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Highly Integrated, Dual Band/Tri-mode SiGe BiCMOS Transmitter IC for CDMA Wireless Applications

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Abstract — **A highly integrated transmitter IC fabricated in Conexant's 0.35 um SiGe BiCMOS process and packaged in a 6mm x 6mm Land Grid Array (LGA) package provides dual band/tri-mode transmitter functionality in a CDMA handset meeting TIA/EIA 98-D specifications. This chip upconverts the I/Q baseband signals to RF in two stages and delivers the amplified RF signal to the power amplifier. It consists of the following stages: an I/Q modulator, VHF VCO, VHF PLL, IF VGA, UHF LO buffer, UHF PLL, 3 wire serial interface, RF image reject upconverter, a cellular PA driver and dual PCS drivers. It is designed to deliver 8 dBm in CDMA mode in Cellular band, 11 dBm in AMPS mode and 9 dBm in CDMA mode in PCS band at 90 mA, 88 mA and 108 mA respectively at nominal supply and temperature. It also provides IF dynamic range of 80 dB in the IF VGA and RF Gain dynamic range of 20 dB in Cellular band and 15 dB in PCS band. The IC operates from a supply ranging from 2.7 V to 3.3 V and a temperature range of -30C to 85C.**

I. INTRODUCTION

Due to constant demand for lower cost as well as shrinking form factors from hand set manufacturers, there is a great need for higher levels of integration in RFICs. A highly integrated dual band, tri-mode transmitter IC for a CDMA handset compliant with the TIA/EIA 98-D specifications [1] is presented. This IC eliminates the transmit IF SAW filter, RF image reject SAW filters and integrates both the transmit VHF PLL as well as the UHF PLL from the previous generation transmitter IC offering from Conexant [2]. An additional feature provided is the support of dual transmit IF frequencies for Cellular and PCS bands that facilitates a single IF frequency on the receiver side for Cellular and PCS bands thereby eliminating an IF SAW filter in the receive path. All these provide a significant reduction in cost and board area. This level of integration is provided without any penalty in current consumption and die size which has been achieved by appropriate system partitioning, fabrication in Conexant's 0.35 um SiGe BiCMOS process [3] and packaging in a 6mm x 6mm Land Grid Array (LGA) package.

II. KEY SYSTEM REQUIREMENTS

CDMA transmitter design requires up-conversion of I/Q analog base band signals to RF. A minimum of 90 dB of power control dynamic range is required from the transmitter in the CDMA system to meet open and closed loop requirements at the antenna. The minimum controlled output power sets the requirement for the in band noise power and resulting carrier to noise ratio. Over part of this dynamic range the transmitter should also meet the spectral mask requirements, which typically sets the cascaded linearity (as measured by adjacent channel power ratio, ACPR) requirements at higher output powers and the spurious and in band noise requirements at lower output powers [4]. Owing to the full duplex architecture of the CDMA system, the noise in the receive band during transmit operation also requires careful consideration as it could potentially degrade the CDMA receiver sensitivity which is typically isolated from the transmitter chain with a duplexer. In AMPS mode, the critical requirements are the maximum output power and less than 5% residual amplitude modulation which translates to better than 35 dBc of carrier suppression and side-band rejection from the I/Q modulator.

III. TRANSMITTER DESIGN

Based upon the above requirements, the transmitter was designed as a dual up-conversion architecture (Fig. 1) with the gain, noise as well as the gain control distributed appropriately between the IF and RF stages [4].

