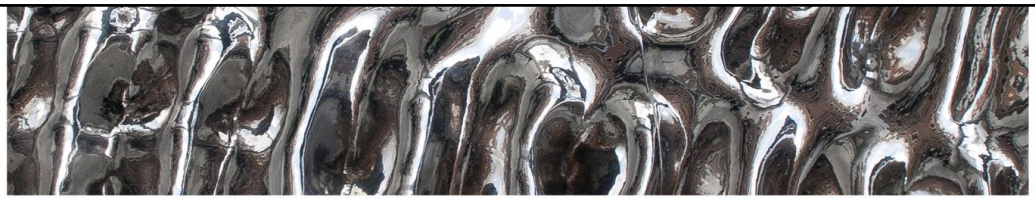

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INF4420

Digital to Analog Converters

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Outline

- Resistor string DACs
- Charge redistribution DACs
- Current source DACs

Introduction

Digital to analog converters (DACs), takes a digital input word, and converts it to a voltage or current proportional to the input value.

Usually the DAC will use an arrangement of switches and resistors, capacitors, or current sources, to generate an output that is a fraction of or proportional to some reference current or voltage (bandgap).

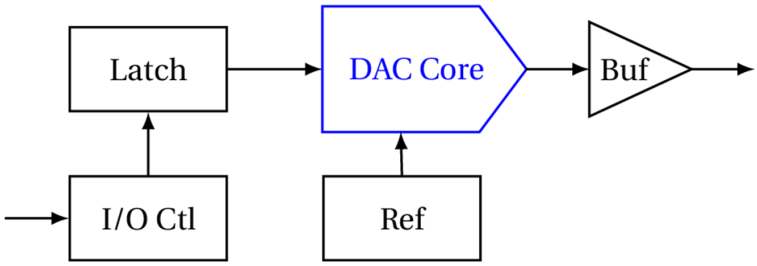
Introduction

Proper layout (to reduce mismatch) is critical for performance. Switches are also critical (signal dependent Ron, clock feed-through, and charge injection).

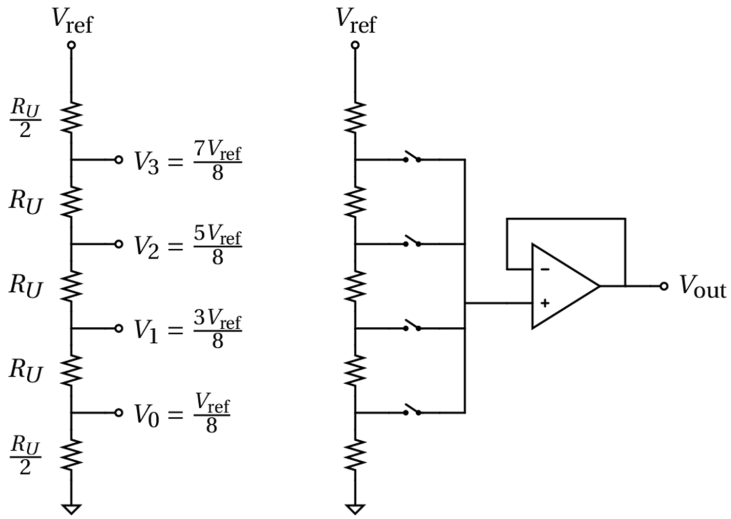
DACs find numerous applications, from trimming and calibration circuits to high-end video DACs, and communication circuits.

Introduction

Outline of the full digital to analog converter.

