The MSM5100™ cdma2000 + AMPS + gpsOne™ + Bluetooth Multimode ASIC for 3G Handsets

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Abstract — **The MSM5100 ASIC forms the heart of a high-featured cdma2000 3G handset that is gpsOne position location capable. The gpsOne technology meets the accuracy requirements set by the FCC for E911 Phase II. This ASIC performs baseband processing for the spectrum of air interfaces supported: IS-2000 Release 0, IS-95A/B, AMPS, GPS, and Bluetooth 1.1. The ASIC itself is both a merging effort of two previous ASIC designs, MSM3300 and MSM5000, and the addition of new functionality. The new functionality includes USB speed enhancements and increased IS-2000 physical layer support. Also, several new VLSI challenges were met in creating this product, including our product in the 0.18 um process and integrated voltage regulators. Altogether, the MSM5100 makes a significant leap forward in 3G handset functionality.**

I. Introduction

The MSM5100™, an integrated Mobile Station Modem™ (MSM) produced by QUALCOMM, Incorporated, forms the core of a full-featured third generation CDMA handset. It is based primarily on two predecessors, the MSM5000™ and the MSM3300™. The MSM5100 was an achievement in feature integration and support for new cdma2000 physical layer features. Critical to its success was the use of a new digital CMOS process and new packaging technology.

II. MSM Family

The MSM roadmap (Figure 1) shows the parallel paths between the IS-95-A/B[1] and the cdma2000-1x[2] ASICs that make up the MSM 3xxx and 5xxx series. Each upward arrow represents a pin-compatible transition to 1x standard support with identical levels of integration and application features. The MSM3000[3] is shown at the bottom-left, with the features that it first introduced. The MSM5100 is shown at the middle-right as primarily an integration step of the two paths. The MSM5100 also bears many feature similarities to the MSM5500, which is the first commercial ASIC with 1xEV[4] standard support.

The MSM5100 is a mixed-signal baseband ASIC package that enables manufacturers to meet or exceed the specifications of 3G handsets for cdma2000 1x systems worldwide, in radio bands such as 800 MHz cellular (North & South America, Korea, Japan, China, Australia), 1900 MHz PCS (North & South America), 1800 MHz PCS (Korea), 450 MHz (Eastern Europe), and 1900-2100 MHz IMT2000 (Europe and Asia).

III. The MSM Predecessors

The following feature breakdown of the MSM5100's predecessors illustrates how features are introduced in various ASICs at various points in time and at various levels in the product line. Each of these features was completely integrated and tested on its original platform, significantly reducing the integration time and risk for a chip as complex as 5100.

The MSM3300 ASIC on which the MSM5100 is largely based, primarily added the following new features:

- Position location processor based upon gpsOne™ technology. It is capable of extracting ranging measurements from Global Positioning System (GPS) satellites and the cellular/PCS CDMA network.
- Bluetooth baseband processor.
- MP3 (MPEG1 Layer3) music decode and an interface to external stereo DAC.
- Compact Media Extension (CMX) support for applications requiring time-synchronized multimedia outputs of MIDI-based music, text, graphics and voice. The embedded QDSP2000 supports a 16-polyphony, 128-instrument MIDI wave-table synthesizer.
- Integrated mass-storage device (MMC) controller.

The MSM5000 ASIC which also preceded the MSM5100, primarily added the following 1x features:

- IS-2000 1x, P_REV 6 standard compliant, including fast forward power control, Radio Link Protocol

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(RLP3) for packet data, and backward compatibility to IS-95-A/B and AMPS.

- Fundamental Channel support of IS-2000 1x provides a near doubling of network voice traffic capacity over IS-95-A.
- Supplemental Channel support for at data rates up to 153.6 kbps forward or reverse links.
- Turbo and Convolutional encoder / decoder functionality at all data rates.
- Large on-chip SRAM to assist processor loading issues at the higher data rates.
- Quick Paging Channel for improved standby time.
- A new 16x CDMA searcher that is additional to and independent from the 8x searcher.
- Enhanced transmit gain control stepping.

