Millimeter Wave Direct Quadrature Converter Integrated with Antenna for Broad-Band Wireless Communications

Ji-Yong Park, Seong-Sik Jeon, Yuanxun Wang, and Tatsuo Itoh

Department of Electrical Engineering, University of California, Los Angeles,
405 Hilgard Ave., Los Angeles, CA 90095-1594, U.S.A.

E-mail : jypark@ee.ucla.edu

***Abstract* — A compact quadrature modulator/demodulator integrated with a 40 GHz patch antenna for millimeter wave wireless applications is proposed. Anti-parallel diode sub-harmonic mixers are constructed for broad-band direct quadrature conversion. Overall phase and amplitude imbalance between the mixer I and Q output channels are less than 1.2 ° and 1 dB respectively. An average conversion loss of mixers of -14.6 dB is achieved in the frequency range from 39.75 GHz to 40.25 GHz. A communication link is built based on a pair of the proposed front-ends. Data transmission at up to 1 Gb/s data rate for QPSK modulation is successfully demonstrated.**

I. INTRODUCTION

The limited available spectrum at the lower end of the microwave bands is due to the recent dramatic growth in demand for wireless communications. Many services requiring high data rate such as LMDS, WLL, wireless CATV, point-to-point radio are turning to millimeter frequencies for more available spectrum and broad-band capability. Compact and low cost designs of millimeter wave communication front-ends thus become necessary for extensive applications.

In this paper, a direct quadrature frequency converter integrated with an antenna is proposed. A 40 GHz patch antenna is designed to have 10 dB bandwidth of 1.64 GHz for broad-band communication. The integrated antenna design reduces the interconnection loss that is a significant issue at millimeter frequencies [1]. The quadrature mixer provides the direct conversion capability for digitally modulated signals. More importantly, the existence of I/Q output channels can greatly reduce the post-stage signal processing load and increase the system throughput when an advanced system such as an adaptive beamforming array is under consideration [2]-[3].

Sub-harmonic mixers with anti-parallel diode pairs (APDPs) are used for the quadrature mixer design. They have been widely studied because of the advantage of low LO frequency, LO noise suppression and no bias circuit [4]. Many applications of sub-harmonic mixers with APDPs have been proposed for millimeter wave and sub-millimeter wave mixers [5]-[8], modulators [9]-[10] as well as direct conversion mixers [11]-[12]. By using an APDP direct conversion mixer design, the need for costly millimeter wave LO sources is eliminated as well as the additional IF mixers and filters.

This paper is organized as follows: The overview of the front-end system is first given. Then the design of each building block of the system including the antenna and the quadrature modulator/demodulator is introduced and the performance is validated with measured results. Finally, a communication link is set up by using a pair of integrated front-ends to examine the data modulation, transmitting, receiving and demodulation function. The link test shows successful transmission of QPSK data at up to 1 Gb/s data rate.

II. FRONT-END CIRCUIT OVERVIEW

Figure 1 shows the circuit structure of the proposed frequency converter consisting of sub-harmonic direct quadrature conversion mixers integrated with a planar antenna at a 40 GHz RF carrier. A direct-coupled rectangular microstrip patch antenna is designed and integrated. The inset feed and transformer to the antenna are used to match impedance.

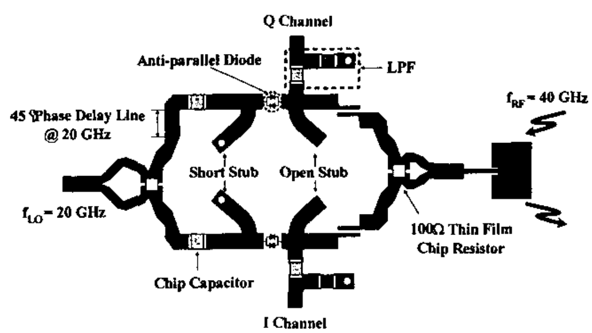

Fig. 1. The circuit architecture of the direct quadrature converter integrated with a planner antenna (circuit size: 1 × 0.73 inches).

A sub-harmonic direct quadrature conversion mixer is composed of two pairs of anti-parallel diodes, open and short stubs, 45 ° phase delay line at 20 GHz, low pass

0-7803-7239-5/02/$10.00 © 2002 IEEE

filters and Wilkinson power dividers for a RF of 40 GHz and a LO of 20 GHz, respectively. In order to terminate the RF and LO leakage, open and short stubs are optimized to a quarter-wave length at 20 GHz and a half-wave length at 40 GHz. Bandpass filters and capacitors work for IF decoupling. A phase delay line of 45 ° at 20 GHz is inserted in one of the LO power split paths after the LO Wilkinson power divider. This line will be 90° long at 40 GHz (even harmonic of 20 GHz), and the two mixers can each generate in-phase and quadrature IF mixing signal. Two identical direct quadrature converters, which are integrated with an antenna are fabricated. One acts as a modulator and the other as a demodulator. The proposed modulator and demodulator are fabricated on RT/Duroid 5880 with dielectric constant of 2.2 and substrate thickness of 10 mil. The Agilent HSCH-9251 GaAs Schottky barrier anti-parallel diodes are used for the sub-harmonic mixers. Agilent ADS 2001 is utilized to predict harmonic mixer performance and antenna characteristics.

