Integrated Even Harmonic Type Direct Conversion Receiver for W-CDMA Mobile Terminals (Invited paper)

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Abstract — **This paper is the first demonstration of the overall performance of the integrated even harmonic type direct conversion receiver (EH-DCR) with the RAKE receiver. The configuration of the integrated EH-DCR and its evaluation results based on the 3GPP definition are indicated. The RX LTCC module with the SiGe RX-IC, and BiCMOS ABB-IC are developed to achieve high integration of the receiver with filters. The integrated EH-DCR with low second order distortion can achieve high sensitivity and selectivity of the W-CDMA receiver, even with interference due to the transmitting signal. Described evaluation results satisfy the specifications defined by 3GPP. This paper clarifies effectiveness of the integrated EH-DCR for the third generation mobile terminals.**

I. INTRODUCTION

In the wireless communication, implementation of small sized terminals is one of important market demands. Based on this requirement of miniaturization, high integration of RF circuits has been developed for "the one chip radio" [1]. The direct conversion receiver (DCR) is an effective technique to miniaturize mobile terminal [2]-[4]. The DCR consists of no large sized IF circuits like a SAW transversal filter, and there are no spurious responses that require the high-Q RF filter. But this DCR has serious issue of lower sensitivity, due to even-order mixing products of the quadrature mixer.

In our previous works, the even harmonic type direct conversion receiver (EH-DCR) was proposed for reducing the even order mixing products [5]-[11]. The EH-DCR consists of the even harmonic quadrature mixer (EH-QMIX) with the even harmonic mixer (EHM). The EHM with an anti-parallel diode pair (APDP) [12]-[16] is very common circuit technique especially for millimeter-wave region, because of the halved LO frequency. This EHM has another superior technical feature of low even order mixing products without any external balun circuits. Therefore the proposed EH-DCR can achieve almost the same performance as that of the heterodyne receiver [5][10].

Based on technical features mentioned above, a 2GHz band EH-DCR was developed for the W-CDMA mobile terminals [17][18]. The developed EH-DCR consists of a passive-type EHQMIX [19] and an analog baseband IC (ABB-IC) [20]. The developed EH-DCR is evaluated with the baseband RAKE receiver. Effectiveness of the EH-DCR architecture is confirmed with the experimental investigation based on the 3GPP definition [21].

In this paper, the integrated EH-DCR for W-CDMA mobile terminals is presented. For miniaturization of the EH-DCR, a RX LTCC module [22] with a SiGe RX-IC [23] and the ABB-IC are developed. Also experimental investigations are demonstrated for enough characteristics for W-CDMA mobile terminals based on 3GPP specifications.

II. ARCHITECTURE

The configuration of the integrated EH-DCR is indicated in Fig.1. As shown in the figure, this integrated EH-DCR consists of a RX LTCC module [22], passive LPFs and an ABB-IC [20]. Also this EH-DCR is implemented with a SPDT switch (SW), a duplexer (DUP), an isolator (ISO), a PHEMT high power amplifier (HPA) [24] and a TX-IC, as an overall W-CDMA transceiver. The developed EH-DCR has technical features as follows:

(a) The EH-DCR and the dual bias feed LNA [25] for improving sensitivity.
(b) The RX LTCC module for high integration even with matching circuits and inter-stage filters.
(c) The ABB-IC with digital variable gain amplifiers (DVGAs) for high accurate gain control of 1 dB step. This improves measurement accuracy of receiving signal.
(d) The indicator output of the ABB-IC. Faster acquisition of the W-CDMA receiver is available with use of the indicator output voltage.

In the W-CDMA system, transmitting and receiving are done at the same time. The interference due to the transmitting signal (TX signal) makes sensitivity degradation as follows:

(a) Gain/NF degradation of the RX front-end, due to saturation by TX signal.
(b) Additional baseband noise by AM detection of the TX signal. Due to second order distortion of the quadrature mixer in the RX front-end, envelope of the TX signal falls into baseband.
(c) HPA noise at receiving band. NF of the receiver is degraded by additional noise of the transmitter.

