Mixed signal systems and integrated circuits

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Contents

• Mixed signal systems
• High speed A/D converters
• High speed D/A converters
• Sigma delta A/D and D/A converters
• Wireless systems and RF CMOS circuits
• PLL and related systems
Aim of this lecture

• Understanding basic current mixed signal systems
  – Wireless transceiver
  – Image sensor and Plat panel display

• Understanding basic mixed signal circuit building blocks: basic operation method and basic design method
  – A/D and D/A converter
  – Sigma-delta modulation
  – Phase Lock Loop and Delay Lock Loop
  – Low Noise Amplifier
  – Frequency Mixer
  – Voltage Controlled Oscillator and Frequency Synthesizer
  – Image Sensor, LCD driver, Organic EL driver

• Understanding current design methodology
1. Mixed signal systems
Current electronics and mixed signal technology
A new consumer electronics era has been emerged. Key technologies are the digital multimedia and System on a Chip.
The LCD driver is a simple example of a mixed signal LSI.
The LCD driver is an array of DA converters.
Digital consumer electronics and networking drive current electronics.
Mixed signal technology : Digital networking

The mixed signal technology enables a high speed digital networking.

Data conversion
Data and clock recovery

Equalization
Noise cancellation

Encryption
Error correction

Analog circuit
Digital circuit
x-DSL

ADSL and VDSL use the mixed signal technology

- **ADSL-service**, 0.5–8Mbps (Dwn)/1Mbps (Up) for 5–6Km
- **VDSL-service**, 13–52Mbps (Dwn) for 0.3–1.5Km

- 96-tap Decision Feedback Equalizer (DFE)
- T=8 Reed-Solomon Forward Error Correction (FEC)

4~256-QAM modulation
- → 60MHz 10-bit ADC and DAC for VDSL
- → 5MS/s 14-bit ADC and DAC for ADSL
Digital storage also needs high speed the mixed signal technologies.
Mixed signal SoC for DVD RAM system

This enables a high readability for a weak signal from the DVD RAM pickup.

World fastest and highly integrated mixed signal CMOS SoC

0.18um- eDRAM

24M Tr
16Mb DRAM

500MHz
Mixed Signal

Goto, et al., ISSCC 2001
Recent developed mixed signal CMOS LSIs

5G RF LAN
- 12b 50MHz ADC 2ch
- 12b 50MHz DAC 2ch

AFE for ADLS
- 12b 20MHz ADC+DAC

Digital network
- 1394b (1GHz)

AFE (Analog Front End)

AFE for Digital Camera
- 12b 20MHz ADC+AGC

2GHz RF CMOS
Digital consumer products are ramping up rapidly

The DVD (mixed signal) shipment exceeds a conventional VTR (analog)

The digital camera (mixed signal) shipment exceeds a conventional optical camera

It reaches over 30 Million in the world.
Application area in mixed signal CMOS tech.

Almost all the products need the mixed signal CMOS LSI tech.

**Wireless**
- Cellular phone: PDC, W-CDMA
- RR-Net: Bluetooth, IEEE802.11
- Broadcast: STB, DTV, DAB
- Optical: FTTH, OC-xx
- Metal: ADSL, VDSL, Power line modem
  - Serial: IEEE1394, USB, Ethernet
  - Parallel: DVI, LVDS
- DVD, VDC, HDD
- LCD, PDP, EL, Audio drive
- Camera, Others
- Switching supply, Every LSIs (On-chip)

**Network Communication**

**Recording**

**Output**

**Input**

**Power supply**
Digital technology in real world

Digital signal suffers heavy damage in the real world. But, a digital can address this issue by own advantages, but needs help of the analog tech.

Advantages of Digital Tech.
- High robustness
- Programmability
- Time shift (memory)
- Error correction
- High Scalability

Pure digital
- Noise
- Distortion
- Interference
- Limited bandwidth

Real world
- Damaged digital
- Reconstruction

Recovered digital

Mixed signal technology (Analog+Digital)

Not only digital, but also analog; ADC, DAC, Filter, and PLL are needed
The role of current analog technology is an interface between digital technology and outer physical world. Analog supports digital.

**Clock Generation**

**Digital signal Processing and control**

**Power supply**

**Analog**: Physical aspects

**Digital**: Meta-physics

(Sense and actuate organ; Mouse, Eye, Ear, Nose, etc.)

(Digestive organ, Circulatory organ)

**Energy conversion**

**Interface**

**Outer world**

- Wireless com.
- Wired com.
- Recording
- Image
- Audio
- Motor
- Sensor
Basic technology for digital network and storage

The analog and the data converter technologies are needed for a digital network and digital storage

Network
Storage media

Analog technology
- RF
- Optical I/F
- Cable drive
- Signal Generation

Digital technology
- Mod/ Demod
- Channel select
- Error correction
- Protocol
- Encryption

Analog technology
- A/D Converter
- D/A Converter

Digital technology
- MPEG2, 4
- DSP
- Codec
The development of ADCs has contributed to the progress of digital consumer electronics.
Progress in A/D converter; video-rate 10b ADC

ADC is a key for the mixed signal technology.
We have reduced the cost and power of ADC drastically;
1/2,000 in Power and 1/200,000 in cost!

