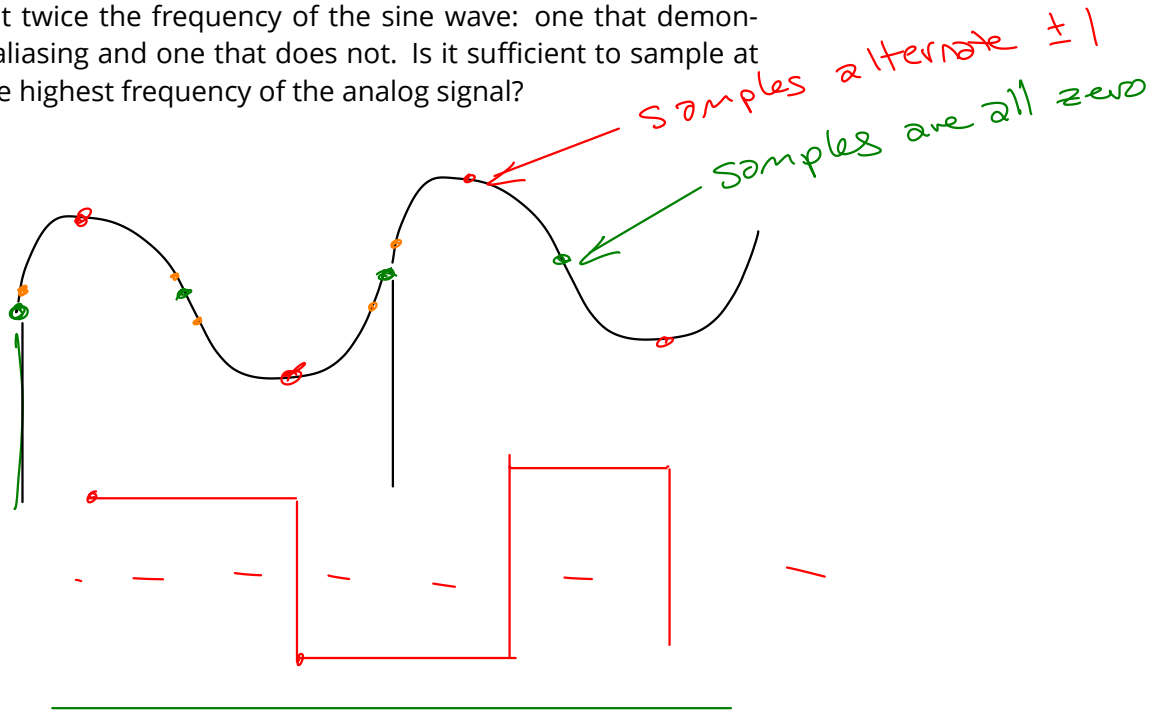
Analog Interfaces

Exercise 1: Draw a sine wave and indicate two sets of sampling points at twice the frequency of the sine wave: one that demonstrates aliasing and one that does not. Is it sufficient to sample at twice the highest frequency of the analog signal?



Exercise 2: What minimum sampling rate would be required to digitize a 10 kHz square wave if you wanted to include frequency components up to the 7'th harmonic (at 70 kHz)?

sample rate $>$ 2x f_{max}

$>$ 2 x 70 kHz

$>$ 140 kHz.

Exercise 3: A signal with range of ±3 V must be quantized so that the quantization error is less than 1 mV. What minimum number of bits of resolution is required?

$\Delta = 2mV$

3 → 2mV 2999

: −3 → 0

$V = 3 - (-3) = 6$ V

steps $\frac{6}{0.002} = 3000$

$2^n - 1$

0

Δ 1mV } $\Delta/2$ is worst-case quantization error

$2^{n-1} > 2999$

$2^n > 3000$

$\log_2 2^n > \log_2 3000$

$n > 11.55$

use $n = 12$ bits

Exercise 4: A signal-to-noise power ratio of about 48 dB is considered "good enough" for speech communication. Approximately how many bits per sample are required to obtain this quantization SNR?

$$\frac{S}{N} > 48\,dB$$

$$1.76 + 6n > 48$$

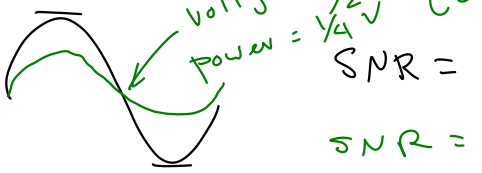
$$6n \gtrsim 46$$

$$n \gtrsim 8$$

Exercise 5: When quantizing a full-scale sine wave, what quantization SNR would be achieved with a resolution of 12 bits? What if the signal's voltage range was only half of the full-scale range?

