Analog Module Architecture for Space Qualified Field Programmable Mixed-Signal Arrays

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Analog Module Architecture for Space Qualified Field Programmable Mixed-Signal Arrays

- Introduction
- FPAA Applications for Space
- Overview of Existing Technology
- Challenges and Strategies
- APL's FPAA Architecture
- Analog Design in a Digital Process
- Programmable Circuit Example
- Future Development Directions
- Conclusions
- Acknowledgements

Introduction to FPAA Technology

Definitions:

- FPAA: Field-Programmable Analog Array
- FPMA: Field-Programmable Mixed-Signal Array
- CAB: Configurable Analog Block (or AMOD)
- PCA: Programmable Capacitor Array

An FPAA is to analog circuits as an FPGA (Field-Programmable Gate Array) is to digital circuits.

An FPMA is a combination of FPGA and FPAA modules.

The Case for FPAA Technology in Space

- Pre-Flight-Qualified Parts
- Quick Turnaround Time
- Cheap
- Simple to Build, Easy to Debug

Targeted Applications:

- Housekeeping Circuits
- A/D, D/A (to moderate resolutions)
- Pulse Shaping
- Oscillators
- Modulators
- Filters
- Integrated Signal Processing Systems

Overview of Existing FPAA/FPMA Technology

Commercial:

- Motorola *DPAD2*
  —Is now out of the FPAA business, but designers may produce the chip independently.
- Zetex (Fast Analog Solutions, Ltd.) *TRAC*
  (`http://www.fas.co.uk`)
- Sidsa *FIPSOC*
  (`http://www.sidsa.com`)

University Research:

- University of Toronto, Iowa State University
  (`http://www.eecg.toronto.edu/ vgaudet/fpaa`)
- CPE, Lyon, France (`http://www.cpe.fr`)
- University of Edinburgh

FPAA Challenges

- Speed especially through interconnect (routing)
- Accuracy (device matching)
- Digital noise (clock feedthrough)
- Analog noise (power supply, thermal, shot, 1/f noise)
- Power Consumption
- Resource Allocation (quantity and granularity of analog blocks)
- Resource Utilization

FPAA Strategies

- Switched-Capacitor Circuits:
  Makes use of S-C switches as interconnect
- Current Conveyors:
  Switch resistance has little effect on current-mode circuits
- Arithmetic Blocks:
  More difficult to implement many standard analog circuits
- External Components:
  Not scalable. Loses some major advantages for spaceflight applications
- Pulse-width modulation (PWM) computation
  Interesting concept in early stages of development; easy to interface to digital subsystems.
- Antifuse Interconnect:
  Low resistance interconnect compared to RAM-based interconnect
  One-time programmable
- Differential Architecture:
  Increases dynamic range and accuracy
  Difficulty of design can be eliminated with good design software

