Highly Integrated ASICs for CDMA Cellular/PCS Phones

Introduction

The first generation of Cellular and Personal Communication Services (PCS) phones that are based on Code Division Multiple Access (CDMA) relied on limited integration of RF and IF functions (see Figure 1). Integrated Circuits (IC's) were designed to handle automatic gain control (AGC) amplification, upconversion, and power amplification in the transmit chain. In the receive chain, IC's were developed to handle low noise amplification and downconversion, and receive

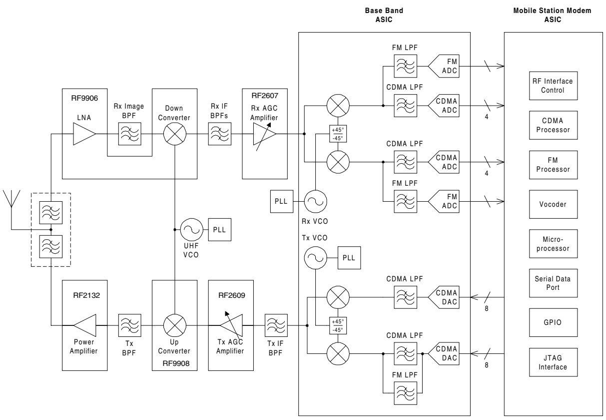

Figure 1. 1st Generation CDMA Cellular Phone Architecture

AGC amplification. Baseband ASIC's were developed separately and included modulation, demodulation, analog/digital conversion, and all other digital processing circuitry. The next generation of phones followed very rapidly with new ideas for integration and chip partitioning (see Figure 2). Phone designers chose to remove quadrature modulation and demodulation functions from the baseband ASIC's and place them in the analog RF/IF chips to alleviate mixed-signal isolation issues and allow for lower power CMOS designs. In order to lower chip count and save valuable phone board real estate, phone designers moved to integrate the transmit AGC amplifier with the transmit upconverter. To accommodate this new CDMA architecture which pushes toward higher levels of integration, RF Micro Devices developed three new integrated circuits. The RF9957 CDMA/FM Receive AGC/Demodulator, the RF2667 CDMA/FM Receive AGC/Demodulator and the RF9958 CDMA/FM Transmit Modulator/AGC/Upconverter are all monolithic IC's that are fabricated in an advanced bipolar Silicon process. All three of these low-cost IC's operate at a 3V power supply and are provided in small QSOP plastic packages.

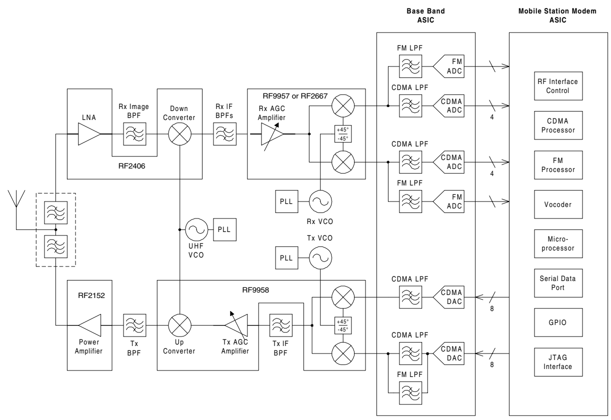

Figure 2. 2nd Generation CDMA Cellular Phone Architecture

Transmit IC

The RF9958 integrates three functions into a single QSOP-28 package: quadrature modulation, variable gain amplification, and upconversion (see Figure 3). In a transmit system the RF9958 receives baseband information from a mixed-signal or digital ASIC in the form of in-phase/quadri-phase (I/Q) data. The RF9958 provides differential input ports that are driven with the I/Q waveforms riding on a DC reference of 0.6VDC. Single-ended operation can also be accommodated if the I/Q data is driven into the ISIG and QSIG pins with the IREF and QREF pins capacitively coupled to ground (see Figure 4). In both cases, the 0.6VDC reference is applied to all four pins.

