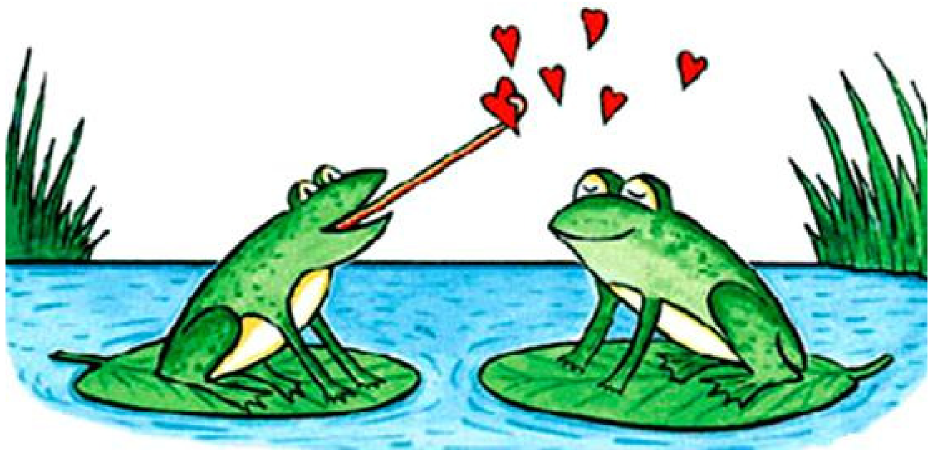
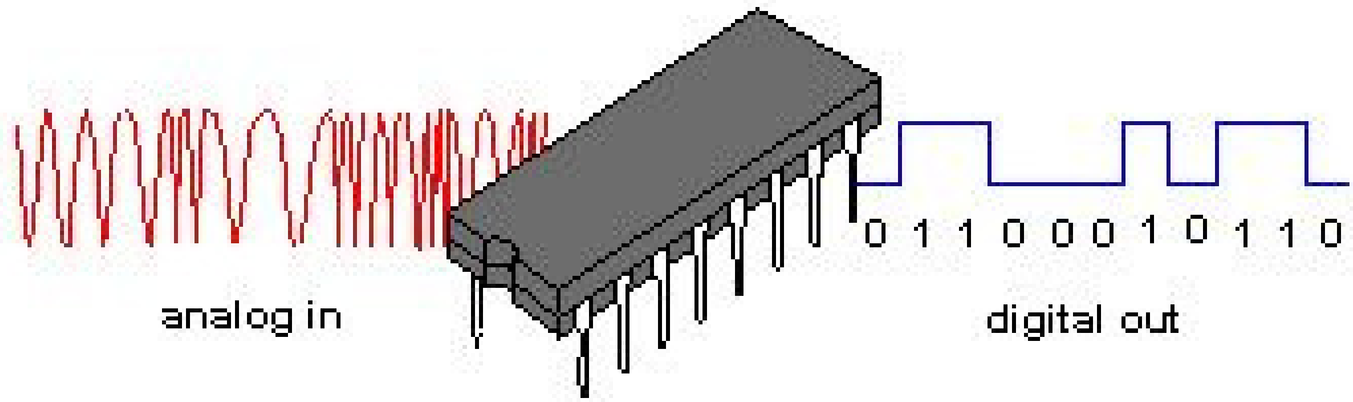
Marrying Analog and Digital Worlds



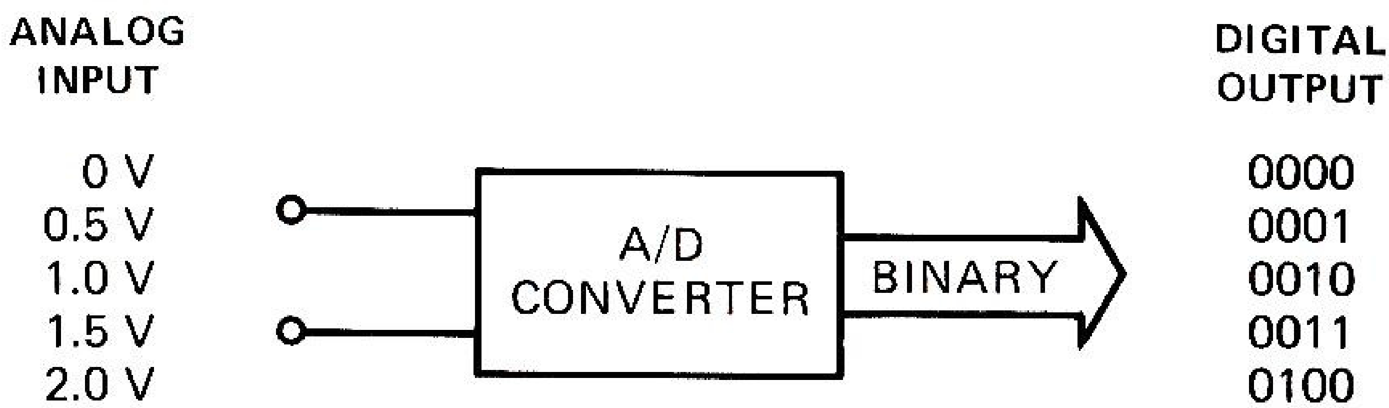
10110 **ABC**

New England Radio
Discussion Society
May 2017 – AI2Q

Integrated circuits help mate analog and digital domains.



An *analog-to-digital converter* (*ADC*) block diagram

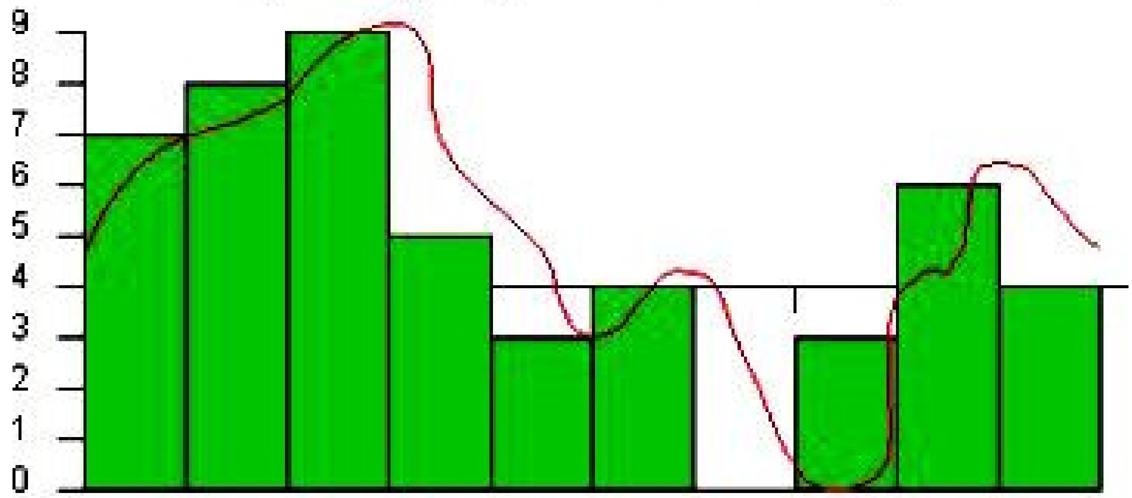


The A/D or ADC samples an analog voltage at various points.

