Switched-Current Signal Processing

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Outline

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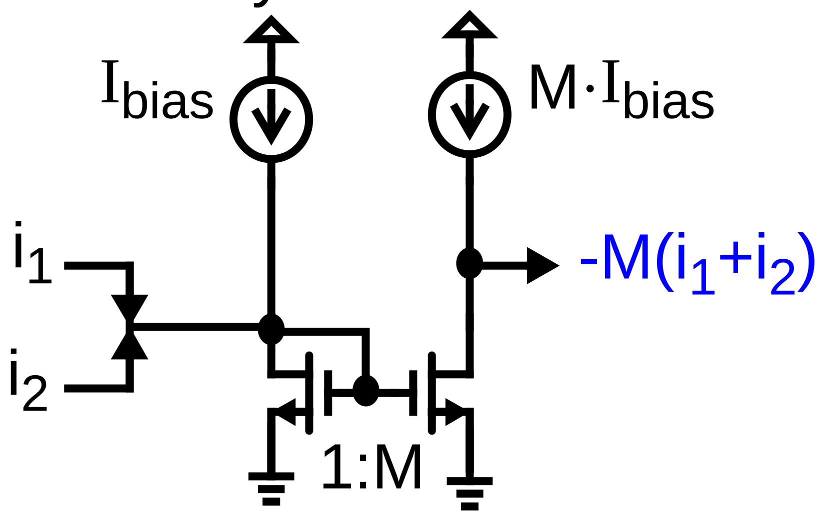
Switched-Current (SI) Circuits

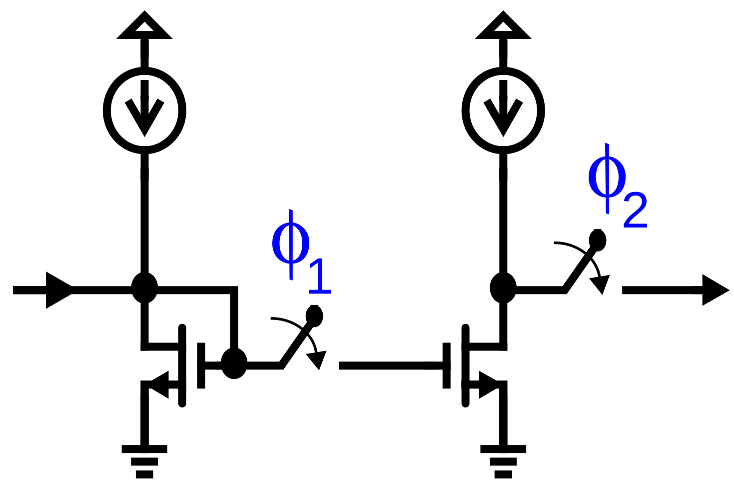
- Used for discrete-time signal processing
- Signals are processed in the current domain, as opposed to the voltage domain
- No need for high-impedance nodes to get high gain
  - So, there is the potential for higher bandwidth
- SI circuits consist only of transistors, which means they are ideal for implementation in an all-digital process

SI Building Blocks

- The basic current mirror allows us to do three of the fundamental signal processing functions:
  - Inversion, addition, and scaling
- We can use the SI Sample-and-Hold circuit to do the fourth:
  - Delay



