Sandbridge SDR Processor Technology with Application to MIMO-OFDM Receivers

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Agenda

Sandbridge Introduction
- Market Observations
- Sandbirdge Solution

Architecture

Software
- IDE
- Compiler
- Simulator

Communications
- 2.5G / 3G
- WLAN
- DVB-T

MIMO OFDM DVB-T

Results

Summary
Sandbridge Technologies

E-Gang
Bridging The Gaps
Scott Wookley, 03.01.03

Guenter Weinberger
CEO, Sandbridge Technologies

Guenter Weinberger runs a company that is barely two years old, has only 40 employees and has yet to earn a dime. But, boy, does this guy have big dreams. "I don't want to appear too far away from reality," he says, "but we have the technology to become the next Intel."

What 78,000-employee Intel is to the PC industry, Weinberger thinks his shop, Sandbridge Technologies, can be to the cell phone industry—which spent $20 billion on chips last year.

He aims to achieve this audacious feat by solving one of the most glaring—and annoying—problems for cell customers: the alphabet soup of incompatible standards that hinders a multitude of networks from easily hooking up with one another. Today's global traveler must lug different phones for different countries (and endure incompatible voice mail boxes and different phone numbers and bills).

In the U.S., three utterly incompatible network schemes hurt service and befuddle consumers. Time Division Multiple Access (AT&T Wireless and Cingular), Code Division Multiple Access (Verizon, Sprint and T-Mobile) and Groupe System Mobile (again, AT&T and Cingular)—plus a separate stand-alone scheme for Nextel—all vie for adopters. And even more new wireless standards, such as the three flavors of Wi-Fi, are spreading fast.

Weinberger's new chip acts like a wireless Rosetta stone, able to imitate any other chip—and thereby mimic any of today's cell phones. To a Sandbridge chip it doesn't matter if your cellular carrier is Sprint or Nextel or whether you are in Europe (GSM) or South Korea (CDMA). Just download a bit of software and your phone can talk the local language.

Sandbridge chips' multilingualism also applies to Wi-Fi or Bluetooth, the most popular data transmission standards. Once a phone or laptop can jump among all available standards, it can easily hop to whichever network is fastest and cheapest. That will help pry open the last-mile jam, letting future devices provide instant access to the best network and cheaply adapt to new standards that allow signals to carry more data or travel longer distances.

Traditionally, engineers who wanted multilingual phones had to laboriously design custom chips, "(Dual-mode" cell phones that can hop between, say, TDMA and GSM, have been around for years.) Once they are finally designed, such chips can be mass-produced cheaply and consume a reasonable
What is it that we eventually carry with us?

It has a color screen, camera, audio and antenna …
… but all features need high computing performance and ultra low power consumption

- **Wireless communication** 2G – 2.5G – 3G – WLAN – BT – etc.
  - GSM/IS-95a,b/IS-136/PDC/ iDEN – CDMA2k/GPRS/EDGE – FDD/TDD/TD-SCDMA/Jap.WCDMA/CDMA2k-3x– 802.11a,b,g

- **Radio broadcast** GPS – radio – TV – etc.
  - Location based services/911/tracking services – AM/FM/DAB – Sat./Terr.TV

- **Encryption** – decryption – media encode – media decode

- **Games** – speech to text – natural language processing

sources: In-Stat/MDR, TSR, Dresdner, Dataquest
A Whole Industry’s approach failed …

... with multimedia

... on advanced wireless systems ...
The Sandbridge Approach …

**SandBlaster™ DSP**
- Programmable
- Ultra-low power
- High-performance
- Multithreaded

**SandBlaster™ Tools**
- Improved productivity C compiler
- 70% reduction in time-to-market
- User-friendly

**DSP Platform**
- Scalable & Programmable
- Integrated Sandblaster cores
- Up to 2Mbit/sec data rate
- 40,000 RISC MIPS
- Low Cost 0.13um CMOS
- Integrated protocol stack

**DSP Ref Design**
- Low Cost
- Power Efficient
- Ultra-high performance
- Fully tested / validated
- Dedicated Customer Support
- Flexible and upgradeable

