Wide-band Millimetre Wave Down-converter Based on Six-port Circuit for Radar and Sensing Applications

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***Abstract*—In this article a millimetre-wave (mm-wave) down-converter based on a six-port correlator and zero bias Schottky diode is presented over 10 GHz bandwidth, from 72 to 82 GHz. The six-port is designed in such a way to have excellent phase resolution at four output ports witch leads to very accurate symbol position for QPSK demodulator. A prototype circuit has been manufactured with miniaturized hybrid microwave integrated-circuit (MHMIC) technology on a $127\mu m$ ceramic substrate. The results are validated using a computer model of the circuit based on S-parameter measurements for QPSK demodulator for center frequency of 77 GHz.**

***Index Terms*—Demodulator, Directional Coupler, QAM Modulator, Receiver, Reflection Coefficient Measurement, Schottky Diode, Six-port Interferometer.**

1. Introduction

Receivers in the mm-wave is under great development during the last decade due to the great amount of applications. The use of a six-port correlator for modulation and demodulation has been well studied [1]— [5]. Zero bias Schottky diode based on homodyne detectors have been widely used in the mm-wave frequency regime because its sensitivity, compact dimensions, good noise performance and fast response time [6], [7], [8]. The use of six-port technology in combination with Schottky diode at 77 GHz frequency is innovative, original, and very promising for not only automotive radars but also for multi-Gb/s wireless communications and imaging systems.

The focus of this study is on demodulator based on six-port circuit for 77 GHz radar application. The six-port is designed in such a way that its input impedance is matched to the conjugate of the input impedance of the diode (50Ω) which result in maximum power transfer between them.

Furthermore,the performance of proposed technique is evaluated for Quadrature Phase Shift Keying (QPSK) demodulator. It shows good performance on bandwidth efficiency and bit error rate. The proposed technique has potentially the advantage of low-complexity in design, low power consumption, high signal to noise ratio, compactness and simplicity in realization.

2. Principal of Six-port Based Down-converter

The studied six-port interferometer is a linear passive microwave network with four hybrid 90° hybrid coupler and a 90° phase shifter. The anti-parallel Schottky diode pairs are used to realize the single balanced harmonic diode at RF and LO ports. The layout of six-port with diode detectors is shown in Fig. 1.

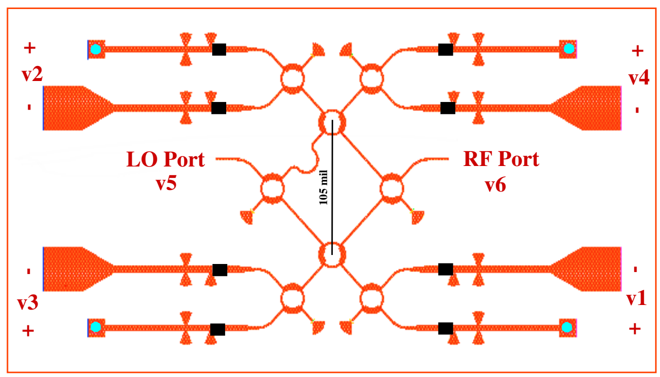

Figure 1. Layout of six-port phase correlator with diode detectors.

By injecting the signal from the local oscillator to port 5 and the RF signal to port 6 and neglecting the reflections at ports 5 and 6, we obtain:

$$v_5 = V_{LO}\cos(\omega_{LO}t) \quad , \quad v_6 = V_{RF}\cos(\omega_{RF}t), \tag{1}$$

and then we have:

$$v_1 = -v_3 = V_{LO}\cos(\omega_{LO}t) + V_{RF}\sin(\omega_{RF}t), \tag{2}$$
$$v_2 = -v_4 = V_{LO}\sin(\omega_{LO}t) + V_{RF}\cos(\omega_{RF}t). \tag{3}$$

Considering the non-linear characteristic of the diodes:

$$I(v) = a_0 + a_1 v + a_2 v^2 + a_3 v^3 + a_4 v^4 ..., \tag{4}$$

and all outputs are connected together on a high impedance resistor to have:

$$I_{IF} = I_1 - I_2 - I_3 + I_4 \tag{5}$$
$$I_{IF} = 2a_2(v_1^2 - v_2^2) + 2a_4(v_1^4 - v_2^4) + ... \tag{6}$$
$$I_{IF} = 2a_2V_{LO}^2\cos(2\omega_{LO}t) - 2a_2V_{RF}^2\sin(2\omega_{RF}t) - \tag{7}$$
$$..4a_2V_{LO}V_{RF}\sin(\omega_{LO}t - \omega_{RF}t) + ... \tag{8}$$

As the results show, the DC current and all odd harmonics products are suppressed. This means that the six-port can only be used as a down-converter. A detailed discussion of the six-port correlator for mm-wave down-converter can be found in [5], [7], [8].

3. Simulation and Measurement results

The six-port circuit was designed and simulated with electromagnetic simulation tool software of Keysight Technologies: Momentum of Advanced Design System (ADS). It was fabricated in Miniaturized Hybrid Microwave Integrated Circuit (MHMIC) and the die size is $2.54 \times 2.54 cm$. A photo of the complete MHMIC circuit for full two port measurements and measurement set-up are depicted in Fig.2. Several of the most important measured and simulated S parameter of the MHMIC circuit are shown in Figs. 3 to 4.