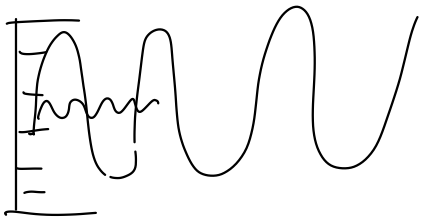
$10\log_{10}(2^2) = 6\,dB$

$10\log_{10}(2) = 3$



$SNR = 1.76 + 6 \cdot 12 = 73.76\,dB.$

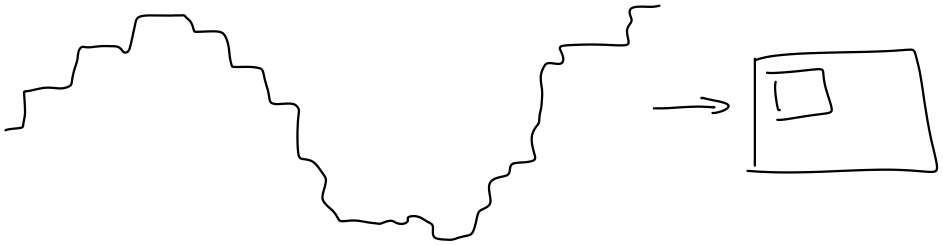
$SNR = 73.76 - 6 = 67.76\,dB$



OR: only have 11 bits of resolution

$SNR = 1.76 + 6 \cdot 11 = 67.6\,dB$

Exercise 6: A DAC outputs a digitized 1 kHz sine-wave signal. The analog output is analyzed and the power at 1 kHz is found to be 1 W while the power at all other frequencies adds up to 10 mW. What is the ENOB?