Core technology equally applicable to Networking, Storage, Automotive, GP-DSP, etc.
ONE platform for ALL Mobile Devices

Compiler

Architecture

Optimize

Cost / Power
Performance

Sandbridge provides the raw processor platform

Implement any feature in SW

AAC, MP3, IS-95, GSM, CDMA, GPS, Bluetooth, IS-136, 802.11b, PDC, Java, MPEG-4, 802.11a, TD-SCDMA, USB, USCDMA, WCDMA, AAC, WCDMA, Jav, CDMA, 802.11b.
Sandbridge One Global Solution

**SW Applications**

- Communication
  - 2.5G
  - 3G
  - WLAN
  - GPS
  - ...
- Video
  - MPEG2/4
  - Photo
  - Video clip
  - Conferencing
  - ...
- Audio
  - MP3
  - AAC
  - Atrac3
  - Vocoders
  - ...
- Broadcasting
  - GPS
  - Dig. TV
  - Dig. Audio
  - ...
- Voice Recognition
  - Speech-to-text
  - Command
  - Language
  - ...

**HW Platform**

- One Digital Solution
- RF
- Memory
- USIM
- MMC/SD
- Peripherals Circuits

**Applications**

- Games
  - E-commerce
  - M-commerce
  - Encryption
  - ...
- Security
Handset design at C level in min. time

Simulation Speed (1GHz Laptop)

<table>
<thead>
<tr>
<th></th>
<th>Millions of Instructions Per Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB</td>
<td>24.639</td>
</tr>
<tr>
<td>TI C64x (Code Composer)</td>
<td>0.114</td>
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<tr>
<td>TI C62x (Code Composer)</td>
<td>0.106</td>
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<tr>
<td>SC140 (Motorola)</td>
<td>0.002</td>
</tr>
<tr>
<td>ADI Blackfin (Visual DSP)</td>
<td>0.013</td>
</tr>
</tbody>
</table>

Complete system design in C

- Cycle accurate simulator delivers immediate feedback
- Design for conformance in C

AMR Encoder (out-of-the-box C code)

System performance by design

- Parallelizing compiler generates production assembly code
- Multithreading (sea-of-threads) ensures concurrent execution

SB 24.639
TI C64x 0.114
TI C62x 0.106
SC140 0.002
ADI Blackfin 0.013
Architecture
Sandbridge Design Approach

- Beginning to-end design
- All components of design considered
Sandblaster Architecture Performs

Compilable DSP

C programmed Latency hiding architecture

System Productivity Advantage
9-12+ months

Java Processor

3G Applications Standard

Control Processor

3G, xDSL, 802.11 Control Stacks
Multithreaded Architecture Enables C

Key to Low Power Implementation

Thread 0
# Monitoring FCCH&SCH
lu r1,M(r2)
lvr1,M(r2)
call (De_scrambler)
stu r3,M(r2)

Thread 7
# Monitoring CPICH
lu r1,M(r2)
lvr1,M(r2)
call (De_scrambler)

Thread 6
# Handover Code
csrr r1,sr2
lu r1,M(r2)

Thread 5
# FIR Filter
lvu vr1,M(r4)vmacs
vr3,vr1,vr2,wr0
loop lcr0,label(4x)
Thread 4
# Pulse shaping Code
lvuvr1,M(r4)vmacs vr3,vr1,vr2,wr0
loop lcr0,label(4x)

Thread 3
# WCDMA Handover Code
csrr r1,sr2
lu r1,M(r2)

Thread 2
# Exit Code
.
.