The data converter provides a link between the analog world of transducers and real-world signals and the digital world of signal processing and data handling.

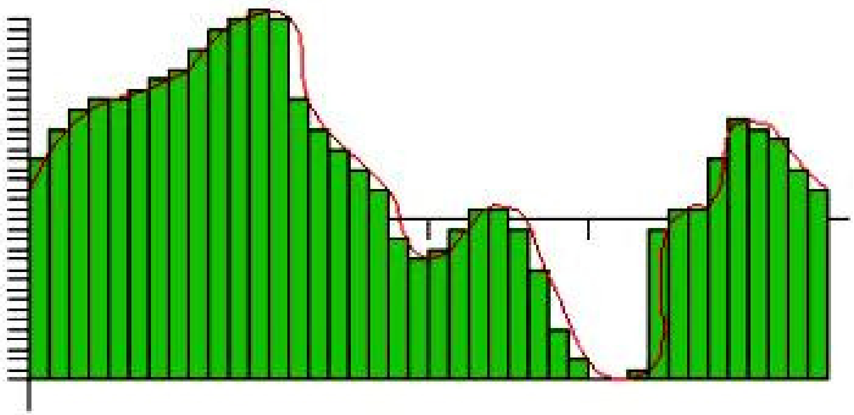
assume that:

- fs = 1000 samples per second
- N = 10 (dividing the y-axis to 10 intervals)



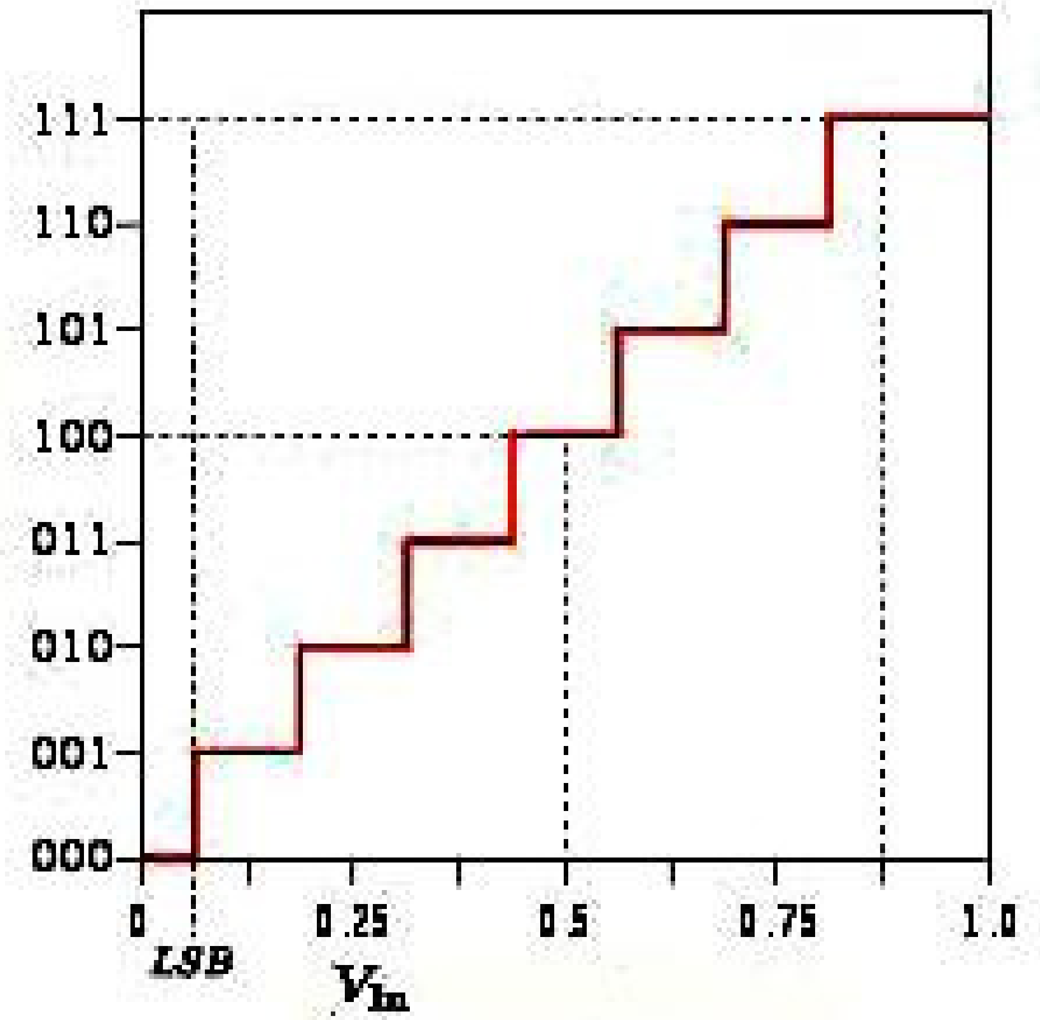
If the *sample rate* is fast enough the captured signal can reasonably resemble the input.

And, if we increase the sampling rate and the sampling precision by a factor of four, we will get the following digitized data.



Therefore, in order to digitize the analog data accurately, we need to sample the analog signal as fast as possible with an A/D that has large number of bits.

Typical A/D coding scheme



The analog signal is continuous in time. But, it's necessary to convert this to a flow of digital values.