On a historical note, the MSM5000 may well be the world's first and only Turbo decoding device that has shipped over a million units as of December 2001.

For market segmentation reasons, the MSM5105 removed the Turbo code support and on-chip SRAM of the MSM5000. This slightly limits the higher data capabilities of that ASIC. Alternately, the full-featured MSM5100 returns support of those features and adds many more.

The MSM3100 ASIC which preceded the MSM5100, 5105, and 3300, primarily added the following features:

- Integrated transmit digital to analog converters.
- Integrated voice CODEC directly interfaces to the microphone and earpiece.
- Integrated clock PLLs for added flexibility in selection of VCTCXO frequency.
- Universal Serial Bus (USB) controller.
- Tri-mode software for support of 800 MHz CDMA, 800 MHz AMPS, and 1900 MHz CDMA in a single phone.
- QDSP2000 Digital Signal Processor Core for higher performance on applications such as voice recognition.
- Removable Universal Identity Module (R-UIM) card interface supported; (i.e., CDMA SIM card).

IV. ASIC Statistics

The MSM5100 ASIC is only available in the 208-ball Fine-Pitch Ball Grid Array (FBGA) package, sized 15mm x 15mm. See Figure 2 for a high-level diagram of interfaces.

The ASIC design database was completed in October 2000. The MSM5100 chipset sampled in March 2001, and entered volume production near the end of 2001, including system software and reference phone design.

The MSM5100's digital section is made in a 0.18 um CMOS process, operates at a supply V_{dd} of 2.3 - 3.0 Volts. In nominal operation, the ARM7TMDI microprocessor runs at 33 MHz and the QDSP2000 application DSP runs at 27 MHz.

V. Voltage Regulators

The speed of the 0.18 um process over the previous process allows us to drop the internal supply voltage to run the digital circuits for an equivalent clock rate. To do this, on-chip voltage regulators are added to this ASIC.

There are several voltage regulators for the digital core. They regulate the external (2.5 to 3.0 V) to the internal core voltage of (1.625 to 1.98 V).

The voltage regulators are under software control. In the process of optimizing current consumption, the controller software has implemented dynamic voltage switching to match speed requirements.

VI. USB Improvements

For MSM5100, the USB design is modified from the earlier MSM3100 device to reduce the servicing load of the microprocessor and to support increased data rates. The packet size of the endpoints, DS and DM, are enlarged; and new forward and reverse link FIFOs are added.

VII. gpsOne Technology

The MSM5100 is the first commercial ASIC to offer position location technology over a 3G CDMA network. Using the gpsOne™ hybrid solution, a mobile handset with MSM5100 collects measurements from both the GPS constellation and the CDMA network in order to provide a position fix. QUALCOMM, together with Snaptrack, developed the hybrid solution to take advantage of the complementary nature of the CDMA and GPS networks. GPS receivers typically excel in rural areas, generally seeing four or more satellites. Conversely, in dense urban areas and inside buildings, GPS receivers often see an insufficient number of satellites to calculate a position fix, but have access to multiple cell sites. By combining the two information sources, gpsOne position location solutions can provide a position fix with as few as one satellite and one cell site.

When a request for position location is issued, the handset takes measurements of the pilot signals it receives, and then requests assistance from the Position Determination Element (PDE). The PDE sends GPS assistance information to the handset. This additional

information allows the mobile unit to acquire the GPS signal much more rapidly than a standalone GPS receiver and enhances the sensitivity of the gpsOne receiver by 20 to 30 dB.

The GPS receiver in MSM5100 directly leverages baseband and RF processing blocks and used by the CDMA receive chain to achieve a high level of integration. In contrast with discrete conventional solutions commonly found in the industry, the MSM5100 device includes a gpsOne core tightly linked to the on-chip DSP. This high level of integration provides industry-leading performance while having negligible impact on handset size, weight, and power.

