Direct IQ Modulator for 38 GHz Frequency Range

Siniša Jovanović[1], Aleksandar Nešić[2] and Vladimir Orlić[2]

Abstract: **A simple low-cost direct IQ modulator with original configuration at 38 GHz frequency range is introduced in this paper. The modulator consists of a subharmonic mixer with two antiparallel diode pairs. An original design and characteristics of the input circuit that supply LO and modulation signals to the mixing diodes is discussed and described in details. The realized IQ modulator has conversion loss of 19 dB with more than 40 dB LO suppression and 32 dB of the symmetrical signal suppression.**

Keywords – **Subharmonic mixer, direct IQ modulator**

I. Introduction

One of the most convenient methods of producing a modulated RF signal at millimeter-wave frequencies is with diode-mixer based direct IQ modulators. Since direct mixers with a local oscillator at transmitting frequencies have relatively poor LO suppression, the optimal solution could be IQ modulators based on sub-harmonic mixers with LO frequency at half of the output frequency [1]. In the standard IQ modulator configuration there is a 90° phase shift between the LO carriers entering I and Q mixers. For sub-harmonic mixers it is more convenient to introduce the required 90° phase shift at the mixers' RF port with a 90° hybrid coupler as presented on Fig.1.

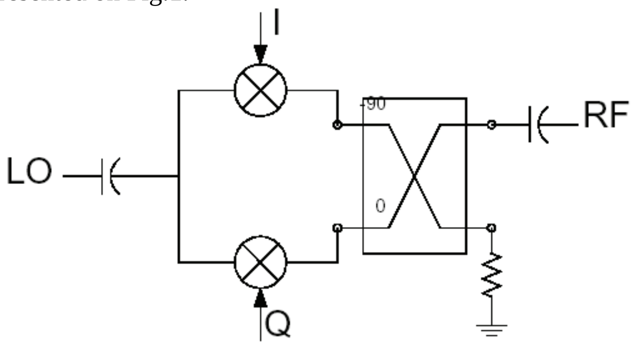

Fig. 1. Configuration of a simple direct IQ modulator

A very good suppression of all even harmonics of the LO signal can be achieved by using antiparallel diode pairs as mixing devices in sub-harmonic mixers. In such a case the input part of the subharmonic mixer should introduce one half of the LO signal combined with an I or Q modulating signal to the input of the corresponding pair of antiparallel diodes as shown on Fig. 2. The output part should combine RF signals generated at the diodes with a proper phase shift of 90°. Both the input and output part of the presented configuration (within the doted rectangles on Fig.2) can be easily realized as printed microstrip circuits. In that manner the whole direct modulator consists, in addition to microstrip circuits, of only a few discrete components: two antiparalell diode pairs, terminating 50 Ω on resistor, and 100 Ω resistor within the Wilkinson power divider. Such simple configuration is suitable for obtaining direct IQ modulator that operates at high microwave or milimeter wave freqeuncies.