III. Measurements and Discussion

A. Quadrature Modulator/Demodulator Integrated with Antenna

Figure 2 shows microstrip patch antenna return loss. The center resonant frequency of the antenna is 39.8 GHz and 10 dB bandwidth is 4.1 %. The gain of the patch antenna is around 3.5 dBi within 500 MHz bandwidth of the 40 GHz central frequency. The patch antenna size is 88.5 × 120 mils.

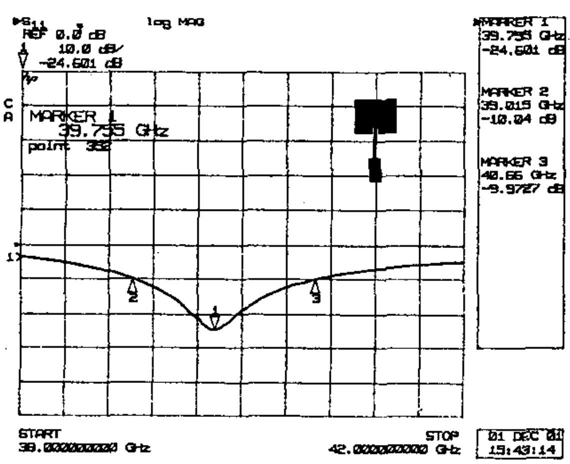

Fig. 2. Measured return loss of the microstrip patch antenna.

In order to measure RF performance of the direct quadrature converter integrated with an antenna, the transmitter system is located in the distance of 47 cm for far field measurement. Figure 3 shows the average conversion loss for I and Q channels as a function of LO power. The conversion loss is defined by the ratio of the RF power right before the microstrip patch antenna to the IF power. The conversion loss is lower than -15 dB from 10 dBm to 14 dBm of LO power. Figure 4 compares I with Q channel waveforms at an IF of 10 MHz. It shows less than 1.2 ° phase difference between I and Q channels in terms of a quadrature phase.

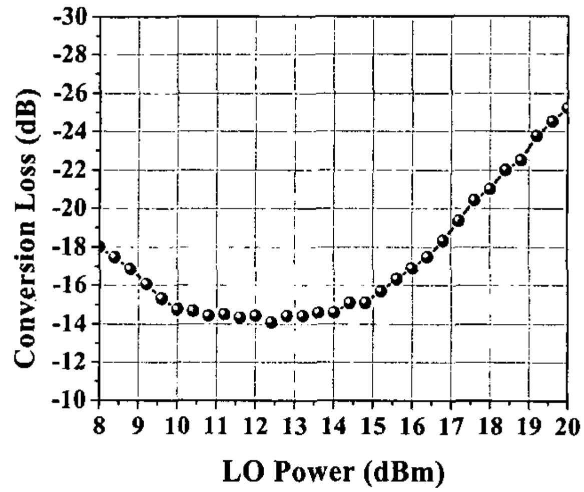

Fig. 3. Measured conversion loss vs. LO power at IF = 100 MHz (RF power is based on the right before antenna).

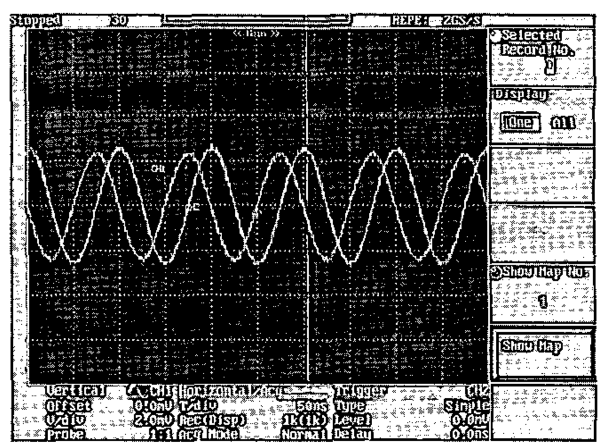

Fig. 4. Measured phase comparison of I and Q channels at IF = 10 MHz.

Figure 5 shows the measured conversion losses as a function of the RF signal with LO power of 11.8 dBm. Within the frequency range of 39.75 GHz to 40.25 GHz, it has a 1 dB power imbalance between I and Q channels.

