UMTS Base Station Receiver Fits in Half-Inch Square

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How much integration is possible while still meeting macrocell base station performance requirements? Process technology dictates that certain key functions are produced in specific processes: GaAs and SiGe in the RF realm, fine-line CMOS for high speed ADCs, and high-Q filters cannot be implemented well in semiconductor materials. Yet the market continues to demand higher integration.

With that in mind, Linear Technology has applied system-in-package (SiP) technology to build a receiver occupying about one-half square inch (just over 3cm²). The boundaries of the receiver are the 50Ω RF input, the 50Ω LO input, the ADC clock input and the digital ADC output. This leaves the low noise amplifier (LNA) and RF filtering to be added for the input, LO and clock generation, and digital processing of the digital output. Within the 15mm × 22mm package is a signal chain utilizing SiGe high

frequency components, discrete passive filtering and fine-line CMOS ADCs.

This article presents a design analysis for the LTM9004 µModule® receiver implementing a direct conversion receiver.
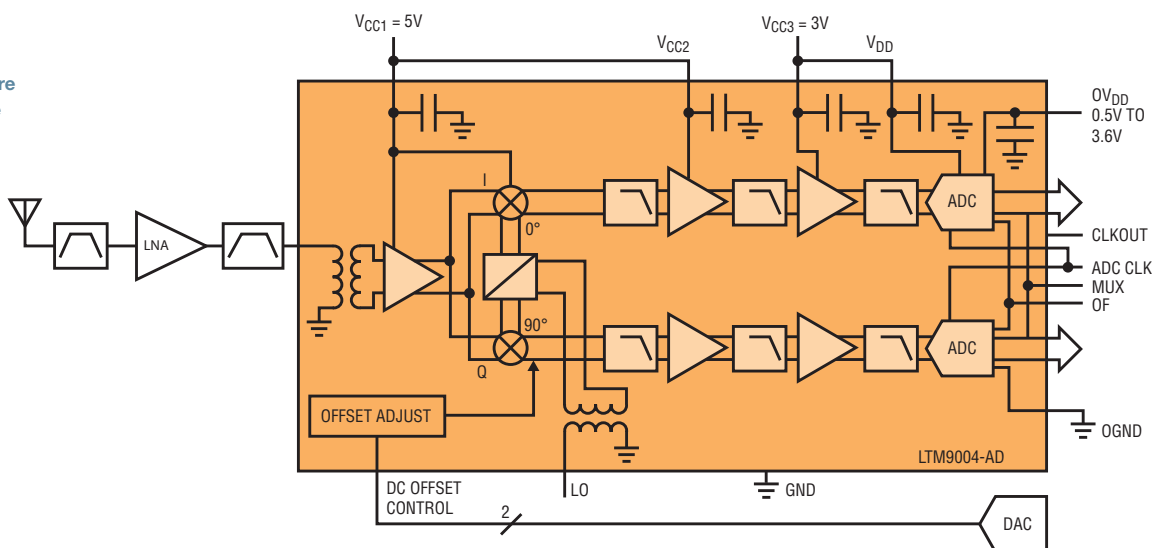
DESIGN TARGETS

The design target is a Universal Mobile Telecommunications System (UMTS) uplink Frequency Division Duplex (FDD) system specifically the Medium Area Base Station in Operating Band I as detailed in the 3GPP TS25.104 V7.4.0 specification. Sensitivity is a primary

consideration for the receiver; the requirement is ≤(−111dBm), for an input SNR of −19.8dB/5MHz. That means the effective noise floor at the receiver input must be ≤(−158.2dBm/Hz).

DESIGN ANALYSIS: ZERO-IF OR DIRECT CONVERSION RECEIVER

The LTM®9004 is a direct conversion receiver utilizing an I/Q demodulator, baseband amplifiers and a dual 14-bit, 125Msps ADC as shown in Figure 1. The LTM9004-AC lowpass filter has a 0.2dB corner at 9.42MHz, allowing four WCDMA carriers. The LTM9004 can be used with an RF front end to build a complete UMTS band uplink receiver. An RF front end consists of a diplexer, along with one or more low noise amplifiers (LNAs) and ceramic bandpass filters. To minimize gain and phase imbalance, the baseband chain implements a fixed gain topology, so an RF VGA is required preceding the

Figure 1. Direct conversion architecture implemented in the LTM9004 µModule receiver

The LTM9004 is a direct conversion receiver utilizing an I/Q demodulator, baseband amplifiers and a dual 14-bit, 125Msps ADC. The LTM9004-AC lowpass filter has a 0.2dB corner at 9.42MHz, allowing four WCDMA carriers.