Thread 1
# WCDMA Main
Start Thread0
Start Thread1
Start Thread2

Code & Data Sharing Across Threads

Java Processor

System Productivity Advantage
9-12+ months

Highly Parallel
Fast Cross Thread Interrupts

Compilable DSP
C programmed
Latency hiding architecture

Hardware Scheduled
Fully Interlocked
C Programmed

Code Processor

3G Applications Standard
3G, xDSL, 802.11
Control Stacks

Latency hiding architecture

Sea of Threads

Start Thread33
Start Thread24

Start Thread14
loop lcr1,0xf0

3G, xDSL, 802.11
Control Stacks
High Parallelism
- Vector / SIMD data parallelism
- Multiple instruction issue
- Thread-level parallelism
0.18um CMOS ASIC
Single DSP Core
SW Programmable

- External Bus for L2 memory
- Internal Inst/Data memory
- Control Interfaces: I^2C, SPI, TDM, A/D, D/A
SB3000 Handset Chip

- Replicated SBTC core
- Low Power design
Sandbridge Software Tools
Sandblaster Tools

SaDL

C

C++

Java

Sandblaster Compiler

sb.o

Binary Translator

x86
asm

C

x86
asm

compiled simulator

dynamic simulator
Compiler Optimizations – Dragon Book +

**Loop Optimizations**
- Loop Invariant Code Motion
- Strength Reduction
- Induction Variable Elimination
- Loop Splitting
- Software Pipelining

**Vector Optimizations**
- Vector Loads
- Vector Stores
- Vector Arithmetic
- Vector Reduction
- Saturating Vector Operations

**DSP Optimizations**
- Saturation Arithmetic
- Fixed Point Semantic Analysis
- Bit-exact ETSI compliance

**Multithreaded Optimizations**
- OpenMP
- Automatic Parallelization
- Automatic Multithreading

**Interprocedural Opts.**
- Constant Propagation
- Memory Disambiguation
- Function Inlining
- Alias Analysis
Java Support

Java J2ME implementation

- KVM 1.0 bytecode engine
- CLDC 1.0
- MIDP 1.0 support provided
  - MIDP 2.0 3Q04
- Multiple Java threads execute on multiple H/W thread units
  - First known hardware multithreaded KVM
  - Sandblaster tools compile KVM with Java-specific optimizations
  - Java is another application on the Sandblaster processor
  - A java thread is scheduled on any available hw thread unit
    - Dynamic number of hardware thread units may be used
  - Synchronization mechanisms fully supported
  - Multithreaded Garbage collection supported
Development Environment

Host Platform (Windows, Linux)

Application Software (C)

Integrated Dev. Environment

Compile

Assemble & Link

Performance Analysis

Debug

Simulate

Target Platform

SW Tool Kit

SandBlaster™ Dev. Board
Integrated Development Environment (IDE)

Based on Java open source netbeans

- Enhanced with
  - C compilation and editing tools
  - Source debugger
  - Project management
  - Scripting languages

Automatic Error recognition

Works in multiple languages too!
DVB-T MIMO OFDM
Communications System
Implementation
Integration

- MMI
- APPLICATION TASKS
- PROTOCOL STACK
- L1 CONTROL
- L1 BASEBAND SW
- DATA I/O
  - LCD, KPD ...
- IF
- RF
Development Methodology

**MATLAB physical layer**
- End-to-end UTRAN + UE
- Channel models
- Configurable via test-scripts
- BER/FER measurement

**Simulation level C**
- Fixed point
- UE only
- Fixed configuration
- Performance measurement

**Product level C**
- Partitioned for real-time
- Using actual peripherals
- Integrate with L1 control + L2/L3

**Physical layer testing**
- UTRAN model validated against test equipment
- models & test cases specifications used to test Matlab & C
DVB-T Receiver

OFDM Receiver
DVB-T Rx with Spatial Diversity Input

OFDM Receiver
Sandbridge OFDM Receiver implemented in Software
MIMO OFDM DVB-T Rx Performance

Multiple receivers with equal weight combining

64 QAM, Rate $\frac{1}{2}$, portable Rayleigh fading,
$10^{-11}$ Quasi Error Free BER conforming to
ETSI EN 300 744 V1.4.1 (2001-01)
Communications Results

% SB3000 Utilization

- 802.11b: 1/2/5.5/11Mbps
- GPS: 75m .5sec xyz
- AM/FM: 5m .1sec xyz
- Bluetooth
- DVB-T OFDM Rx
- GPRS
- WCDMA: Class 10/12 64/384/2k Kbps