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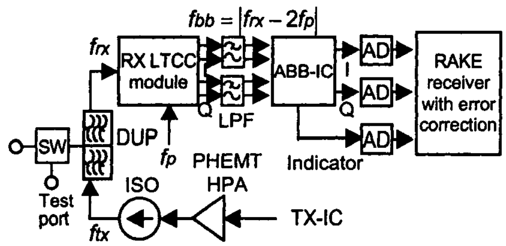
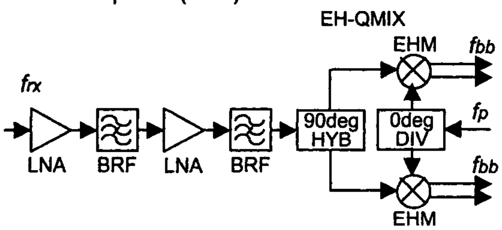
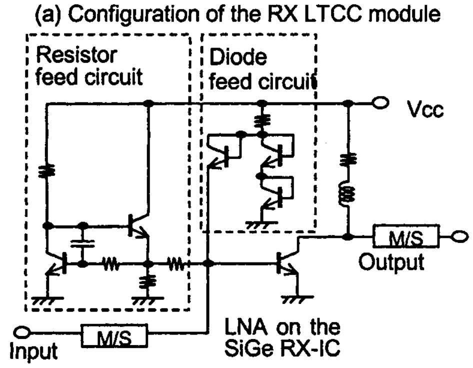


Fig.1 Configuration of the integrated EH-DCR with a duplexer (DUP) and a transmitter.

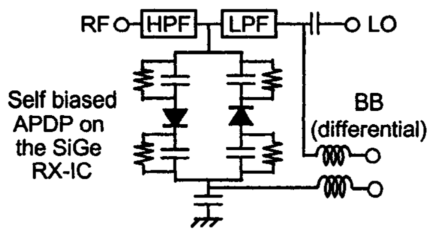


(a) Configuration of the RX LTCC module



M/S : Matching Circuit

(b) Dual bias feed SiGe HBT LNA



(c) EHM with the self biased APDP

Fig.2 Configuration of the RX LTCC module. The module is fabricated with the SiGe RX-IC for two stage LNAs and two self-biased APDPs.

To achieve enough sensitivity of the DCR, following techniques are used in the W-CDMA transceiver:

(a) The dual bias feed SiGe LNA for improvement of P1dB [25].
(b) The EH-DCR with well-matched monolithic APDPs for reduction of "AM detection"
(c) The PHEMT HPA with low noise characteristic [24].

III. THE RX LTCC MODULE AND THE ABB-IC

The configuration of the RX LTCC module is indicated in Fig.2. The photograph of the RX LTCC module with the SiGe RX-IC is indicated in Fig.3. 0.5 μm SiGe HBT (IBM 5HP) is employed for the RX-IC. The dual bias feed SiGe HBT LNA and the self biased APDP [26] are integrated on the RX-IC. Inter-stage band rejection filters (BRFs) are used for reduction of the TX signal. These BRF and passive components for the passive type EH-QMIX are implemented inside a LTCC substrate. Also the RX-IC is fabricated on the LTCC substrate with the flip-chip technique. The dual bias feed SiGe HBT LNA and the passive type EH-QMIX [20] with the self biased APDP [26] are used for the module. This self biased APDP is an effective technique to reduce extreme gain dependence on the LO level variation [26]. Characteristics of the RX LTCC module are summarized in Table I. By employment of the passive type EH-QMIX, low current consumption of 12.5 mA can be achieved.

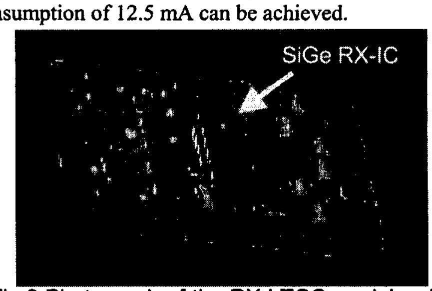
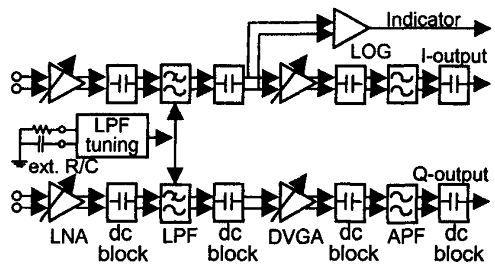


Fig.3 Photograph of the RX LTCC module with the SiGe RX-IC. The RX-IC is fabricated on the module by the flip-chip technique.

Table I Characteristics of the RX LTCC module

Frequency	2.1GHz band
Gain	21.5 dB
NF	3.4 dB
IIP3	-17.5 dBm
IIP2	+25.8 dBm
I/Q mismatch	0.3 dB/1.4 deg
LO level	8 dBm
Power consumption	3.0V, 12.5 mA
Size	5mm x 10mm



(a) Block schematics of the ABB-IC

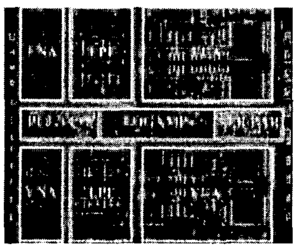

(b) Photograph of the ABB-IC

Fig.4 Configuration and photograph of the ABB-IC [20]. 0.6 μm BiCMOS is employed for the IC.

