB. It will be shown that the very wideband return loss is due to the quadrature hybrid coupler.

Index Terms—Dielectric rod, millimeter-wave antenna, 60 GHz, quadrature hybrid coupler, circular polarization.

I. INTRODUCTION

In consumer, industrial and automotive areas, the need for high data rate communication inevitably increases. The use of wireless communication has also rapidly increased, much faster than its wireline counterpart. As a result, the required bandwidth doubles every 18 months [1]. Moreover, the number of wireless devices owned per user has been ever increasing. Not only will the wireless devices connect people to people, but also people to machines and machines to machines. Nevertheless, the Industrial, Scientific, Medical (ISM) application band at 2.4 GHz has been overcrowded by numerous commercial products of end users. The availability of 7 GHz (US) and 9 GHz (Europe) around 60 GHz (ISM-band) is able to accommodate high data rate and dense local wireless communication. Furthermore, the propagation condition in the 60-GHz wireless channel enables frequency reuse [2].

However, these interesting properties come not only with the advantage. In this frequency band, the wave is highly attenuated so that the front-end devices of the receiver-end have to be very sensitive, otherwise the radio wave will be effectively undetected. This situation thus limits the communication distance. To tackle it, increasing antenna gain is proposed allowing more margin in the link budget. Some approaches to increase the antenna gain at 60 GHz have been reported. In [3], [4], though high gain performance can be achieved, the relative large dimension and increasing complexity of the complete antenna system may limit its use, e.g. due to manufacturability and repeatability issues. This inherent limitation further prevents the feasibility of the antenna to add more features. For example to promote spectral efficiency, duplex communication by exploiting dual circular polarization is often used.

In this work, a 60-GHz dielectric rod antenna with an optimized dielectric shape to obtain the high realized gain and dual circular polarization is proposed. The antenna is not prone to rotation around its axis while facilitating the spectral efficiency. The measured gain and axial ratio bandwidth of this simpler antenna structure are higher than what is reported in [5]. This low-sidelobe rod antenna is suitable for short-range point-to-point wireless communication and automotive radar applications [6].

II. DESIGN METHODOLOGY

A. Dielectric rod antenna

The detailed dimensions of the rod are depicted in Figure 1. The rod will be fed by a patch antenna. The tapered section is to reduce the Side Lobe Level (SLL), and the uniform section is to produce maximum gain. The maximum end-fire radiation is obtained by adjusting the length of those sections. The diameter of the rod supports an HE_{11} hybrid mode if it meets the following relationship

\[ D_\lambda \sim \frac{3}{\varepsilon_r^{3/2}} \sqrt{1 + 2L_\lambda} + 0.2, \]  

where \( D_\lambda \) and \( L_\lambda \) are the diameter and total length of the rod in terms of free-space wavelength.

For even larger gain, smaller 3dB beamwidth and lower SLL, the cylindrical part of the dielectric can be lengthened as shown in the design template presented in [6]. To feed the antenna, low-cost 60-GHz RPC-1.85 connectors are utilized.

TPX or polymethylpentene is the material for the dielectric rod. Its relative permittivity \( \varepsilon_r \) and loss tangent tan\( \delta \) are 2.13 and \( 4.8 \times 10^{-4} \), respectively. The diameter of the rod base is made large to have sufficient surface area for strong adhesion. Note that the thickness of this rod base should not be larger than 0.16\( \lambda \). Otherwise, though the impact is not dramatic, the realized gain will deteriorate.

B. Quadrature hybrid coupler

In Figure 2, the coupler excites the patch antenna via electromagnetic coupling to the upper layer. When port 1 is excited, the coupler acts as a 3dB power divider with a phase difference of 90°. This phase difference causes the patch to radiate circular polarization. The characteristic impedance of the through and coupling lines is 50/\( \sqrt{2} \) and 50Ω, respectively. The length of those lines is \( \lambda/4 \). The two arms should be electrically far from the edge of the patch to maintain the...
polarization purity of the patch radiator. The square patch antenna is used to ensure identical performances for both resulting polarization senses.

Flexible Liquid Crystal Polymer (LCP) laminate is used here and has $\epsilon_r = 3.16$ and $\tan\delta = 0.002$. The dielectric constants of the coverlay and adhesive materials used in the laminate are not available at 60 GHz. Nonetheless, it is known from the PCB manufacturer that their effective dielectric constant is approximately 3.

The $0^\circ$-plane and $90^\circ$-plane that will be used in this paper for the far-field radiation pattern are also given in Figure 2.

The antenna resonance occurs approximately at 61 GHz, and the antenna’s (-20dB) isolation bandwidth is 1.1 GHz. The measurement results are in a good agreement with the simulation results. Moreover, the Thru-Reflect-Line (TRL) calibration has been performed. For that purpose, it is necessary that the 60-GHz RPC connectors with uniform impedance profiles are used. This was checked using Time Domain Reflectometry (TDR) measurement technique. With the TRL calibration, the influences of microvia, RPC connector and transmission line are de-embedded. From a simple calculation, the amount of loss of approximately 2.9 dB can be removed from the measurement.

In Figure 5, it is shown that different materials on top of the patch antenna can have a predominant effect in shifting the resonance frequency. Despite its thin dimension, the double tape
or any kind of adhesive material, which material properties are often unavailable, may cause 2-3 GHz shift depending on its $\epsilon_r$.