$S = 1W$

$N = 10mW$

$\frac{S}{N} = \frac{1}{0.01} = 100$

$\frac{S}{N} = 10\log_{10}(100) = 20\,dB$

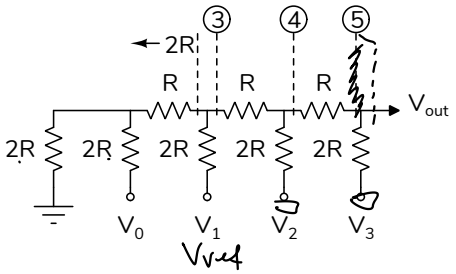
$20\,dB = 1.76 + 6n$

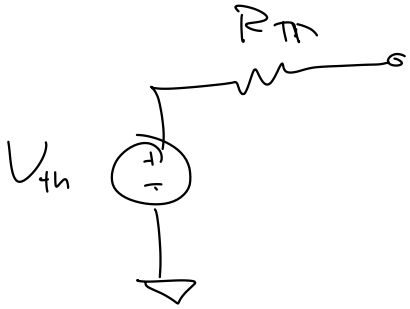
$18 = 6n$

$ENOB = n = 3$ bits

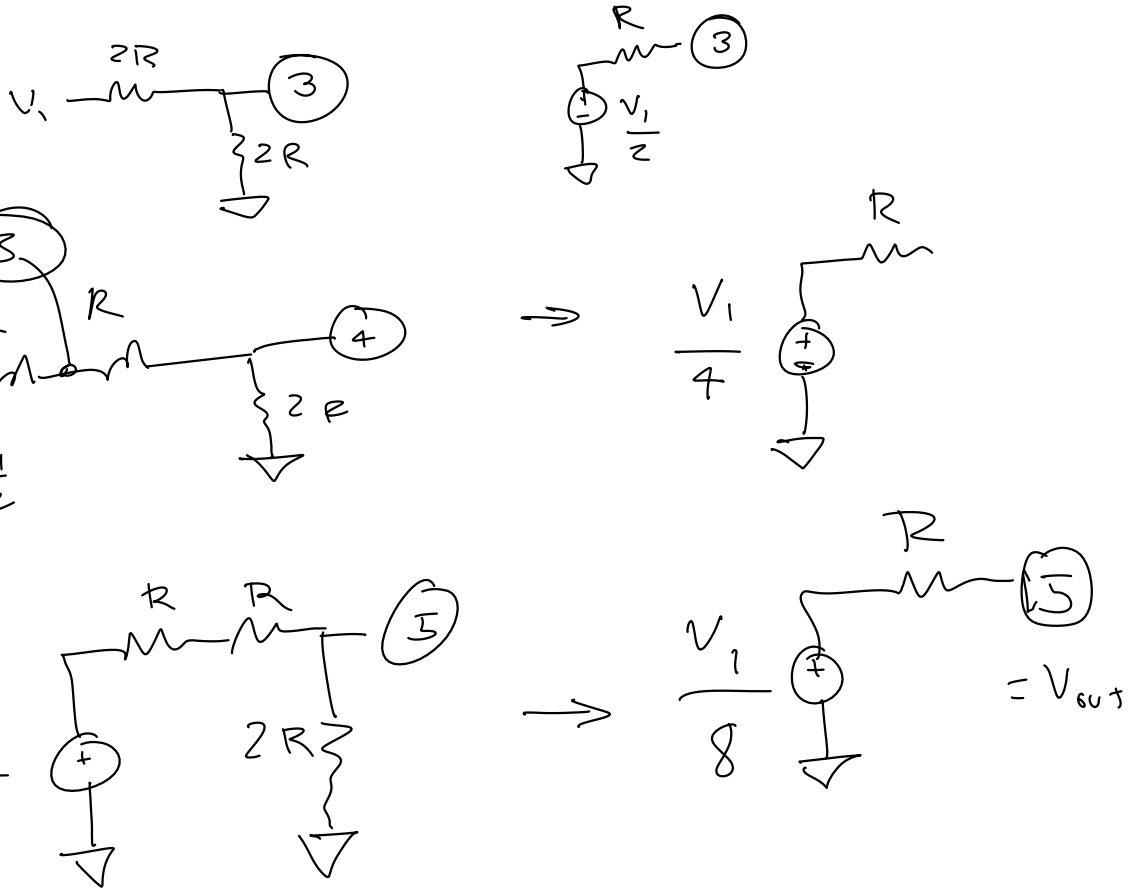
$1.76 + 24.6 \quad 146\,dB.$

Exercise 7:



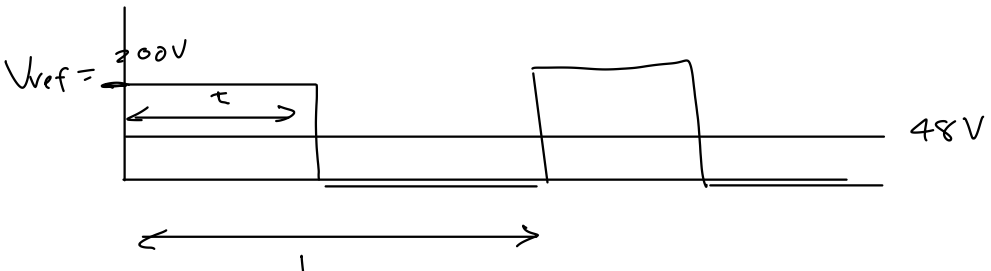


Assume V_1 is set to V_{ref} and all other inputs are zero (grounded). Find the Thevenim resistance (resistance to ground at V_{out} with all V_i shorted) and voltage (V_{out} with $V_1 = V_{ref}$). *Hint: Do this at the labelled nodes.*



Exercise 8: You are using a PWM DAC to convert a 200 VDC supply to a 48 VDC output. The switching frequency is 25 kHz. What is the duration of each PWM pulse?

