# A SAW-less Dual-Band CDMA Diversity and Simultaneous-GPS Zero-IF Receiver

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*Abstract*—We present a dual-band (Cellular & PCS) dual-path zero-IF receiver for CDMA2000 diversity, monitoring and simultaneous-GPS. The secondary path is a SAW-less diversity CDMA receiver which can be also used for advanced features like monitoring when supported with an additional external VCO. A GPS receiver is integrated with its dedicated VCO allowing simultaneous positioning during a cellular call. The circuit is implemented in a 0.25μm 40GHz-fT BiCMOS process and uses a HVQFN 56-pin package. It consumes a maximum 300mW from a 2.8V supply in dual-modes. The chip area is 12.8mm2.

*Keywords*—CDMA, diversity, GPS, zero-IF, SAW-less.

## I. INTRODUCTION

WIRELESS network market trends are leading to ever growing data-rates as a consequence of the increasing user demand and services. In order to guarantee high data-rates and improved Quality-of-Service (QoS), two basic approaches can be considered: increase the number of cells in a given area or promote the use of multiple antenna techniques, either at a base-station level and/or in the mobile handset. The multi-antenna techniques appear to be the most appropriate solution since it moves the physical implementation challenge into integration domains. It also shares many similarities with the general convergence towards multi-band multi-standard low-power and cost-effective integrated solutions.

## II. SYSTEM CONSIDERATIONS

### A. Diversity

The most straightforward way to implement diversity is to duplicate the main receiver (RX) and have two identical RX paths in parallel. It is then possible to make sure that mismatches between the two RX chains are under control and minimized so that the diversity benefit is optimized. However, the main drawback of integrating diversity in such a manner is the second receiver additional current consumption and increased Bill-Of-Material (BoM). Indeed, 3GPP2 standard

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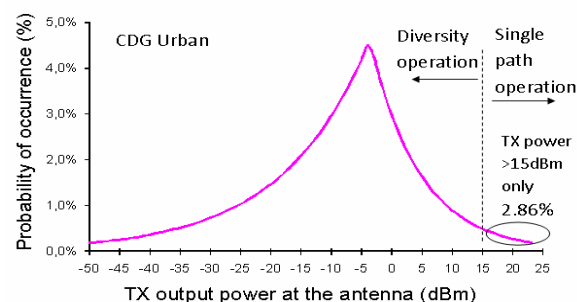
Fig. 1 Probability density function of CDMA TX output power

[1] puts stringent requirements in linearity and TX rejection for primary RX path in order to meet *BER* under worst case conditions [2].

In order to overcome this issue, we can notice that diversity is not a requirement from the 3GPP2 standard [1], but a built-in feature to improve sensitivity of the receiver in field conditions with highest probability. If we look at the probability of occurrence relative to the CDMA transmitter (TX) power (figure 1), we see that only 2.86% of TX power is above +15dBm (CDG Urban). In addition, the probability that the 900kHz-offset single-tone AMPS jammer is present can be estimated to be less than 30%. These considerations allow the relaxation of test conditions compared to standard conditions in order to optimize the linearity and rejection requirements of the secondary path and therefore its power consumption.

For this reason, the secondary RX path was designed such that most of the specification items (gain, *NF* …) match with the primary RX path, although its *IIP3* and TX rejection are lower. By doing so, secondary RX path alone is not able to achieve targeted *BER* under worst case test conditions described in the 3GPP2 standard: there is then no diversity benefit in most stringent conditions and secondary RX path should simply be turned-off.

However, for field conditions with highest probability, secondary RX path achieves targeted *BER* and the two receivers in parallel bring predicted diversity benefit. In addition to that, primary RX path do not need maximum linearity under relaxed conditions as well: its current consumption can be scaled and optimized. The net result is that we are able to operate the two receivers with almost the same amount of current than primary path only under worst

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case conditions.