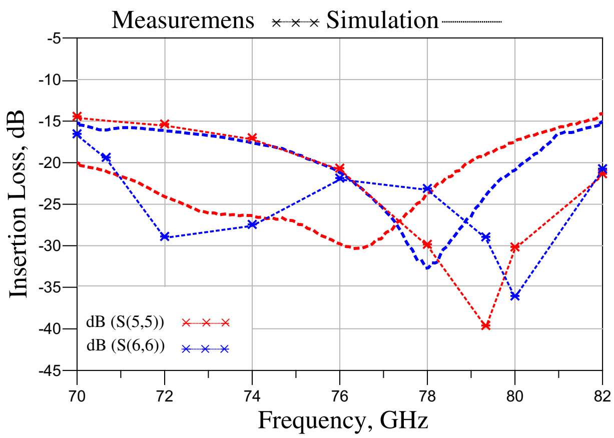

Figure 3. Reflection coefficients at LO and RF ports of six-port interferometer (Measurements and simulation).

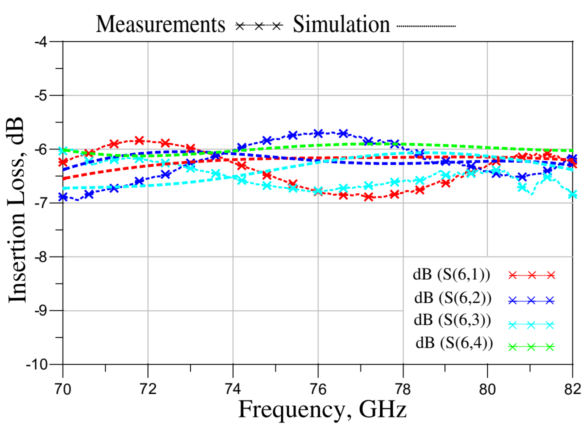

Figure 4. Insertion losses magnitudes between RF port 6 with diode loads (Measurements and simulation).

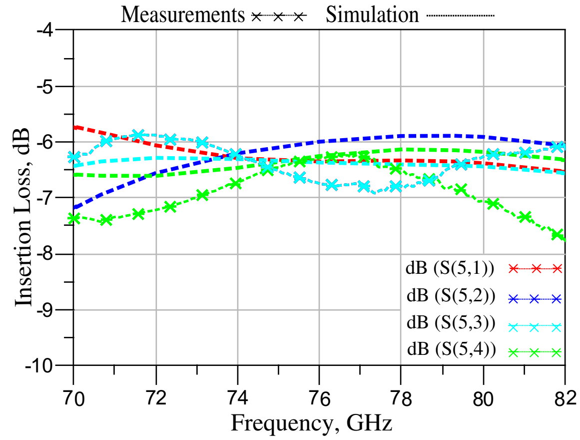

Figure 5. Insertion losses magnitudes between LO port 5 with diode loads (Measurements and simulation).

The reflection coefficients at RF port and LO port (S_{55} to S_{66}) are shown in Fig.3. For a reference reflection coefficient of less than -15 dB, the six-port correlator with four 90° coupler gets the frequency bandwidth of 70 to 82 GHz (12 GHz). Measurement and simulation results for insertion losses at LO and RF ports are shown in 4 which are in the range of -5.7 dB to 7.2 dB (theoretical value = -6 dB). As it is shown, all the ports are well matched with good isolation and return losses.

The six-port down-conveter can be use also as a homodyne receiver, if the input frequencies are the same (see equations 1 to 8). Simulated output signal constellation for QPSK and input-output voltage signals are presented in Fig. 6.

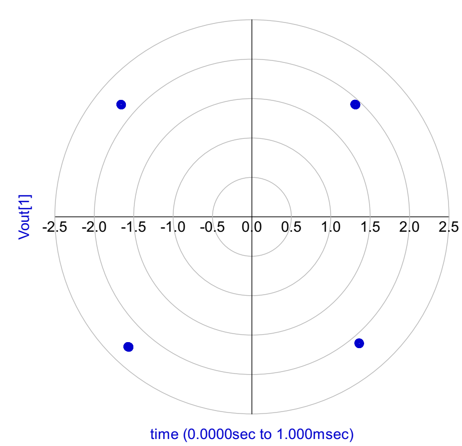

Figure 6. Insertion losses magnitudes between RF port 6 and LO port 5 with diode detector ports (Measurements and simulation).

As seen, the position of each symbol in the output complex plan are very closed to expected values. When the highly sensitive GaAsSb-based diodes are integrated with six-port correlator, high-performance mm-wave receivers can be realized.

Figure 2. MHMIC circuit for two port measurements and laboratory measurement set-up (millimetre wave probe station and network analyser).

4. Conclusion

The passive and linear six-port correlator is designed, manufacture and measured for 77GHz demodulator circuit. The excellent phase resolution of the six-Port correlator in combination with zero bias Schottky diodes leads to very accurate symbol positions. The error vector demodulation of designed demodulator is very low because of very accurate symbol position of presented circuit. A six-port interferometer and QPSK demodulator was designed in ADS Momentum software and fabricated in ceramic substrate. Acceptable simulation and measurement results have shown and we have an acceptable error for this low-cost, small down-converter circuit.

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