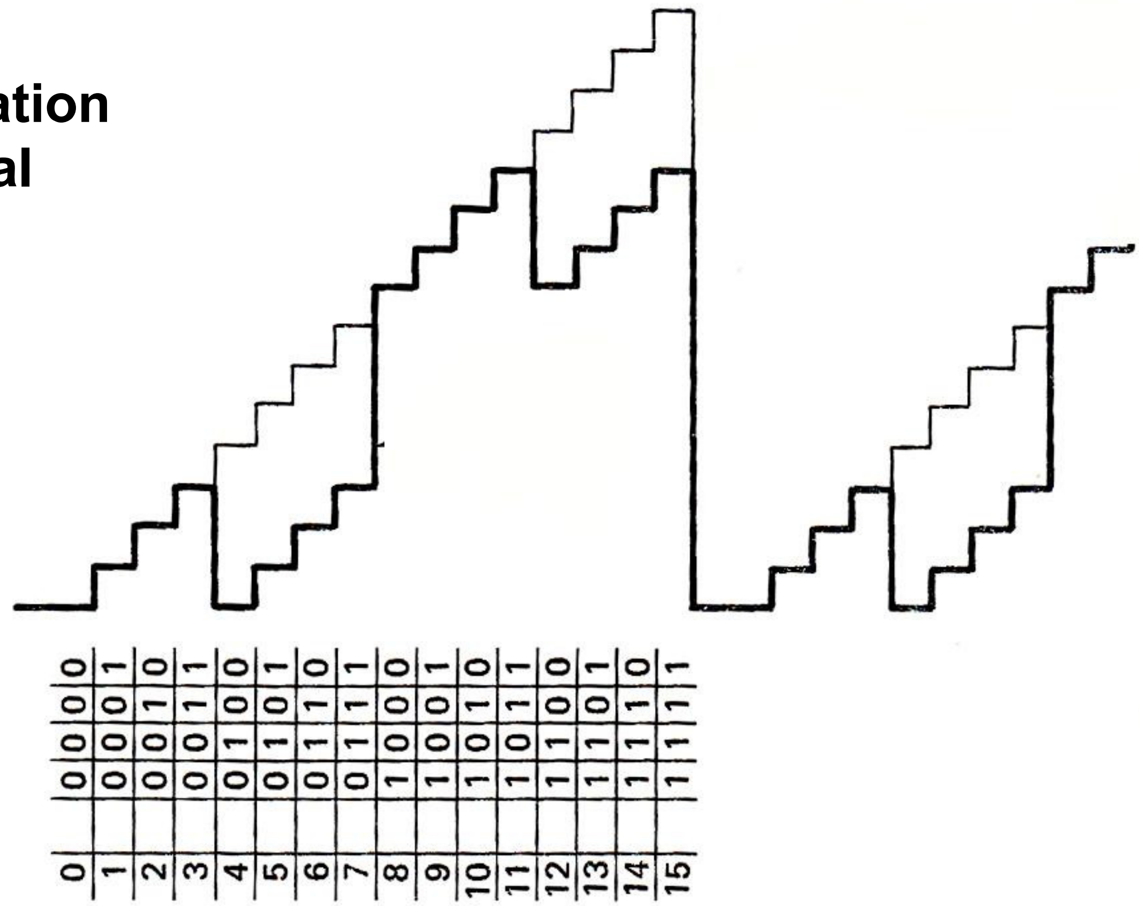
The rate at which new digital values are sampled from the analog signal is important.

The rate of new values is called the *sampling rate*, *sample rate*, or the *sampling frequency* of the data converter.

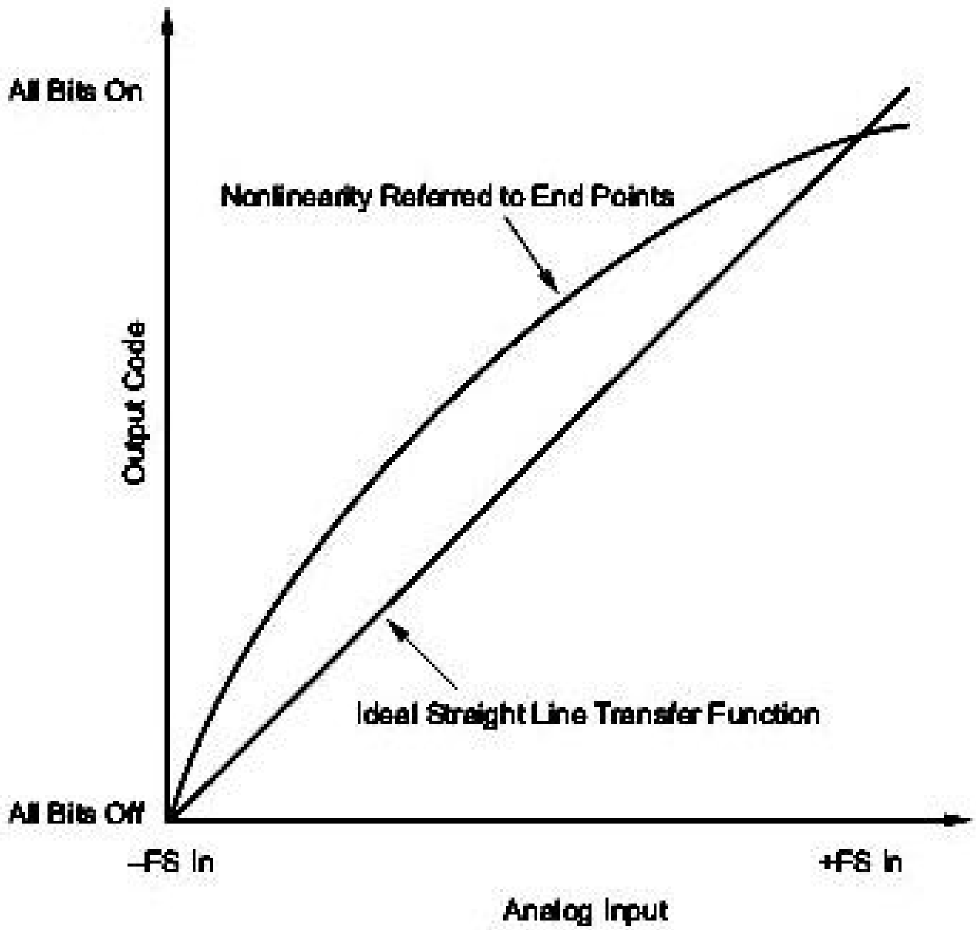
In the *Flex Radio* Model 6500 HF *software-defined radio* (*SDR*) ham radio transceiver, for example, the receiver section's A/D sampling rate is 255-Msamples per second, and the A/D generates 16 bits of data for every sample!

ADCs are also used in digital voltmeters, cellphones, and digital oscilloscopes, to name a few applications.

Ideal digitization versus actual digitization

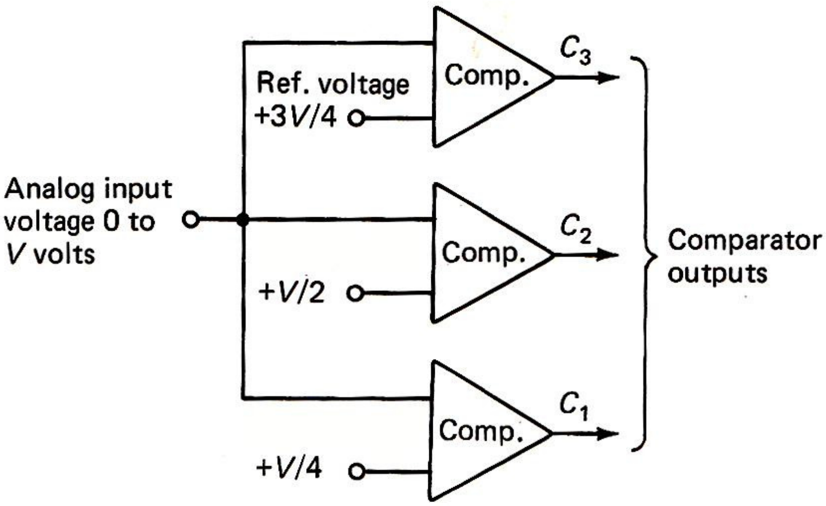


Data converters suffer from non-linearity errors.



