Balanced MMIC QPSK modulator with low amplitude and phase errors

Seong-Mo Moon, Han Lim Lee, Dong-Hwan Shin, In-Bok Yom and Moon-Que Lee

A broadband monolithic microwave integrated circuit (MMIC) quadrature phase shift keying (QPSK) modulator with low amplitude and phase errors is proposed. The presented modulator adopts two wideband reflection-type binary BPSK modulators, each consisting of a modified Lange coupler with additional $\lambda/4$ transmission lines, varactor diodes, inductors and resistors. The proposed QPSK modulator is implemented in 0.15 µm GaAs low-noise pHEMT process. The measurements show an error vector magnitude and a demodulated I/Q offset <5.8% root-mean-square and −16.1 dB, respectively, from 18 to 26.5 GHz.

Introduction: There have been many researches on modulators for direct-conversion architectures [1–5]. Despite there being various modulation specifications, one of the key design issues is the operational bandwidth to maintain a good error vector magnitude (EVM). One method to obtain good EVM is to use balanced architectures such as an active Gilbert cell-based modulator [1] and passive reflection-type modulators [2–4]. The Gilbert cell-based modulator has a compact size, but increases circuit complexity and power consumption. A more general modulator topology that can be used is a balanced reflection-type modulator using push–pull or quadrature balanced schematics. However, these architectures require binary phase shift keying (BPSK) modulators to be well balanced and matched. In this Letter, a new monolithic microwave integrated circuit (MMIC) quadrature phase shift keying (QPSK) modulator using a modified Lange coupler with additional $\lambda/4$ transmission lines is proposed to achieve a broadband frequency range.

Design: Fig. 1 shows the circuit diagram of the proposed broadband QPSK modulator configured by a Lange I/Q power divider, a Wilkinson I/Q combiner and two orthogonal BPSK modulators, each consisting of modified Lange couplers marked as a dotted red-line box and back-to-back connected diodes with a resonance circuitry. The modified Lange coupler adopts a series $\lambda/4$ transmission line at one output port so as to behave like a ring hybrid coupler. Also, a shunt $\lambda/4$ transmission line is added at the other output port to achieve an even wider operational bandwidth. In addition to better broadband performances compared with the conventional ring hybrid circuit, the proposed modified Lange coupler reduces the IC implementation size.

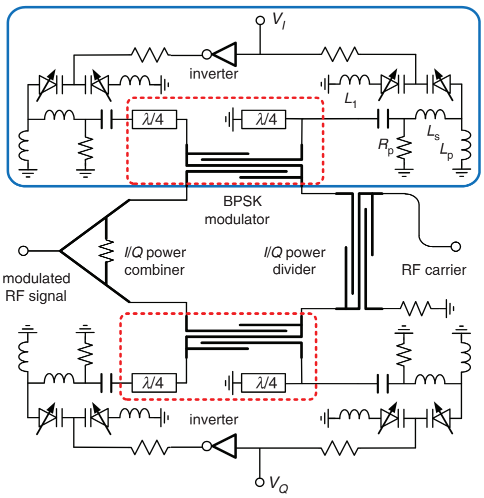

Fig. 1 *Circuit diagram of proposed broadband QPSK modulator*

For the reflective circuitry of the proposed BPSK modulator, the reverse-biased back-to-back diode acts as a capacitive tuning circuitry and is resonated with the series inductors, L_1 and L_S, while parallel elements, L_P and R_P, enhance the relative phase tuning range and the constant insertion loss. Based on the phase range enhancement by the parallel inductor and the constant insertion loss by the parallel resistor, the reflective circuitry can achieve a phase shift range more than 180° and a flat insertion loss variation.

Fig. 2 shows the functional BPSK modulator adopted in Fig. 1. When the RF carrier is injected into the input port P_1, the modulated BPSK signal corresponding to the high or the low control I/Q voltage $V_{I/Q}$ is expressed as

$$S_{21}|_{\text{high}} = \frac{-j}{2}(\Gamma_P - \Gamma_N) \text{ for high } V_{I/Q} \tag{1}$$

$$S_{21}|_{\text{low}} = \frac{-j}{2}(\Gamma_N - \Gamma_P) \text{ for low } V_{I/Q} \tag{2}$$

where Γ_P is the reflection coefficient corresponding to the high control voltage, and Γ_N to the low control voltage. Note that (1) and (2) always maintain an equal amplitude and a 180° phase difference, and thus the ideal function of the 180° biphase modulator can be achieved.

