Lecture 6

- reference sources
- DA converters
- spectrum analyzers
- signal generators

DAC - digital to analog converter

It's the opposite of ADC

ADC

Analog voltage → Digital code

0 V → 0

5 V → 255

0000 000

1111 1111

DAC

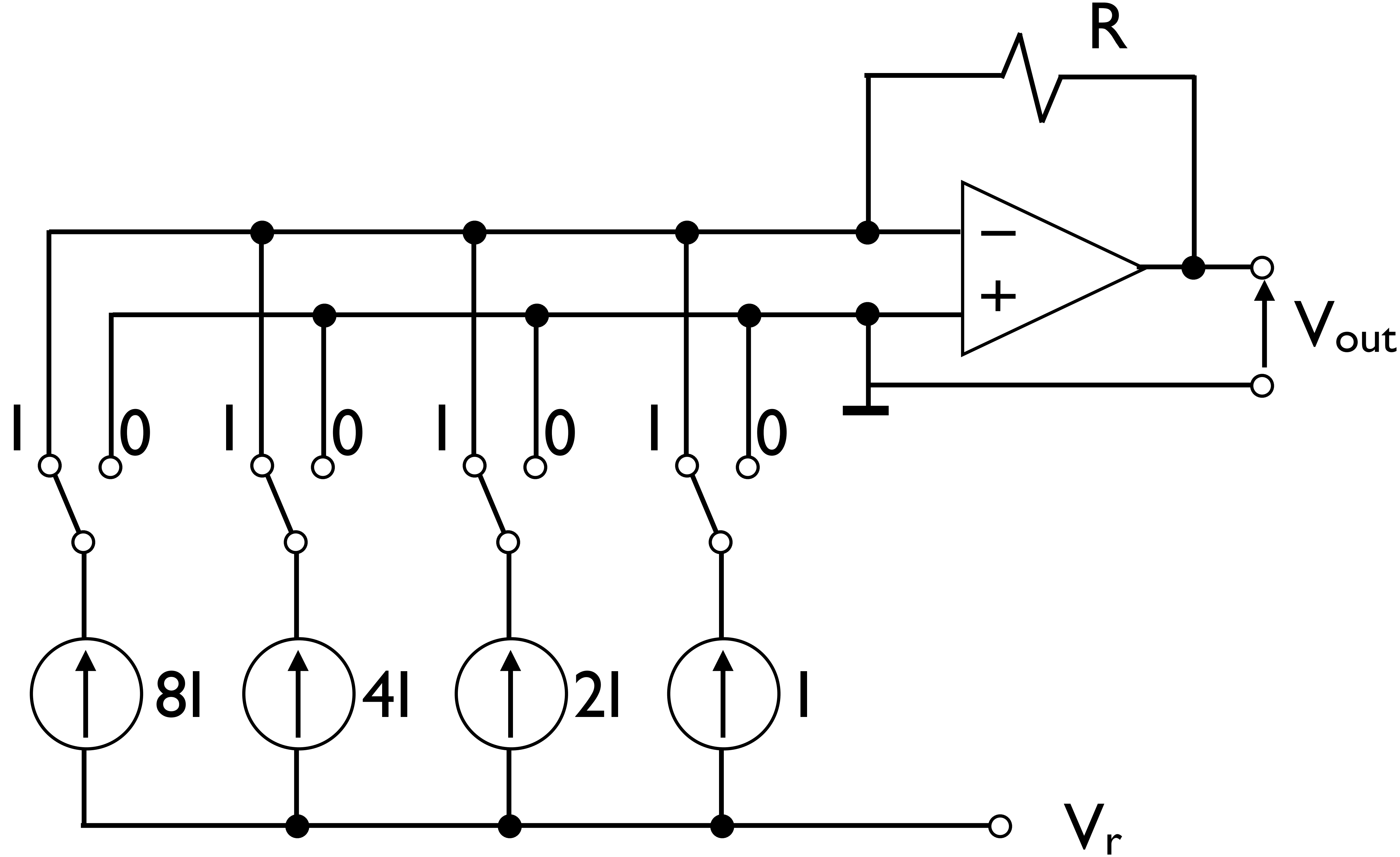
Digital code → Analog voltage