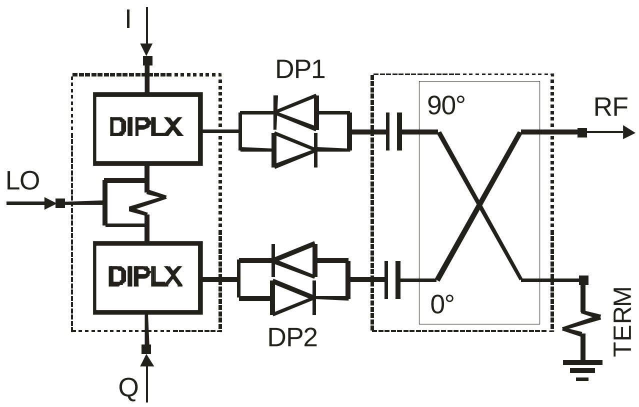

Fig. 2. Configuration of subharmonic mixer operating as direct IQ modulator

II. Design of the Input Double Diplexer Circuit

Input circuit of a direct IQ modulator has a function to divide LO signal to two equal and symphase samples. It also functions as a diplexer that combines low frequency I (or Q) modulating signal with high frequency LO signal. On Fig. 3. is presented a layout of a microstrip input circuit for direct subharmonic IQ modulator operating at output frequency of 38 GHz. Instead of using usual Wilkinson divider, LO signal is divided with a λg/4 line with high Zc that is coupled at the both sides with a folded λg/4 high Zc lines [2] (λg for given dielectric substrate and at the LO frequency). One side of the folded line is connected to the mixing diodes, while the other side is connected to the virtual ground provided by a parallel open stub with Zc=50 Ω and length of λg/4 at f_{LO}.

A line which connects I (or Q) modulation input port with corresponding mixing diodes has another parallel open stab with Zc=50 Ω and length of λg/4 at $f_{RF}=2f_{LO}$.which functions as a band-stop filter at the output RF frequency. Two parallel stubs are separated with high Zc line with length of λg/2 at f_{LO}.

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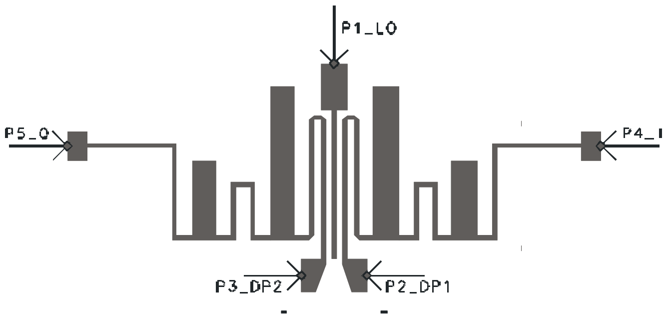

Fig. 3. Proposed layout of microstrip input circuit

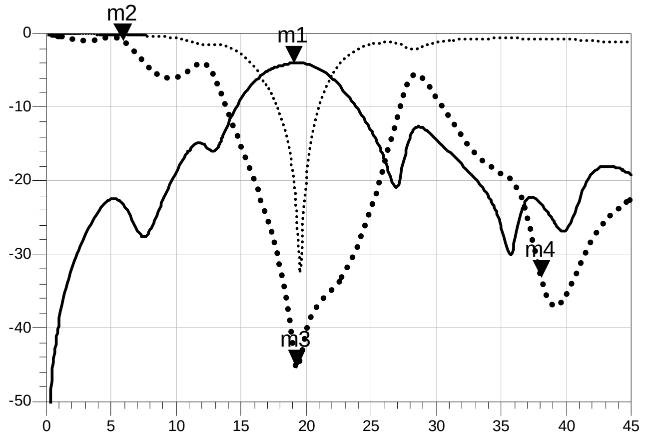

Fig. 4. S-parameters [dB] EM simulation frequency [GHz] response for the input circuit: S_{21} (solid line), S_{24} (black doted line), and S_{11}

Fig 4. shows EM simulation [3] frequency response for significant S-parameters of the five-port input circuit. Transmission from the LO port (P1_LO at Fig.3) to the one of two mixing diode ports (P2_DP1 or P3_DP2) is presented as a solid line on Fig.4. showing insertion loss of about 4dB at f_{LO} (marker m1). Transmission from the I (or Q) input port (P4_I or P5_Q) to the corresponding mixing diode port is presented as black doted line showing insertion loss lower than 1dB from DC up to about 6 GHz (marker m2), while at the f_{LO} (m3) and f_{RF} (m4) insertion loss is about 45 dB and 33 dB, respectively. Return loss at the LO port (gray doted line) is very good at f_{LO}, however this is under assumption that mixing diodes' input impedance is close to 50 Ω at f_{LO}. According to these results the proposed input circuit will easily perform its designed function within the direct IQ subharmonic modulator.