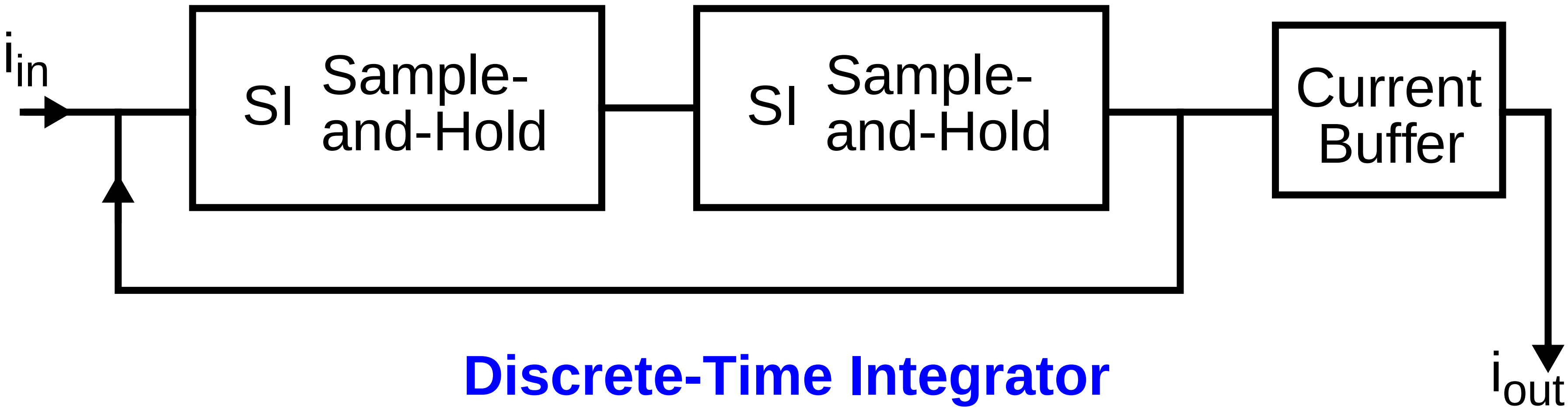
Basic Current Mirror



SI Sample-and-Hold

SI Building Blocks

- We can make more complicated blocks out of these two:
  - Integrator
  - Differentiator
  - Quantizer



Discrete-Time Integrator

Comparison with Switched-Capacitor (SC) Circuits

- SC Circuits require:
  - linear capacitors
  - high-gain op amps
  - voltage headroom

- SI Circuits require:
  - only MOSFETs

- So SI circuits seem ideal for integration with digital circuits as supply voltages decrease
- In reality, however, circuit nonidealities cause severe performance degradation

Circuit Nonidealities

- Transistor mismatch
- Finite output impedance
- Charge injection

Example: Threshold Voltage Mismatch

ideal:

$$i_{out} = i_{in}$$

with mismatch:

$$i_{out} = i_{in} + \frac{\beta_0}{2}\Delta V_T^2 - \sqrt{2\beta_0 i_{in}}\Delta V_T$$

State-of-the-Art SI Circuits

- SI circuit has much smaller area and power dissipation
- SC circuit has much higher SNDR (Signal-to-Noise-and-Distortion-Ratio)

Sigma-Delta Audio Frequency A/D Converters

Parameter	Switched-Capacitor	Switched-Current
Process	0.5 um	1.2 um
Area	9.5 mm^2	0.03 mm^2
Power	70 mW	1 mW
Voltage	3.3 V	5 V
Sampling Rate	3.072 MS/s	5.12 MS/s
Bandwidth	20 kHz	20 kHz
SNDR	100 dB	80 dB
Reference	[Fogelman ‘01]	[Rodriguez-Calderon ‘02]

State-of-the-Art SI Circuits

- SI A/D converter does not have the speed of the SC circuit, but it does have smaller area, less power, and a lower supply voltage

High-Speed A/D Converters

Parameters	Switched-Capacitor	Switched-Current
Process	0.35 um	0.35 um
Area	3.4 mm^2	0.62 mm^2
Power	655 mW	60 mW
Voltage	3.3 V	1.9 V
Sampling Rate	200 MS/s	40 MS/s
Bandwidth	30 MHz	5 MHz
SNDR	43 dB	40 dB
Reference	[Uyttenhove ‘03]	[Hughes ‘01]

Low-Voltage A/D Converters

- SI circuits should work well at low voltages
- But SC A/D converters still seem to be better, even at very low supply voltages

Low-Voltage A/D Converters

Parameter	Switched-Capacitor	Switched-Current
Process	0.18 um	0.8 um
Area	0.14 mm^2	4 mm^2
Power	62 uW	2 mW
Voltage	0.65 V	1.5 V
Sampling Rate	1.024 MS/s	12 kS/s
Bandwidth	16 kHz	4 kHz
SNDR	59 dB	49 dB
Reference	[Sauerbrey ‘03]	[Chen ‘98]

Conclusion

- Switched-current circuits seem to have great promise
- In practice, nonidealities limit performance severely
- More work needs to be done to compensate for these non-idealities

A/D Converter	Process	Area	Power	Voltage	Sampling Rate	Bandwidth	SNDR	Reference
SC Audio	0.5um	9.5mm2	70mW	3.3V	3.072MS/s	20kHz	100 dB	[Fogelman ‘01]
SI Audio	1.2um	0.03mm2	1mW	5V	5.12MS/s	20kHz	80 dB	[Rodriguez-Calderon ‘02]
SO Audio	0.18um	0.14mm2	62uW	0.65	1.024MS/s	16kHz	59 dB	[Sauerbrey ‘03]
SC 1MHz	0.65um BiCMOS	6.1mm2	22mW	2.7V	100MS/s	1MHz	57 dB	[Henkel ‘02]
SI 1MHz	0.8um	0.48mm2	60mW	5V	6.67MS/s	10kHz	65 dB	[de la Rosa ‘00]
non-SI Nyquist	0.35um	3.4mm2	655mW	3.3V	200MS/s	30MHz	43 dB	[Uyttenhove ‘03]
SI Nyquist	0.35um	0.62mm2	60mW	1.9V	40MS/s	5MHz	40 dB	[Hughes ‘01]

Table 1:

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