0 → 0 V

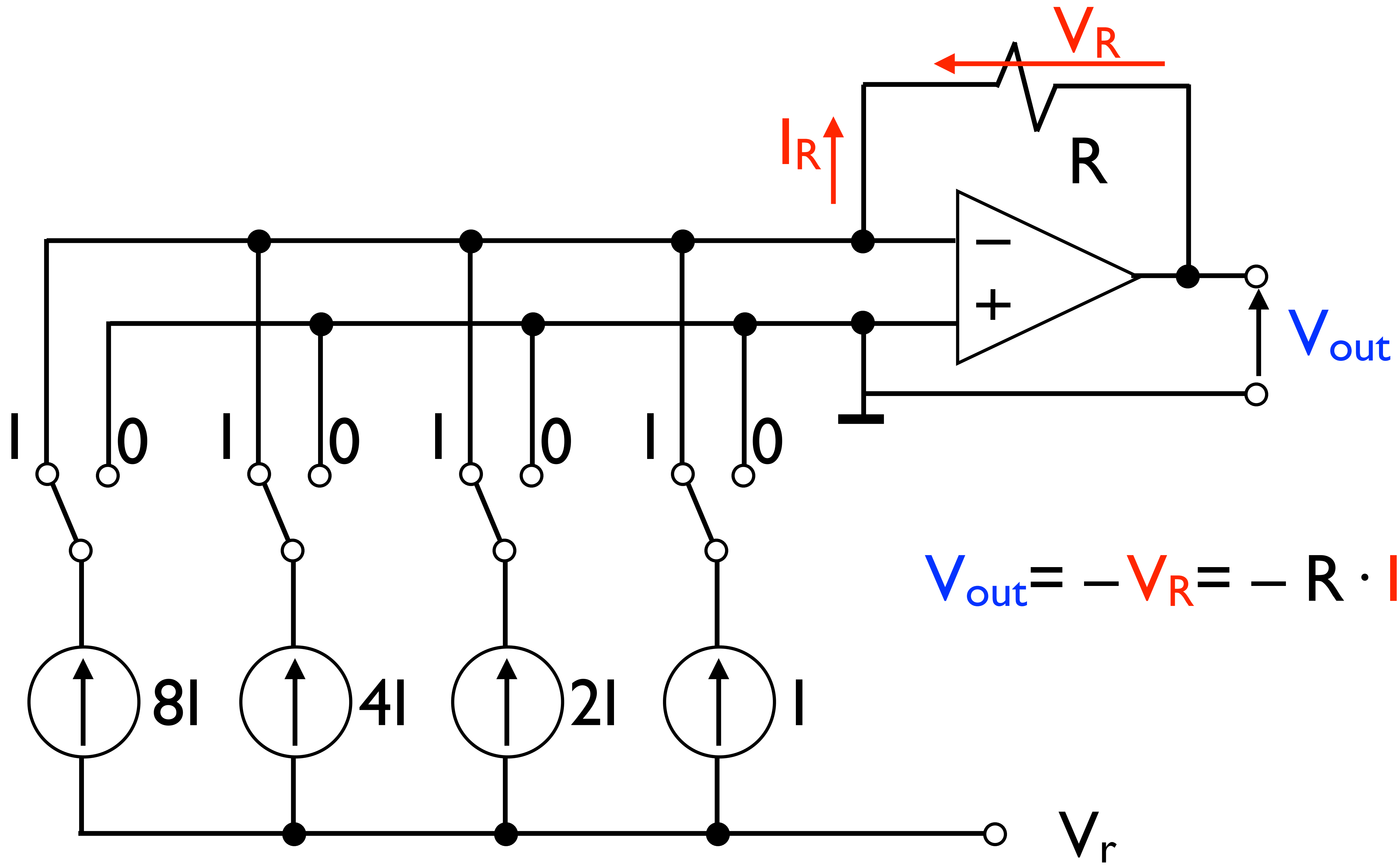
255 → 5 V

I - DAC with switched over current sources

Structure

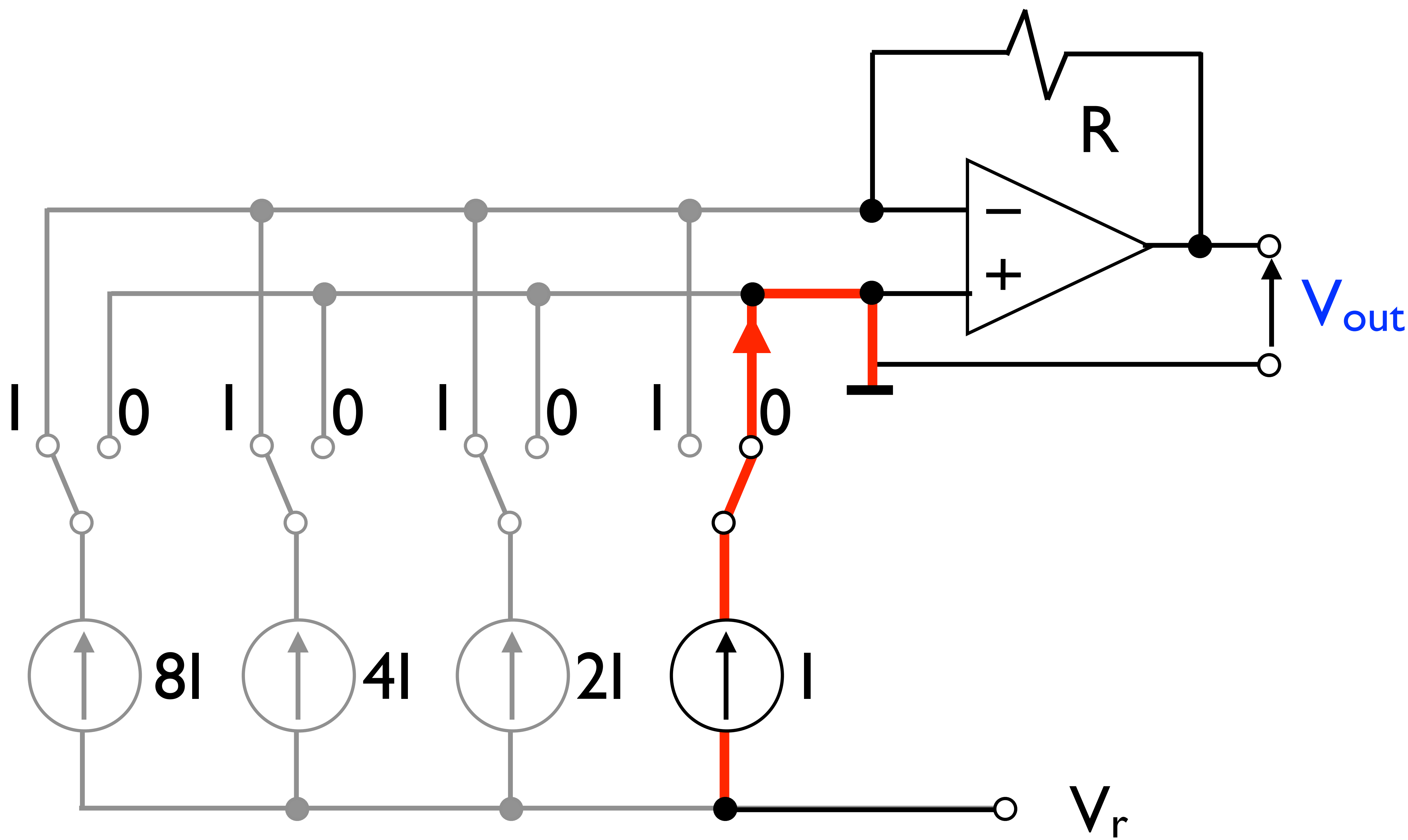