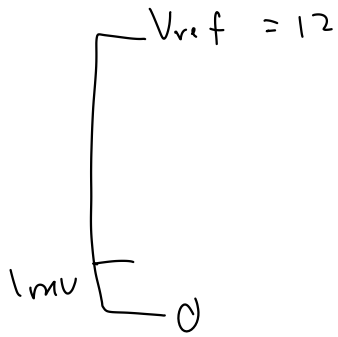
$$V_{out} = V_{ref} \cdot \frac{t}{T}$$



$$T = \frac{1}{25\text{kHz}} \qquad t = \frac{V_{out}}{V_{ref}} \cdot T$$

$$= \frac{48}{200} \cdot \frac{1}{25\times10^{3}} = 9.6\,\mu s$$

Exercise 9: You are designing a PWM DAC and need resolution of 1 mV with a full-scale output of 12 V. How many bits of resolution are required? The pulse frequency is 10 kHz. What is the clock frequency?



$$2^n \geq \frac{12}{0.001}$$

$$n \geq \log_2(12{,}000)$$

$$\geq 13$$

use $n = 14$ bits

$$T = \frac{1}{10\text{kHz}}$$

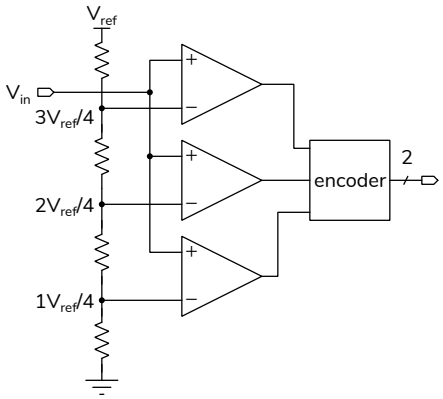
$$T = 2^n T_{clock} \qquad T_{clock} = \frac{T}{2^n} = \frac{100\,\mu s}{2^{14}}$$

$$f_{clock} = \frac{1}{T_{clock}} = \frac{2^{14}}{100\times10^{-6}} \approx 16.4\ \text{MHz}$$

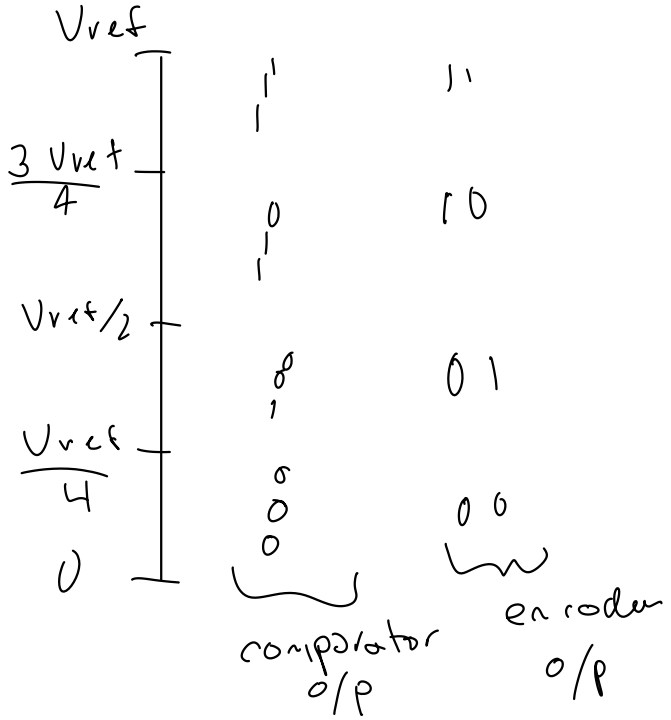
Exercise 10: Rank the different DACs described above in terms of sampling rate relative to clock rate and complexity relative to resolution.

	sampling rate / clock rate	complexity issues
binary weighted	1	resistor matching.
PWM	$\frac{1}{2^n}$	(1 counter) clock rate
Σ-Δ	varies	clock rate