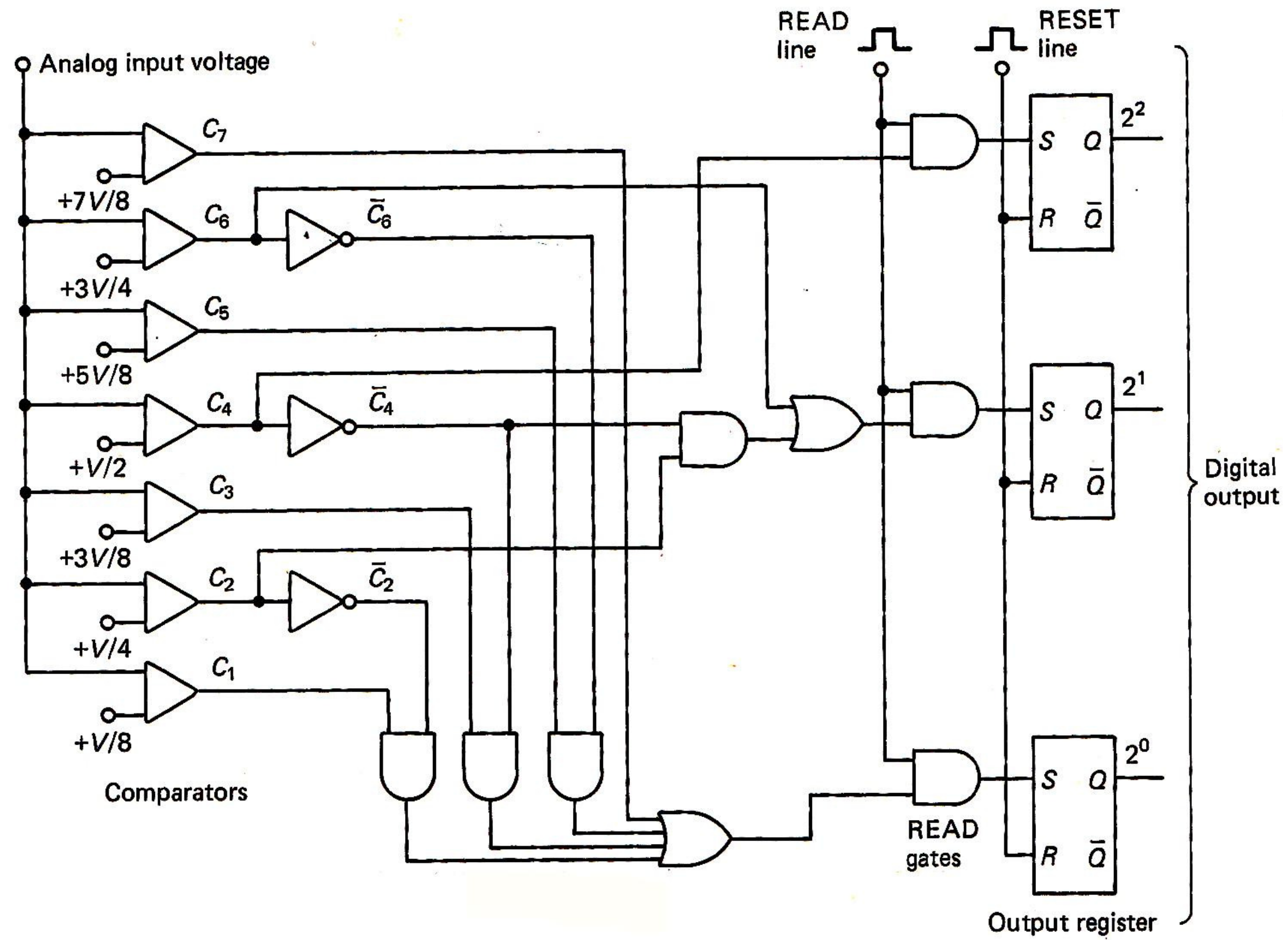
Simultaneous A/D conversion relies on analog comparators. These A/Ds are also called *flash A/D* converters.

$2^n - 1$ comparators are required to convert to a signal with *n* bits.



Input voltage	Comparator output		
	C_1	C_2	C_3
0 to $+V/4$	Low	Low	Low
$+V/4$ to $+V/2$	High	Low	Low
$+V/2$ to $+3V/4$	High	High	Low
$+3V/4$ to $+V$	High	High	High

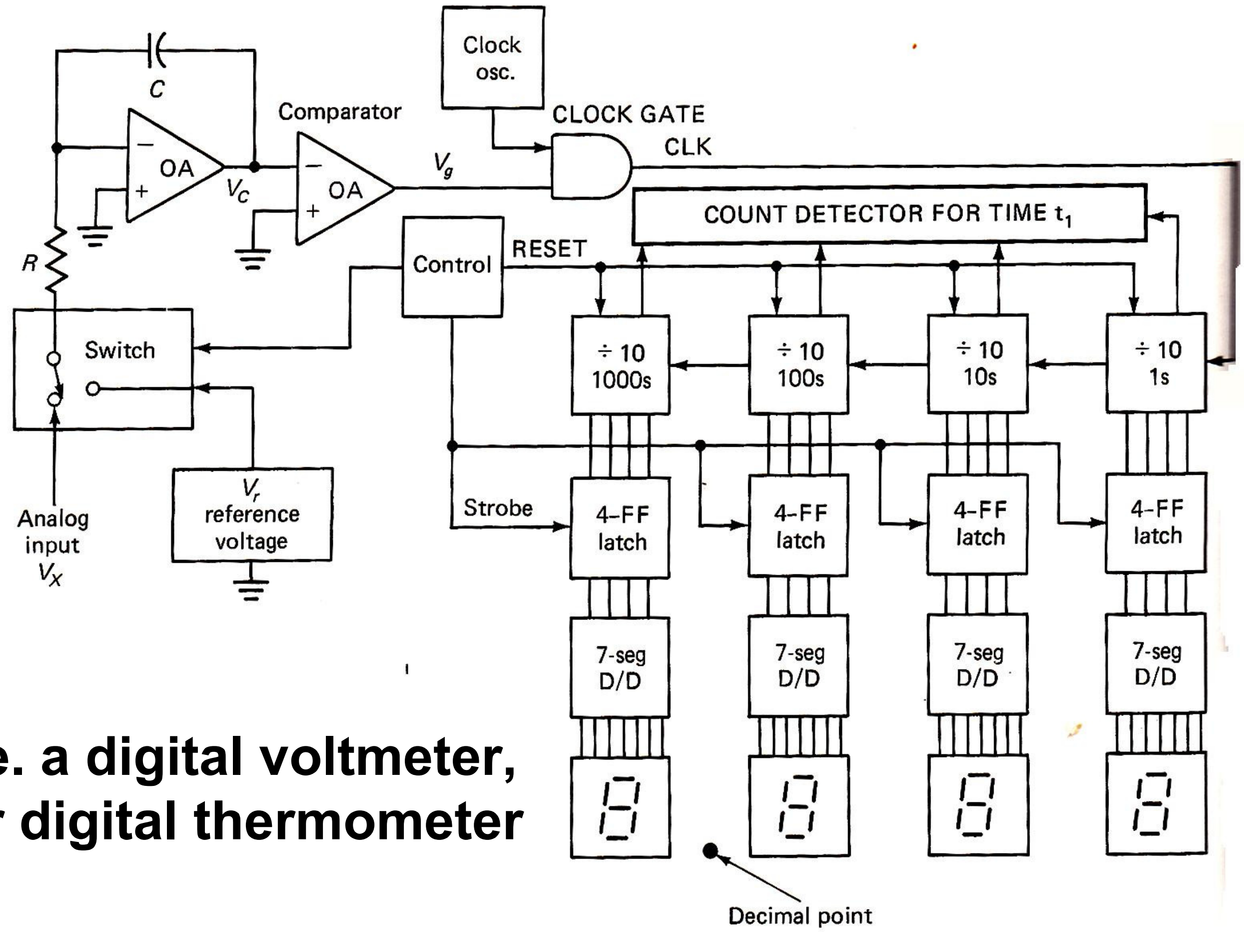
This block diagram is for a 3-bit simultaneous A/D