I - DAC with switched over current sources



$$V_{out} = -V_R = -R \cdot I_R$$

I - DAC with switched over current sources



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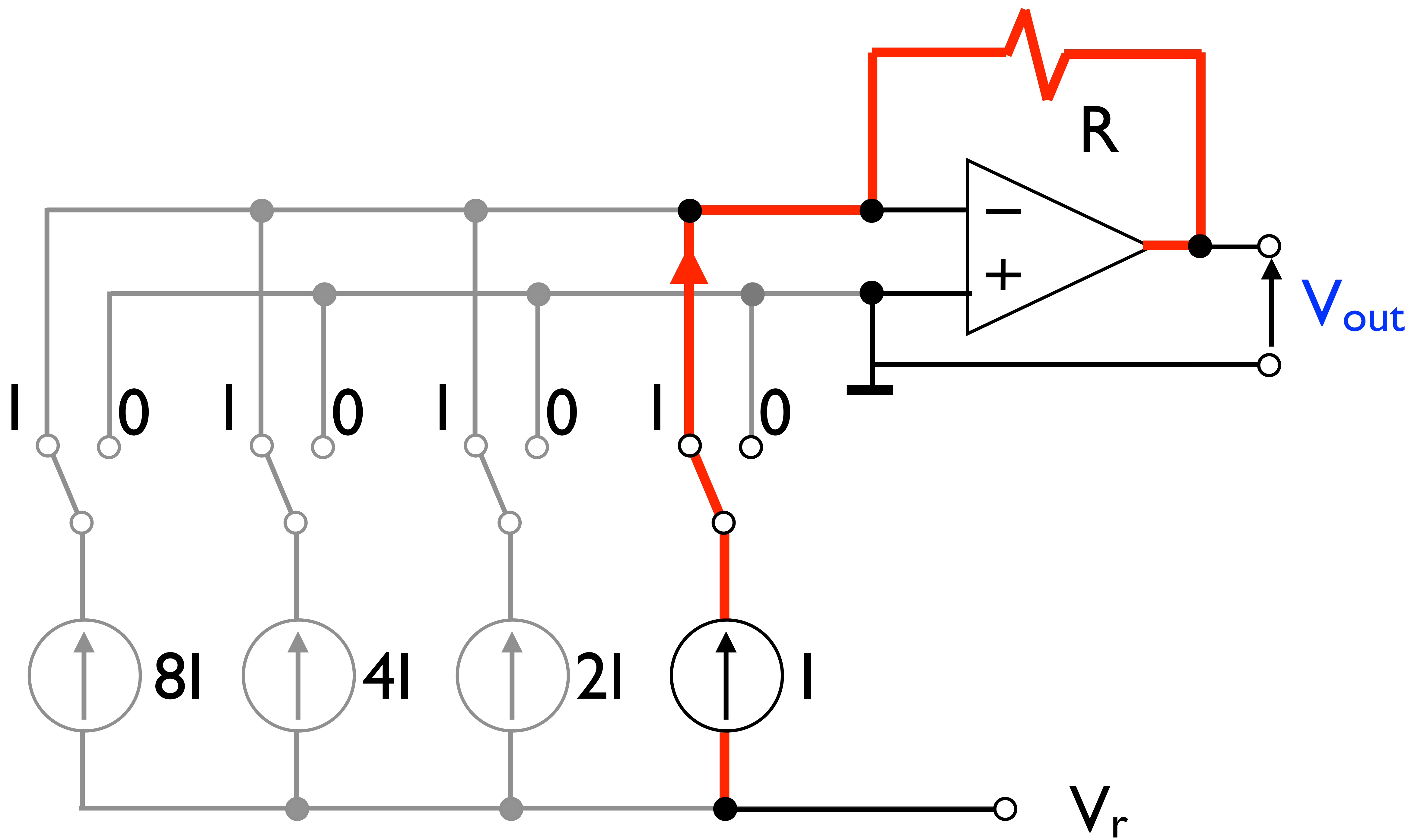
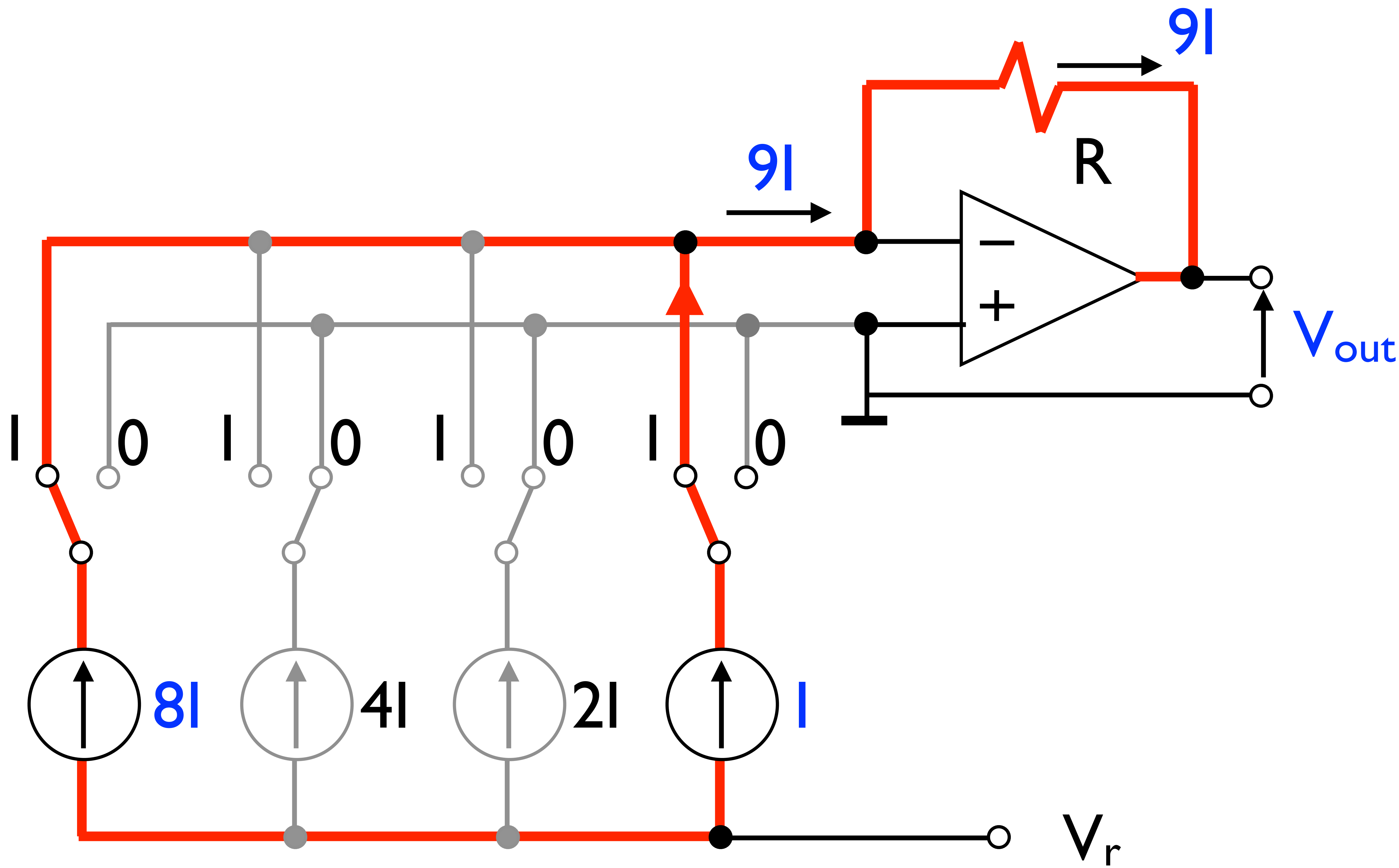
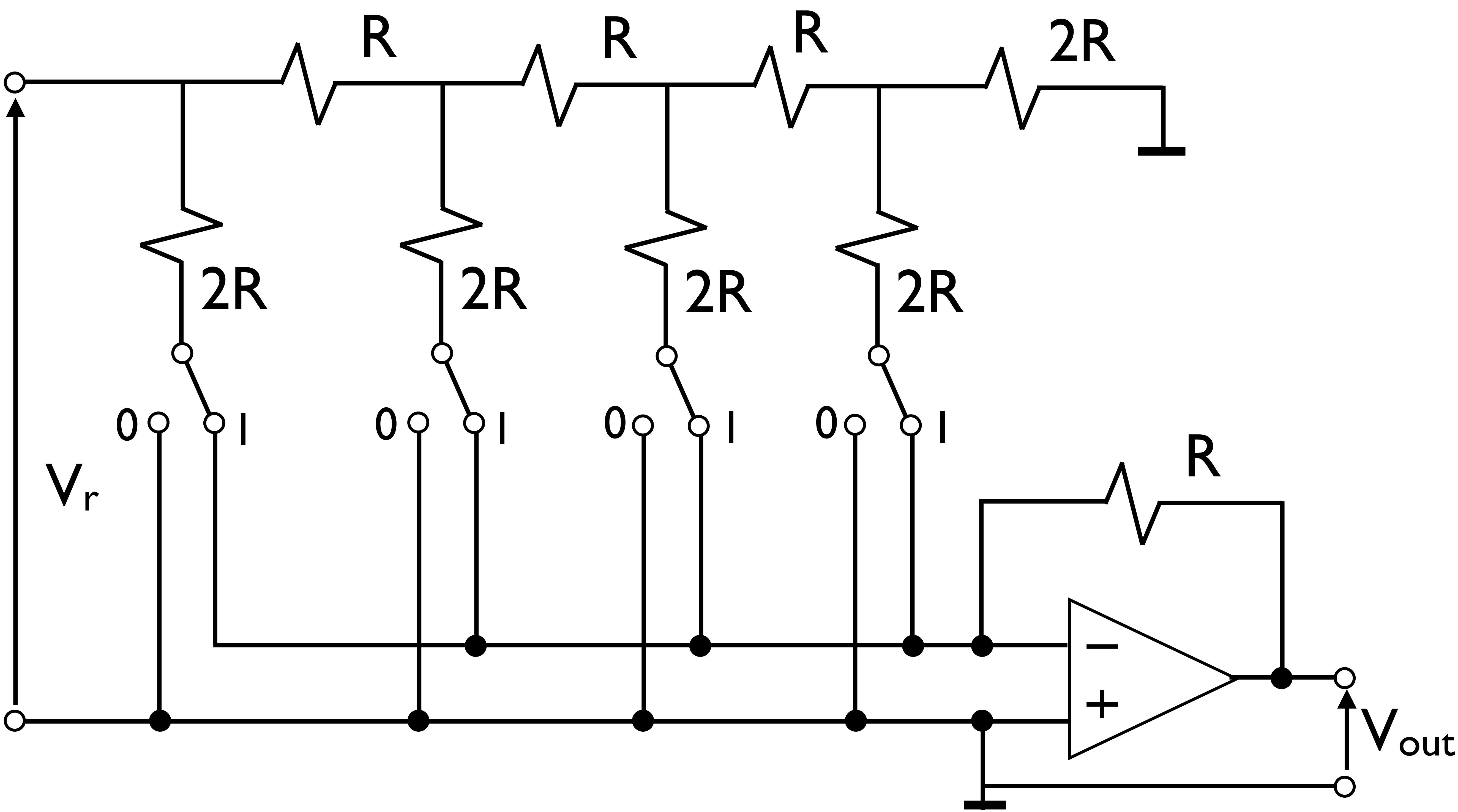