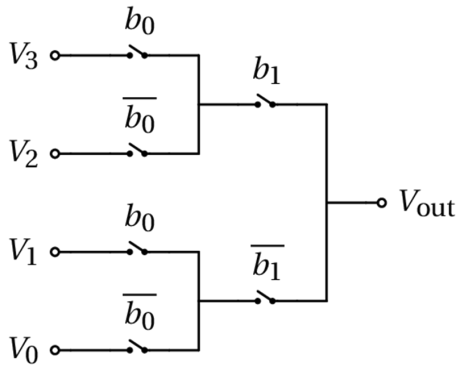


Resistor string converters

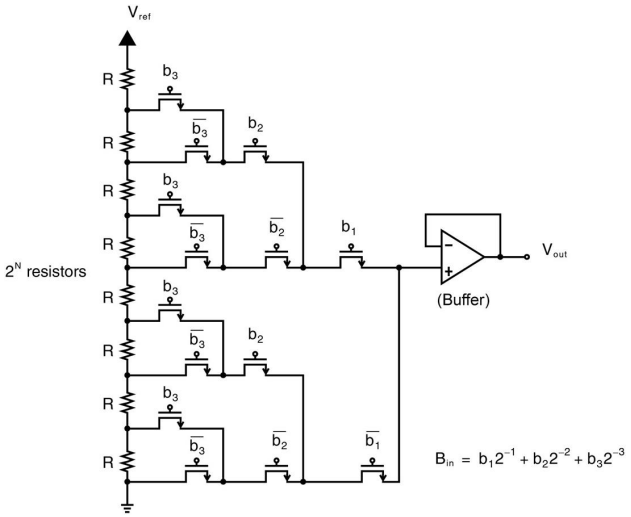


Resistor string converters

Different switching schemes are possible

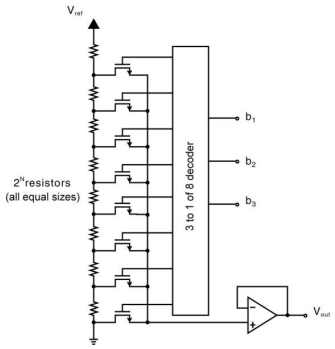


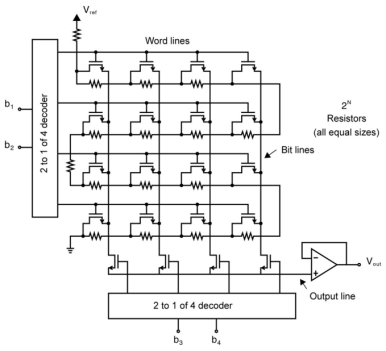
Resistor string converters



Resistor string converters

Alternatives for decoding (digital decoding)





Mismatch

Resistors are affected by systematic and random mismatch, causing a deviation from their ideal value.

Linear gradient in resistor values gives rise to a parabolic INL. Harmonic distortion!

Good layout is important. Trimming or calibration may be necessary.

Output settling

There is inherent resistance in the resistive divider. Switches have both Ron and parasitic capacitance (also for switches turned off).

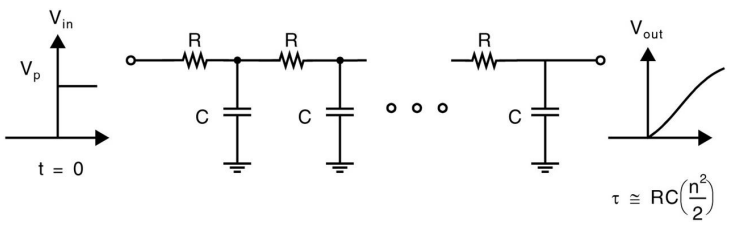
Resistance is code dependent. Capacitance is approximately constant.

Gives rise to exponential settling.

Output settling

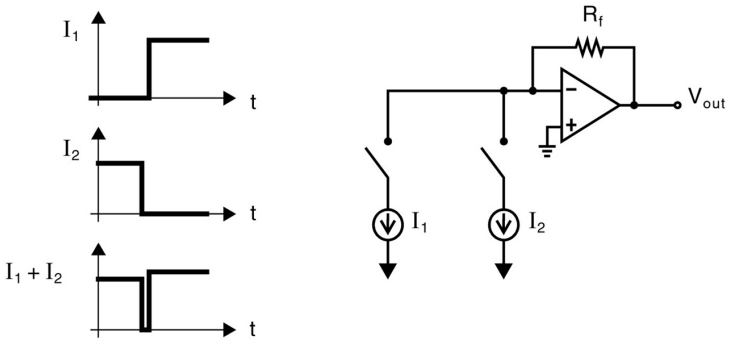
Approximate the time constant using zero-value time-constant.

$$\tau \approx RC\frac{n^2}{2}$$



Glitching

Glitching caused by timing skew between DAC units, can be attenuated by filtering or removed by a T/H output.