Direct conversion is very fast. Flash A/D converters can operate at GHz/second sampling rates, but usually at only 8- or 10-bits of resolution (or fewer), since the number of comparators needed, $2^N - 1$, doubles with each additional bit.

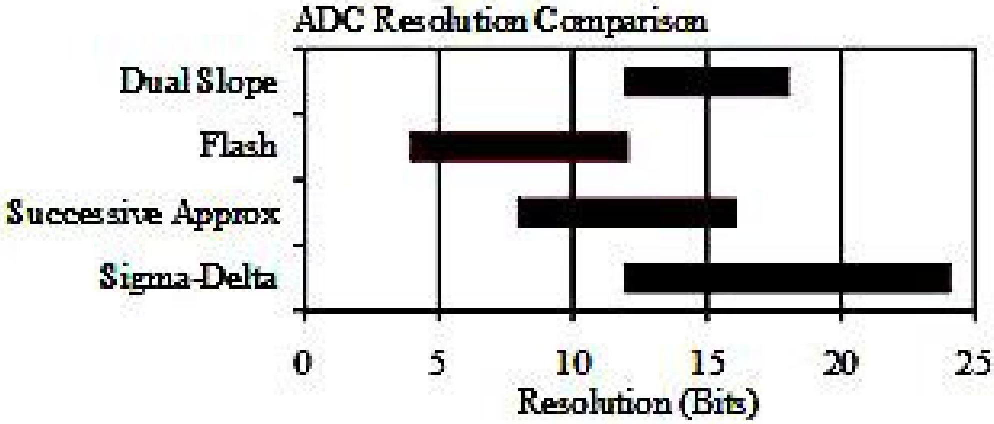
By comparison, other types of A/D converters, though slower, can have 24 bits of resolution – or more!

Block diagram of a *dual-slope A/D* with a display



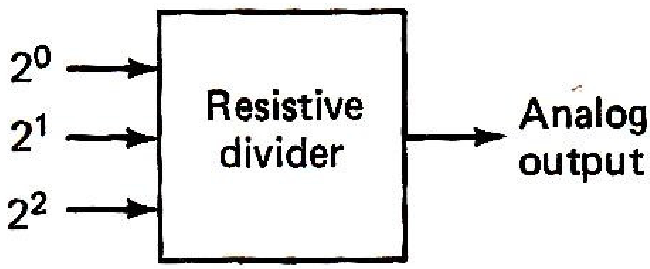
i.e. a digital voltmeter, or digital thermometer

ADC Types Comparison



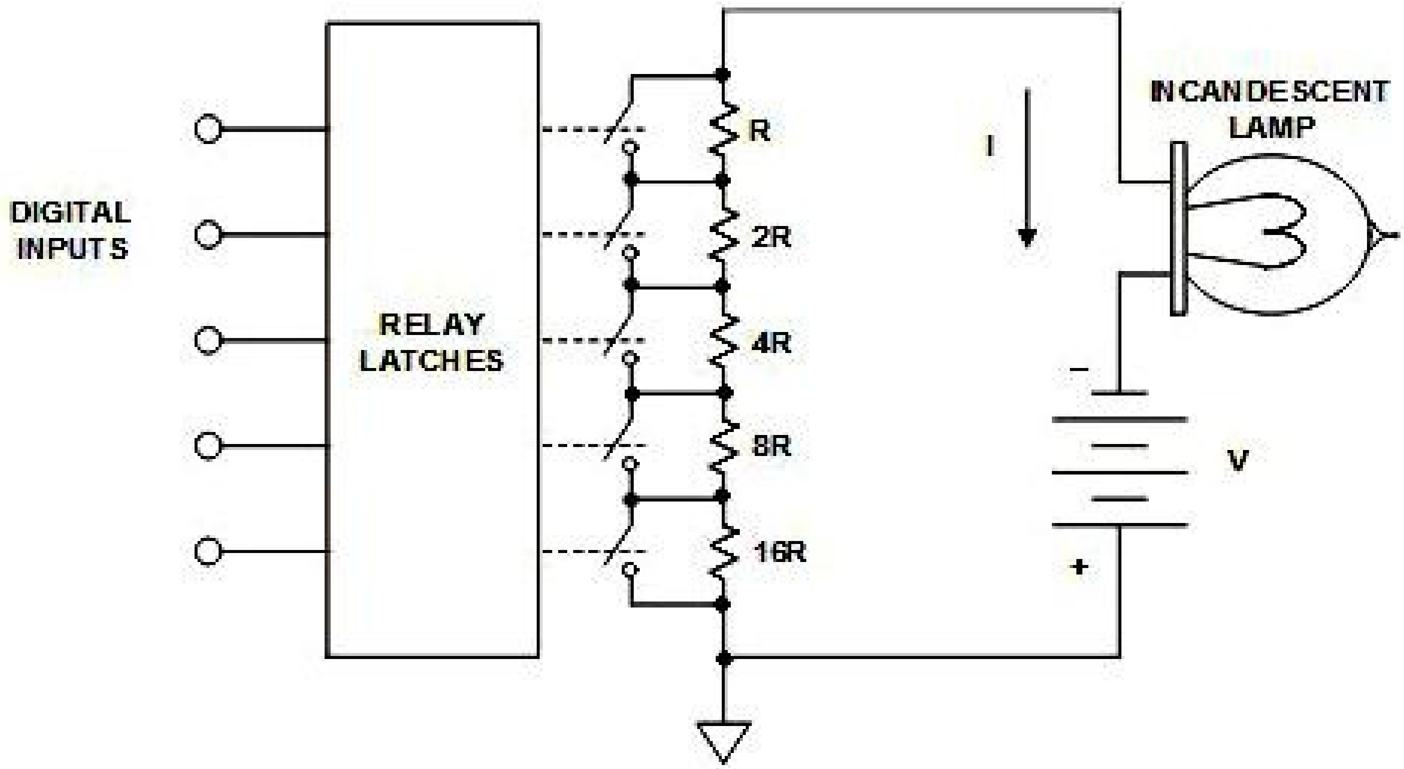
Type	Speed (relative)	Cost (relative)
Dual Slope	Slow	Med
Flash	Very Fast	High
Successive Appox	Medium – Fast	Low
Sigma-Delta	Slow	Low