A. IF section

The IF section of the transmitter up-converts the I/Q analog base band signals to an IF frequency with an in phase-quadrature (I/Q) modulator. The quadrature local oscillator signals for the IF up-conversion are generated by a VHF VCO and a divide by 2/4 circuit. The VHF VCO which is locked by an on chip VHF PLL utilizes an

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external tank and an internal amplitude leveling loop for providing consistent phase noise even with external tank Q variations. Due to an accurate control of the amplitude and phase mismatch between I and Q paths at IF frequencies,

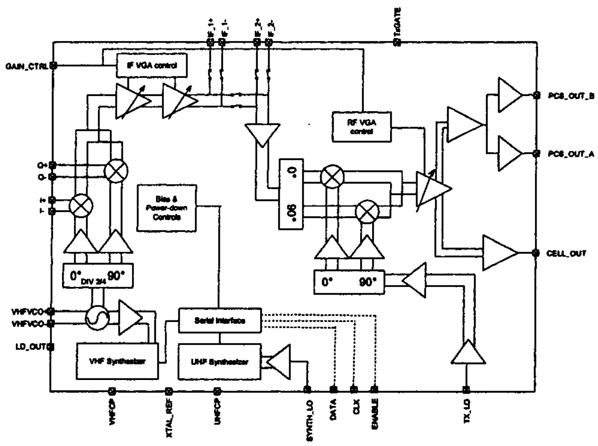

Figure 1. Simplified block diagram of the transmitter

it is possible to achieve better than 35 dBc of carrier and side-band suppression. The IF signal from the I/Q modulator is fed to an IF variable gain amplifier (VGA) which provides the IF gain as well as 80 dB of power control. The IF gain is controlled by an analog VGA control voltage. The current consumption in the VGA is reduced as the gain is reduced which enables current savings at lower output power. The IF VGA is carefully designed to meet the linearity, gain and noise requirements over the 80 dB dynamic range. The IF section is terminated in a 1 port external L-C filter that provides a reduction of receive band noise as well as any other harmonics. The receive band noise is reduced by the L-C filter such that the overall cascaded receive band noise of the transmitter IC is entirely dominated by the following RF section. A switch matrix is provided at the IF VGA output which enables choosing of two different 1 port L-C filters for tuning at 2 different IF frequencies. This enables choice of different IF frequencies for Cellular and PCS bands and allows optimization of the 1 port L-C filter for each band independent of the other.

B. RF section

The filtered signal from the IF VGA output is fed to the RF stage internally. The IF signal is first up-converted by an image reject mixer to an RF frequency in either cellular band or in PCS band as determined by the external UHF local oscillator (TX_LO) frequency. The image reject mixer can be configured to be either low side or high side injection through the 3 wire serial interface. The quadrature IF and LO signals are obtained using RC-CR networks. Programmability of the IF RC-CR network is provided to enable choosing of different IF frequencies.
The up-converted RF signal is then fed to an RF stage with RF gain control which is utilized in lowering the in band noise floor at lower output powers. The RF gain control is approximately 15 dB in PCS band and 20 dB in cellular band. The conditioned signal is then fed to a power amplifier (PA) driver that amplifies the RF signal in the desired band to a level that is sufficient for an external PA to deliver the required maximum output power at the antenna. One PA driver in cellular band and two PA drivers in PCS band are provided. This facilitates the use of a split band filter in the PCS band which provides better rejection of receive band noise. In order to optimize the linearity requirement at maximum output power and current consumption at backed off output powers, class AB stages are utilized for the PA drivers. Integrated baluns are utilized to convert the differential RF signals to single ended so that they can drive the single ended SAW filters between the PA driver and the PA. Also, the receive band noise generated by the RF section has to be sufficiently low such that the noise which is subsequently reduced by the cascaded loss of the SAW filter loss, PA gain and the duplexer loss in the receive band does not desensitize the receiver. This requirement effectively sets the maximum gain and noise figure in the RF section. The remaining gain has to be provided by the preceding IF section. This IC supports the variable data rate mode of transmission in IS-95 systems where the transmitter is shut off when no voice activity is present thus reducing interference to other users.

C. VHF and UHF PLLs

Two integer-N PLLs with four steps of programmable charge pump currents are provided to enable the frequency control of the transmit VHF VCO and the external UHF VCO shared by the receiver as well. A block diagram of the PLLs is shown in Figure 2.