LTM9004. Here is an example of typical performance for such a front end:

• Rx frequency range: 1920 to 1980MHz

• RF gain: 15dB maximum

• AGC range: 20dB

• noise figure: 1.6dB

• IIP2: +50dBm

• IIP3: 0dBm

• P$_{1dB}$: −9.5dBm

• rejection at 20MHz: 2dB

• rejection at Tx band: 96dB

Given the effective noise contribution of the RF front end, the maximum allowable noise due to the LTM9004 must then be −142.2dBm/Hz. Typical input noise for the LTM9004 is −148.3dBm/Hz, which translates to a calculated system sensitivity of −116.7dBm.

Typically, such a receiver enjoys the benefits of some DSP filtering of the digitized signal after the ADC. In this case, assume the DSP filter is a 64-tap RRC lowpass with alpha equal to 0.22. To operate in the presence of co-channel interfering signals, the receiver must have sufficient dynamic range at maximum sensitivity. The UMTS specification calls for a maximum co-channel interferer of −73dBm. Note the input level for −1dBFS within the IF passband of the LTM9004 is −15.1dBm for a modulated signal with a 10dB crest factor. At the LTM9004 input this amounts to −53dBm, or a digitized signal level of −2.6dBFS.
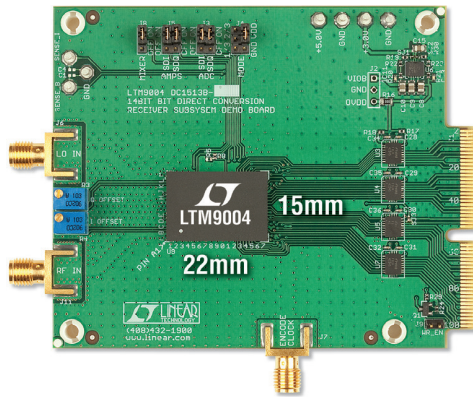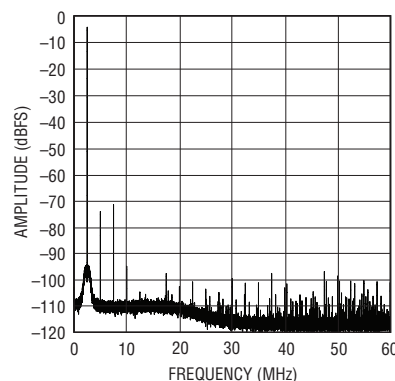

Figure 2. Minimal external required circuitry is required to build a complete receiver

With the RF automatic gain control (AGC) set for minimum gain, the receiver must be able to demodulate the largest anticipated desired signal from the handset. This requirement ultimately sets the maximum signal the LTM9004 must accommodate at or below −1dBFS. The minimum path loss called out in the specification is 53dB, and assumes a handset average power of +28dBm. The maximum signal level is then −25dBm at the receiver input. This is equivalent to −14.6dBFS peak.
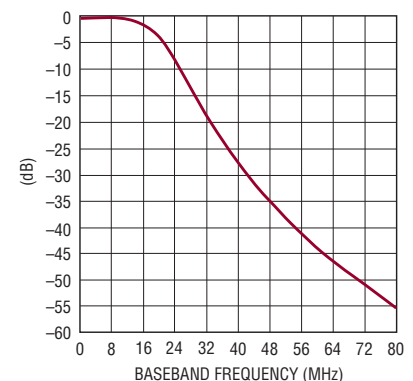
There are several blocker signals detailed in the UMTS system specification. Only a specified amount of desensitization is allowed in the presence of these signals—the sensitivity specification is −115dBm. The first of these is an adjacent channel 5MHz away, at a level of −42dBm. The level of the digitized signal is −11.6dBFS peak. The DSP post-processing adds 51dB rejection, so this signal is equivalent to an interferer at −93dBm at the input of the receiver. The resulting sensitivity is −112.8dBm.