Conversion can also be from the digital domain to the analog world. Here's a simplified example of a 3-bit *DA converter*, or *DAC*.



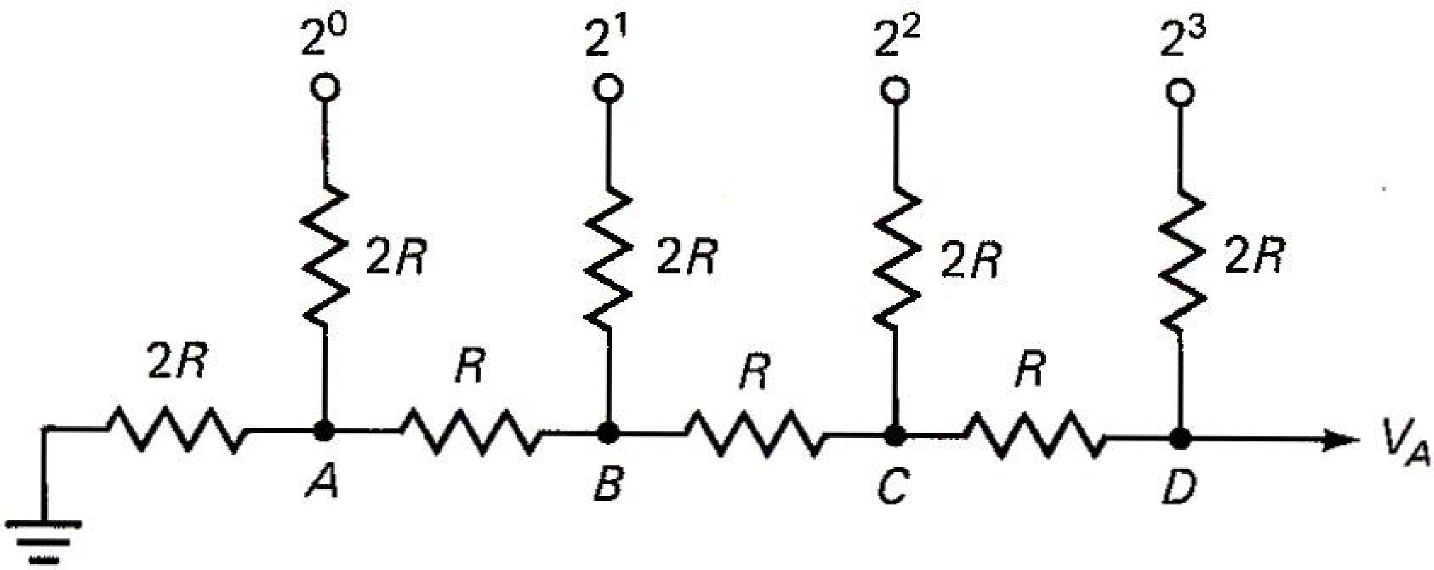
Digital input			Analog output
0	0	0	0 V
0	0	1	+1 V
0	1	0	+2 V
0	1	1	+3 V
1	0	0	+4 V
1	0	1	+5 V
1	1	0	+6 V
1	1	1	+7 V

An early DAC, ca. 1921:



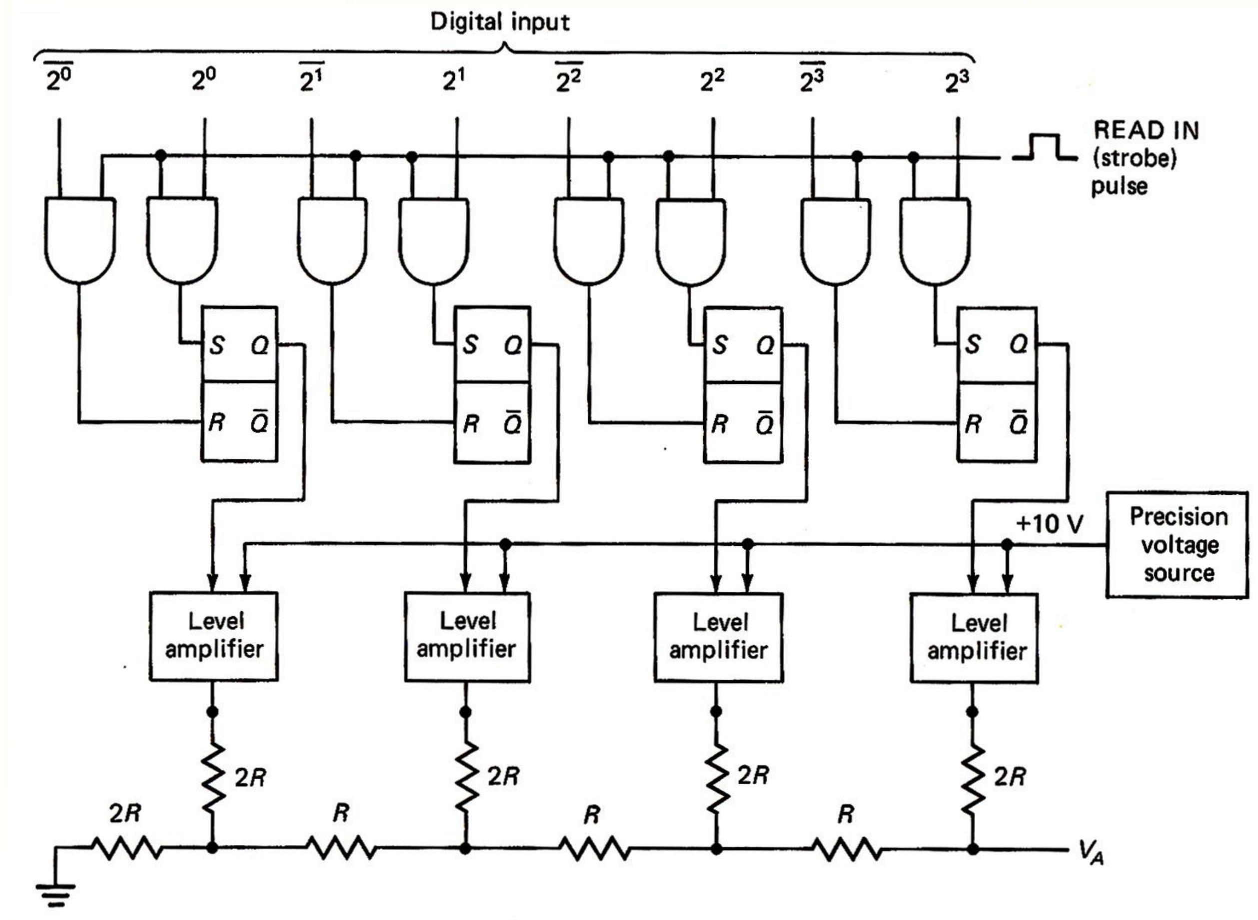
Adapted from: Paul M. Rainey, "Facsimile Telegraph System,"
U.S. Patent 1,608,527, Filed July 20, 1921, Issued November 30, 1926