From Fig. 4 and Fig. 5, good phase and power balance are achieved between I and Q channels for use in a direct quadrature mixer. Figure 6 shows the measured IF power as a function of RF power. Both the power of I and Q channels show good linearity as RF power is increased.

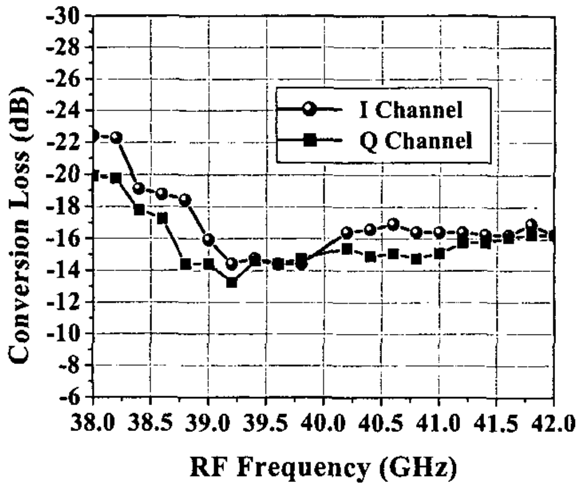

Fig. 5. Conversion loss vs. RF carrier for I and Q channels at LO = 11.8 dBm (RF power is based on the right before antenna).

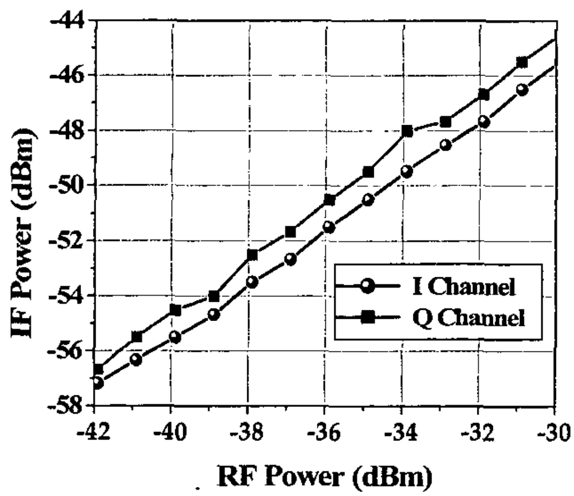

Fig. 6. Measured IF power vs. RF power of I and Q channels at IF = 100 MHz, and LO = 11.8 dBm.

B. Communication Link Test for QPSK Signal.

The communication link test set-up is depicted in Fig. 7. A pair of the integrated front-ends is used as transmitter/modulator and receiver/demodulator. The data is modulated in QPSK format and the modulation/demodulation is straightforward for the proposed system. A SONY Tektronix AWG520 arbitrary waveform generator is used to generate the based-band data at a sampling rate up to 1GSPS. The unfiltered 0101 binary sequence and pseudo random binary sequence are applied to the modulator at each I and Q channel. The demodulated baseband signals for both I and Q channels is shown in Fig. 8 after modulation, transmission, reception and demodulation.

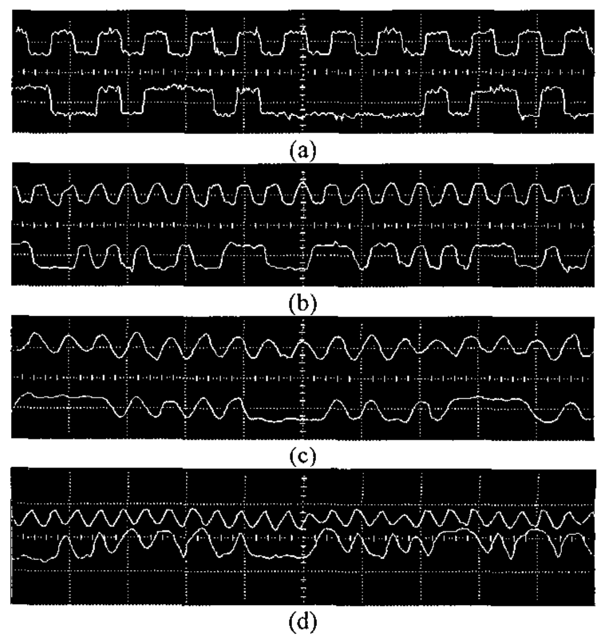

Fig. 8 The demodulated 0101 binary sequence and pseudo random binary sequence at I and Q channels (a) 50 Mb/s (50ns/div, 2mV/div) (b) 200 Mb/s (20ns/div, 2mV/div) (c) 350 Mb/s (10ns/div, 2mV/div) (d) 500 Mb/s (20ns/div, 2mV/div).

