Interferometric Quadrature Down-Converter for 77 GHz Automotive Radar: Modeling and Analysis

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Abstract— **This paper describes a millimeter wave quadrature down-converter module based on the interferometric principle. The computer model of the six-port interferometer is implemented using S-parameter measurements of a 90° hybrid coupler fabricated on thin alumina substrate. This model is validated by full two-port measurements of the six-port. Down-converter error vector modulation results are analyzed using an envelope simulation. The proposed architecture is suitable for low-cost, high-performance, reconfigurable millimeter wave automotive radar and communication front-ends.**

Index Terms – **millimeter wave circuits, frequency conversion, modeling, microstrip, six-port.**

I. Introduction

Modern automotive radar systems require miniature transceivers with low-power consumption. At millimeter-wave frequencies, where interconnection losses between circuits are significant, a compact design of the front-end module is especially attractive. In addition, transceiver architectural innovations will lead to major improvements.

The design of low-cost and efficient down-converters is part of this research. A 77 GHz interferometric quadrature down-converter is presented and analyzed using a realistic computer model based on millimeter wave circuit measurements and manufacturer models of related components. This module requires a reduced LO power, as compared to conventional ones, using anti-parallel diodes acting as LO-driven switches or Gilbert cells. It operates in either homodyne or low IF heterodyne architectures.

II. Interferometric Down-Converter Model

Fig. 1 shows the block diagram of the six-port interferometric down-converter, composed of four 90° hybrid couplers, four power detectors, and two wide-band differential amplifiers. The unknown RF input signal emerged from the low noise amplifier (LNA) is injected at port 6, and the reference signal provided by the local oscillator (LO), at port 5, according to equations (1) and (2). The phase difference between the input signals is $\Delta\varphi(t) = \varphi_6(t) - \varphi_5$ and their amplitude ratio is α.

$$a_5 = a \cdot \exp(j\varphi_5) \quad (1)$$

$$a_6 = \alpha \cdot a \cdot \exp(j\varphi_6(t)) = \alpha \cdot a_5 \cdot \exp(j\Delta\varphi(t)) \quad (2)$$

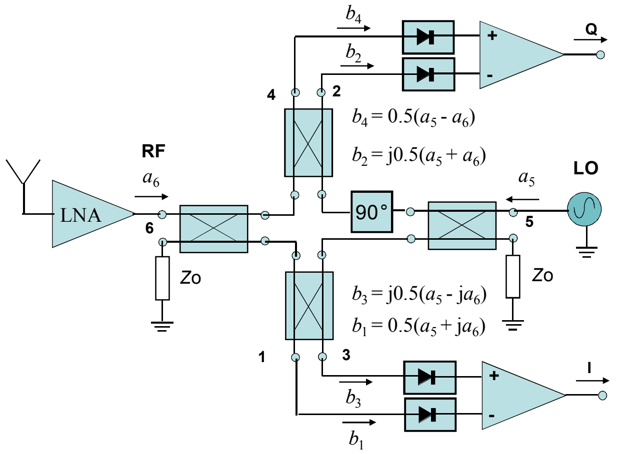

Fig.1 Block diagram of the six-port interferometric quadrature demodulator

The quadrature down-converted signal is obtained at the differential amplifier outputs:

$$\Gamma = I + jQ = (V_3 - V_1) + j(V_4 - V_2) = \alpha \cdot Ka^2 \cdot \exp(j\Delta\varphi(t)) \quad (3)$$

Equation (3) confirms down-conversion for either the homodyne or the low IF heterodyne architectures [1], [2]. Due to circuit symmetry, the DC offset is theoretically zero. In practice, this value is not null, but can be easily compensated.

The six-port model is implemented in the Advanced Design Software (ADS) of Agilent Technologies using S-parameter measurements of a 90º hybrid coupler, designed and fabricated on thin alumina substrate ($\varepsilon_r = 9.9$, $h = 127$ µm).

Fig. 2 shows micro-photographs of the calibration kit and of the 90º hybrid coupler measurement configurations. In order to avoid via holes, the 50 Ω loads use a quarter wavelength transmission line sector as a wide-band millimeter wave short-circuit. This coupler has around 0.5 mm^2; the two quarter wave length widths are 127 µm and 287 µm, respectively, and their related radiuses are 164 µm and 155 µm.

A "Through Reflect Line" (TRL) calibration standard has been used in the Agilent Network Analyzer (PNA Series) calibration. It consists of one through, two open, and one line standards, as seen in Fig. 2. The measuring reference plan is situated on the center of the through line. In order to provide connection to ground signal ground (GSG) 150 µm probes, coplanar to microstrip transitions are included.