A resistive network can be used as a *binary ladder* in a DAC, whose output voltage V_A is a weighted sum of the digital inputs.



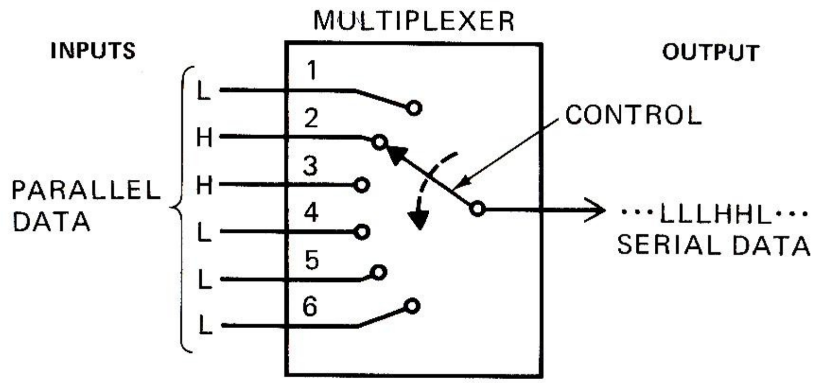
This is called an *R2R ladder*.

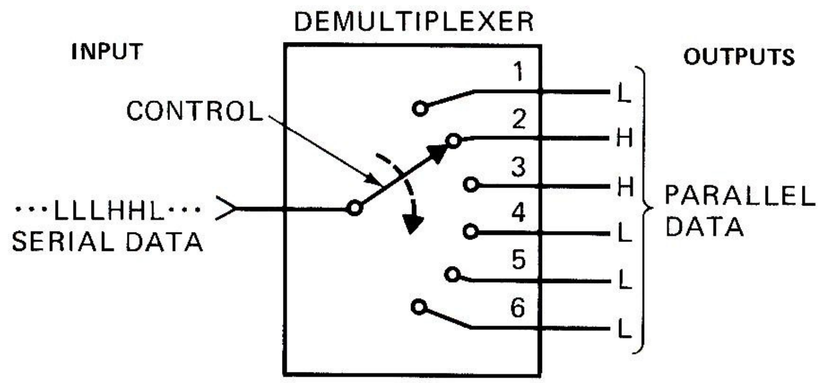
This diagram depicts a simple DAC.
It uses Set-Reset flip-flops and an R2R ladder.



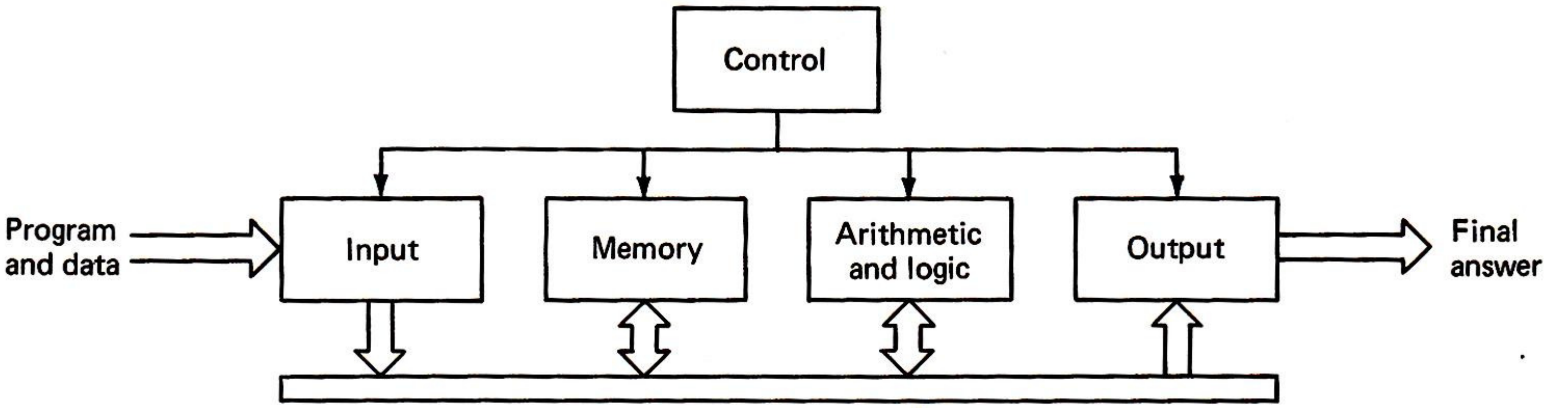
A ***multiplexer***, or ***MUX***, can be used as a very fast electronic rotary switch.

MUXes are sometimes used to expand multi-channel A/D and DAC configurations.





Data converters (A/D and DAC) devices are typically supported by microcomputer systems.