III. Design of the Output Circuit

The output RF signal generated at mixing antiparallel diode pairs should be combined with a proper phase shift of 90°, which can be performed with standard branch coupler. However, for better suppression of the subharmonic LO signal a modified version of the branch circuit presented on Fig. 5 can be used. This coupler has four parallel open stubs (Zc=50 Ω, L= λg/4@f_{LO}) added at all inputs. These stubs operate as bandstop filters at subharmonic LO frequency range.

EM analysis results of the circuit from Fig. 5 are presented at Fig.6. and 7 showing good phase and amplitude S_{21}/S_{31} balance from 37 to 39 GHz (Fig.7. and M1 at Fig.6.) as well as good S_{21}, S_{31} and S_{41} suppression at LO frequency (M2 at Fig. 6).

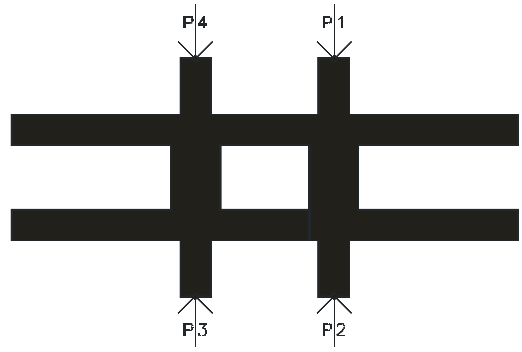

Fig. 5. Proposed layout of modified branch coupler

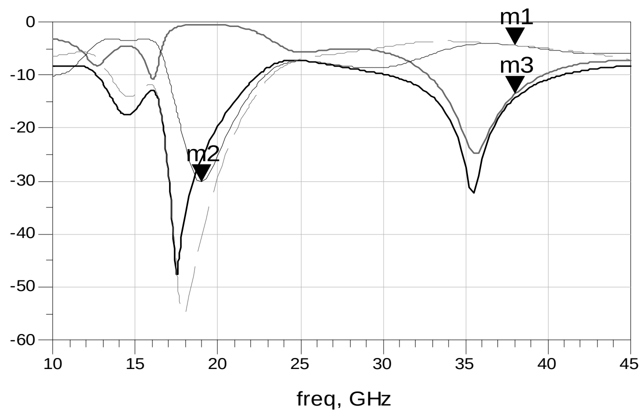

Fig.6. Modified branch's S_{11}, S_{21}, S_{31} and S_{41} EM analysis results

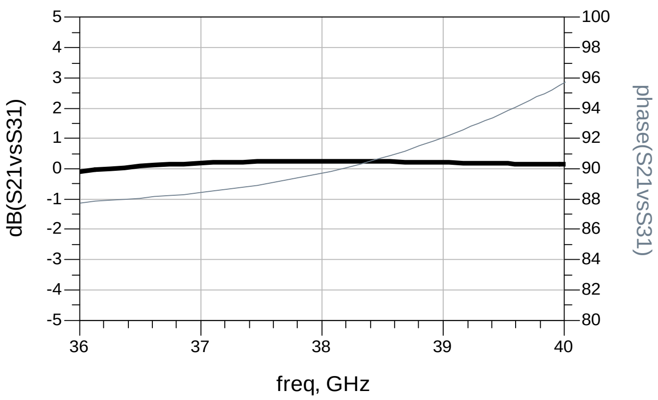

Fig. 7. S_{31}/S_{41} amplitude (thick line) and phase (thin line) balance

The required AC coupling in the output circuit is obtained with coupler presented on Fig. 8. which consists of two mutually coupled folded quarter-wavelength microstip lines [2]. EM simulation results of S_{21} and S_{22} parameters are presented on Fig.9 showing good insertion and return loss at RF frequency (markers M1 and M2) and good isolation at LO and near to DC frequencies.

The modulator is realized with standard photolithograph technology as uniplanar microstrip circuit on dielectric substrate RO4003 (ε_r=3.38, h=0.2 mm). Overall circuit size is 17×17 mm. Besides two π attenuator cells at both I and Q ports, the only discrete components are two GaAs flip chip anti-parallel schottky diodes MA4E1318 and terminating resistor. Fig.10. shows a photo of the realized modulator.

