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Comparators in Nanometer CMOS Technology

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Preface

This book describes circuit engineering efforts for comparators. Comparators are key components for analog-digital converters and consequently for modern wireless and mobile communication. Electronic circuits for latest mass applications like WIFI or WLAN modems, mobile phones, and smart phones are realized as so-called systems on chip (SoC). Such SoCs are realized in nanometer CMOS technology and contain a lot of digital circuits for digital signal processing but they also contain analog circuits which often form the key devices for good overall performance. The importance of comparators nowadays is often underestimated. They are, however, important to obtain high-performance analog-digital converters and wireless receivers and transmitters. The improvement of analog-digital converters is the final issue in bringing the digital signal processing as close as possible to the antenna. Therefore, comparators need to be improved also. Sense-amplifier type comparators are also important for SRAMs and DRAMs as well as some optical receivers.

In fact, progress in CMOS technology and circuit design allows the revolution in modern wireless and mobile communication. UMTS, HSPA+, and LTE as well as Ultra Wide Band (UWB) and Software Defined Radio were important keywords in research of the last years for SoCs. All these applications require high-samplerate analog-digital converters, which rely on high-performance comparators. For application in mobile devices, low-voltage operation and low power consumption are important issues of comparators.

To make all this possible for a mass market, analog circuit design in nanometer CMOS technology is an important key factor. This book concentrates on one subtopic of analog circuit design, i.e., comparators. This is especially justified since in the literature very often only analog-digital converters are described without characterizing the properties of the comparators being implemented in detail. Starting from the basics of comparators and the poor transistor characteristics in nanometer CMOS, seven high-performance comparators developed by the authors in 120 nm and 65 nm CMOS are described extensively. These comparators cover sample rates from 500 MHz to 7 GHz and supply voltages from 0.5 to 1.5 V. Their power consumption is in the milliwatt range down to 18 μW. Detailed descriptions of measurement methods for the characterization of advanced comparators are introduced in addition.

Although comparators are being used since several decades in many integrated circuits, it was still possible to develop new topologies or to modify and expand known comparator topologies to improve their performance. This book introduces newest results of development of comparators in deep-sub-micron and nanometer CMOS and describes methods for comparator design dealing successfully with the nanometer hell of physics. Numerous detailed circuit diagrams and plots of measured results allow a fast comprehension.

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Contents

Symbols

C_{ox}	Gate oxide capacitance per gate area $\left[\frac{F}{m^2}\right]$
C_x	Capacitance [F] (x stands for an index, which depends on the context)
D_x	Diode (x stands for an index, which depends on the context)
e	Elementary charge, 1.60218×10^{-19}As
f_x	Frequency [Hz] (x stands for an index, which depends on the context)
f_t	Transit frequency [Hz]
GB	Gain-bandwidth product
g_x	Transconductance of a transistor or small-signal conductance (x stands for an index, which depends on the context)
g_{DS}	Output conductance [S]
g_m	Effective small-signal transconductance of the latch of a comparator [S]
$high$	Logical high
I_{dsat}	Saturation current [A]
$\overline{i_{sn}^2}$	Mean-square of current due to shot noise [A^2]
$\overline{i_{tn}^2}$	Mean-square of current due to thermal noise [A^2]
I_x	Current [A] (x stands for an index, which depends on the context)
i_x	Small-signal current [A] (x stands for an index, which depends on the context)
k	Boltzmann constant, $1.38065 \times 10^{-23} \frac{Ws}{K}$
L_x	Gate length [μm] (x stands for an index, which denotes a transistor)
low	Logical low
M_{meta}	Average number of metastability errors per second $\left[\frac{1}{s}\right]$
N_x	n-MOS transistor (x is a number)
P[X]	Probability that an event X occurs
V_{ST}, V_{STx}	Switching threshold of an inverter [V] (x is the number of the inverter)
P_x	Power [dBm] (x stands for an index, which depends on the context)
Px	p-MOS transistor (x is a number)
Q_x	Charge [As] (x stands for an index, which depends on the context)