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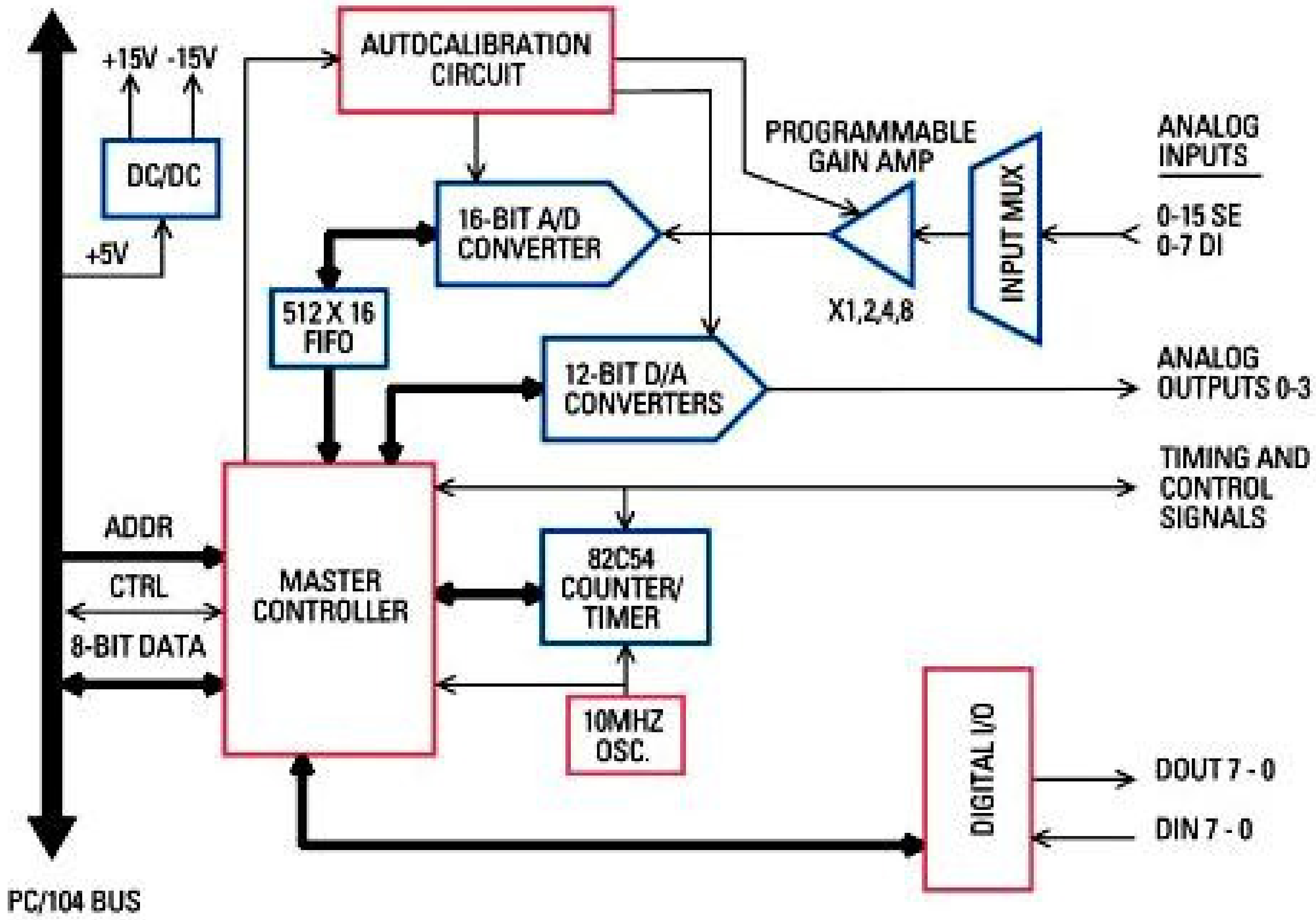
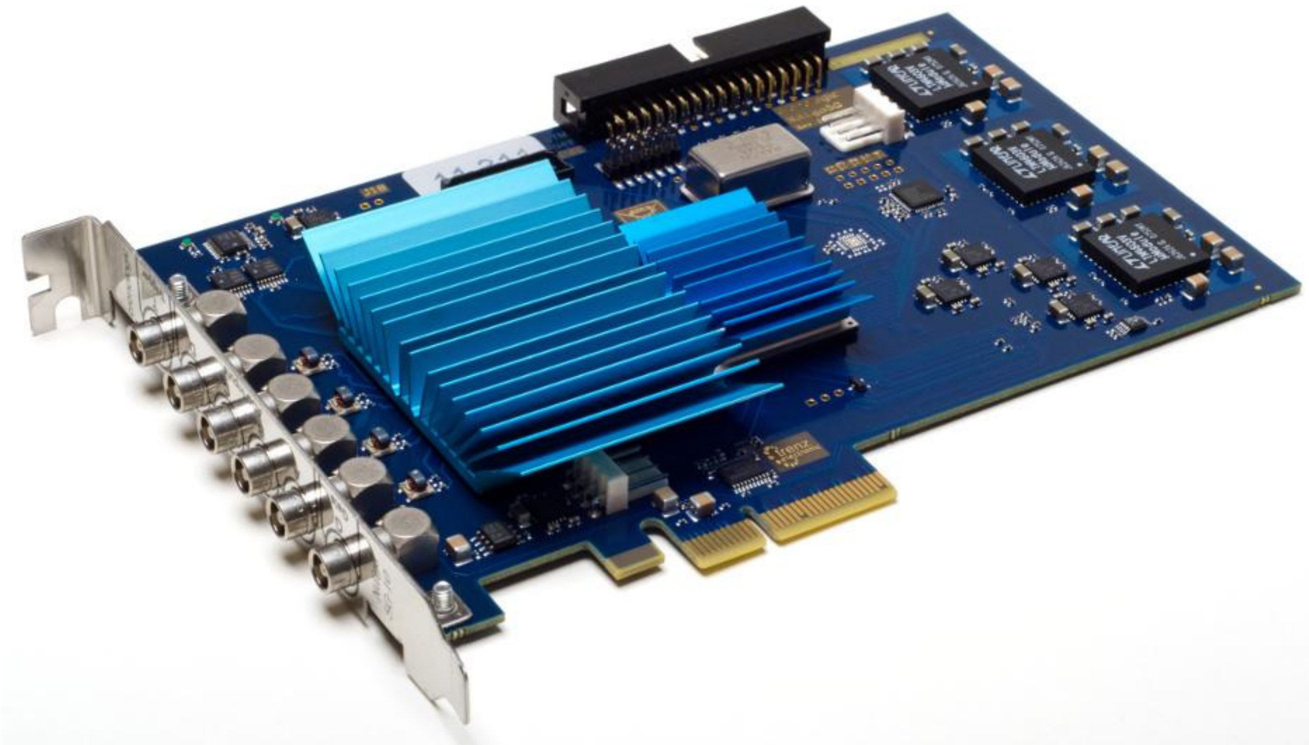


AUTOCALIBRATION CIRCUIT
+15V
-15V
DC/DC
+5V
PROGRAMMABLE GAIN AMP
ANALOG INPUTS
16-BIT A/D CONVERTER
INPUT MUX
0-15 SE
0-7 DI
512 X 16 FIFO
X1,2,4,8
12-BIT D/A CONVERTERS
ANALOG OUTPUTS 0-3
TIMING AND CONTROL SIGNALS
ADDR
MASTER CONTROLLER
82C54 COUNTER/ TIMER
CTRL
8-BIT DATA
10MHZ OSC.
DIGITAL I/O
DOUT 7 - 0
DIN 7 - 0
PC/104 BUS

This is a 5-Gbit/s multi-channel A/D card that delivers 10 bits of resolution and outputs data to a high-end PC's *PCIexpress* bus. It costs thousands of dollars.



This *PCI bus* card samples at a much slower 110-ksamples/sec with 12-bits of resolution, and sells for $425.

That's all for now!
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