Table II Characteristics of the ABB-IC

Gain range	-1 dB- 86 dB
Gain step	1 dB
Input noise density	4.0 $nV/Hz^{0.5}$
IIP3	-20 dBV
Integral non-linearity	0.6dB
Diff. non-linearity	0.3 dB
Power consumption	3.0V, 12 mA

The configuration and the photograph of the ABB-IC [20] are indicated in Fig.4. 0.6 μm BiCMOS (ADI) is employed for the ABB-IC. This ABB-IC consists of LNAs for improvement of the input noise density, dc blocks for compensation of the dc-offset component, LPF for receiving channel selection, DVGA for gain control of 1 dB step, all pass filters (APFs) for phase equalization, and a LOG amplifier for indication of the receiving power. In addition, the cut-off frequency of LPFs is stabilized by gm-c configuration. The passive LPF between the RX LTCC module and the ABB-IC suppresses interference in the next adjacent channel. Therefore this LPF relaxes the required IM3 of the ABB-IC, and the current consumption of the ABB-IC can be reduced. Characteristics of the ABB-IC are summarized in Table II.

IV. OVERALL CHARACTERISTICS

All circuit components of a measured EH-DCR are implemented on the printed circuit board with the transmitter and BB-LSIs. The RF performance of the EH-DCR is indicated in Table III. Measured results include insertion loss of a SW and a DUP. With use of the passive type EH-QMIX, high dynamic range can be achieved. With low current consumption of 24.5 mA, this is almost the same dynamic range as hetero-dyne architecture.

For confirmation of specifications defined by 3GPP, the EH-DCR is characterized with the RAKE receiver. Bit error rate versus input RX signal power is indicated in Fig.5. This figure indicates sensitivity degradation of 0.14 dB by the TX signal. With The EH-DCR performance with the RAKE receiver is summarized in Table IV. Reference measurement channel of 12.2ksps is employed for the characterization. Reference sensitivity of -120.7 dBm can be achieved at BER of 0.001. These results are in agreements with the specifications defined by 3GPP.

Measured results clarify the effectiveness of the EH-DCR for the third generation terminals. In experimental investigations, low noise and high instantaneous dynamic range of the proposed EH-DCR can be confirmed.

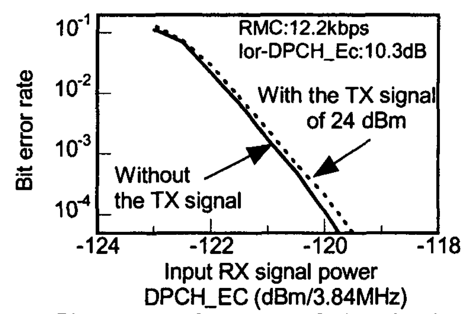


Fig.5 Bit error performance of the developed EHDCR wirh the RAKE receiver.

Table III Characteristics of the EH-DCR

Frequency	2.1 GHz band
Maximum gain Gmax	104 dB
NF @Gmax	5.3 dB
IIP3 @Gmax	-17.3 dBm
IIP2 @Gmax	30 dBm
Gain step	1 dB
I/Q mismatch	0.5 dB / 5 deg
Power consumption	3.0V, 24.5 mA

The EH-DCR includes a SW and a DUP.

V. CONCLUSION

The integrated EH-DCR for W-CDMA mobile terminals is described in this paper. For integration, the RX-LTCC module for the front-end and the ABB-IC for the back-end are developed for miniaturization. This is the first demonstration of the integrated DCR and its performance with the RAKE receiver.

Table IV Overall receiver characteristics defined by reference measurement channel of 12.2kbps

	measured	specification
Reference sensitivity	-120.7 dBm	< -117 dBm
ACS	-41.5 dBm	> -52 dBm
Inter-modulation	-38.5 dBm	> -46 dBm
Spurious response	10^{-6}	< 10^{-3}
In-band blocking		
Blocker@ 10MHz	< -35.7 dBm	> -56 dBm
Blocker@ 15MHz	< -35.2 dBm	> -44 dBm
Out-band blocking	10^{-6}	< 10^{-3}

(1) Reference sensitivity is defined at BER of 10^{-3}.
(2) ACS, inter-modulation and in-band blocking are defined as blocker levels with BER of 10^{-3}.
(3)Measurement condition of out-band blocking
Band 1: 2050-2095 MHz, 2185-2230 MHz, -44 dBm
Band 2: 2025-2050 MHz, 2230-2255 MHz, -30 dBm
Band 3: 1-2025 MHz, 2255-12750 MHz, -15dBm
(4) In in/out-band blocking, the number of frequencies that do not satisfy the required BER is less than 24.

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