A Novel Circularly Polarized W-Band Direct Detection Receiver for Six-Port Polarimetric Radar Systems

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ABSTRACT

A circularly polarized silicon integrated W-band direct detection receiver (DDR) for use in six-port polarimetric radar systems has been designed, numerically optimized and fabricated. The major advantage of the receiver is a novel low-loss, purely planar dual patch antenna (DPA) layout, which allows the receiver to be manufactured using monolithic integration. The measurement results for the receiver demonstrate a good cross polarization discrimination (XPD) > 14 dB @ 76 GHz over a wide range of the scan angle (12 dB @ ±20°).

INTRODUCTION

Prototypes of millimeter wave polarimetric radar systems have successfully demonstrated their capability in automotive applications, e.g. measurement of the lateral and longitudinal velocity [4], evaluation of the road condition [5], and collision avoidance [6]. However, the availability of miniaturized low-cost components is a prerequisite for serving the high-volume automotive market. A promising polarimetric radar system for automotive applications, based on a six-port approach, was patented [2,3]. The radar system requires four linearly polarized (LP) and two circularly polarized (CP) direct detection receivers. Thus, monolithically integrated components can be employed conveniently. Though a variety of designs for LP integrated direct detection receivers was developed [8], existing designs for CP antennas do not comply with monolithic integration, since they do not employ a purely planar circuit layout [7,1].

We therefore propose a novel purely planar dual patch antenna direct detection receiver (DPADDR), which is fully compatible with monolithic integration. The use of two almost-quadratic patches eliminates the need of phase shifters, resulting in a smaller chip size and higher sensitivity of the receiver. We applied a generic two-step approach, comprising a simple transmission line equivalent circuit model of the antenna and full-wave EM simulation and optimization tools to dimension the layout and optimize the receiver's XPD and sensitivity.

We fabricated the DPADDR on a silicon substrate with backside metalization using a flip chip technique to integrate the detector diode. Experiments demonstrate the efficiency of this receiver conception.

Although primarily intended for use in six-port polarimetric radar systems, the DPADDR can find many applications in short-haul communication systems as well.

THEORY

Circularly polarized operation requires phase quadrature and equal magnitude of the antenna's orthogonal current components. This can be accomplished by feeding the radiating elements of the antenna with a phase shifter, e.g. a 90° hybrid. However, for millimeter wave integrated antennas, this approach has several drawbacks. The use of a phase shifter increases the chip size and causes additional

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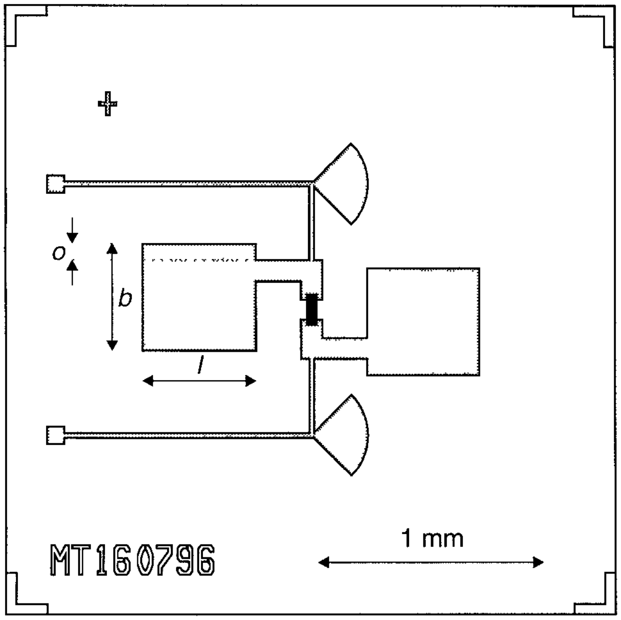

Fig. 1. Layout of the DPA.

ohmic losses. Furthermore, matching of the detector diode becomes difficult due to the highly reflective character of Schottky detector diodes at millimeter wave frequencies. To overcome these shortcomings, we employ the DPA. Here, phase quadrature is achieved by directly exciting two slightly de-tuned fundamental modes (TM01 and TM10) of an almost-quadratic patch resonator. The use of two patches operated in differential mode yields a purely planar circuit layout (Fig. 1, $a = 60\,\mu$m, $b = 550\,\mu$m, $l = 500\,\mu$m).

By properly adjusting the aspect ratio of the patches and positioning the feeding point of the patches, phase quadrature, and hence circular polarization is achieved. The detector diode is located at the center of the antenna. Two impedance transformers connecting the diode to the patches match the impedance of the patches and the detector diode. The biasing network is used to support both the video signal and the bias current.

DESIGN

To dimension the antenna layout, a two-step approach proved to be most efficient. In a first step, we employed a simple transmission line equivalent circuit model of the antenna to obtain a rough estimate of the antenna's dimensions. In a second step, this was used as an initial guess for an EM simulation and optimization based on the combination of a method of moments (MoM) code and a nonlinear simplex optimization scheme. The objective function embraces the XPD and the matching of the detector diode, thus focusing on the receiver's sensitivity. The optimization includes the dimensions of the patches, the position of the feeding point of the patches, and the dimensions of the impedance transformer. The optimization accounts for the parasitic radiation of the impedance transformer and the biasing network. After the optimization, a simulated XPD > 19 dB @ 76.5 GHz was achieved (without optimization: 4.8 dB).

The DPA receiver was fabricated on a high-resistivity silicon substrate with backside metalization. The detector diode was integrated using flip chip technique. However, monolithic integration of the diode is possible with only minor changes of the layout. Fig. 2 shows the DPA receiver.