1 - DAC with switched over current sources



2 - DAC using R-2R Resistance ladder



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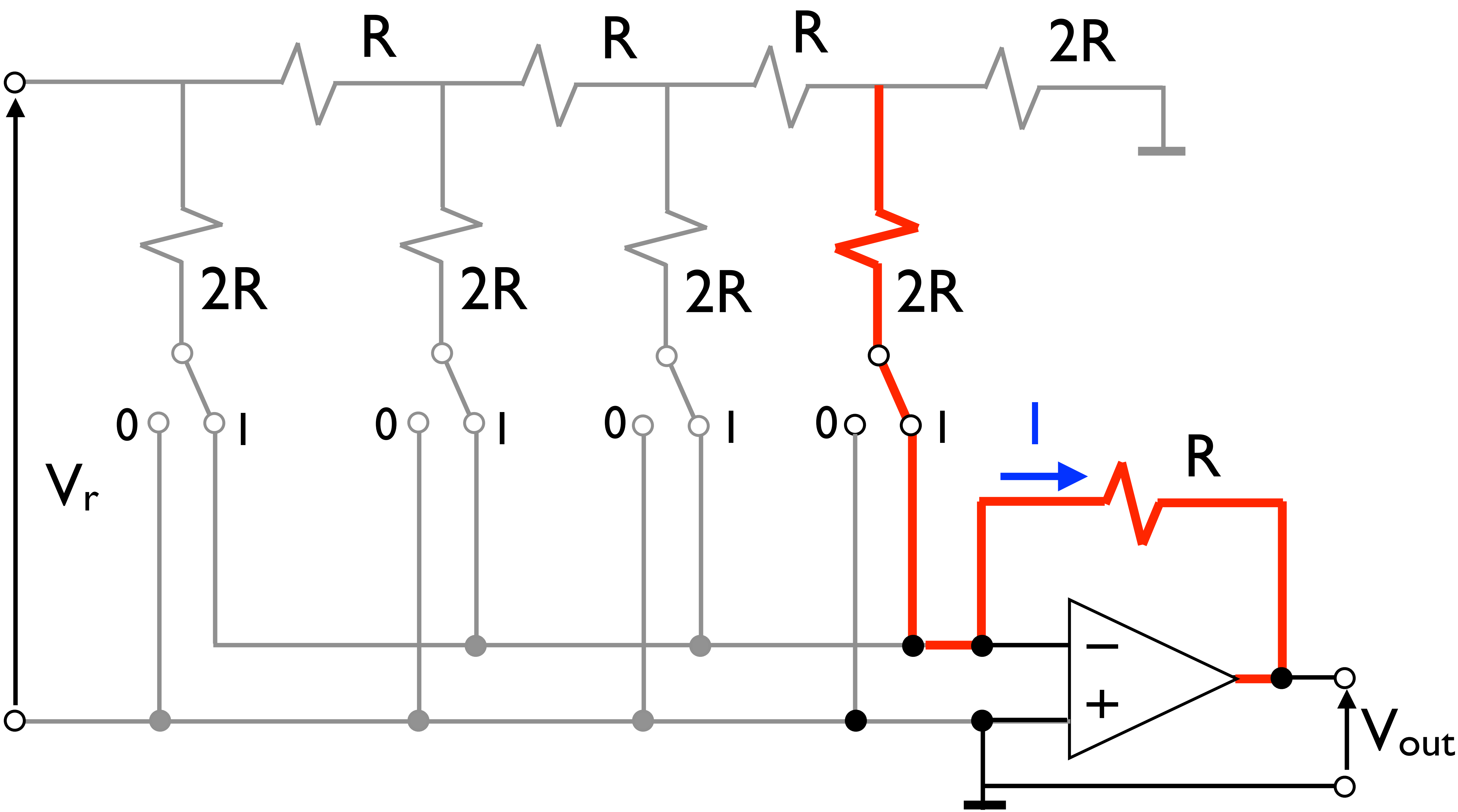