Besides, by taking into account the coupling level between antennas estimated to be −12dB for the worst case, and a specific gain partitioning across the diversity path consisting of attenuating the leaked TX levels in the front-end, the cross-modulation noise can be overcome with +3dB margin on sensitivity under standard's default test conditions. This allows to remove the intermediate SAW filters between LNAs and mixers, and consequently saves BoM and cost.
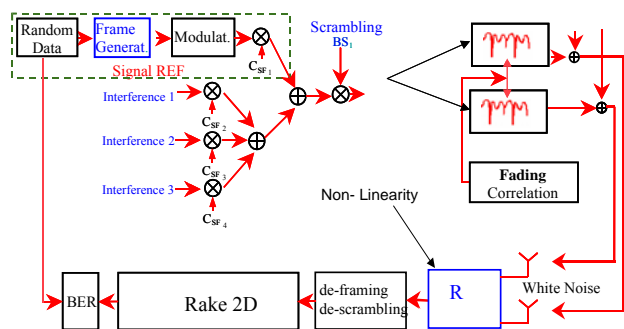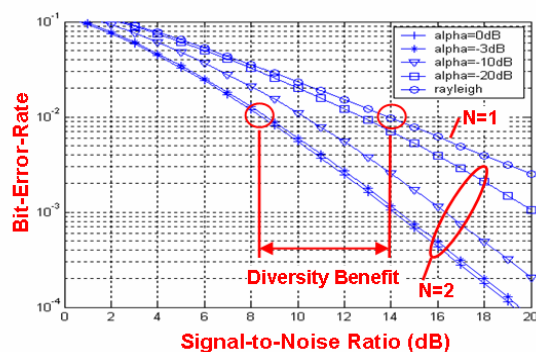


Fig. 2 Diversity benefit model



Fig. 3 Diversity benefit: for a dual-path RX ($N$=2), and a $BER$=$10^{-2}$, the required $SNR$ can be lowered by more than 5dB, compared to a single-path RX ($N$=1), even if a mismatch ($alpha$=−3dB) is applied between the two paths

A system study was performed to verify diversity benefit for field conditions with highest probability. A tool was built (Fig. 2) including an RF path model and a dual rake RX, allowing the study of diversity performance versus different parameters (RF, interferer, fading…). Fig. 3 depicts the diversity gain in a dual-path RX case ($N$=2), compared to a single-path RX ($N$=1). A couple of dB mismatch between the two paths doesn't significantly impair the diversity benefit.

*B. Simultaneous-GPS*

GPS RX path has been specified to be able to perform simultaneous positioning during a cellular call. Compared to stand-alone GPS mode of operation, the presence of CDMA TX signal at the main antenna while receiving GPS signal sets very high constraints on the GPS RX path. Due to the coupling between antennas, high TX power leakage can be

found at secondary antenna. This leads to additional noise contributors compared to stand-alone GPS: TX noise in GPS band, reciprocal mixing noise linked to TX signal (or its 2nd harmonic in CDMA CEL band), cross-modulation linked to TX leakage signal and GPS LO leakage at LNA input, 2nd-order intermodulation product caused by TX leakage, 2nd-order or 3rd-order intermodulation product due to TX leakage signal and any strong out-of-band blocker.

In Cellular mode, the transmitter's second harmonic lowest frequency is located at 1648MHz, which is only 72MHz away from the GPS band (1575.42MHz). At PA output, this jammer is very high compared to the GPS RX levels (−152dBm/2MHz), and we can expect some TX noise in the GPS band. Maximum desensitization target for simultaneous-GPS (S-GPS) being specified at 1dB, we get then strong linearity requirements on top of already stringent *NF* specification (3dB worst case) for complete RX GPS path including SAW filters: GPS LO leakage at GPS LNA input below −90dBm, *IIP2* and *IIP3* at GPS LNA input respectively above 40dBm and −5dBm. In order to solve the coexistence issue of having S-GPS and cellular operation while maintaining attractive power consumption, a SAW filter has been considered between LNA and mixer to manage the CDMA TX leakage signal and strong out-of-band blockers.