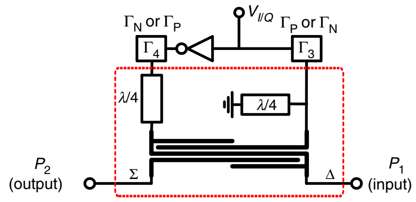

Fig. 2 *Block diagram of proposed BPSK modulator*

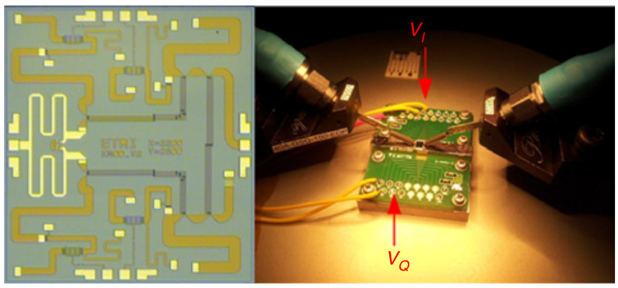

Fig. 3 *Chip photograph of proposed QPSK modulator and its on-wafer measurement setup for K-band*

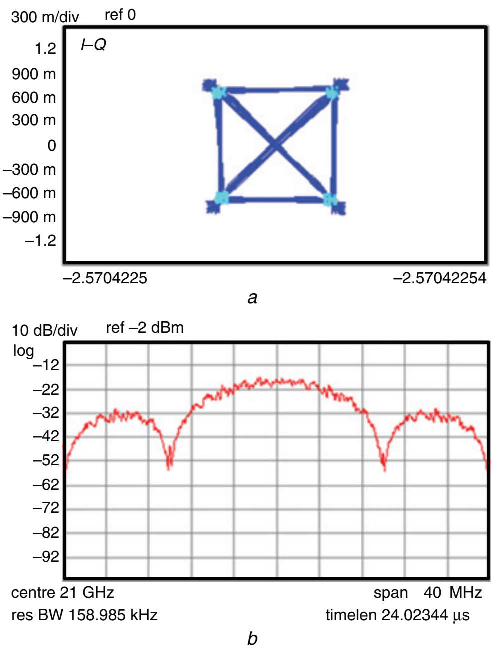

Fig. 4 *Measured QPSK modulation quality results at 21 GHz with 10 Mbit/s datarate*

a I/Q vector diagram
b Output spectrum

Measurements: Figs. 3*a* and *b* show the photographs of the designed I/Q modulator and its on-wafer measurement setup, respectively. The

83640B signal generator is used to provide the CW carrier signal and the pseudorandom QPSK datastream for the test is obtained from the 4438C vector signal generator. Then, the modulated signal is directly analysed by an Agilent MXA signal analyser for the digital modulation qualities. The measured QPSK modulation data including an *I/Q* vector diagram, an error against time plot, an output spectrum and a performance summary at 21 GHz are plotted in Fig. 4. The output power is over −2 dBm with a data rate of 10 Mbit/s when the injected RF carrier power is 6 dBm and the amplitudes of baseband *I/Q* signals are 3 V_{pp}.

The measured EVM is a 2.4% root-mean-square (RMS) and the amplitude error is below 1.68% RMS, while the phase error is below 1.04° in the RMS at the RF carrier frequency of 21 GHz. Fig. 5 shows the EVM of the demodulated signals without any adjustments in baseband signals or biasing. For the QPSK signal, the measured EVM is <5.8% RMS at the RF carrier frequency from 18 to 26.5 GHz. Also, the measured conversion loss and the demodulated *I/Q* offset are <8.4 and −16.1 dB, respectively, at the RF carrier frequency from 18 to 26.5 GHz.

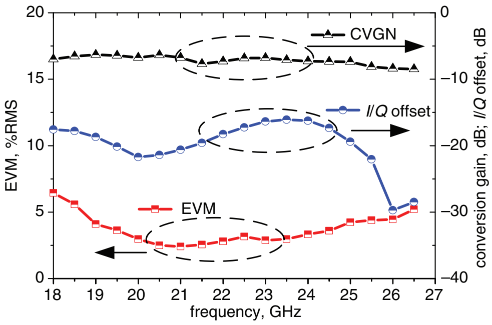

Fig. 5 *Measured EVM, conversion loss and I/Q offset from 18 to 26.5 GHz*

Conclusion: A broadband MMIC *I/Q* vector modulator has been implemented and verified with the RF carrier frequency from 18 to 26.5 GHz. The measured EVM showed <5.8% RMS in the operation band. Since this modulator module has low amplitude and phase imbalances as well as low power consumption, it is suitable for broadband direct digital modulated applications.

Acknowledgment: This research was funded by the MSIP (Ministry of Science, ICT and Future Planning), Korea in the ICT R&D Program 2013.

30 July 2013
doi: 10.1049/el.2013.2444
One or more of the Figures in this Letter are available in colour online.

Seong-Mo Moon, Dong-Hwan Shin and In-Bok Yom (*Satellite and Wireless RF Technology Research Section, ETRI, 138 Gajeong-ro, Yuseong-gu, Daejeon 305-700, Republic of Korea*)

Han Lim Lee (*Electrical Engineering, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea*)

Moon-Que Lee (*Electrical and Computer Engineering, University of Seoul, Siripdae-Gil 13, Dongdaemun-gu, Seoul 130-743, Republic of Korea*)

E-mail: mqlee@uos.ac.kr

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