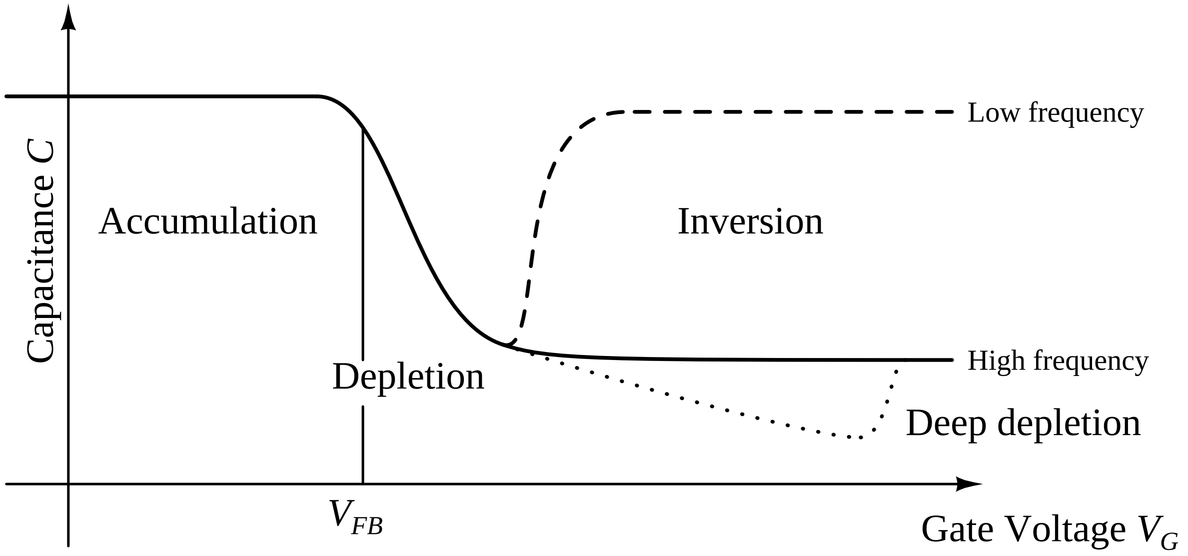
The APL FPAA Architecture

- Uses Actel's Metal-to-Metal antifuse technology (fabrication process for the RT-SX product family)
- Core resources:
  - Operational amplifiers
  - Programmable capacitors (PCAs), 6-bit precision
  - Programmable resistors, assorted values
  - Switches with selectable complementary clocks
- All resources are independent and linked into circuit with antifuses
- Both switched-capacitor and continuous-time circuits possible
- Implemented in digital fabrication technology: Integration with digital cells to form an FPMA is straightforward.

Designing Analog Circuits in a Digital Fabrication Process

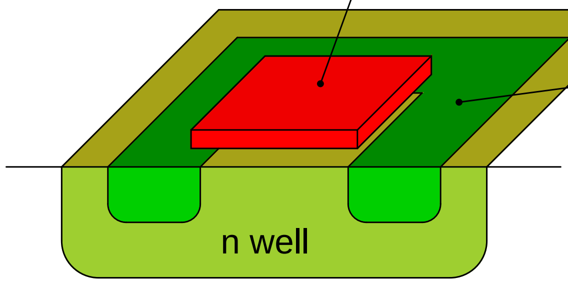
- Accurate resistors are difficult to achieve even with clever layout strategies.
- Operational Amplifier must operate with low supply voltage.
- Digital process lacks bipolar devices, JFETs, other low-noise options.
- Double-poly capacitors are not available and metal-poly capacitance is extremely low: Use accumulation-mode MOSCAPs instead.