The receiver must also contend with a −35dBm interfering channel ≥10MHz away. The IF rejection of the µModule receiver will attenuate it to an equivalent digitized signal level of −6.6dBFS peak. With the DSP post-processing it amounts to −89.5dBm at the receiver input and the resulting sensitivity is −109.2dBm.

Out-of-band blockers must also be accommodated, but these are at the same level as the in-band blockers which have already been addressed.

Figure 3. Single tone FFT

Figure 4. Baseband frequency response

The LTM9004 can be used with an RF front end to build a complete UMTS band uplink receiver.

In all of these cases, the typical input level for −1dBFS of the LTM9004 is well above the maximum anticipated signal levels. Note that the crest factor for the modulated channels will be on the order of 10dB–12dB, so the largest of these will reach a peak power of approximately −6.5dBFS at the LTM9004 output.

The largest blocking signal is the −15dBm CW tone ≥20MHz beyond the receive band edges. The RF front end will offer 37dB rejection of this tone, so it will appear at the input of the LTM9004 at −32dBm. Here again, a signal at this level must not desensitize the baseband μModule receiver. The equivalent digitized level is only −41.6dBFS peak, so there is no effect on sensitivity.

Another source of undesired signal power is leakage from the transmitter. Since this is an FDD application, the receiver described here will be coupled with a transmitter operating simultaneously. The transmitter output level is assumed to be ≤(+38dBm), with a transmit to receive isolation of 95dB. Leakage appearing at the LTM9004 input is then −31.5dBm, offset from the receive signal by at least 130MHz. The equivalent digitized level is only −76.6dBFS peak, so there is no desensitization.

One challenge of direct conversion architectures is 2nd order linearity. Insufficient 2nd order linearity allows any signal, wanted or unwanted, to create DC offset or pseudo-random noise at baseband. The blocking signals detailed above will then degrade sensitivity if this

pseudo-random noise approaches the noise level of the receiver. The system specification allows for sensitivity degradation in the presence of these blockers in each case. Per the system specification, the −35dBm blocking channel may degrade sensitivity to −105dBm. As we have seen above, this blocker constitutes an interferer at −15dBm at the receiver input. The 2nd order distortion produced by the LTM9004 input is about 16dB below the thermal noise, and the resulting predicted sensitivity is −116.6dBm.

The −15dBm CW blocker also gives rise to a 2nd order product; in this case the product is a DC offset. DC offset is undesirable, as it reduces the maximum signal the A/D converter can process. The one sure way to alleviate the effects of DC offset is to ensure the 2nd order linearity of the baseband μModule receiver is high enough. The predicted DC offset due to this signal is <1mV at the input of the ADC.

Note that the transmitter leakage is not included in the system specification, so the sensitivity degradation due to this signal must be held to a minimum. The transmitter output level is assumed to be ≤(+38dBm), with a transmit to receive isolation of 95dB. The 2nd order distortion generated in the LTM9004 is such that the loss of sensitivity is <0.1dB.

There is only one requirement for 3rd order linearity in the specification. In the presence of two interferers, the sensitivity must not degrade below −115dBm. The interferers are a CW tone and a WCDMA channel at −48dBm each.

These appear at the LTM9004 input at −28dBm each. Their frequencies are such that they are 10MHz and 20MHz away from the desired channel, so the 3rd order intermodulation product falls at baseband. Here again, this product appears as pseudo-random noise and thus reduces the signal to noise ratio. The 3rd order distortion produced in the LTM9004 is about 20dB below the thermal noise floor, and the predicted sensitivity degradation is <0.1dB.

MEASURED PERFORMANCE

Using the evaluation boards shown in Figure 2, the LTM9004-AC achieved excellent results as shown in Figures 3 and 4. The test setup consisted of two Rohde & Schwarz SMA 100A signal generators for RF and LO, a Rohde & Schwarz SMY 01 generator for the ADC clock and TTE inline filters.

The LTM9004-AC consumes a total of 1.83 W from 5V and 3V supplies. AC performance includes SNR of 72dB/9.42MHz and SFDR of 66dB.

CONCLUSION

The LTM9004 exhibits the high performance necessary for UMTS base station applications, yet offers the small size and integration necessary for very compact designs. By utilizing SiP technology, the μModule receiver utilizes components made on optimum processes (SiGe, CMOS) and passive filter elements. ■