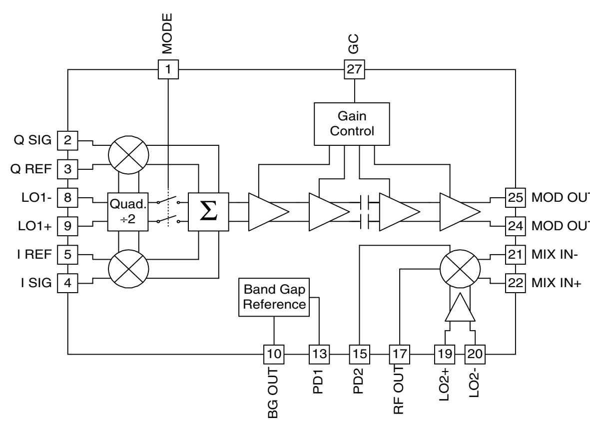

Figure 3. RF9958 Functional Block Diagram

The local oscillator (LO) signal onto which the I/Q data is modulated can also be provided to the part differentially or single-endedly. In general, differential drive is always recommended for ideal operation because it provides symmetrical swings on-chip that give better phase accuracy, but single-ended drive will work adequately. In order to split the incoming LO signal into two signals that are in phase quadrature, the RF9958 utilizes a divide-by-two flip-flop circuit. Consequently, the LO signal provided to the part must be twice the desired carrier frequency. It is common, in an RF transceiver, to use a voltage-controlled oscillator (VCO) that operates at twice the carrier frequency so that VCO leakage into other components of the system does not appear as co-channel interference. The flip-flop circuitry can operate up to 360MHz, which translates to a carrier of 180MHz. If a higher carrier frequency is desired, the flip-flop circuitry can be adapted to operate at higher speeds with minimal effort. Under normal operation the outputs of the flip-flop circuitry are mixed with the I/Q data and sent on to the AGC amplifier. The RF9958 features an option to pass the flip-flop outputs directly to the AGC amplifier and bypass the I/Q mixers. This option is useful for dual-mode (CDMA/FM) phone designers that prefer to do frequency modulation (FM) by modulating a VCO, where the output of the VCO is connected to the LO input of the RF9958. In this instance the modulation and VCO frequencies are operated at twice the desired frequency. Pin 1 (MODE) on the part is the mode select switch that chooses either CDMA or FM mode operation. Logic "high" selects CDMA mode while logic "low" selects FM mode.

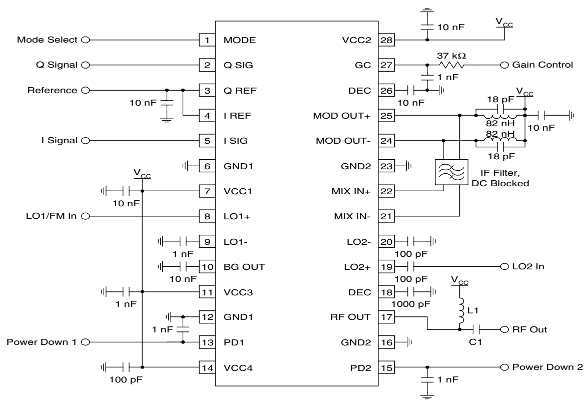

Figure 4. RF9958 Application Schematic

In the IS-98 CDMA cellular system, the cellular base station sends control signals to the mobile phone directing the transmit AGC amplifier to increment or decrement its gain in 1dB steps. As the mobile strays further from the base station, the transmit AGC amplifier is directed to increase its gain and hence, its output power, while the reverse occurs as the mobile approaches the base station. The transmit AGC amplifier in the RF9958 has an 88dB gain range and is controlled by an external DC voltage that is typically generated by a digital ASIC chip on the phone board. With a nominal 300mVp-p I/Q input signal, the AGC amplifier will output over a range of -91dBm to -3dBm into a 200Ω differential load. In FM mode, the AGC amplifier can drive +2.5dBm into the same load. The gain is controlled by varying a DC voltage on Pin 27 (GC). With a 37kΩ series resistor (refer to Figure 4), the specified voltage range is from 0.5VDC to 2.5VDC. Over the majority of the DC control voltage range, the gain adjusts with good linearity; the AGC amplifier also exhibits excellent temperature tracking (see Figure 5). Typically the output of the AGC amplifier is connected to an IF bandpass filter which in turn is connected to an upconverter.

