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V-BAND QUADRATURE PHASE SHIFT KEYING DEMODULATOR USING WR-12 SIX-PORT

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Abstract—A direct 61 GHz demodulator, based on a rectangular waveguide (WR-12) six-port, is presented in this letter. The six-port device, composed of four 90° hybrid couplers fabricated in a metal block of brass, is implemented in ADS software. Good agreement between QPSK demodulation results using an ideal six-port model and a second one, based on the S-parameter measurements of a 61 GHz hybrid coupler, is achieved.

1. INTRODUCTION

In 2001, the Federal Communications Commission (FCC), which standardizes and enforces spectrum usage, has allocated 7 GHz of unlicensed bandwidth in the V-band for indoor wireless communications. This bandwidth provides high data rate transmission. The propagation of V-band indoor signals has the ability of decreasing the interference to other collocated systems, and increasing the frequency reuse factors and space efficiency [1]. Due to its high path loss, the V-band is an attractive candidate for short-distance sensors and indoor communications based on Pico-cell zone [2, 3].

The six-port is a passive linear component, first developed in the 1970s for accurate automated measurements of the complex reflection coefficient in microwave network analysis [4]. Tatu et al. presented in [5] a V-band six-port, based on four 90° hybrid couplers, designed in MHMIC technology using a 9.9 relative permittivity 125 μm substrate. Various millimeter-wave front-end architectures, fabrication technologies, and modulation schemes were proposed in recent years [6, 11].

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In this letter, the proposed six-port computer model is based on the S-parameter measurement results of the 90° hybrid coupler fabricated at 61 GHz, using the rectangular waveguide technology, and on the block diagram presented in [5]. WR-12 is the standardized rectangular waveguide, suitable for V-band and E-band. In the following, the measurement results of the hybrid coupler and the simulation results of the six-port device are presented. A communication link has been simulated using a quadrature phase shift keying (QPSK) modulated signal along with a six-port demodulator model based on coupler measurement results.

2. RECTANGULAR WAVEGUIDE HYBRID COUPLER

The four-port hybrid coupler represents the core component of the six-port circuit, dedicated to various millimeter-wave applications [12, 14]. A new 90° hybrid coupler is designed and fabricated at 61 GHz, in a small metal block of brass, using WR-12 standard rectangular waveguide technology. The commercial software High Frequency Structure Simulator (HFSS) of Ansoft Corporation is used for the coupler design. Figure 1 shows its layout and the energy balance through its ports. All four ports allow access by standard WR-12 flanges to the measurement equipment. The S-parameters of the WR-12 coupler are measured using the "Agilent Network Analyzer E8362B". Figure 2 shows the phase of the transmission scattering parameters (S_{12} and S_{13}). The phase difference obtained at 61 GHz is

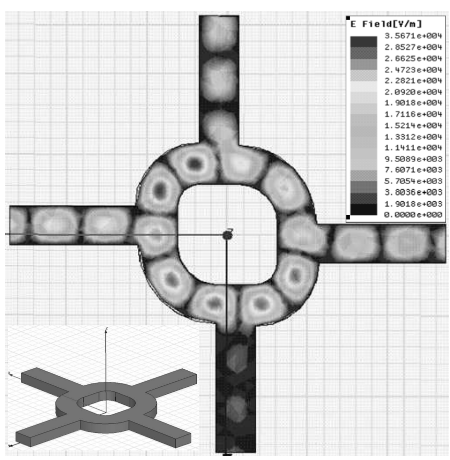

Figure 1. Layout (energy balance) of the 90° hybrid coupler.

a multiple of 90°. In addition, the transmissions S-parameter phase is unbalanced by about 10° over a frequency band of 3 GHz (60–63 GHz). Due to the symmetry of the circuit, equal measured isolations between ports 1–4 and 2–3 of −18 dB are obtained, as shown in Figure 3. The measured power split and return loss versus frequency are −3.8 dB and −15 dB, respectively, at the operating frequency of 61 GHz.

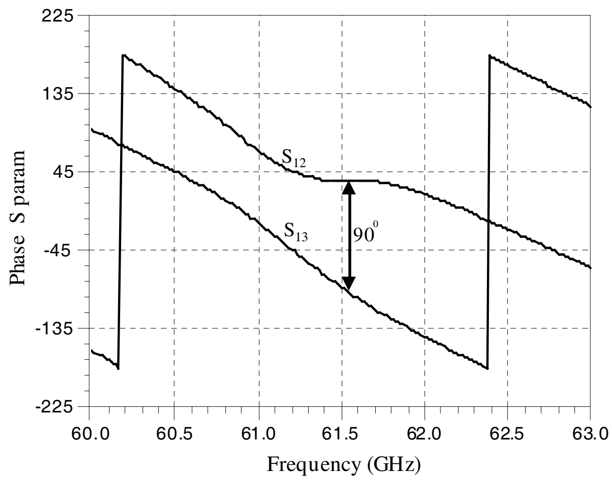

Figure 2. Measured coupler transmission S-parameter phases (S_{12} and S_{13}).