### III. RADIO RECEIVER ARCHITECTURE

The RX employs a main and a secondary antenna for dual RX modes (Fig. 4). The circuit is realized with two separate paths from the RF input to I/Q baseband output, with shared LO generation, biasing and digital blocks. The main path design [3], [4] employs 16dB gain LNAs, with a *NF*<1.5dB, and a high *IIP3*>8dBm relative to cross-modulation noise reduction; external SAW filters are also used to further reject the coupled TX interferers.

The alternate path consists of a SAW-less dual CDMA path plus a GPS path. The secondary CDMA path uses integrated single-to differential interfaces between LNAs and mixers without the need of heavy filtering. Both CDMA and GPS paths employ a common reconfigurable 5th-order elliptic baseband channel filter to reduce die area [4]. The LO frequency plans are generated with two integrated ΣΔ fractional PLLs, two integrated GPS and CDMA VCOs, and a third external CDMA VCO.

Both path's mixers use inductive degeneration to provide an *IIP3*>5dBm and a *NF* <5dB, with an *IIP2*-calibration system. The calibration block (Fig. 5) consists of a single 7-bit programmable resistive network connected to the mixer differential outputs, and presenting the advantage of low layout size. The resistive network is controlled via the digital serial bus. A switch arrangement at the mixer outputs helps to preserve symmetry no matter what the calibration value is. The *IIP2*-calibration occurs during the handset manufacturing process where the digital code for optimum *IIP2* is stored into the phone's digital baseband once for all its life-time.

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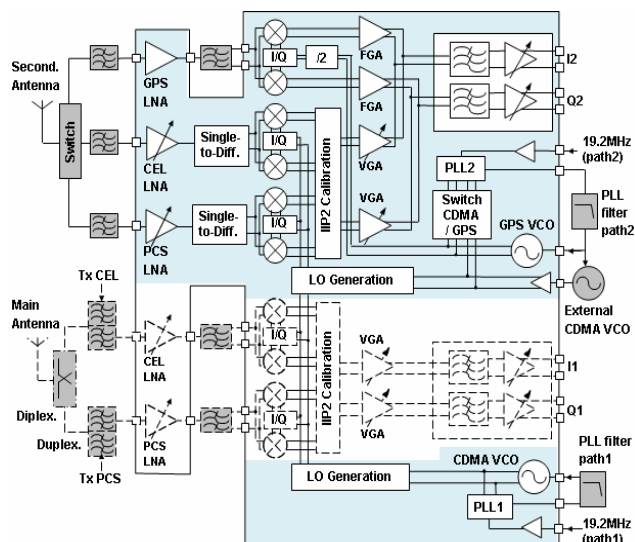Vol:3, No:6, 2009

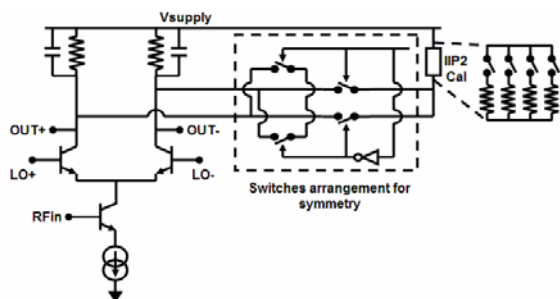Fig. 4 Block-diagram of the diversity receiver (filled area)



Fig. 5 IIP2 calibration circuit

Integrated CDMA and GPS VCOs are placed at opposite sides to limit inductive coupling. The monitoring VCO is placed off-chip to avoid VCO pulling whenever both RX operate in close channels. "8-shaped" inductors are also employed at critical points in the mixers and LO blocks. Simulations and measurements proved that coupling between two "8-shaped" coils, placed roughly at 300μm from each other, can be reduced by about 20dB compared to traditional coils. The choice of "8-shaped" coils reduces the LO feed-through into LNAs and mixers, diminishes the coupling between both RX paths in dual-modes, and lowers the interactions among other radiation sources like bondwires and the seal-ring.