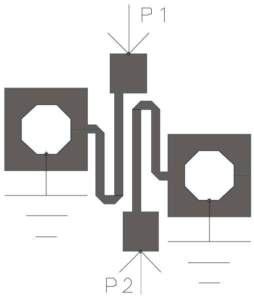

Fig. 8. Proposed layout of modified branch coupler

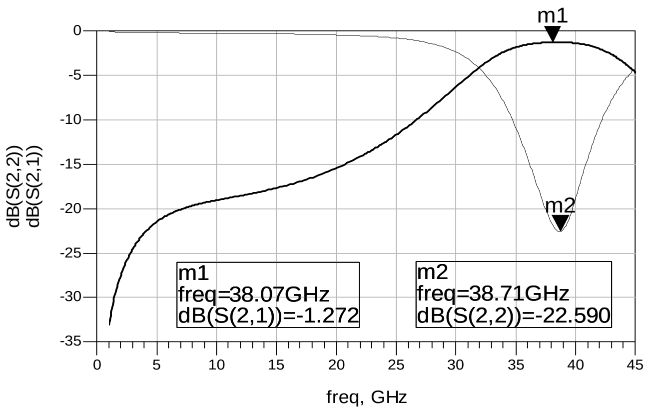

Fig. 9. Proposed layout of modified branch coupler

IV. Modulator Realization

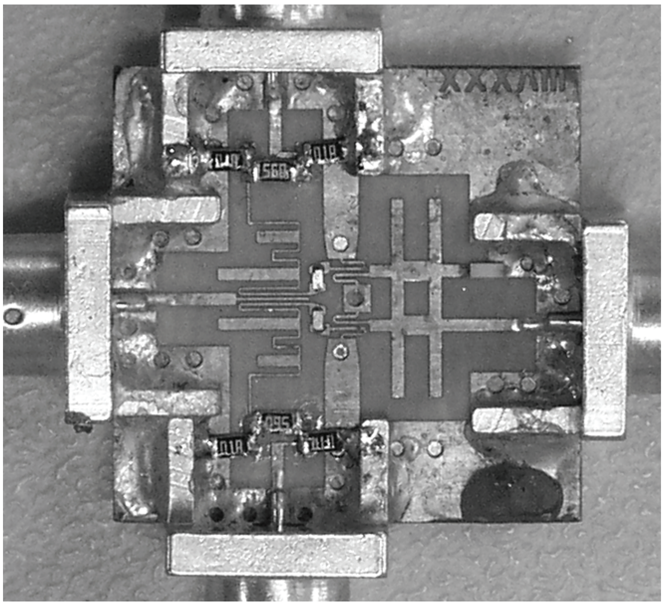

Fig. 10. Photo of realized direct IQ modulator for 38GHz

V. Measured Results

The realized modulator is tested with the Baseband Signal Processor for digital RR link with direct IQ modulator [4]. This processor can provide diferent types of testing signals for I/Q ports. At the first, from the processor are provided two eqal-level single-tone signals with mutual phase shift of 90° for SSB test. Optimal working point of the modulator is achieved with LO signal level of about +16 dBm and I/Q signal level of -7 dBm. Measured SSB test results are presented on Fig. 11. showing supression of the simetrical signal of 32.8 dB, which is a result close to the maximum value (35 dB) than can be measured with the available Baseband Signal Processor. Measured results also show exellent LO signal supression of 39 dB which is confirmed with measured output signal spectrum for OQPSK signals with capacities of 8.8, 17.6 and 35.2 Mbit/s presened on Fig. 11-14.