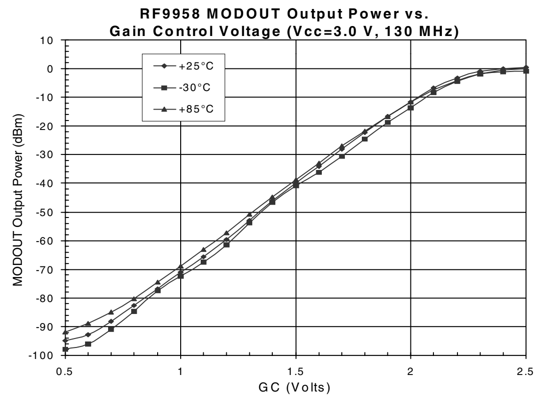

Figure 5. Plot of RF9958 AGC Output Power vs. Gain Control Voltage

The upconverter on the RF9958 is specifically designed around IS-98 specifications but its excellent performance allows it to be used in a variety of applications. It has a typical power gain of 0.5dB (source impedance = 200Ω, load impedance = 50Ω), an output IP3 of +14dBm, and a noise figure of 15dB. It also features a double-balanced mixer that provides LO and IF rejection at the RF output. The IF port is differential with a 200Ω balanced input impedance. The LO port is symmetrical and can be driven differentially or single-endedly. Since most 900MHz VCO's have single-ended outputs, the input impedance of the upconverter LO port is designed to be 40Ω single-ended into either Pin 19 (LO2+) or Pin 20 (LO2-). At the RF output of the upconverter, an impedance transformer is required to present a 50Ω output impedance. This can be accomplished with just two components: a shunt inductor and a series capacitor (refer to Pin 17 in Figure 4). The shunt inductor actually serves two purposes. It acts as a choke to provide DC voltage to the upconverter and it performs an impedance transformation. The series capacitor completes the transformation to 50Ω. This L-C combination can be adjusted to conform to a system's particular frequency range.

In some cases, the quadrature modulator and AGC amplifier are needed, but an external upconverter is preferred. To accommodate an external upconverter for special applications, the RF9958 features a "power down" capability for its internal upconverter. To enable the internal upconverter, the user shorts Pin 10 (BG OUT) and Pin 15 (PD2). Pin 15 is the upconverter "power down" pin and Pin 10 provides a DC reference voltage needed to bias the active circuitry in the upconverter. To "power down" the internal converter, Pin 15 (PD2) is grounded, which results in a 20mA power supply current savings.

Receive ICs

The RF9957 performs all necessary receive IF signal amplification and then demodulates down to I/Q baseband data (see Figure 6). In a typical cellular phone receiver, a low-noise amplifier (LNA)/mixer IC amplifies and then downconverts the RF input signal from the antenna to an IF frequency (refer back to Figure 2). The IF signal then typically passes through a surface acoustic wave (SAW) bandpass filter. The RF9957 takes the signal at this point and outputs baseband I/Q data into an external mixed-signal IC.

The IF inputs of the RF9957 are designed to accommodate either differential or single-ended signals, depending on the SAW filter characteristics. In dual-mode applications where there are two different IF bandwidths, two distinct IF filters are used and thus two IF input ports are required on the RF9957. To date, most system designers have used a differential SAW filter for the CDMA path and a single-ended filter for the FM path, so the application schematic reflects these common choices (see Figure 7). The CDMA input port (Pins 4 and 5) and the FM input port (Pins 8 and 9) are selectable with Pin 14 (IN SEL). A logic "high" selects the CDMA input while a logic "low" selects FM.