B. Radiation pattern analysis

The antenna system is designed to have circular polarization. To measure its radiation pattern, there are four methods to measure the $AR$, namely the rotating-source method, the polarization-pattern method, the phase-amplitude method and the multiple-amplitude-component method [7]. The first method is currently not available to be performed autonomously in our 60-GHz anechoic chamber. The next two methods require very accurate phase measurement, especially at 60 GHz. The last method is used here as also suggested in [8]. The measurement can be performed by rotating the linearly polarized horn antenna at $0^\circ$, $45^\circ$, $90^\circ$ and $-45^\circ$ positions. At least three positions are already sufficient to be able to compute the polarization ellipse.

The ellipse equation eliminating the unknown semi-major and -minor axes, i.e. $a$ and $b$, respectively, in polar coordinates is

$$Ae^4 - 4(A + 1)e^2 + 4(A + 1) = 0,$$

where

$$A = \frac{G_0^2 + G_z^2 + 4\left(\frac{G_{0z}G_z}{G_{45}}\right)^2 - 2G_0G_z - 4G_{0z}G_z - 4G_4^2G_z}{(G_0 + G_z)^2},$$

$e$ is the eccentricity and $G_{0,45}$, $G$ is the antenna gain for $0^\circ$, $90^\circ$, $45^\circ$ positions, respectively. Note that the gain value is not complex. The $AR$ and the realized co- and cross-polarized gain of the antenna can be obtained through:

$$AR = \frac{a}{b},$$

$$\text{max}(G_{\text{RHC}P,\text{LHC}P}) = \frac{G_{45}}{2}\left(\frac{AR+1}{AR+1}\right)^2,$$

$$\text{min}(G_{\text{RHC}P,\text{LHC}P}) = \frac{G_{45}}{2}\left(\frac{AR-1}{AR+1}\right)^2.$$

The total realzed gain $G_{\text{tot}}$ is the sum of the two orthogonal components, e.g. $G_0$ and $G_z$.

After the $AR$ is obtained using equation (3), the realized gain of the circularly polarized antenna can be calculated by means of equation (4). The polarization mismatch is thus taken into account. The polarization sense can be observed by evaluating the field in either RHCP or LHCP wave component:

$$E_{\text{RHCP}} = \frac{1}{\sqrt{2}}(E_\theta + jE_\phi),$$

$$E_{\text{LHCP}} = \frac{1}{\sqrt{2}}(E_\theta - jE_\phi).$$

$E_\theta$ and $E_\phi$ are the fields from any two orthogonal cuts, e.g. $E_0$ and $E_\phi$, respectively. Note that the fields are complex. By looking which absolute field is largest for $\theta = 0$, the polarization sense can be determined.

In Figure 6, the measurement facility and manufactured dielectric rod antenna are depicted. It can be seen at the top that the linearly polarized horn antenna is used for the measurement of the radiation pattern and at the bottom the manufactured dielectric rod antenna is positioned. The footprints for attaching two RPC connectors are shown in Figure 6(b).

From Figure 7, it is clear that the shapes of the measured co-polar pattern and $AR$ pattern agree with the simulated ones. Also the measured antenna gain is as simulated with achieved 14.6dBi gain for $\theta = 0$, but the measured $AR$ is slightly better than the simulated one.

From the measurement, $E_{\text{LHCP}}$ has a lower value than $E_{\text{RHCP}}$, especially in the direction of the main lobe. Hence, the antenna radiation has right-hand circular polarization as predicted from the simulation.

The measurement results in the $90^\circ$-plane are also in good agreement with the simulation results (see in Figure 8). From the observation for $\theta < 0^\circ$, the waves are influenced by the RPC connectors and termination load (obstacles) which slightly shift the lobe’s maxima and minima. For $\theta > 0^\circ$, the smaller as predicted $AR$ is partly responsible for these higher side lobes.

In Figure 9, the (-20dB) isolation bandwidth is illustrated. Hence, the useful antenna performance is measured for the bandwidth of 1.1 GHz.

In Figure 10, the performance of the dielectric rod antenna is summarized for both $0^\circ$-plane and $90^\circ$-plane. It can be observed that the obtained gain is around 15 dBi. The $AR$ in the frequency band of interest is below 0.5 dB. Although it is not mentioned here for brevity, the 3dB $AR$ bandwidth
covers the whole 60-GHz ISM band. This is mainly due to the use of the quadrature hybrid coupler. The 3dB beamwidth for both principle planes is similar over the frequency band, showing the symmetry property of the rod’s radiation pattern. The sidelobe level is measured to be around -9.5 dB.

IV. Conclusion

The dielectric rod antenna with dual circular polarization has been designed, manufactured and measured. The resonance peak occurs around 61 GHz, and a 15dBi circularly-polarized antenna gain is realized. The measured radiation pattern has right-hand circular polarization. The port-to-port (-20dB) isolation bandwidth is 1.1 GHz. This high port-to-port isolation of the antenna enables duplex communication with reduced complexity of the RF front-end devices, e.g. it avoids the use of a duplexer filter or a switch. Further, the antenna structure is easy and low cost to manufacture and can support the short-range point-to-point-communication and automotive applications.

ACKNOWLEDGEMENT

The authors would like to thank A.C.F. Reniers for the valuable support in the measurement.

REFERENCES