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C. Hannachi, M. Egels, A. Venouil, P. Pannier, S O Tatu. A Miniature Low-Profile MHMIC Antenna Array For Millimeter-Wave Identification Readers. 2024 IEEE International Symposium on Antennas and Propagation and INC/USNC-URSI Radio Science Meeting (AP-S/INC-USNC-URSI), Jul 2024, Firenze, France. pp.2689-2690, <10.1109/AP-S/INC-USNC-URSI52054.2024.10686578>. <hal-05005869>

HAL Id: hal-05005869

<https://hal.science/hal-05005869v1>

Submitted on 25 Mar 2025

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A Miniature Low-Profile MHMIC Antenna Array For Millimeter-Wave Identification Readers

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Abstract—In this paper, a high directive miniature 60-GHz 8-by-1 microstrip antenna array is presented and analyzed. To achieve a reduced size and ease of integration into MMID reader devices, the proposed antenna array has been designed on a thin ceramic substrate ($\epsilon_r = 9.9$, $h = 127 \mu\text{m}$), using an MHMIC (Miniature Hybrid Microwave Integrated Circuits) fabrication process. The proposed array configuration has exhibited excellent performance in terms of realized gain (peak gain of 14 dB) and radiation efficiency (around 75%). All those features make it a suitable candidate for integrated MMID readers to locate transponders in high-density sensor networks.

I. INTRODUCTION

Millimetre-wave identification (MMID) is the transformation of the RFID concept into a millimeter-wave regime. The use of a higher carrier frequency enables directional readers and tags in a small volume, as well as the implementation of high data-rate (higher than gigabit) communications. Thanks to shorter wavelengths at millimeter-wave frequencies, antenna elements and antenna arrays would be smaller and highly directive resulting in MMID readers with the capability of selecting between different transponders (tags) by manual scanning or by angle-of-arrival (AoA) [1-3].

Recently, the 60 GHz unlicensed Industrial-Scientific-Medical (ISM) band from 57 to 64 GHz is getting lots of interest, due to its potential to meet the MMID miniaturization requirements. For instance, a four-element antenna array on an alumina substrate at 60 GHz may have a size of around 10 mm by 5 mm being small enough to be integrated into portable handsets. This paves the way for several applications requiring pointing functionalities such as in biosensor networks in which micro-scale biosensors can be integrated into miniaturized tags and can be separated by directive reader [4-5].

In this paper, a miniature 60-GHz 8-by-1 microstrip antenna array suited for MMID applications is designed, implemented, and investigated. The proposed antenna array configuration is fed with an integrated grounded broadband via-hole-less transition from coplanar to microstrip line (GCPW-to-MS). The antenna array prototype is designed on a thin-film ceramic substrate alumina ($\epsilon_r = 9.9$, $h = 127 \mu\text{m}$), using an MHMIC (Miniature Hybrid Microwave Integrated Circuits) fabrication process. To verify the conformity of the antenna to the MMID application requirements, a comprehensive performance analysis of the radiation pattern and scattering parameters is performed, as part of this study.

II. ANTENNA DESIGN, FABRICATION, AND RESULTS DISCUSSION

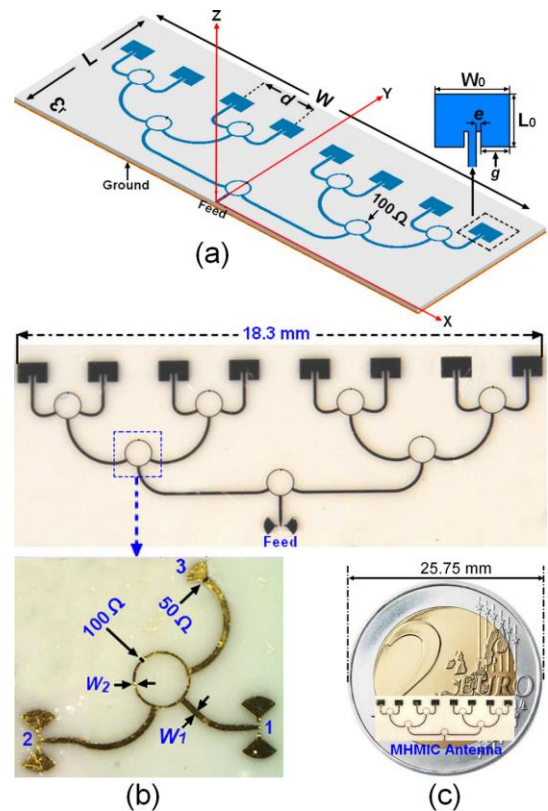


Figure 1. The 60 GHz 8-by-1 antenna array: (a) design with the geometrical parameters; (b) micro-photograph of the fabricated MHMIC antenna array prototype including the Wilkinson power divider/combiner; (c) real size view of the prototype.

