RF Design Challenges for CDMA Cellular and PCS Mobile Handsets (*Invited Paper*)

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Abstract

This paper outlines the key RF design parameters for Code Division Multiple Access (CDMA) protocol based cellular and PCS Mobile Handsets. Technical challenges pertaining to the receiver and transmitter are discussed.

Introduction

CDMA is becoming increasingly popular as a digital standard for carriers around the world. The CDMA Protocol has a wide band channel of 1.23 MHz which is used simultaneously by many subscribers. Each subscriber uses a different Walsh Code to allow communication without interference with others. CDMA has enhanced user capacity, improved voice quality, and reduced interference. CDMA standards for the Cellular and PCS bands are described in IS-98 and J-STD-018 documents respectively. The US Cellular Band uses 824-849 MHz for Transmit (Tx) and 869-894 MHz for Receive (Rx) and the US PCS Band uses 1850-1910 MHz for Tx and 1930-1990 MHz for Rx. The modulation technique used is OQPSK for the Mobile Tx and QPSK for the Mobile Rx. In this protocol, the mobile handset transmits and receives simultaneously i.e. full duplex. Table 1 compares IS-98 based CDMA with TDMA, PDC and GSM digital standards.

Standard	IS-98	IS-54	PDC	GSM
Multiple access method	CDMA/FDM	TDMA/FDM	TDMA/FDM	TDMA/FDM
Duplex method	FDD	FDD	FDD	FDD
Full Duplex	Yes	No	No	No
Channel Spacing	1.25 MHz	30 KHz	25 KHz	200 KHz
Modulation	OQPSK/QPSK	Pi/4 DQPSK	Pi/4 DQPSK	GMSK
Bit Rate	1.2288 kb/s	48.6 kb/s	42 kb/s	270.833 kb/s

Table 1

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RF Architecture for CDMA

A typical RF block diagram of a CDMA Handset is shown in Figure 1.

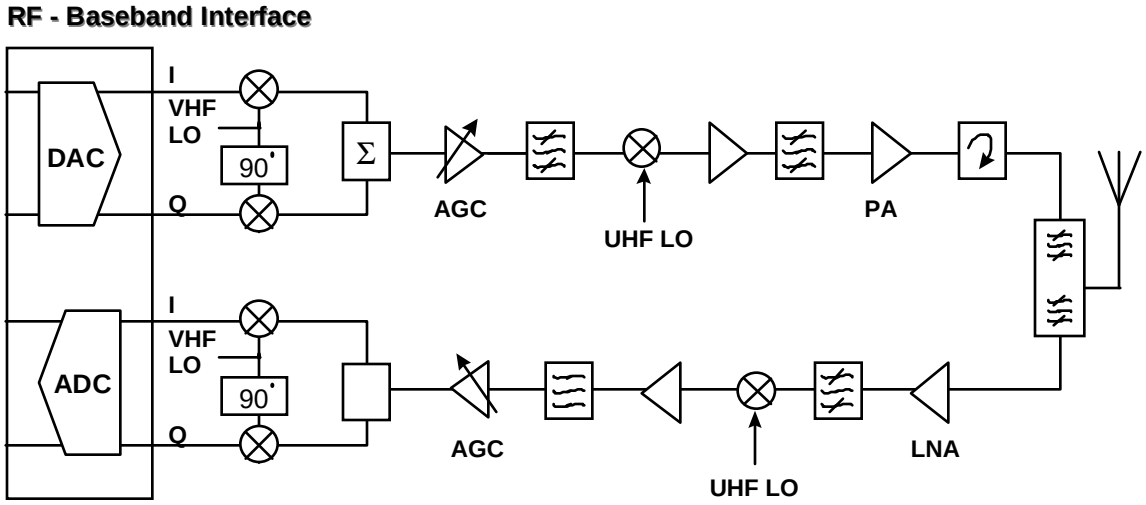

Figure 1

Receiver Design Requirements

The IS-98 and J-STD-018 standards specify that the receiver must be capable of receiving a CDMA signal within the range of -104 dBm to -25 dBm, in practice the dynamic range must be greater than this to allow for component tolerances.

The standards also specify the required performance of the receiver in the presence of strong unmodulated interfering signals. These requirements are slightly different for PCS and Cellular. These tests are Intermodulation Distortion (IMD) and Single Tone Desensitization (STD). For the Cellular band the IMD specification should be met with three different Rx levels of -101, -90 and -79 dBm with 2 interfering tones of -43, -32 and -21 dBm respectively. The Cellular STD test requires a better than 1% FER for an Rx level of -101 dBm and an interfering tone of -30 dBm.

Key Receiver Design Parameters

- **Noise Figure :** The lower receive signal requirement determines the required NF of the receiver. The LNA NF and subsequent Rx chain requirements can be analyzed. This also determines the tradeoff between the transmitter's Rx Band Noise and the duplexer rejection from Tx to Rx.