## IV. SECONDARY PATH

Secondary CDMA path LNAs use off-chip inductor (L1), to ease matching tuning between the LNA and the converter (Fig. 6). The converter employs a single BJT with a degenerated emitter. An active solution is preferred to an on-chip transformer [5] to avoid coupling issues with the main path in dual-modes. The voltage gain transfer functions at the converter outputs (Fig. 6) are equal with phase inversion whenever $Z_E$, $Z_C$ are equivalent, where $Z_E$, $Z_C$ are respectively the Q2's collector and emitter impedances, and $gm$ is its

transconductance. Furthermore, the converter is designed to provide 3dB power attenuation; this is to help attenuating the jammers at the mixer input, and thus to ease the cross-modulation test pass with acceptable *NF* (<3dB) at the RX input. The gain loss is compensated throughout the baseband filter. The converter draws 2mA.

The GPS LNA input impedance is set close to 50Ω, so a unique external series capacitor is needed for matching. The LNA features 15.5dB gain, 1.2dB *NF*, +3.7dBm *IIP3*, and draws 4mA. The mixer uses resistive degeneration to get an area-effective design, and avoid issues provoked by inductive coupling. No *IIP2*-calibration is used due to lower *IIP2* requirement in GPS mode.



$$G_{v,C} = \frac{-Z_C}{\dfrac{1}{gm} + Z_E}$$
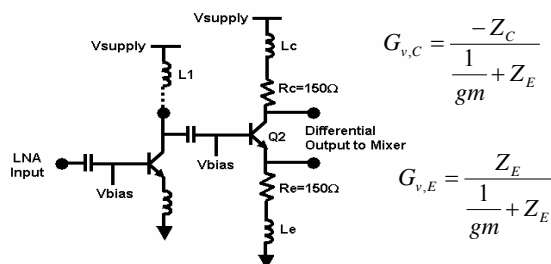
$$G_{v,E} = \frac{Z_E}{\dfrac{1}{gm} + Z_E}$$

Fig. 6 CDMA SAW-less front-end including the LNA and the single-to-differential active converter

## V. LO GENERATION

LO generation circuit is shown in Fig. 7. In diversity mode, the I/Q LO is generated by the main ΣΔ PLL plus integrated CDMA VCO, and dividers by-2 and by-4. In monitoring mode, the main path operates with the main PLL plus CDMA VCO; the alternate path employs the alternate ΣΔ PLL plus an external CDMA VCO in the range of 1.7-1.8GHz; the I/Q LO is then provided to CEL and PCS mixers via dividers by-2 and by-9/8, respectively [4]. In S-GPS mode, the main path operates always with the main PLL plus CDMA VCO, while the GPS path uses an internal GPS VCO at 3.15GHz with the alternate PLL, and provides the I/Q LO via a divider-by-2. The CDMA VCO is designed with high-Q LC-tank elements to fulfill the stringent phase noise specification, with a frequency range covering 3.2GHz to 4.2GHz (27%), and 10mA current consumption. Both PLLs use the same 2nd-order ΣΔ MASH11 modulator. A 3rd order external passive loop filter attenuates the ΣΔ noise, and the loop bandwidth is set around 10kHz to minimize the integrated phase noise impacting the EVM while meeting the settling time requirement (~100μs).

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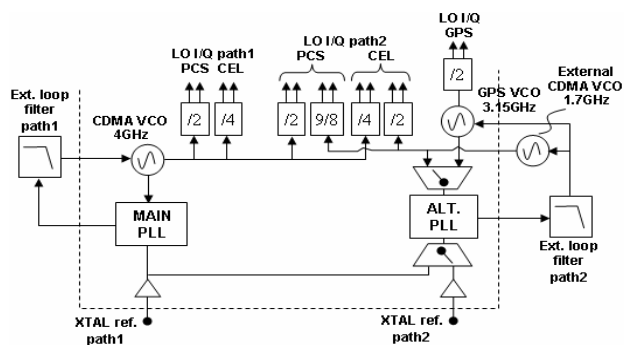International Journal of Electrical and Computer Engineering
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Fig. 7 LO generation and distribution towards main and alternate paths