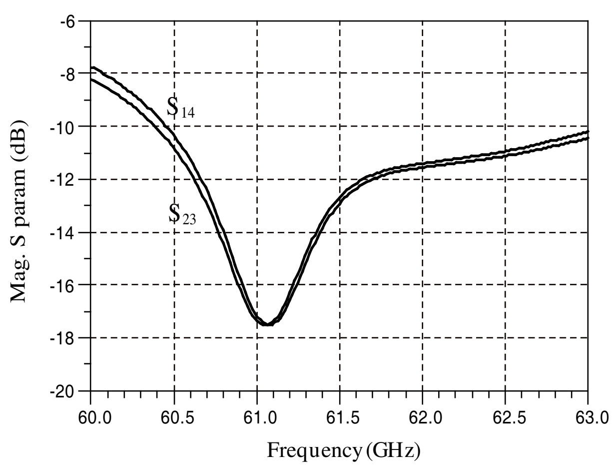

Figure 3. Measured coupler isolation ports, S_{14} and S_{23}.

3. SIX-PORT DEVICE

The six-port computer model is generated in Advanced Design System (ADS) using the coupler measured results. Isolation of −23 dB between the two input ports and return loss of −15 dB in a 250 MHz bandwidth around 61 GHz, as well as −7.4 dB for the transmission between input and output ports, are obtained.

A harmonic balance simulation using this six-port model is performed. The phase between RF and LO signals is swept in a 360° range and the RF power is set to −25 dBm. The RF six-port output voltage magnitude (V_1 to V_4) variations versus this phase shift are shown in Figure 4. As seen, due to the 90° hybrid couplers, the minimal magnitude values are shifted by 90° multiples, suitable for a high-quality I/Q mixer. Periodical maximal and minimal values are obtained for each output voltage. Theoretically, the minimal value is zero. However, in practice, due to inherent errors of fabrication process, this is a nonzero value and the phase shift between V_4 and V_1 minimal value is 75°, which is considered a tolerable error for QPSK demodulation purpose. Moreover, due to the differential approach proposed in [5] and showed in Figure 5, these errors will be reduced.

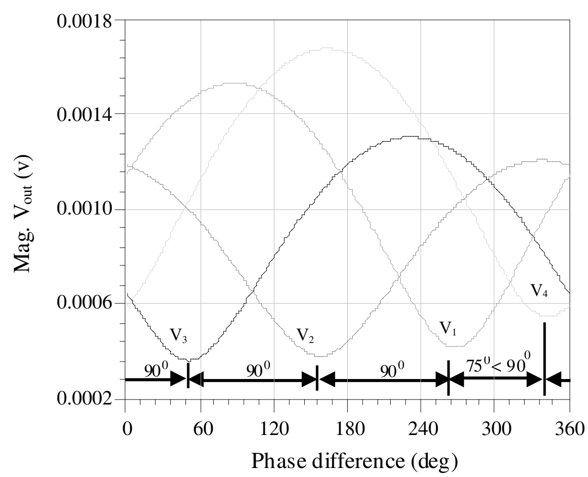

Figure 4. Simulation results of V_{out} magnitude versus RF input phases shift.

4. QPSK DEMODULATION

In order to obtain a QPSK signal, the LO phase has been swept through four possible states (45°, 135°, 225° and 315°). Figure 5 shows the block diagram of this simulation [5]. The demodulated I/Q signals are acquired by analog signal processing, using some baseband circuits. The RF and LO power are set to −20 dBm and −25 dBm, respectively, while the operating frequency is fixed at 61 GHz.

Ideally, the QPSK constellation points are usually located around a circle, at a uniform angular difference of 90°. Figure 6 shows the constellation diagrams (I/Q) of the QPSK demodulator. The simulations are performed by means of two six-port models: an ideal one and a model based on hybrid coupler measurements. It can be seen that for the second six-port model, these points are somehow not

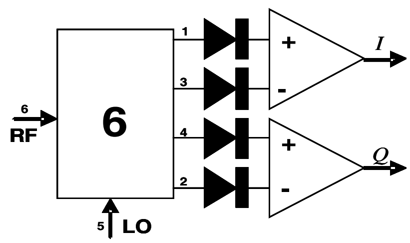

Figure 5. ADS QPSK demodulator block diagram.

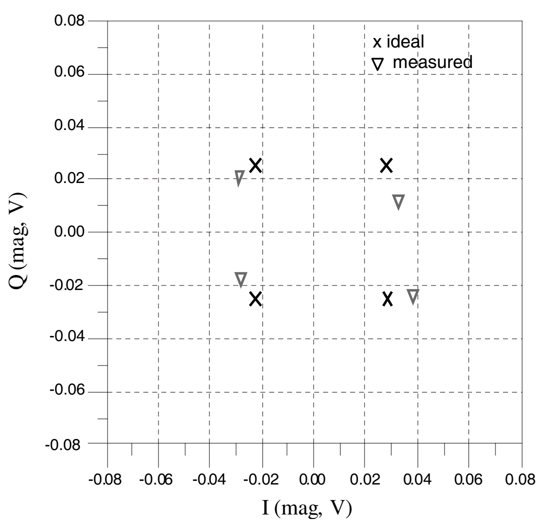

Figure 6. Demodulated QPSK signals.

positioned squarely as supposed, due to the hybrid coupler fabrication errors (see Figure 4), but nearly equivalent to the ideal ones. Despite an error around 15° compared to ideal points, due to fabrication process, the waveguide six-port demodulates QPSK signals with good results.

5. CONCLUSION

In this paper, WR-12 90° hybrid coupler measurements and QPSK six-port demodulator results at 61 GHz are presented. In spite of some errors due to the design and the fabrication process, good S-parameters are obtained for both, the coupler and the six-port circuit. The demodulation results of V-band QPSK signals using this WR-12 six-port demodulator validates the design of compact, low-cost, and high-speed future wireless millimeter-wave communications systems.

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