The CDMA input port has a 2.4kΩ differential input impedance. An external resistor can be placed across Pins 4 and 5 to lower the input impedance of the port. The FM input port has a 1.2kΩ single-ended input impedance. The AGC amplifier consists of 4 variable gain stages where the last three are common to both the CDMA and FM signal path. So when selecting

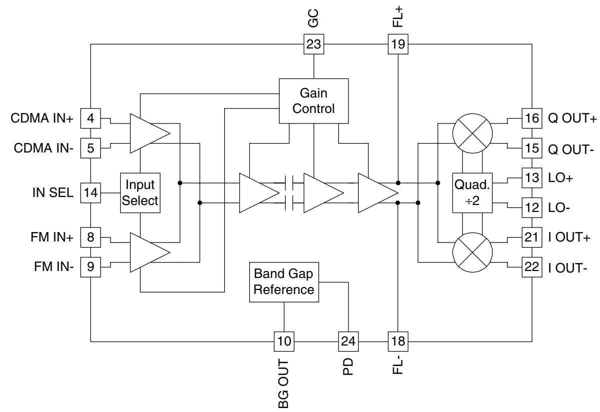

Figure 6. RF9957 Functional Block Diagram

between the two modes, the user is actually choosing which input amplifier stage is being activated.

The AGC amplifier has a typical gain range of 105dB. The typical cascade power gain of the AGC amplifier and demodulator is from -55dB to +50dB (see Figure 8). Since the power gain spec is referenced to a 500Ω source and a 5000Ω load, the cascade voltage gain is from -45dB to +60dB. The cascade noise figure and IP3 performance of the RF9957 are aimed at easy integration into an IS-98 CDMA cellular phone (see Figures 9 and 10). At the output of the amplifier, two pins are provided to allow for bandpass filtering. A parallel tank circuit will provide filtering at the receive IF frequency as well as provide a necessary DC pull-up to the power supply for the AGC output stage. (refer to Pins 18 and 19 in Figure 7).

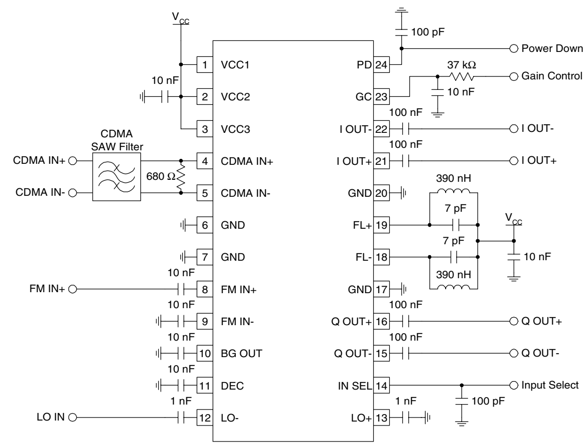

Figure 7. RF9957 Application Schematic.

The output of the AGC amplifier connects internally to the input of the demodulator. The IF signal will enter the demodulator and mix with an LO signal. The output of the mixer will then be I/Q baseband data. The LO input port (Pins 12 and 13) can be driven differentially or single-endedly, but a differential drive will give better phase performance. The input impedance is 400Ω single-ended and 800Ω balanced. The LO circuitry in the RF9957 is very similar to the circuitry in the RF9958 in that it uses a divide-by-two flip-flop architecture to achieve phase quadrature. This implies that the LO frequency must be twice the IF frequency in order to properly demodulate down to baseband. The flip-flop circuitry limits the maximum allowable IF frequency, and in this design the flip-flop circuitry can handle up to about 500MHz (which translates to an IF of 250MHz).