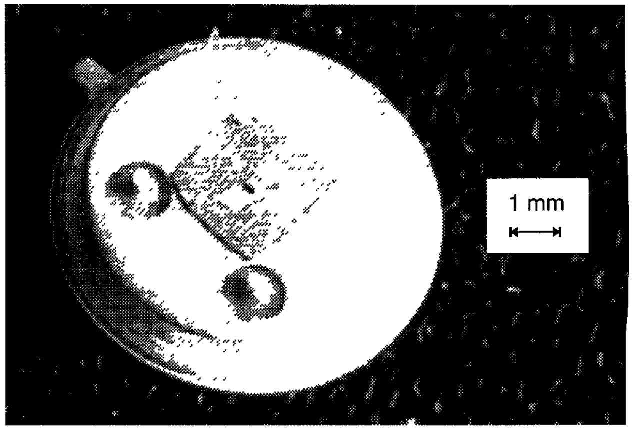

Fig. 2. Photo of the DPA.

MEASUREMENT

To verify the performance of the DPADDR, a novel heterodyne measurement setup was used (See Fig. 3). The receiver (AUT) and a horn antenna radiating the LO signal are mounted on a rotary stage. Thus, signal strength and phase of the LO signal applied to the AUT are kept constant. A second horn antenna with a fixed position (i.e. not mounted on

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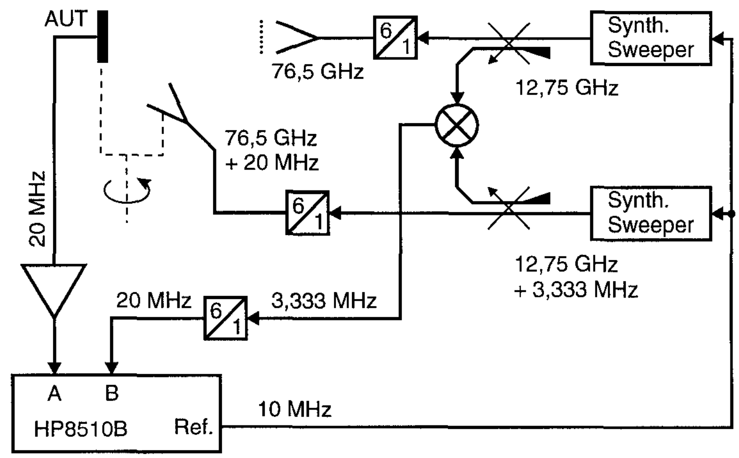

Fig. 3. Measurement setup for millimeterwave detector antennas.

the rotary stage) radiates a RF signal with a frequency offset of 20 MHz relative to the LO signal. A reflector grid mounted in the aperture of the RF horn antenna shifts the polarization of the RF signal from horizontal to vertical without changing its phase. Mixing of the RF and LO signal in the direct detection AUT yields a 20 MHz IF signal. From the magnitude and the phase of the IF signal, the polarization of the receiver is calculated.

Fig. 4 shows the measured XPD in the frequency range 71 – 84 GHz. The antenna exhibits an XPD of 12 dB @ 76.5 GHz (nominal frequency) and 14.8 dB @ 76.0 GHz. Thus, the deviation from the optimum frequency is as low as 0.65%. A minimum 12 dB XPD is maintained over a scan angle range of ±20°.

CONCLUSION

We developed a circularly polarized silicon integrated direct detection receiver for a six-port polarimetric millimeterwave radar system. We used a novel dual patch antenna (DPA) layout, which includes a matching network and a biasing network to operate the Schottky detector. The major advantage of this novel type of antenna is a small-size purely planar circuit layout, which permits a monolithically

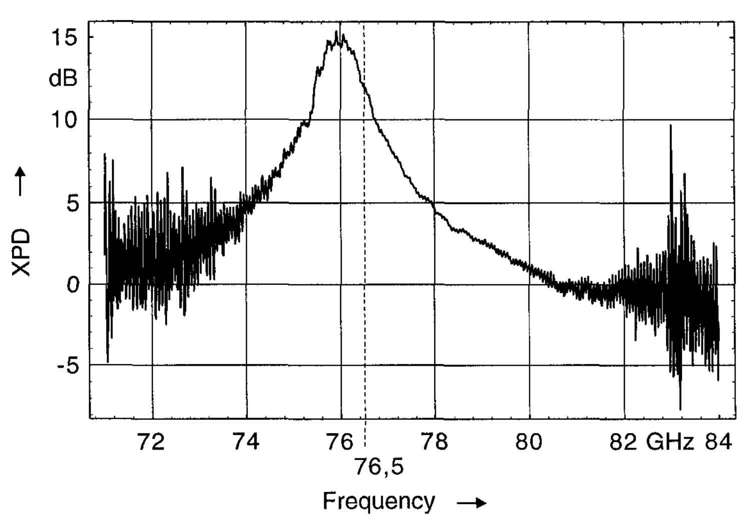

Fig. 4. Measured cross-polarization discrimination (XPD) vs. frequency of the DPA.

integrated fabrication of the receiver. The DPA requires no phase shifting network, resulting in a high-sensitivity, small-size receiver with good polarization discrimination.

We used a generic two-step approach to design the layout. In a first step, we applied an approximate transmission line equivalent circuit model of the antenna to obtain an initial guess for the dimensions of the antenna layout. In a second step, employing a sophisticated EM simulation and optimization process leads to an optimized layout with enhanced XPD and sensitivity of the receiver.

The DPADDR was fabricated on a high- resistivity silicon substrate using flip-chip technique to integrate the Schottky diode. Measurement results demonstrate a good cross polarization discrimination (XPD) > 14 dB @ 76 GHz over a wide range of the scan angle (12 dB @ ±20°). While intended for use in six-port polarimetric radar systems, the DPADDR is also well-suited for short-haul communication systems.

ACKNOWLEDGMENT

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