Accumulation-Mode Capacitor Layout

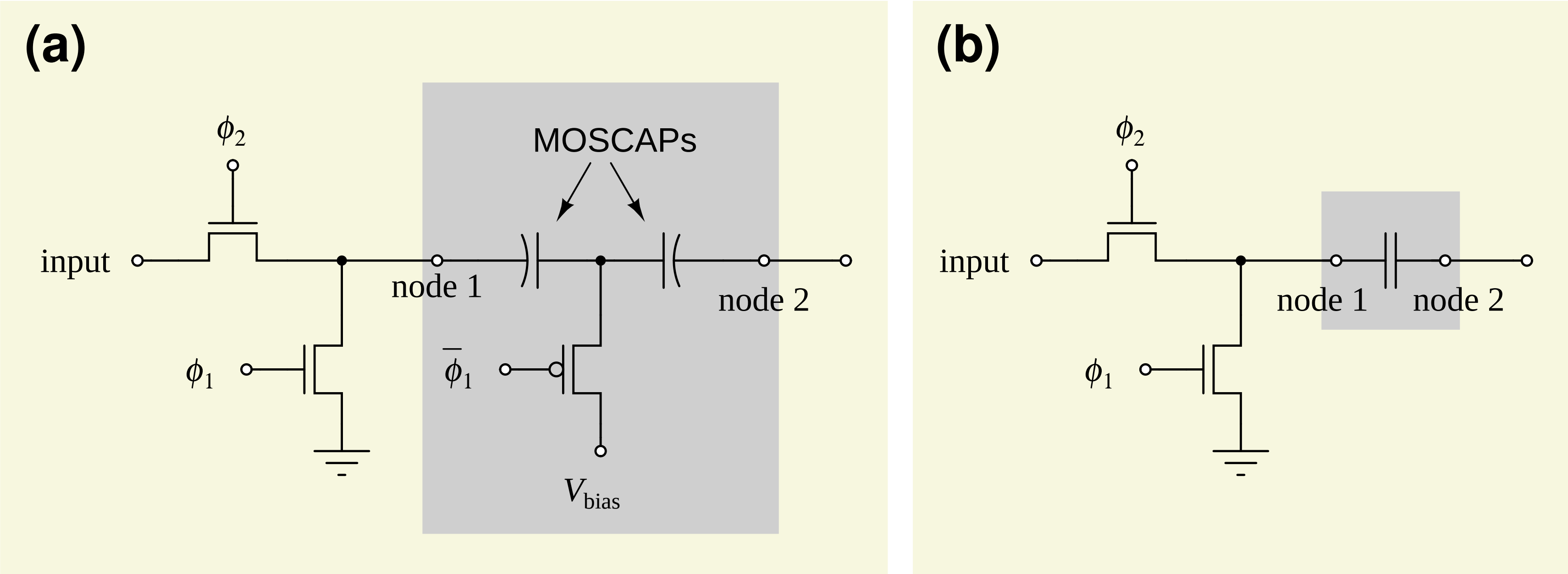


MOSFET gate capacitance is the largest capacitance per unit area available.
BUT: MOSFET capacitance is nonlinear as a function of applied voltage.

Accumulation capacitor changes the threshold and moves curve to the right.



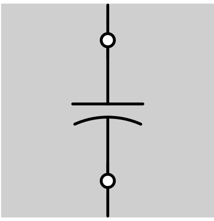
Accumulation-Mode Capacitor Circuit Design



Circuits **(a)** and **(b)** are equivalent in a switched-capacitor system.

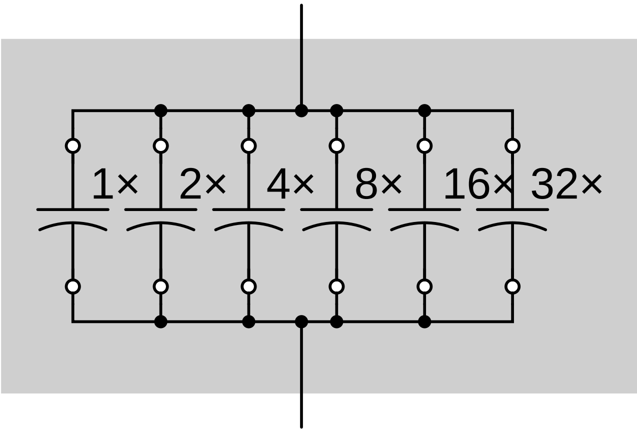
Resources of the Configurable Analog Block