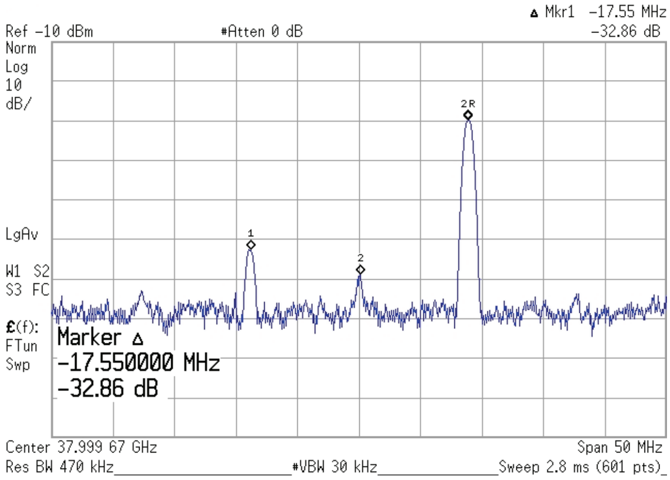

Fig. 11. Measured SSB test results

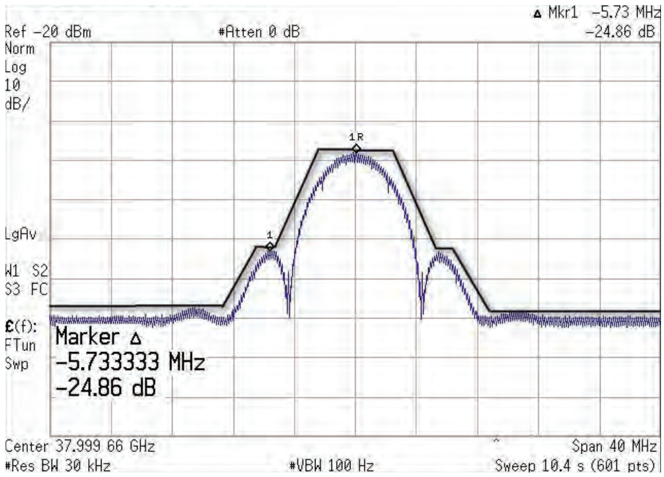

Fig. 12. Measured output signal for 8.8 Mbit/s OQPSK modulation

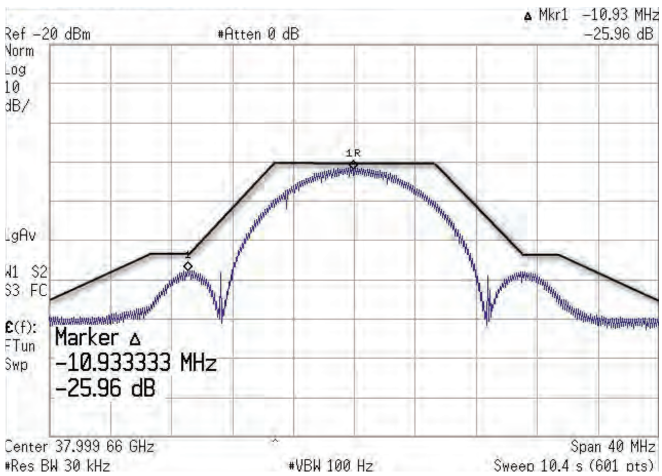

Fig. 13. Measured output signal for 17.6 Mbit/s OQPSK modulation

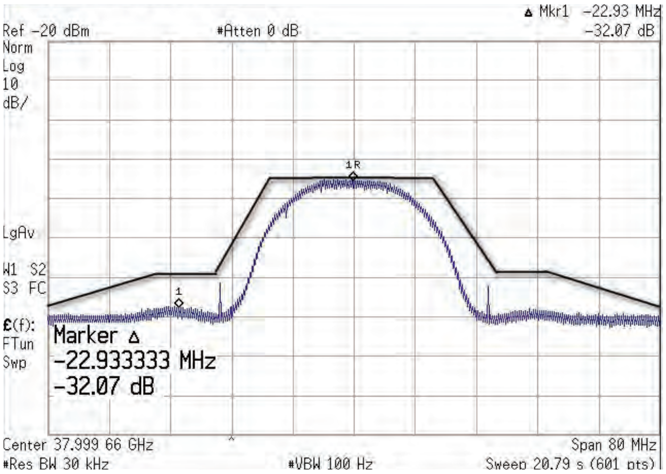

Fig. 14. Measured output signal for 35.2 Mbit/s OQPSK modulation

Recorder spectrums shows no LO leakage above the main lobe level. Together with the signal spectrum Fig.11-14 show recommended limit lines for corresponding signal capacity according to ETSI standard [5]. Side-lobs visible for two lower-capacity spectrums are consequences of adopted signal shaping method [6].