Four different data rates such as 50 Mb/s, 200 Mb/s, 350 Mb/s and 500 Mb/s (QPSK : 100 Mb/s, 400 Mb/s,

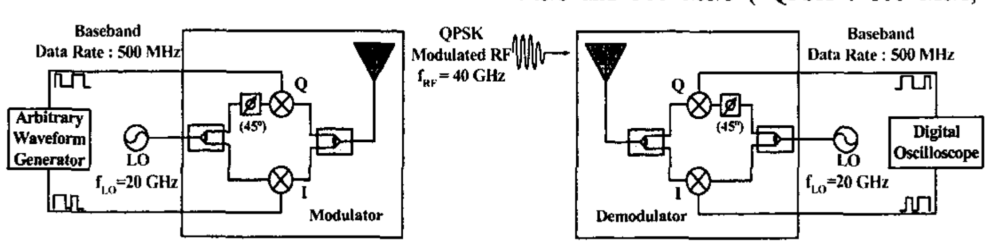

Fig. 7. Block diagram of the modulation/demodulation test set-up.

700Mb/s and 1Gb/s) are applied. From Fig. 8, the communication link demonstrates successful transmission of digital data at up to 1 Gb/s in QPSK format. The broad-band communication capability of the proposed direct quadrature converter integrated with an antenna demonstrates the potential for many advanced wireless applications such as an adaptive beamforming array under research in the author's group [2]-[3].

IV. CONCLUSION

A millimeter wave direct quadrature frequency converter integrated with a microstrip patch antenna for broad-band wireless communications is proposed. It shows 1.2 ° phase difference at IF of 10 MHz and 1 dB power amplitude imbalance in the frequency range of 39.75 GHz to 42.25 GHz. Broad-band data transmission at 1Gb/s data rate in QPSK format has been successfully demonstrated. The proposed simple and compact front-end system can be easily extended for applications in unlicensed millimeter wave frequencies such as the 60 GHz band.

ACKNOWLEDGEMENT

This work was supported by Sony MICRO. The authors would like to thank Kevin M. Leong, Jonathan Fredrick, and Dr. Ryan Miyamoto at UCLA and Seong-Kwon Jang in Korea.

REFERENCES

[1] Y. Qian and T. Itoh, "Progress in active integrated antennas and their applications," *IEEE Trans. Microwave Theory and Tech.*, vol. 46, pp. 1891-1900, Nov. 1998.

[2] S. S. Jeon, Y. Wang, Y. Qian, and T. Itoh, "A novel planar array smart antenna system with hybrid analog-digital beamforming," *2001 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 121-124, May 2001.

[3] S. S. Jeon, Y. Wang, Y. Qian, and T. Itoh, "A novel smart antenna system implementation for broadband wireless communication," accepted in *IEEE Transactions on Antennas and Propagation.*

[4] S. A. Mass, *Microwave Mixers*, Norwood, MA: Artech House, 1993.

[5] M. Cohn, J. E. Degenford, and B. A. Newman, "Harmonic mixing with an antiparallel diode pair," *IEEE Trans. Microwave Theory and Tech.*,, vol. MTT-23, pp. 667-673, Aug. 1975.

[6] R. J. Matreci and F. K. David, "Unbiased, subharmonic mixers for millimeter wave spectrum analyzer," *1983 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 130-132, 1983.

[7] A. V. Raisanen, R. J. Dengler, I. Mehdi, J. E. Oswald, D. Choudhury, and P. H. Siegel, "Subharmonic mixer with planar Schottky diodes in a novel split-block at 200-240 GHz," *1994 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 775-777, May 1994.

[8] K. Kawakami, M. Shimozawa, H. Ikematsu, K. Itoh, Y. Isota, and O. Ishida, "A millimeter-wave broadband monolithic even harmonic image rejection mixer," *1998 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1443-1446, June 1998.

[9] J. Chramiec, "Subharmonically pumped Schottky diode single sideband modulator," *IEEE Trans. Microwave Theory and Tech.*,, vol. MTT-26, pp. 635-638, Sept. 1978.

[10] K. Itoh, M. Shimozawa, K. Kawakami, A. Iida, and O. Ishida, "Even harmonic quadrature modulator with low vector modulation error and low distortion for microwave digital radio," *1996 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 2, pp. 967-970, June 1996.

[11] T. Yamaji, and H. Tanimoto, "A 2 GHz balanced harmonic mixer for direct-conversion receivers," *1997 IEEE Custom Integrated Circuits Conference*, pp. 193-196, 1997.

[12] K. Itoh, T. Katsura, H. Nagano, T. Yamaguchi, Y. Hamade, M. Shimozawa, N. Suematsu, R. Hayashi, W. Palmer, and M. Goldfarb, " 2 GHz band even harmonic type direct conversion receiver with ABB-IC for W-CDMA mobile terminal," *2000 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1957-1960, June 2000.