A. Design and fabrication

The structure of the proposed antenna array with its geometrical parameters is shown in Fig. 1(a) above. It consists of eight patch elements spaced approximately by $0.55\lambda_o$ ($\lambda_o = 5\text{mm}$), and a parallel feed network composed of seven rounded shapes Wilkinson power dividers/combiners, along with the 50Ω transmission lines. Fig. 1(b) shows that the adopted feeding technique uses a grounded broadband via-hole less transition from coplanar to microstrip line (GCPW-to-MS) for S-parameters on-wafer measurement. The Wilkinson power dividers/combiners and the patch element parameters are

optimized individually before being integrated into the feeding network to reach a higher resonant frequency and enhanced radiation performance. For antenna array design implementation, a high permittivity ($\epsilon_r = 9.9$) thin-film ceramic alumina substrate with a thickness of 127 μm is selected to achieve a miniaturized size (the overall size is about 18 mm by 6.8 mm). In Fig. 1(c), the fabricated MHMIC antenna array is depicted on a 2 Euro coin to show its miniaturized size. The optimized geometrical parameters of the antenna array structure are $W = 18.310$, $L = 6.805$, $W_0 = 1.060$, $L_0 = 0.759$, $L_2 = 0.759$, $d = 2.5$, $e = 0.069$, $g = 0.10$, $W_1 = 0.127$, $W_2 = 0.057$, with all units being millimeters.

B. Results and discussion

A Keysight E8362B (10MHz–20 GHz) Vector Network Analyzer, connected with E-band (60–90 GHz) extension modules was employed to ensure S-parameter measurements. This is achieved thanks to an on-wafer structure equipped with ground-signal-ground GSG 150 μm coplanar probes from Cascade Microtech. A thru-reflect-line (TRL) calibration standard was also performed using an integrated TRL kit on the same thin-film alumina substrate for an accurate on-wafer measurement. It should be noted that the measurements were carried out from 60 GHz instead of 57 GHz (the starting frequency of the unlicensed 60GHz frequency band) due to the limitation of our E-band (60–90 GHz) extension modules as mentioned earlier. However, it is possible to extrapolate these results over the 57 to 60 GHz frequency range using the obtained measurements combined with the antenna array ADS momentum simulations [5].

The S-parameter measurements are compared with the ADS software momentum simulations over the frequency range, from 60 to 65 GHz, in Fig. 2(a). As can be seen, measurements and simulations are in reasonable agreement. They respectively achieve an operating frequency band at -10 dB of 1.7 GHz (simulation) and about 2 GHz (measurement). The measured S-parameter using coplanar to microstrip line (GCPW-to-MS) transition shows a relatively wider bandwidth due to the added extra loss and transition mismatch. A slight frequency shift response of about 0.2 GHz (0.3 %) is also observed, which is mainly due to the tolerances in the substrate and fabrication process.

The results of the simulated peak gain and efficiency versus the frequency are plotted in Fig. 2 (b). As can be observed, the designed MHMIC antenna array exhibits a gain of more than 10 dB over the frequency range of 60 to 64.3 GHz. The maximum achieved peak is 14 dB at 62.6 GHz. However, the proposed MHMIC array configuration shows a radiation efficiency of better than 70% from 60.2 GHz to 63 GHz with a maximum of 75% achieved at 61 GHz.

The simulated radiation patterns at 61 GHz in the E-plane are shown in Fig. 2(c). The results demonstrate that the MHMIC antenna array has a high symmetry and a maximum level of radiation in the broadside direction. The half-power beam width (HPBW) is approximately 15° (at -3 dB point), whereas the first side lobe is about 13.4 dB below the main lobe. The exhibited low side lobe level and half-power beam width indicate that the proposed array antenna largely meets the requirements for millimeter-wave identification applications.

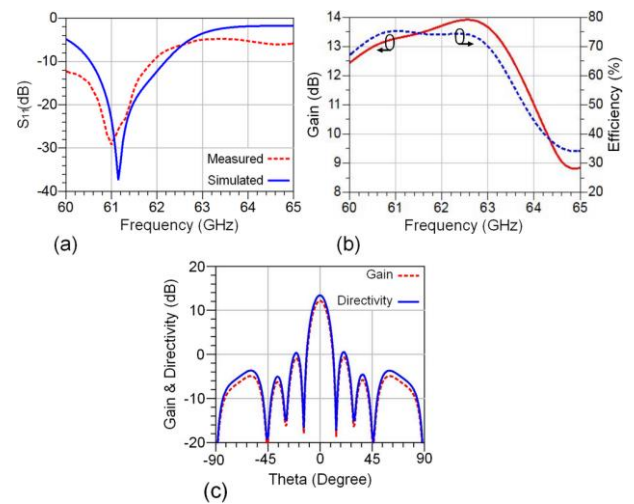


Figure 2. The 60 GHz 8-by-1 antenna array: (a) measured and simulated S-parameters; (b) simulated peak gains and radiation efficiency versus frequency; (c) simulated E-plane radiation pattern.

III. CONCLUSION

Millimeter-wave identification is an extension of the RFID concept to millimeter-waves. The use of a higher carrier frequency enables the use of reader devices with miniature directive antennas, enabling in locating of transponders in high-density sensor networks. In this study, a high directive miniature 60 GHz microstrip antenna array for MMID systems has been designed, fabricated, and tested. The obtained results in terms of radiation efficiency, gain, and compact size (18 mm by 6.8 mm), prove a high optimization level of the proposed array structure and make it a serious candidate for integration in future MMID-integrated reader devices.

ACKNOWLEDGMENT

The authors are grateful to the Poly-Grames Research Center staff, in Montreal, QC, Canada, for the MHMICs fabrication.

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