6-bit Programmable Capacitor Array

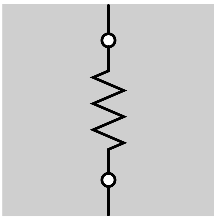


min $= 500\,\mathrm{fF}$

max $= 31\,\mathrm{pF}$

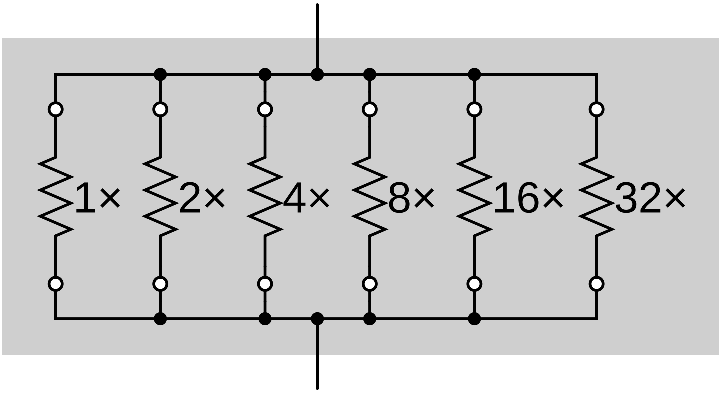


Programmable Resistor Array

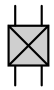


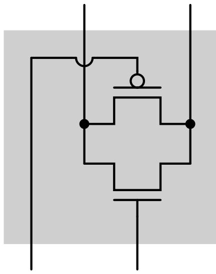
min $= 10\,\mathrm{k\Omega}$

max $= 320\,\mathrm{k\Omega}$

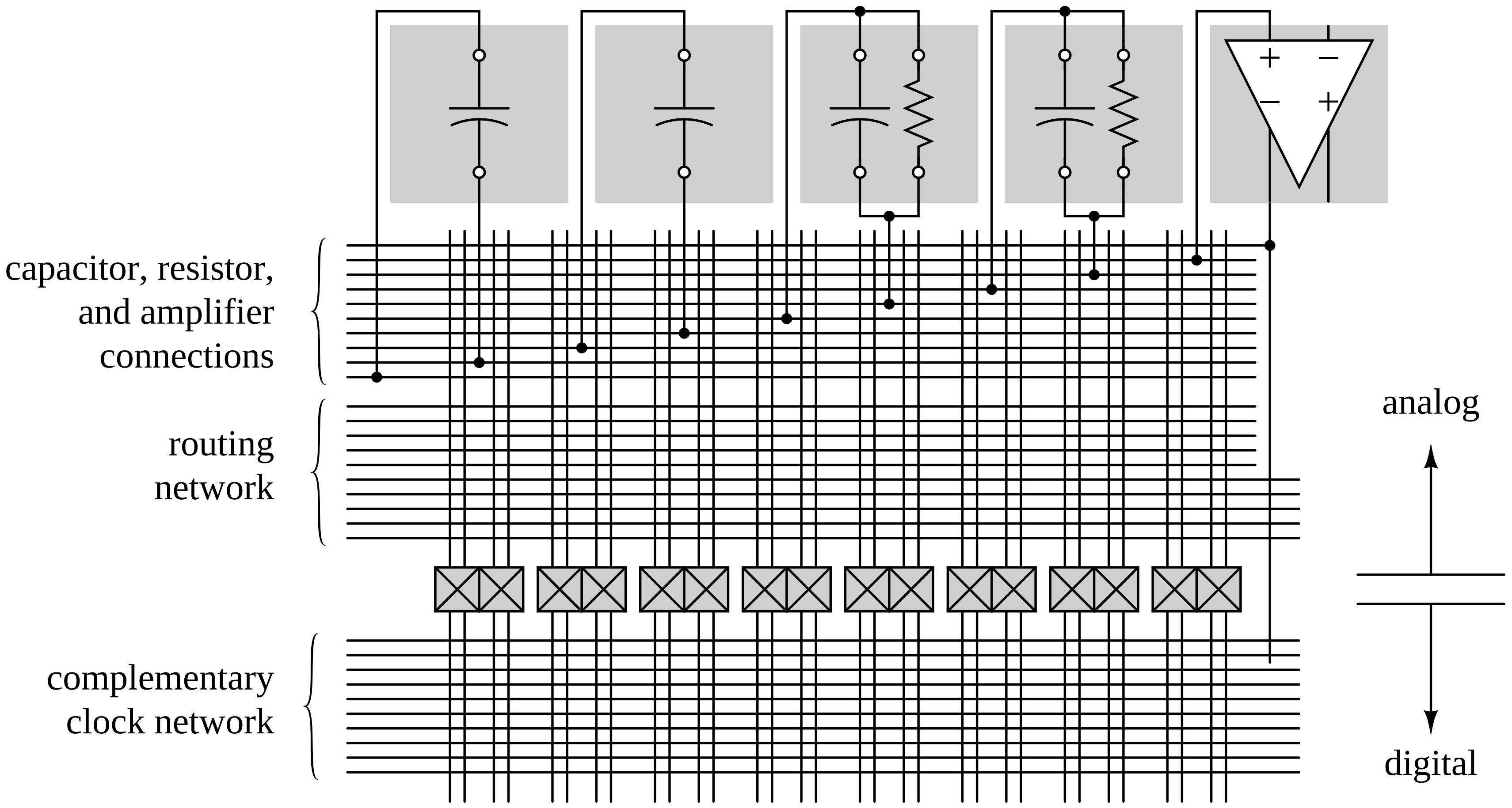


Complementary Switch

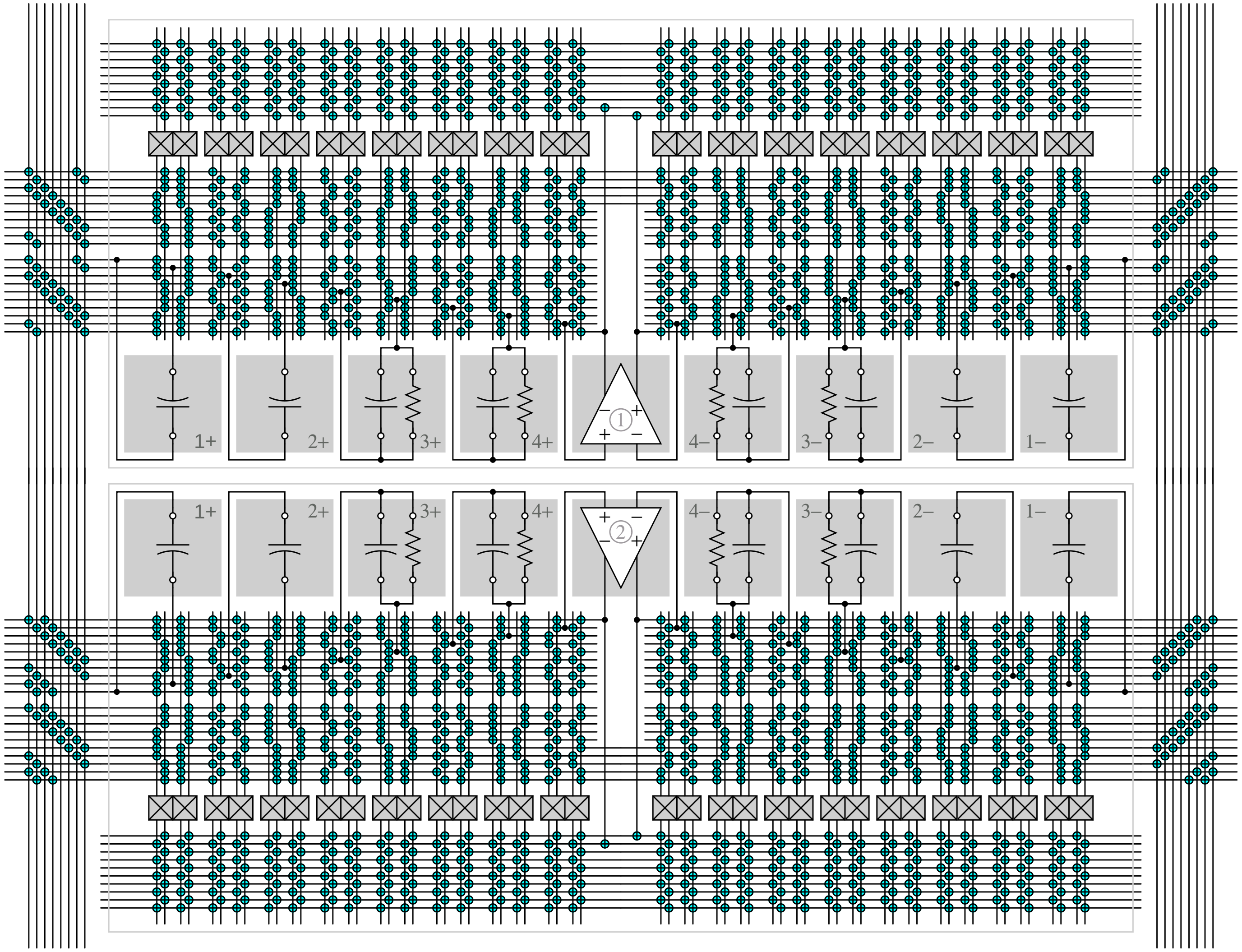




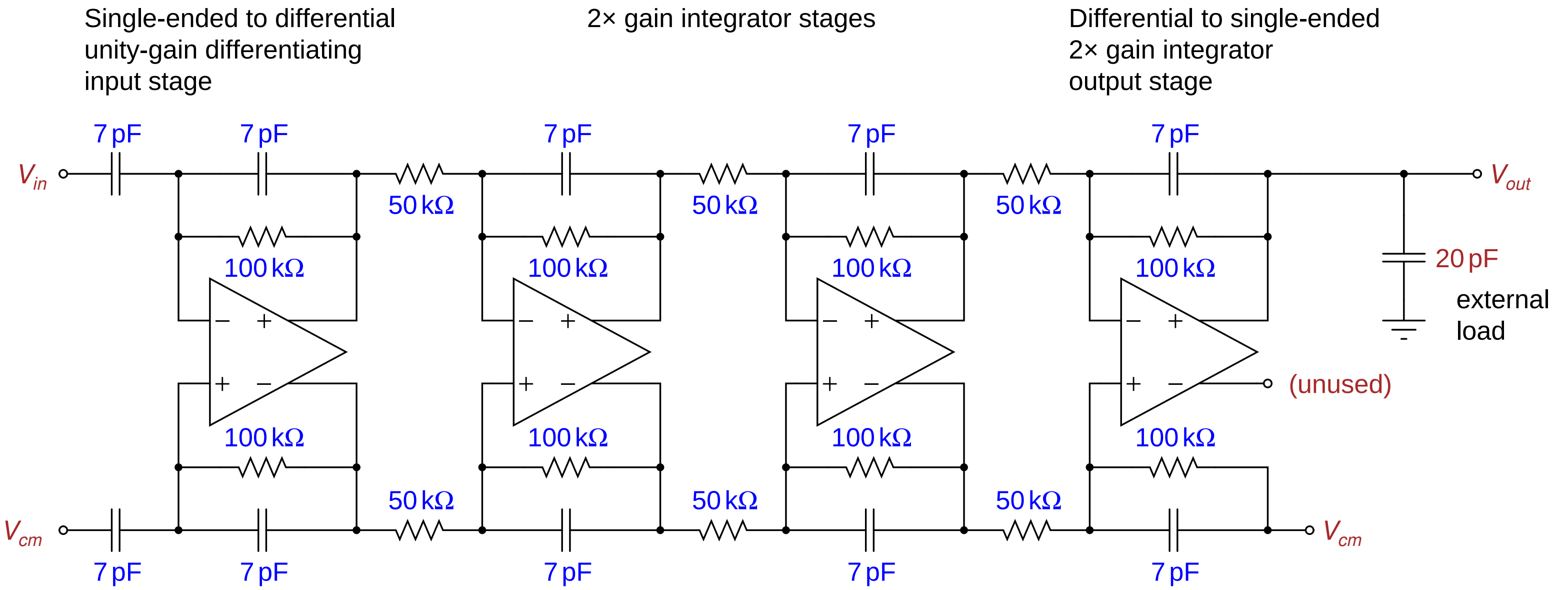
Configurable Analog Block (CAB) Design



FPAA Test Chip Design (partial)

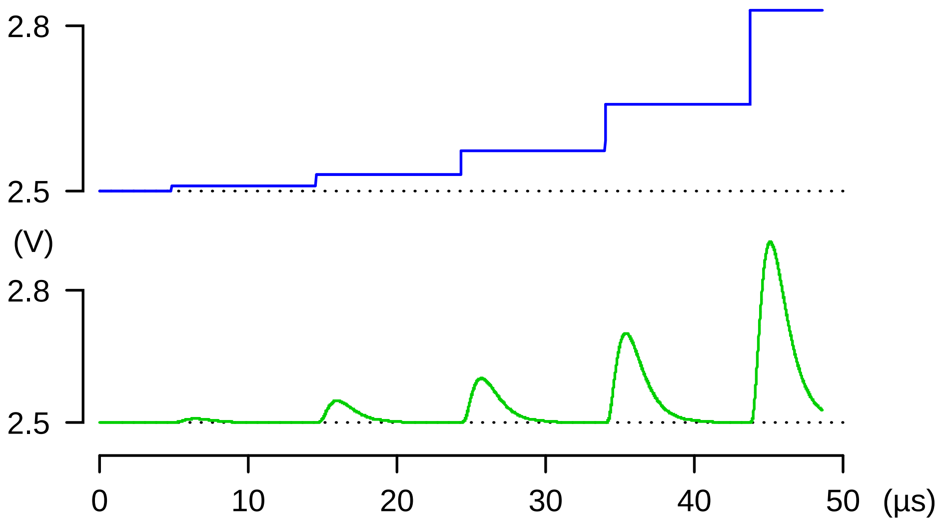


Simulation of Pulse Shaping Chain



System input V_{in}
(single-ended)

System output V_{out}
(single-ended)



Future Development Directions

- FPMA: combine digital modules with the analog CABs
- Circuit examples: program and evaluate typical circuits on the test chip
- Optimizations:
  - Amplifier configurable as comparator
  - Programmable amplifier bias (including shutoff for power saving)
  - Switched-capacitor common-mode circuit
  - Voltage references
  - Optimize routing resources

Conclusions

- The FPAA is a marketable chip
- Need and utility of FPAAs for spaceflight applications is clear
- New antifuse technology (Actel Metal-to-metal) gives adequate bandwidth for most applications, and is available in radiation-tolerant varieties (degree of tolerance to be determined)
- Test chip will reveal the precision and accuracy of programmed cirucits and the versatility of the chosen CAB architecture

Acknowledgements

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  - Chin Li
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For more information:

- *Analog Integrated Circuits and Signal Processing*
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