This technology has been extensively field tested, deployed in Japan, and on October 1, 2001, Sprint PCS began selling phones in the US containing gpsOne technology. This technology provides a level of precision in position location that exceeds the FCC's requirements (typically within 10 to 30 meters) to pinpoint the location of wireless callers to 911.

The MSM5100 solution will also enable a broad range of future 3G GPS-related software and services, including navigation information, area-specific weather forecasts, traffic reports and commercial tracking services, as well as a broad range of entertainment applications.

VIII. New Physical Layer Support

The MSM5100 ASIC design team undertook the effort to incorporate physical layer support of IS-2000, Release A[5] and several other enhancements. Release A is also known as phase 2 of the cdma2000 standard series, as it incorporates more features and requirements. The following handset features are required to meet the standard as published:

- New overhead channels (see list below).
- Auxiliary pilot support.
- Forward power control: 3 new modes.

Below we introduce the abbreviations used for the Release A new overhead channels ("F-" indicating forward link; "R-" the reverse link):

Broadcast Control Channel	*F-BCCH*
Common Control Channels	*F-CCCH, R-CCCH*
Common Assignment Channel	*F-CACH*
Common Power Control Channel	*F-CPCCH*
Enhanced Access Channel	*R-EACH*

The following additional physical layer features, which are newly allowed in the Release A standard, were also incorporated into MSM5100 even though not mandated by the standard:

- VP2 bearer service profile for simultaneous voice and packet data traffic. This requires support of 3 simultaneous traffic channels for both receive and transmit (FCH, SCH, DCCH).
- Space-Time Spreading (STS) transmit diversity option for traffic channels. Note, that the phase 1 standard contained an Orthogonal Transmit Diversity (OTD) option for traffic channels.
- STS and OTD transmit diversity options for the new forward link overhead channels.
- 307.2 kbps data rate (limited support).

Table 1 summarizes the various sets of physical layer parameters of every Release A overhead channel. Most of the forward link channels run at two different convolutional code rates. Most all of these channels may run at three distinct data rates. There are various combinations of data rate and frame size specified as shown. The handset is required to support all code rates, data rates and frames sizes. All together, these total 69 new forward link configurations and 13 reverse, assuming that OTD and STS are both supported.

With the new overhead channels, come significantly new Medium Access Control (MAC) and signaling procedures, including:

- Basic Access procedure including a new MAC layer in handset to select a data rate and frame size before transmitting on the R-EACH.
- New Reservation Access procedure in which requests for access resources are scheduled and these scheduled transmissions (on the R-CCCH) may be power controlled without using a traffic channel.

Table 2 summarizes the modes of Forward Power Control (FPC) from IS-2000-A. As shown, the Release A standard adds FPC_MODEs '100', '101', and '110.' Mode '100' introduces the concept of QIB. Previously, Erasure Indicator Bit (EIB) signaled when the mobile station detected that a frame was received in error and/or not transmitted. The Quality Indicator Bit (QIB) is meant to take into account channel quality estimation and signal good or bad channel quality regardless of whether a frame was transmitted or not. While more complex, this was thought to solve some difficulties of using EIB on the F-DCCH channel where activity may allow frequent no-frame transmissions (termed "DTX"). Modes '101' and '110' introduce 50 Hz feedback for more reliable and efficient power control of the secondary subchannel.

Auxilary Pilots are introduced in the standard to support forward link beam-forming and overlay subsectors. The base stations are allowed to transmit many auxiliary pilots. They may be dedicated to single users or groups of users. The auxiliary pilots are continuously transmitted in a code channel formed by an orthogonal Walsh function (of length 128, 256, or 512 PN chips) or a

Quasi-Orthogonal Function (QOF). The auxiliary pilots can interact with many handoff related signaling messages. The mobile station is required to support auxiliary pilots by the Release A standard. Additionally, if the mobile supports transmit diversity operation, the standard expects that the "Auxiliary Transmit Diversity Pilot Channel" is also supported. This allows for simultaneous use of transmit diversity and auxiliary pilots.