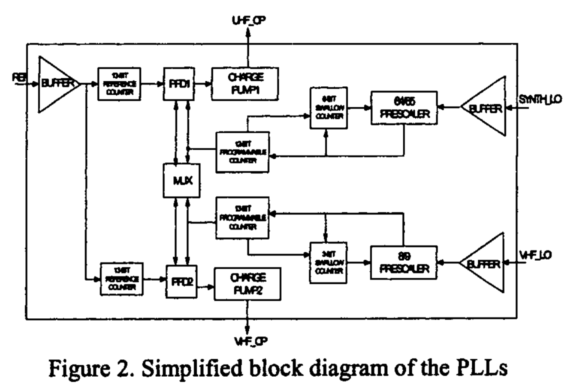

Figure 2. Simplified block diagram of the PLLs

TABLE I

SUMMARY OF MEASUREMENTS IN CELLULAR BAND AT 2.85 V, 27C

Parameter	Measurement	Conditions
Maximum Pout	11 dBm	CDMA
Maximum Pout	14 dBm	AMPS
ACPR at 885 KHz offset	< -52 dBc	CDMA, Pout=-5 to 8 dBm
LO leakage at RF	-20 dBm	
RF image rejection	> 25 dBc	
Rx band noise at +45 MHz offset	-139 dBm/Hz	CDMA, Pout= 8 dBm
I/Q modulator carrier suppression	> 35 dBc	CDMA, AMPS
I/Q modulator image suppression	> 35 dBc	CDMA, AMPS
Minimum Pout	-87 dBm	CDMA
In band noise	-151 dBm/Hz	CDMA, Pout=-77 dBm
Current consumption	90 mA 60 mA 88 mA 6.5 mA 45 uA	CDMA, Pout=8 dBm CDMA, Pout=-87 dBm AMPS, Pout=11 dBm Only UHF PLL is active Sleep Current

The VHF PLL buffers the VHF VCO signal to a 8/9 prescaler which is followed by a 13 bit main counter and a 3 bit auxillary counter. The phase of the output of the 13 bit counter is compared to the phase of a divided down crystal reference frequency signal using a phase frequency detector (PFD). The output of the PFD controls a charge pump circuit (CP) which feeds an external loop filter to generate the tune voltage to control the VHF VCO varactor. The UHF PLL architecture is identical in all respects except for a 64/65 prescaler, a 12 bit main counter and 6 bit auxillary counter. Both the PLLs are programmed and enabled through the 3 wire serial interface. Programmability of various modes of operation of the entire IC is also achieved through the 3 wire serial interface.

IV. MEASUREMENTS

Cascaded measurements of the transmitter IC were obtained after determining the 1 port L-C filters for Cellular and PCS bands between the IF and RF stages.

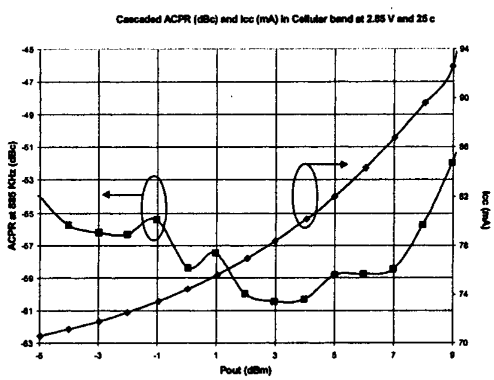

Figure 3. Cascaded ACPR and Icc in Cellular band

The IC delivers a maximum output power of 8 dBm at a current consumption of 90 mA in CDMA mode in Cellular band while meeting ACPR of 52 dbc or better (Fig. 3).

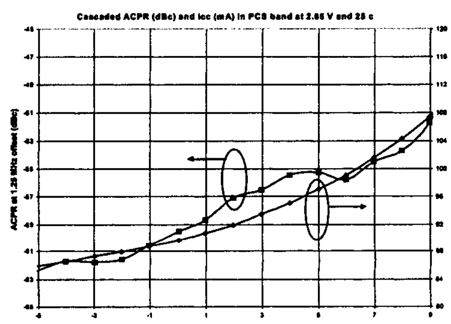

Figure 4. Cascaded ACPR and Icc in PCS band

In PCS band, the maximum ouptut power is 9 dBm at a current consumption of 108 mA while meeting ACPR of 52 dbc or better (Fig. 4).