CMOS technology attained it. dulling past 20 years

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
<th>Power</th>
<th>Cost</th>
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<tbody>
<tr>
<td>1980</td>
<td>Conventional product</td>
<td>20W</td>
<td>$8,000</td>
</tr>
<tr>
<td>1982</td>
<td>World 1st Monolithic</td>
<td>2W</td>
<td>$800</td>
</tr>
<tr>
<td>1993</td>
<td>World lowest power</td>
<td>30mW</td>
<td>$2.00</td>
</tr>
<tr>
<td>Now</td>
<td>SoC Core</td>
<td>10mW</td>
<td>$0.04</td>
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</table>

Analog Devices Inc.

Our development
Progress of video-rate 10b ADC

Power consumption has been reduced to 1/1000 during 10 years.
Conversion frequency has been increased to 15x during 10 years.
The success of CMOS ADC and DAC enabled the low cost mixed signal CMOS LSI. This also enabled low cost and low power digital portable AV products.

**1993 Model: Portable VCR with digital image stabilizing**

- 6b Video ADC
- Digital Video filter
- 8b low speed ADC;DAC
- 8b CPU

System block diagram
Mixed signal system: Digital Camera

A current camera system uses the digital technology.
Ultra-high speed ADCs have been developed.

- **8b, 120MHz, (1984)**
  - World fastest 8b ADC

- **8b, 600MHz ADC (1991)**
  - World fastest 8b ADC

- **6b, 1GHz ADC (1991)**
  - World fastest in production
    - (Dual Parallel method)
Ultra-high speed ADCs have realized Digital Oscilloscopes.

松下通信工業: 10b 100MHz OSC (1986年)

横河電機: 8b 1GHz (1994年)
Progress in high-speed ADC

High speed ADC has reduced its the power and the area down to be embedded.

**World fastest 6b ADC**

| 6b, 1GHz ADC | ISSCC 1991 |
| 2W, 1.5um Bipolar |

**World fastest CMOS ADC**

| 6b, 800MHz ADC | ISSCC 2000 |
| 400mW, 2mm² 0.25umCMOS |

**World lowest Pd HS ADC**

| 7b, 400MHz ADC | ISSCC 2002 |
| 50mW, 0.3mm² 0.18umCMOS |

Reported Pd of CMOS ADCs

- 10mW/Gsps
- 1mW/Gsps

Conversion rate [x100Msps]

1 order down
System: DVD player

A current electrical system is complicated and needs the analog and the memory.
Full DVD system integration in 0.13um tech.

Advanced mixed signal SoC has been successfully developed.

Okamoto, et al., ISSCC 2003

0.13um, Cu 6Layer, 24MTr
Cost reduction in DVD Recorder

The one-chip integration for hole DVD system has been realized. This makes circuit board simpler and contribute to the cost down, as well as the performance up.

'2000 Model

'2003 Model
Scaled CMOS technology

Current Scaled CMOS technology is very artistic.

Matsushita’s 0.13um CMOS technology

Transistor

Cu Interconnection

100nm

SiO₂

Si

Gate

Seven lattices

Cu Interconnect
CMOS as analog device

CMOS has many issues as analog device, but also has a variety of circuit techniques.

<table>
<thead>
<tr>
<th></th>
<th>CMOS</th>
<th>Bipolar</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>Switch action</td>
<td>++</td>
<td>--</td>
<td>Only CMOS can realize switched capacitor circuits</td>
</tr>
<tr>
<td>Low Input current</td>
<td>++</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>High gm</td>
<td>-</td>
<td>+</td>
<td>CMOS is ¼ of Bip.</td>
</tr>
<tr>
<td>Low Capacitance</td>
<td>+</td>
<td>-</td>
<td>This results in Cp issue</td>
</tr>
<tr>
<td>$f_T$</td>
<td>+</td>
<td>+</td>
<td>Almost same</td>
</tr>
<tr>
<td>Voltage mismatch</td>
<td>--</td>
<td>++</td>
<td>CMOS is 10x of Bip.</td>
</tr>
<tr>
<td>$1/f$ noise</td>
<td>--</td>
<td>++</td>
<td>CMOS is 10x to 100x of Bip.</td>
</tr>
<tr>
<td>Low Sub. effect</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Offset cancel</td>
<td>++</td>
<td>--</td>
<td>CMOS has a variety of techniques to address the self issues</td>
</tr>
<tr>
<td>Analog calibration</td>
<td>++</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Digital calibration</td>
<td>++</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Embed in CMOS</td>
<td>++</td>
<td>--</td>
<td></td>
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