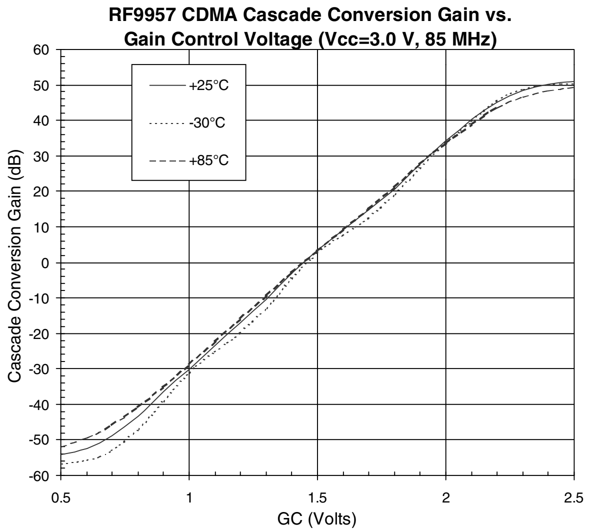

Figure 8. Plot of RF9957 Conversion Power Gain vs. Gain Control Voltage

The output of the demodulator is separated into two ports: I (Pins 21 and 22) and Q (Pins 15 and 16). Both outputs are differential and have 2kΩ balanced output impedances. The power gain specifications for the IC were written for a 5kΩ load on each of the I and Q output ports. If additional voltage gain is desired, then the load impedance should be increased. In order to save power supply current, the RF9957 incorporates a "power down" feature for the Q mixer. When the IN SEL pin is logic "low" (FM mode), the Q mixer shuts down and only the I mixer continues to operate. In CDMA mode, both mixers are in operation. Typically, the I and Q output ports will drive a mixed-signal IC which contains A/D converters and digital low-pass filters.

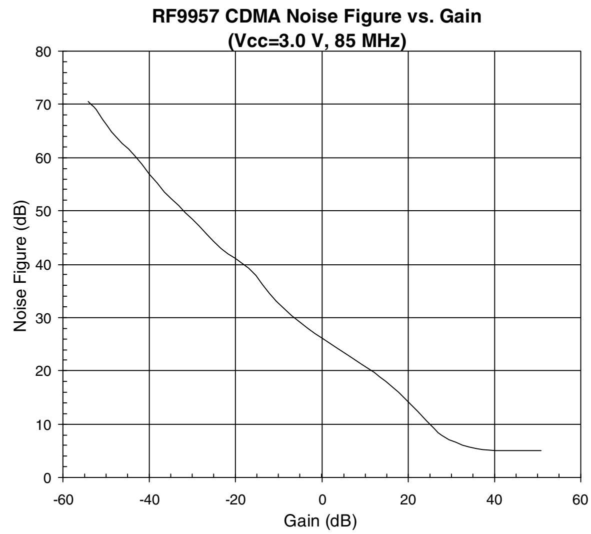

Figure 9. Plot of RF9957 Noise Figure vs. Power Gain

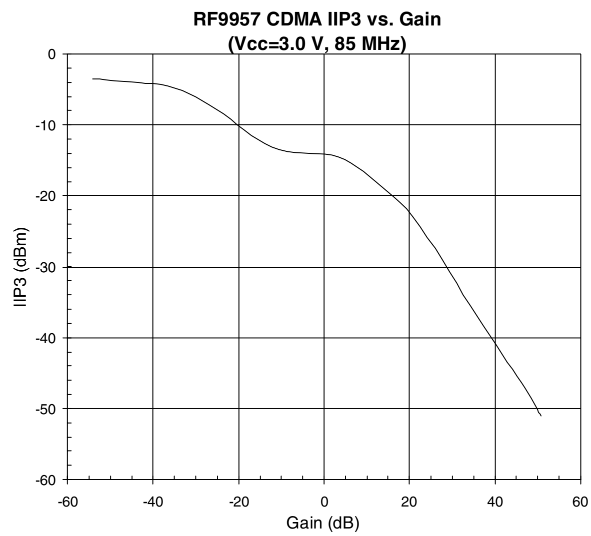

Figure 10. Plot of RF9957 Input IP3 vs. Power Gain

In order to allow greater flexibility, RF Micro Devices also offers the RF2667, which is a slight variation of the RF9957. In the RF2667, the Q mixer "power down" feature has been eliminated, so that when FM mode is selected, both mixers continue to operate. This design change was made to accommodate system architectures that require both I and Q channels to decode FM data. A second difference is in the I and Q maximum output voltage swing. The RF2667 allows up to $2.4V_{PP}$ balanced typical output swing before 1dB compression, whereas the RF9957 allows $500mV_{PP}$. This change was to allow the RF2667 to mate with A/D converters that require higher input voltage levels. Another performance variation is frequency range; the RF2667 will operate up to an IF frequency of at least 300MHz.

Conclusion

Three highly integrated IC's have been created to simplify CDMA cellular transceiver design. The RF9958 packs quadrature modulation, transmit AGC amplification, and upconversion into a single QSOP-28 plastic package. The RF9957 and RF2667 each feature receive AGC amplification and quadrature demodulation in a single QSOP-24 plastic package. All of these IC's are shipping in production volumes and are available today.