The discussion of Release A here merely focuses on the MSM5100's support for the IS-2000 Release A physical layer. The features listed in this section have made the MSM51000 a valuable tool for Release A software development and field test. This development and testing will make it possible to offer commercial Release A support in the MSM6xxx series of ASICs.

IX. Conclusion

A brief overview of a complex ASIC for wireless communications has been presented. The focus has been on the improvements beyond its several predecessors, with special focus on feature integration and 3G CDMA support.

Acknowledgements

The authors would like to thank the entire MSM5100 team, and all other contributors.

References

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[4] TIA/EIA-IS-856, "cdma2000 High Rate Packet Data Air Interface Specification," published November 2000.

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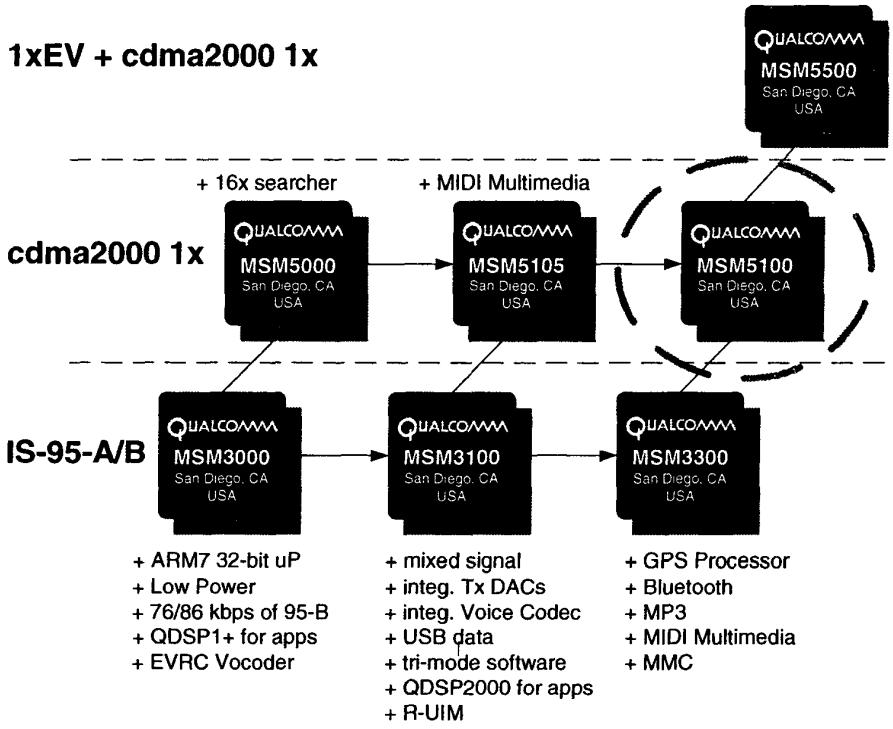

Figure 1. MSM Roadmap of the 3xxx and 5xxx series, highlighting the MSM5100

Table 1. Summary of Release A Physical Layer Requirements for Overhaed Channels

Physical Channel	Code Rate Modes	Modes of Data Rate & Frame Size				Other Handset Notes
		38.4 kbps	19.2 kbps	9.6 kbps	4.8 kbps	
F-BCCH	1/2, 1/4	-	40 ms slot	80 ms slot	160 ms slot	OTD and STS optional
F-CCCH	1/2, 1/4	5,10,20 ms	10,20 ms	20 ms	-	OTD and STS optional
F-CACH	1/2, 1/4	-	-	5 ms	-	OTD and STS optional
F-CPCCH	none	19.2 kbps, unframed				OTD and STS optional
R-EACH	1/4	5,10,20 ms	10,20 ms	5*,20 ms	-	gated preamble mandatory
R-CCCH	1/4	5,10,20 ms	10,20 ms	20 ms	-	gated preamble mandatory
**Enhanced access has 5 ms header at 9600 bps for Reservation Mode*						
Note: Handset selects physical layer mode from BS supported set using MAC Procedures and BS parameters: ACCESS_MODE_MAX_DURATION, MIN_DURATION						