- **AGC :** The upper receive signal requirement determines the gain compression requirements for each stage of the receiver. This also sets the minimum dynamic range requirement of 79 dB and therefore with gain tolerances (frequency, temperature, voltage and part to part) of the chain, the required IF AGC range can be calculated.

- **IMD :** For the three different IMD levels the front end must be designed in such a way that its characteristics

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can address all three cases. It is usually achieved by having LNA bypassing mechanism in place.

- **STD:** This requirement places stringent design challenges on the LNA and Mixer IP3 design, along with driving the rejection specification for the first IF filter.

Transmitter Design Requirements

For the Mobile transmitter the IS-98 and J-STD-018 standards specify Tx power the Tx dynamic power range and limits of spurious emissions. In Class III for Cellular and Class II for PCS the dynamic power range is from -50 to 23 dBm (minimum).

The power output shall not produce above -42 dBc spectrum re-growth defined at particular offsets from the carrier. And the noise floor need to be below -60 dBm/30 KHz. These spectrum re-growth requirements mandate that the Power Amplifier (PA) and other active modules in the Tx chain are not used in the nonlinear region.

The linearity requirements unfortunately lead to a low efficiency PA and consequently shorter battery life. However the standard demands the ability to 'puncture' or switch off the PA when less than full Tx data rate is required, thereby saving dc power. The ability of the CDMA protocol to transit very low power levels has potential for reduced current consumption.

In addition to the Tx power dynamic range required by the standards the designer must take into account part to part and thermal variations. With this consideration the transmitter requires more than 90 dB of power control range. This is a very challenging task.

The move towards lower battery voltages places further design challenges on the CDMA Tx system design.

Key Transmitter Design Parameters

- **Spectral re-growth :** Spectral re-growth is characterized by adjacent and alternate channel power (ACPR) The minimum standards for the CDMA handset transmitter's ACPR (for adjacent and also for alternate channels) are described in the IS-98 and J-STD-018 standards as shown below:

Cellular	Adjacent Channel	
Center Frequency offset	> ± 900 KHz for 30 KHz BW or > ±1.385 MHz for 1 MHz BW	> ±1.98 MHz for 30 KHz BW or > ±2.465 MHz for 1 MHz BW
Spurs. Levels shall be less than either (a) or (b) and (c)	(a) -42 dBc/30 KHz (b) -60 dBm/30 KHz (c) -55 dBm/MHz	(a) -54 dBc/30 KHz (b) -60 dBm/30 KHz (c) -55 dBm/MHz
PCS	Adjacent Channel	
Center Frequency offset	±1.265 MHz for 30 KHz BW or > ±1.75 MHz for 1 MHz BW	
Spurs. Levels shall be less than either (a) or (b) and (c)	(a) -42 dBc/30 KHz (b) -60 dBm/30 KHz (c) -55 dBm/MHz	

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The ACPR is one of the most difficult specs for the driver and the PA designs to meet, and requires optimum device technology selection and circuit design techniques.

- **Power Control:** Reverse power control in open loop requires a Tx level 73 dB higher than Rx level (76dB for PCS) within tolerances. In Closed loop the standard requires Tx power adjustments of 1 ± 0.5 dB placing additional demands on the RF section. A linear power control range of >90 dB is required to allow for AGC, part to part variation, temperature and frequency variations.

- **Rx Band noise:** Since the CDMA standards require full duplex operation it is essential that the handset's transmitter does not interfere with the handset's receiver. A key parameter is the Tx receiver band noise which once generated by the Tx chain is only attenuated by the duplexer prior to the LNA.

- **Signal Quality Factor (Rho):** This is an important measure of the CDMA transmitted signal quality and is defined as:

$$\rho = \frac{\left| \sum_{k=1}^{M} \underline{r}[t_k] \, \underline{y}[t_k]^* \right|^2}{\sum \left| \underline{r}[t_k] \right|^2 \sum \left| \underline{y}[t_k] \right|^2}$$

It is the correlation coefficient between the sampled waveforms $r[t_k]$ (the ideal waveform at the output of the digital baseband FIR filter used as the reference) and $y[t_k]$ which is the complex envelope waveform of the transmitter. The minimum required value of ρ is equal to 0.944 as stated in the IS-98 section 10.3.2 and in J-STD-018 section 4.3.2.

A good Rho in Tx 'puncture' mode requires among other things that the up-converter LO is not pulled by the puncturing process.

References:

1. TIA/EIA/IS-98-A, Recommended Minimum Performance Standards for Dual-Mode Wideband Spread Spectrum Cellular Mobile Stations, April 1996.

2. ANSI J-STD-018 (SP-3385), Recommended Minimum Performance Requirements for 1.8 to 2.0 GHz Code Division Multiple Access (CDMA) Personal Stations, January, 1996.

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