For mentioned optimal LO and I/Q input signal levels measured RF output signal level equals -26 dBm, which means that the IF/RF conversion loss equals 19 dBm.

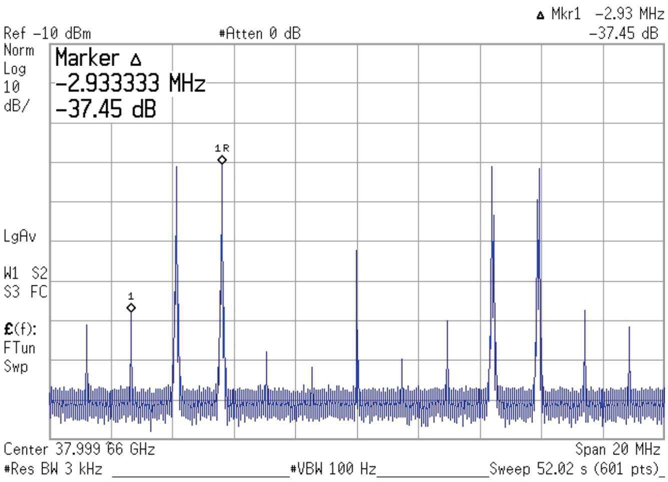

Fig. 15. Measured two-tone distortion test results

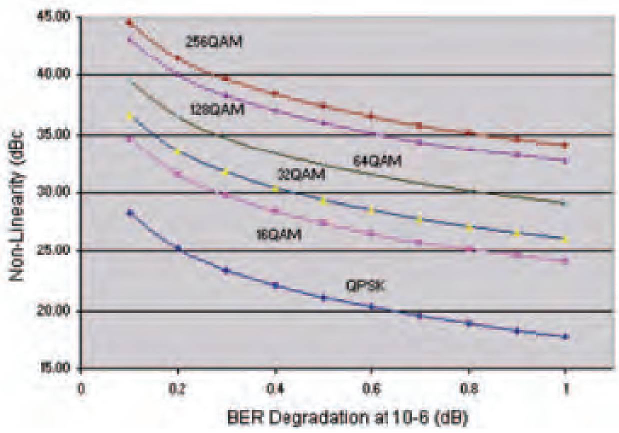

Fig.16. BER 10^{-6} threshold level degradation due to nonlinearity [7]

The realized modulator was tested for nonlinear distortion with two-tone test applied to only one of I/Q branches. Measured results are shown on Fig. 15.

Fig. 15. shows maximum measured nonlinear distortion of about -37 dBc. According to Fig. 16., this distortion level would increase the BER 10^{-6} threshold level for less than 0.5 dB for all QAM modulation schemes up to 128QAM. In case of 256QAM modulation, the presented direct IQ modulator would increase the BER 10^{-6} threshold level for about 0.6 dB according to the measured distortion and Fig. 16.

VI. CONCLUSION

This paper presents a concept, design, realization and measured results for direct IQ modulator with output frequency at 38 GHz range. Because its original and simple configuration it is realizable even with limited technology level. Design of the input and output microstrip circuits of the modulator is described in detail together with characteristics obtained by EM analysis.

For optimal signal levels of P_{LO} = +16 dBm and P_{IF} = -7 dBm the modulator has a conversion loss of 19dB, achieving output signal level of P_{RF} = -26 dBm. The modulator has excellent LO signal supression of 39 dB and SSB better than 32 dB. Measured nonlinear distortion is better than -37 dBc, which ensures qood transmission quality with this direct IQ modulator even with high-capacity modulations up to 256QAM.

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