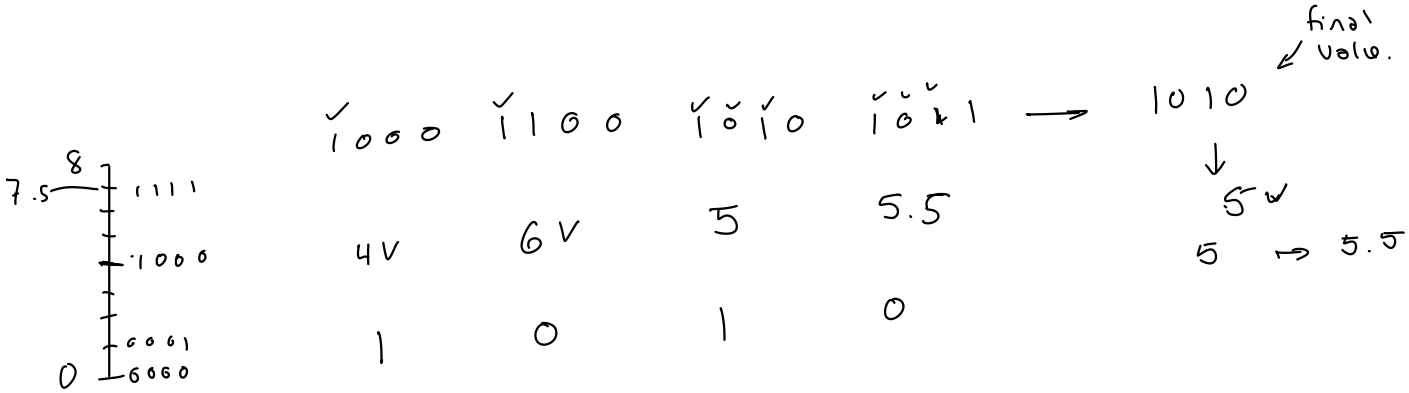
Exercise 11:

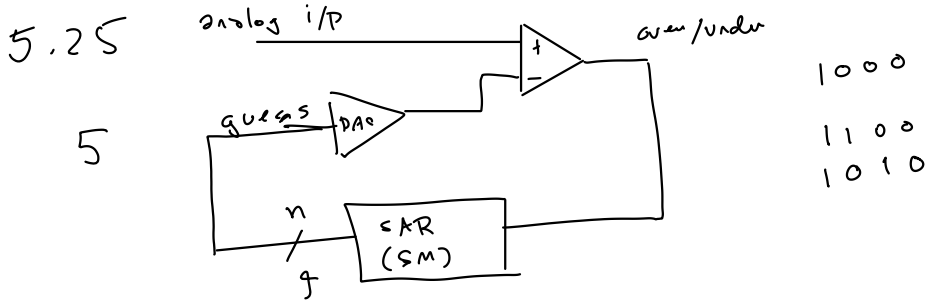


Draw a diagram showing the voltage ranges, the comparator outputs and the binary output for the 4-bit flash ADC above.

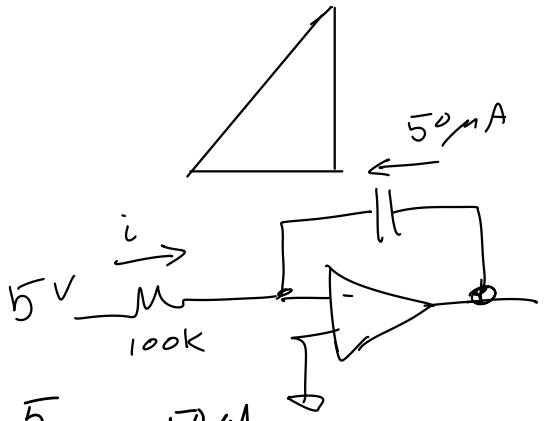


Exercise 12: A SAR ADC using a 4-bit DAC with a full-scale range of 0 to 7.5 V digitizes a 5.25 V signal. What voltages will the DAC output?





Exercise 13: What is the slope of an integrator, in $\mathrm{V/s}$, when charging a 100 nF capacitor with 5 V through a $100\,\mathrm{k\Omega}$ resistor?



$C = 100 \times 10^{-9}$

$V = 5V$

$R = 100 \times 10^{3}$

$i = \frac{V}{R} = \frac{5}{100 \times 10^{3}} = 50\,\mu A$

$Q(t) = CV(t)$

$\frac{dQ}{dt} = i = C\frac{dV}{dt}$

$\frac{dV}{dt} = \frac{i}{C} = \frac{50 \times 10^{-6}}{100 \times 10^{-9}} = 500\ V/s$