Power Management Unit

A digitalized Embedded Linear Voltage Regulator for providing the power supply for 8-, 16- and 32-Bit Microcontrollers

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Introduction
What is a microcontroller and what it is used for?

A Microcontroller is an entire computer on a single chip

- Microprocessor (computing performance e.g., as in your PC)
- Peripherals (e.g., as in your PC: USB port, keyboard plug, graphics engine...)
- Memory (Flash and RAM as in your PC: Hard disk and RAM)

Microcontrollers are used in an incredibly wide range of everyday products

washing machines, mobile phone, DVD player, car, electric motors, display devices, trains, ...
Introduction
Modern high-end cars contain up to one hundred μC

**IN 2010:**
Electronic will grow to a third of a vehicle’s value

**Body & Convenience**
Xenon Light, Seat Position, Climate Control, Dashboard

**Powertrain**
Engine Control, Transmission Control, Battery Management

**Climate Control**
Airbag, Night Vision, Steering

**Chassis**
Active Suspension, Power Steering

**Safety**
Airbag, ABS Brakes, Adaptive Cruise Control

**Light**
Dashboard, Cooling FAN, Park Distance Control, Adaptive Cruise Control

**Suspension**
Door, TPMS, Steering, Brake

**Central Lock**
ABS, ESP

**Mirror**
Door, Central Lock, TPMS

**Transmission**
Battery Management, Engine, Hybrid
Introduction
A brief look into the future of µC Technologies

- **ITRS CMOS logic**
  MPU M1 half-pitch roadmap
  International Technology Roadmap of Semiconductors

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<tbody>
<tr>
<td>Technology (nm)</td>
<td>180</td>
<td>130</td>
<td>90</td>
<td>65</td>
<td>45</td>
<td>32</td>
<td>22</td>
<td>16</td>
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Automotive µC technology roadmap

- **Issues to consider with smaller technology:**
  - Processed Wafer cost
  - More expensive mask cost
  - More sensitive to radiation
  - Higher leakage current
  - Lower voltage headroom
  - Analog do not shrink at same rate (Flash, ADC, Voltage Regulator...)

![Diagram showing technology roadmap](image-url)
Introduction
Key challenges for the microcontroller

- **Computing performance** (~doubles every two years)
  - Environment-/Safety Requirements & comfort features are driving forces for higher integration, performance, scalability

- **Zero defect over 15 to 20 years**
  - High Level of Verification & Testing coverage

- **Low overall energy consumption for battery operation**
  - Low operating power
  - Low stand-by power (< 1µA @ RT)

- **System Costs**
  - Si-Area,
  - Test Time,
  - Package (# of pins)

- **Development Cost/ Time to market**
  - First time right
  - One solution for different Platforms/ Family
  - High reuse factor of Digital/ Mixed Signal & Analog IP
# Introduction

Key challenges for the microcontroller - Solutions

## Trend

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<th>Analog/Digital Tradeoff</th>
<th>Replacement of signal processing from analog to digital</th>
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## Major benefits due to digitalization:

- **System Costs**
  - IP area reduces with technology shrink
  - Reduced # of analogue measurements => less Test Time

- **Flexibility**
  - Less full custom design => Reuse Factor ↑, Cycle time ↑, Verification Level↑
  - Use cases (different parameter) selected from digital registers/ Embedded Flash

- **Robustness**
  - Less sensitivity to Technology variations

- **Testability, Diagnostic**
  - Higher test coverage

## IC Requirements

- A/D and D/A conversion, signal processing
**Introduction**

**Example for digitalization: Linear Voltage Regulator**

**Analog Solution**
- Resistor feedback
- OTA or Opamp w/ Miller C
- Additional sub modules (Buffer, comparators) for diagnostic functions required

**Digital Solution**
- Feedback loop by ADC, PID controller & DAC
- No additional sub modules for diagnostic functions required
Digital Linear Voltage Regulator
Block diagram of Power Management Unit (PMU)
Digital Linear Voltage Regulator

Architecture

\[ H(z) = K_{PR} \cdot \left(1 + \frac{T}{T_N} \cdot \frac{z}{(z-1)} + \frac{T_V}{T} \cdot \frac{(z-1)}{z}\right) \]

**Active Mode:**
- Clock Frequency = 20MHz
- Number of clock cycles per A to D conversion: 13
- Sample time (T): 650ns

**Power Save Mode:**
- Clock Frequency = 100kHz
- Number of clock cycles per A to D conversion: 13
- Sample time (T): 130µs
Digital Linear Voltage Regulator

Digital control algorithm

- Digital Regulator Control
  - PID Core

Diagram:

- adc_out(7:0)
- ref-volt(7:0)
- in_en
- reg_in_clamp
- x mant
- x exp
- dm
- de
- mode
- slave_en
- clampedsu
- integ
- add2mux
- out_en
- carryin
- aluzum
- enc
- int_dac_up, int_dac_dw
- dac_up(3:0)
- dac_dw(3:0)
Digital Linear Voltage Regulator
Realization of different Power Modes

- Transition from Active Mode to Slow Down Mode
Digital Linear Voltage Regulator
Si-Area comparison of two 5V-Regulator concepts

Digital Solution:
Technology: (130nm)
Si-Area: 0.06mm$^2$

Analog Solution:
Technology: (500nm)
Si-Area: 0.63mm$^2$
**Digital Linear Voltage Regulator**

**Simulation & Experimental Results**

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### Features of proposed Digital LVR

- \( V_{out}=1.5V; \ I_{load}=50mA \)
- \( V_{out}=5V,\ I_{load}=100mA \)
- Power Save mode for data retention
  - \( I_q \leq 10\mu A \)

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### Status

- Architecture & Concept has full functionality
- Accuracy of \( V_{out} \): ±2% over temperature

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### Next Steps

- Integration into Embedded Power Product

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For internal use only
Digital Linear Voltage Regulator

Summary of proposed concept

- **Digital control algorithm uses PID controller instead of PI controller**
  - PID control algorithm is faster at load jumps as PI
  - Higher accuracy without trimming of output voltage (≤1%)

- **Digital regulator shrinks function by a factor of five.**
  - Digital solution (ADC & PID controller & HV-DAC) : 0.06mm$^2$
  - Analog solution (OTA incl. Miller compensation & driver) : 0.3mm$^2$

- **Technology concept (130nm) is focused on digital signal processing and low voltage design**
  - 120000 GE/mm$^2$
  - Silicon area of an analogue feedback loop is limited by passive devices

- **No additional circuits necessary for protection and diagnostic functions**
  - Voltage Supply Watchdog, Over current Protection,…
  - Threshold values can be user-defined programmed

- **Active power management features are easy to implement**
  - Meet requirements of body & safety market

- **Digital feedback loop is more flexible**
  - Output voltage can be configured by digital register (e.g. Use-Case)
  - Feedback loop can be adjusted to different sizes of pass devices with parameterizing of control parameters (stored in OTP/NVM)
Innovation for a safe, clean environment!

Thank you for your attention!
Backup
Digital Linear Voltage Regulator
Exemplary pipeline concept of digital control algorithm
We commit.
We innovate.
We partner.
We create value.