## VI. MEASUREMENT RESULTS

The chip is realized in a high substrate resistivity (2kΩ.cm) 0.25μm 40GHz-$f_T$ BiCMOS process. The chip area is 12.8mm². The die microphotograph is shown in Fig. 8.
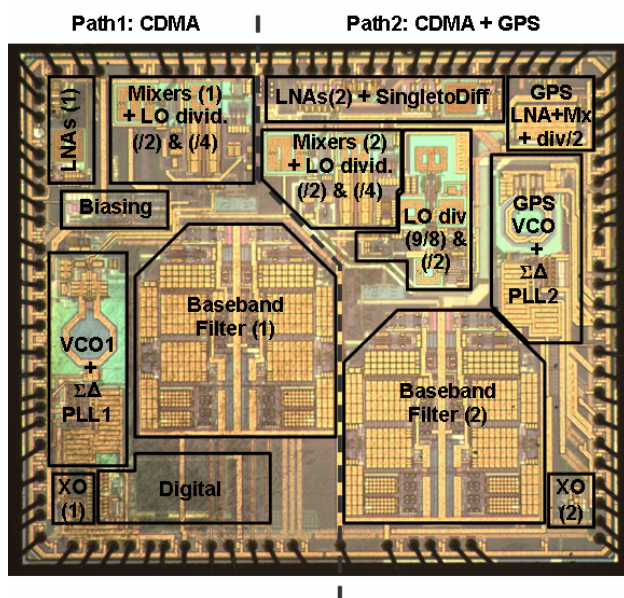


Fig. 8 Die microphotograph

Table I(A) shows the diversity CDMA path results, with 1.1dB minimum sensitivity margin to standard requirement [1] in PCS mode.

Table I(B) provides the S-GPS path results. A 2dB-desensitization is observed in CEL mode, with +15dBm TX PA output, and −12dB antenna coupling. Otherwise, no desensitization is noticed in all the other cases, even with +23dBm TX power. Furthermore, when a −35dBm jammer is introduced at 10 to 35MHz offset from GPS band, no significant cross-modulation noise is noticed. The GPS path consumes 43mA alone, which gives about 111mA for the total chip consumption.

TABLE I
(A) SECONDARY CDMA PATH IN DIVERSITY MODE.

| Parameter | CEL | PCS |
|---|---|---|
| Voltage Gain | 80.3dB | 81.2dB |
| Image Rejection | -44dBc | -33.8dBc |
| Noise Figure | 2.5dB | 3.1dB |
| IIP3 | -8dBm | -8.9dBm |
| IIP2 (w/wo calibration) | 68/45dBm | 68/46dBm |
| Sensitivity margin to standard requirement [1] (Diversity ON) | 5.5dB | 3.7dB |
| Sensitivity margin in Single-Tone test (Diversity ON, TX power (PA)= +15dBm, antenna coupling= −12dB, and jammer= −46dBm at 900kHz (CEL)/1.25MHz (PCS) offset) | 1.9dB | 1.1dB |
| Total chip current consumption | 111mA | 104mA |

(B) SECONDARY PATH IN SIMULTANEOUS-GPS MODE.

| Parameter | GPS |
|---|---|
| Overall Voltage Gain | 70dB |
| Image Rejection | -31dBc |
| Overall Noise Figure | 3.26dB |
| Overall IIP3 | +6.6dBm |
| CEL TX power (PA) for 2dB-desensitization (with -12dB antenna coupling) | +15dBm |
| Current consumption | 43mA |

We note that the measured RX performance varies little upon the operation mode (single or dual), which confirms the validity of applied coupling mitigation techniques. Besides, the measured LO-to-RF leakage is <−100dB, and the RF-to-RF coupling between front-ends (both set in high-gain mode) is <−30dB.

## VII. CONCLUSION

A dual-band CDMA2000 diversity RX using zero-IF architecture has been presented. Measured results validate provided assumptions for CDMA diversity use with a SAW-less configuration. Simultaneous-GPS case has also been validated with worst-case jammers scenarios.

### ACKNOWLEDGEMENT

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