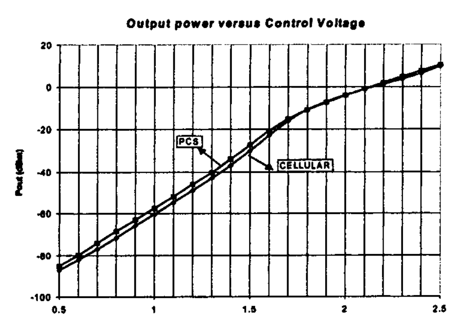

Figure 5. Output power versus Gain control voltage.

TABLE II

SUMMARY OF MEASUREMENTS IN PCS BAND AT 2.85 V, 27C

Parameter	Measurement	Conditions
Maximum Pout	11 dBm	
ACPR at 1.25 MHz offset	< -52 dBc	Pout=-5 to 9 dBm
LO leakage at RF	-15 dBm	
RF image rejection	> 20 dBc	
Rx band noise at +80 MHz offset	-134 dBm/Hz	Pout= 9 dBm
IF modulator carrier suppression	> 35 dBc	
IF modulator image suppression	> 35 dBc	
Minimum Pout	-87 dBm	
In band noise	-144 dBm/Hz	Pout=-77 dBm
Current consumption	108 mA 78 mA 6.5 mA 45 uA	Pout=9 dBm Pout=-85 dBm Only UHF PLL is active Sleep Current

In CDMA modes for both bands, the current consumption is reduced at backed off output power which improves the efficiency. In both bands, > 90 dB of dynamic range is provided by a combination of IF and RF gain control. As indicated in Fig. 5, the minimum controllable output power is –85 dBm. In AMPS mode, the RF blocks are driven into saturation to provide a maximum output power of 11 dBm at a current consumption of 88 mA. Key measured parameters are summarized in Table I for cellular band and in Table II for PCS band. A Typical ACPR plot with an IS-95-A CDMA waveform is shown for cellular band at maximum ouptut power of 8 dBm in Figure. 6.

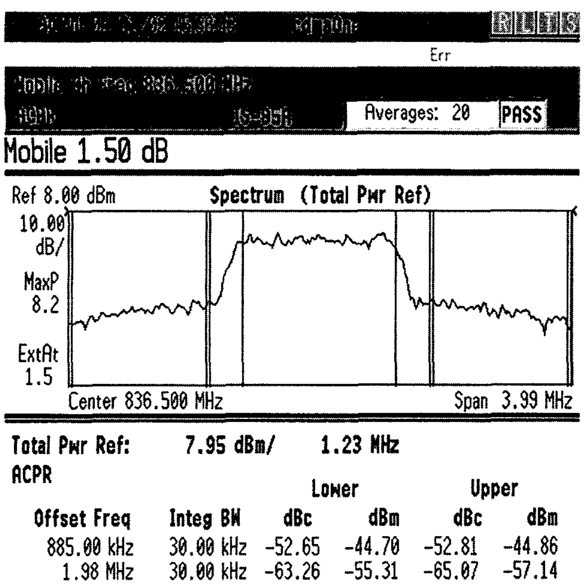

Figure 6. Typical ACPR plot with a CDMA waveform in Cellular band at Pout=8 dBm.

The IC is fabricated in a Conexant's 0.35 um SiGe BiCMOS process. The package is a 40 pin, 6mm x 6mm Land Grid Array Package with a down set paddle to minimize ground inductance.

V. CONCLUSION

A dual band tri mode transmitter IC compliant with the TIA-EIA 98D specifications was fabricated in a 0.35 um SiGe BiCMOS process. The transmitter achieves low current consumption and demonstrates a high level of integration through an appropriately designed dual up conversion architecture.

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