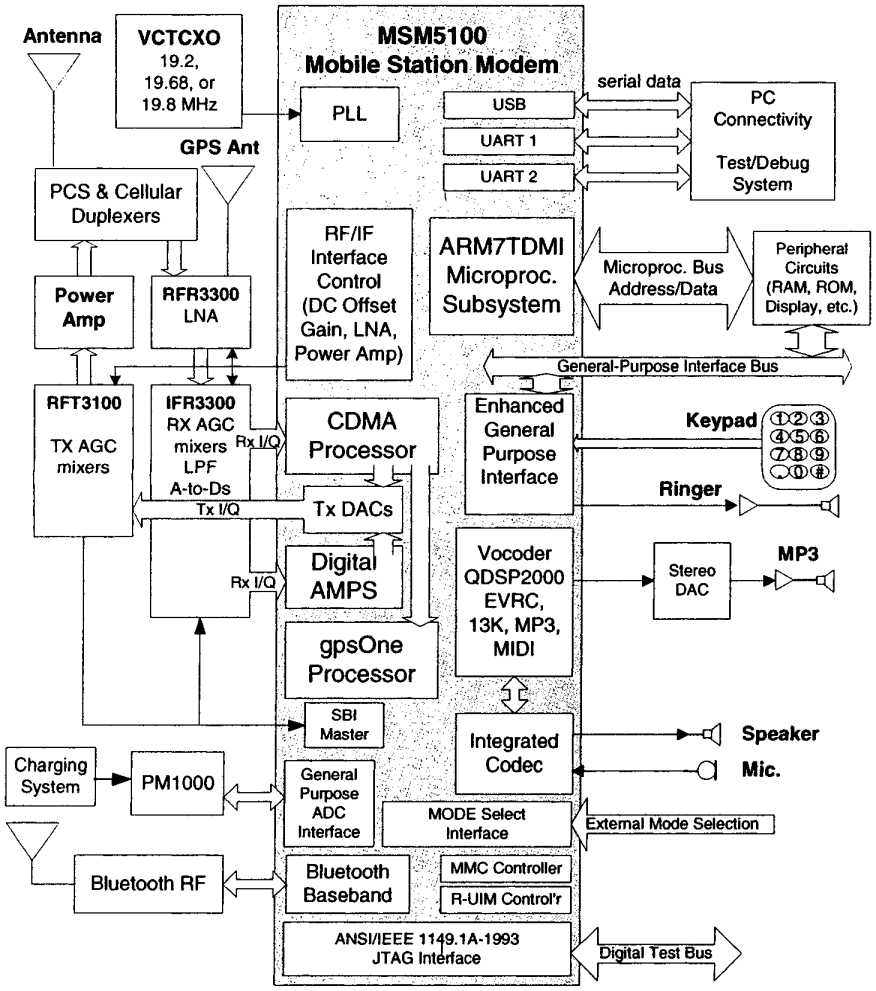

Figure 2. Conceptual diagram of MSM5100 functions integrated in a phone

Table 2. Summary of Forward Power Control Modes

FPC_MODE	Primary Reverse Power Control Subchannel (F-FCH or F-DCCH derived)	Secondary Reverse Power Control Subchannel (F-SCH0 or F-SCH1 derived)
'000'	800 Hz	-
'001'	400 Hz	400 Hz
'010'	200 Hz	600 Hz
'011'	50 Hz (EIB)	-
'100' *	50 Hz (QIB)	-
'101' *	50 Hz (QIB)	50 Hz (EIB)
'110' *	400 Hz	50 Hz (EIB)
'111'	reserved	reserved
* = Added with Release A of IS-2000		