$Q(\zeta)$	Q-function
R_x	Resistor [Ω] (x stands for an index, which depends on the context)
r_x	Small-signal resistance [Ω] (x stands for an index, which depends on the context)
t_x	Time [s] (x stands for an index, which depends on the context)
u_x	Small-signal voltage [V] (x stands for an index, which depends on the context)
V_x	Voltage [V] (x stands for an index, which depends on the context)
V_{tx}	Threshold voltage [V] (x stands for an index, which denotes a transistor)
V_A	Early voltage [V]
V_{DD}	Supply voltage [V]
V_{SS}	Ground/reference potential (0V)
V_{GD}	Gate-drain voltage
V_{DS}	Drain-source voltage
ΔV_0	Initial voltage difference, which causes a latch to regenerate
$\overline{v^2{}_{fn}}$	Mean square of voltage due to flicker (1/f) noise [V^2]
$\overline{v^2{}_{tn}}$	Mean square of voltage due to thermal noise [V^2]
W_x	Gate width [μm] (x stands for an index, which denotes a transistor)
β_x	Transconductance parameter of a MOS transistor $\left[\frac{A}{V^2}\right]$ (x stands for an index, which denotes a transistor)
ε_r	Relative permittivity (depends on material)
ε_0	Vacuum permittivity $8.85419 \times 10^{-12}\,\frac{As}{Vm}$
ϑ	Temperature in Kelvin [K]
μ_n, μ_p	Mobility of an electron (index n) and a hole (index p) $\left[\frac{cm^2}{Vs}\right]$
μ_{OS}	Mean offset voltage [V]
μ_X	Mean of X (unit depends on X)
σ_N	Standard deviation of noise, which is assumed to be a stationary stochastic process with a mean free Gaussian pdf [V]
σ_{OS}	Standard deviation of the offset voltage [V]
σ_X	Standard deviation of X (unit depends on X)

Acronyms

AC	Alternating Current
ADC	Analog-to-Digital Converter
AND	Logical AND
BER	Bit Error Ratio
BiCMOS	Bipolar and CMOS
BPG	Bit Pattern Generator
BPR	Bit Pattern Receiver
CGRAM	Character Generator RAM
CGROM	Character Generator ROM
CML	Current Mode Logic
CMOS	Complementary Metal-Oxide-Semiconductor
COM	Communication Port
DAC	Digital-to-Analog Converter
DC	Direct Current
DEMUX	Demultiplexer
DMM	Digital Multimeter
DRAM	Dynamic Random Access Memory
DSP	Digital Signal Processor
FET	Field Effect Transistor
GUI	Graphical User Interface
HF	High Frequency
HSPA+	High Speed Packet Access +
I2C	Inter-IC bus
IC	Integrated Circuit
IOS	Input Offset Storage
LCD	Liquid Crystal Display
LSB	Least Significant Bit
LP	Low-Power
LTE	Long Term Evolution
MC	Microcontroller

MCML	MOS Current Mode Logic
MOS	Metal-Oxide-Semiconductor
MUX	Multiplexer
NOR	Not OR
NRZ	Non-Return-to-Zero
OOS	Output Offset Storage
OpAmp	Operational Amplifier
OR	Logical OR
pdf	Probability density function
PC	Personal Computer
PDN	Pull-Down Network
PLL	Phase Locked Loop
PRBS	Pseudo-Random-Bit-Sequence
PUN	Pull-Up Network
RAM	Random Access Memory
RF	Radio Frequency
ROM	Read Only Memory
SDR	Software Defined Radio
SMA	Sub-Miniature A
SMB	System Management Bus
SNM	Static Noise Margin
SNR	Signal-to-Noise Ratio
SoC	Systems on a Chip
SPI	Serial Peripheral Interface
SRAM	Static Random Access Memory
STI	Shallow Trench Isolation
UART	Universal Asynchronous Receiver Transmitter
UDSM	Ultra-Deep Submicron
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
UWB	Ultra Wide Band
VGA	Variable Gain Amplifier
VNA	Vector Network Analyzer
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Networks
XNOR	Exclusive NOR
XOR	Exclusive OR