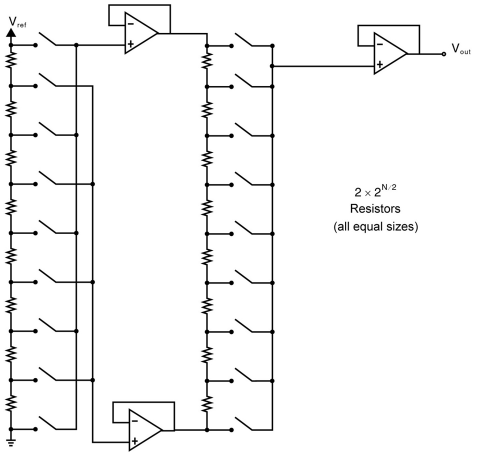
Resistor string alternatives

All circuits so far require 2^N resistors, which must have a certain minimum size due to matching concerns: Large area.

- Multiple resistor string converters
- Binary weighted resistors
- R-2R based converters

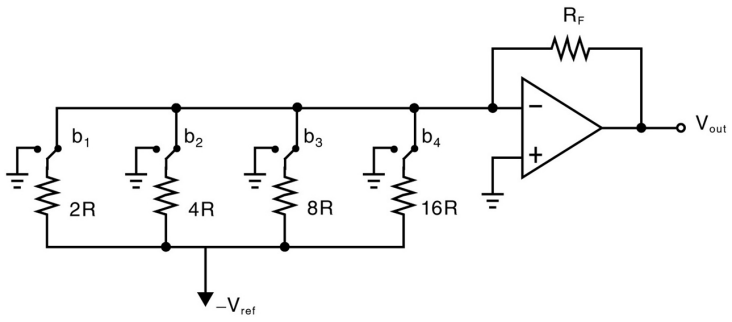
Multiple R-string DAC

- $2 \times 2^{N/2}$ rather than 2^N resistors
- Speed limited by additional buffering



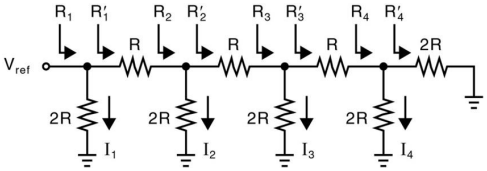
Binary weighted DAC

Can reduce the number of required resistors by using binary weighted values. However, difficult to generate precise values with large component spread. Worse DNL.

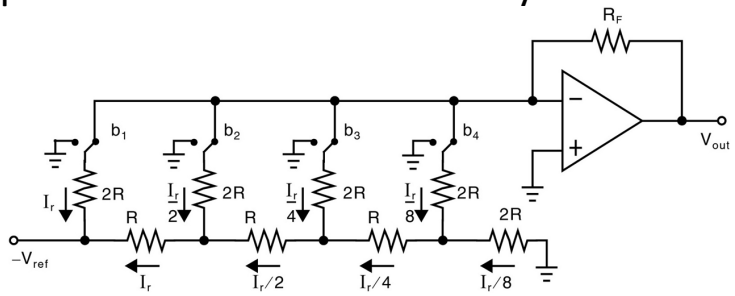


R-2R based DAC

Popular choice for resistive DACs.

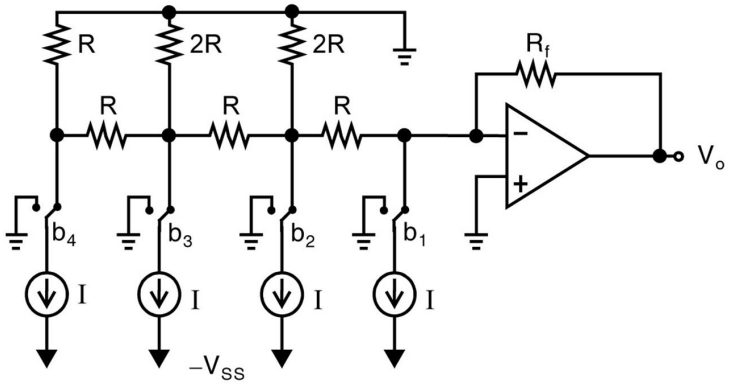


Low spread in component values: R and 2R. Only $2N$ resistors.



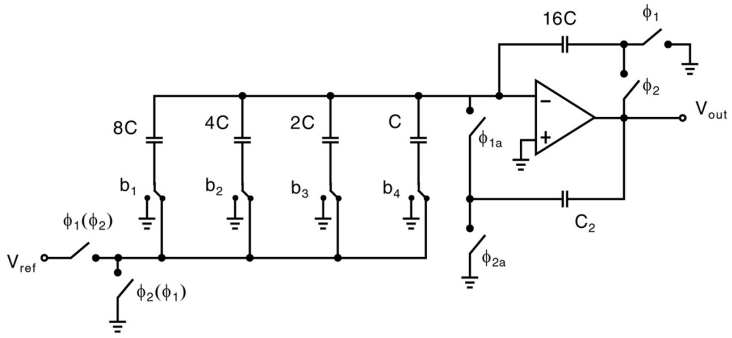
R-2R DAC with current source bias

Several options for biasing the DAC with current rather than a reference voltage.



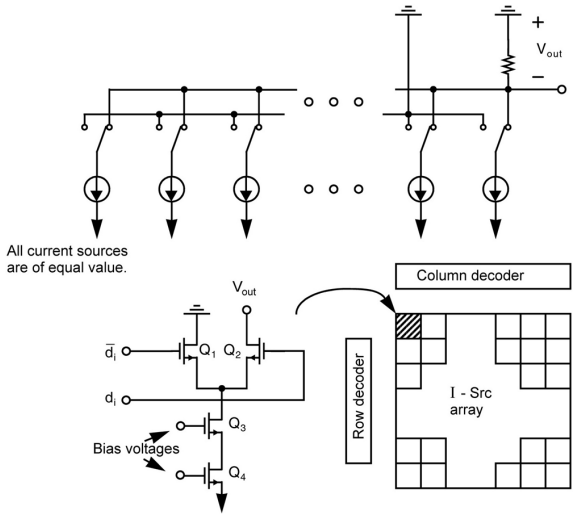
Charge redistribution DAC

Can be viewed as a SC gain circuit, amplifying a fixed reference voltage, where the gain is programmed by selecting capacitors.



Thermometer current steering DAC

- Important!
- Current source output impedance is important for linearity
- Current source matching
- Symmetric switch to avoid triode

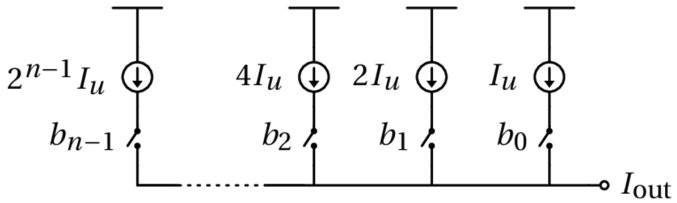


Dynamic element matching

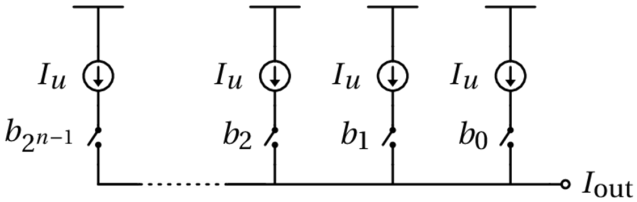
- The current sources in the current steering (CS) DAC are physically arrayed on the die
- Doping gradients etc. gives rise to a position dependent offset
- Straight forward thermometer selection results in non-linearity
- Instead, select the required number of unit current sources at random—decorrelates the systematic non-linearity. White noise instead

Segmented current steering DAC

Unit element CS DAC, good DNL, but 2^N units



Binary weighted, fewer elements, but worse DNL



Segmented: MSBs are unit elements and LSBs are binary, compromize.

Reconstruction filter

The DAC output has a S&H response.

$$H_{SH}(s) \equiv \frac{1 - e^{-sT}}{s}$$

Need an output filter to further attenuate frequency images and smooth out the time domain waveform.

DAC implementation

In most practical cases, fully differential DACs are required. The DACs we have seen can be extended to have fully differential outputs.

Component matching, and its relation accuracy, is an important consideration for DAC implementation. However, this is not covered by the textbook, so we do not go into details.

We already know how to calculate mismatch!

Resources

Mercer, *Digital to Analog Converter Design*