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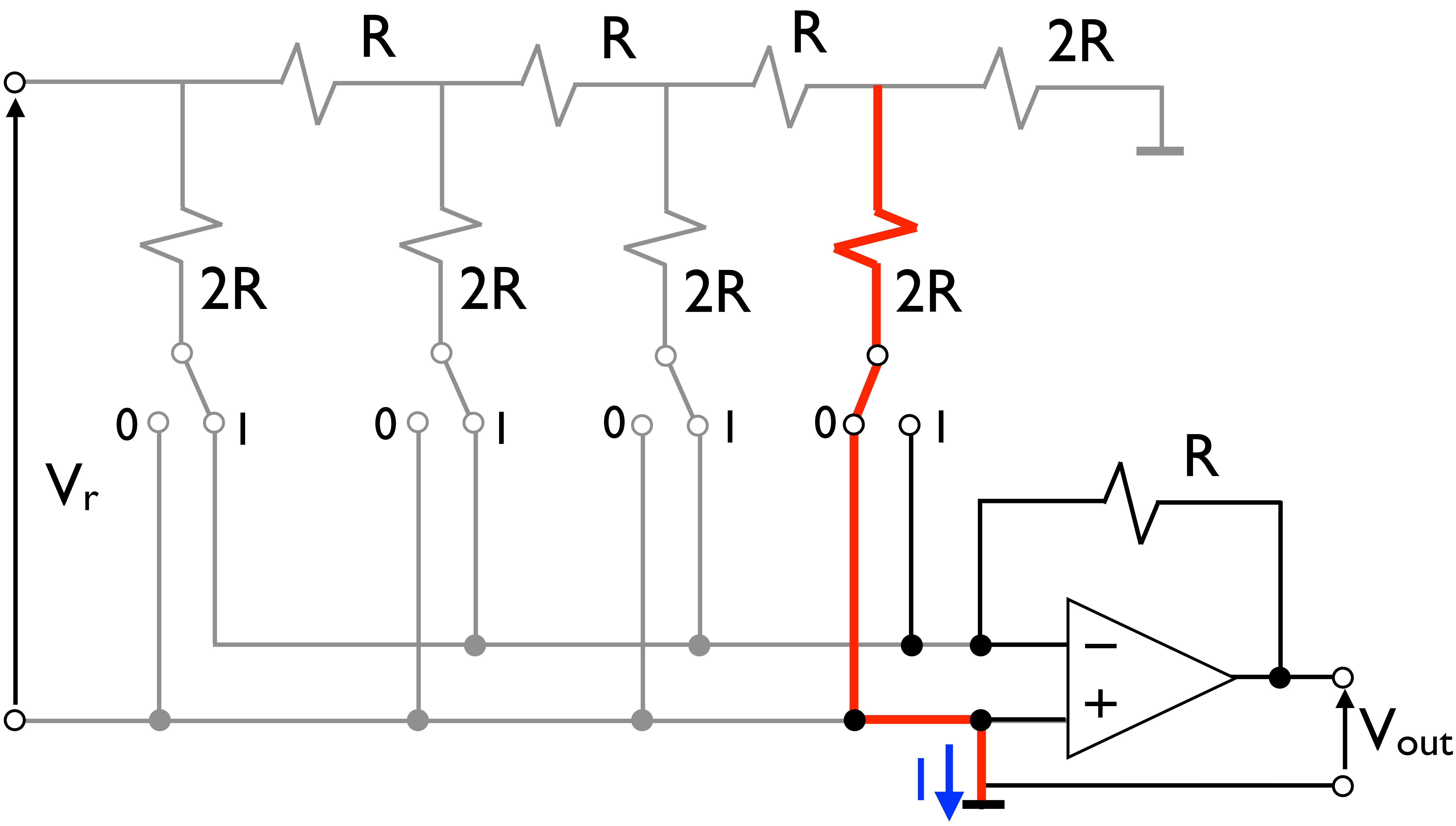
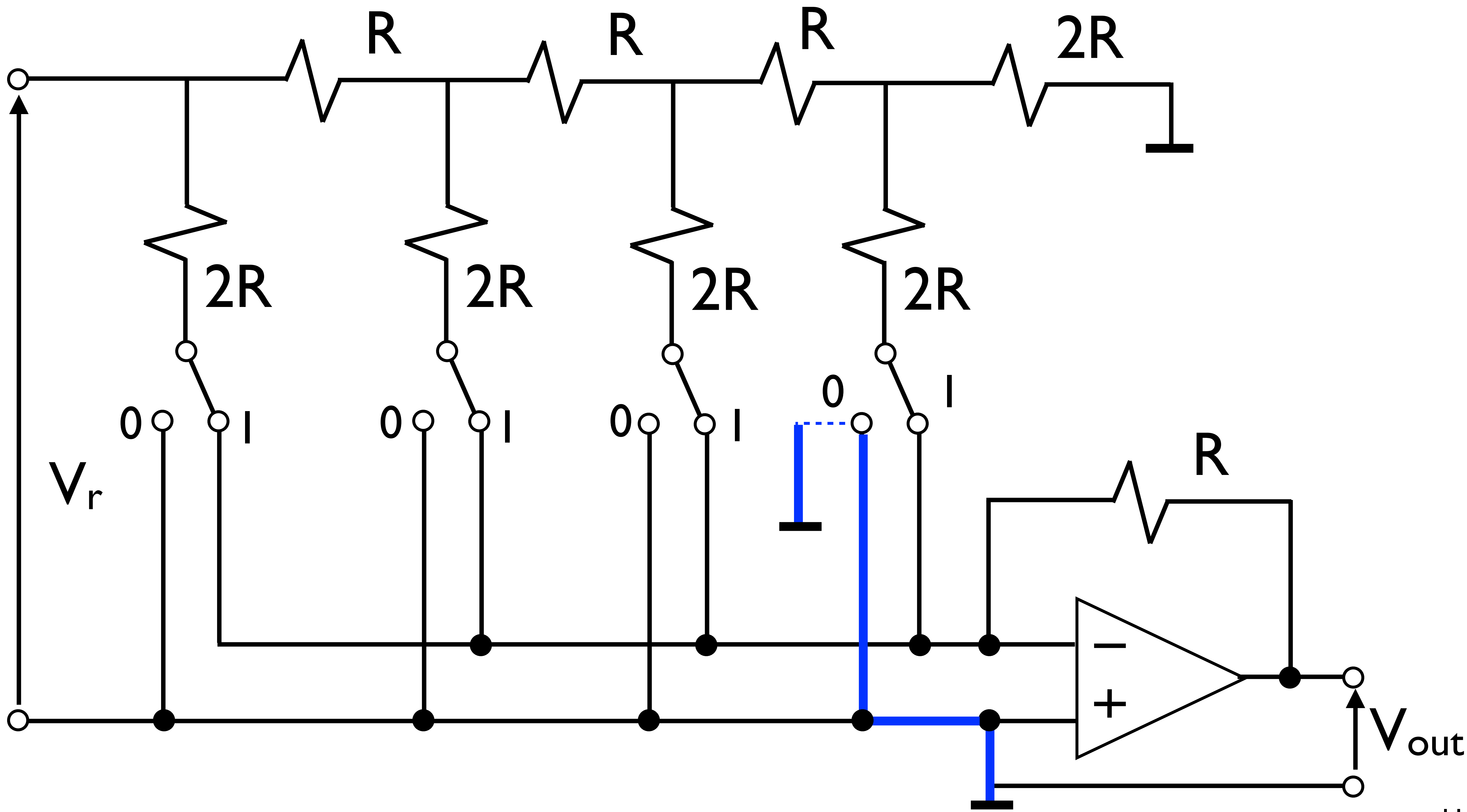


2 - DAC using R-2R Resistance ladder

In both cases 2R is connected to ground



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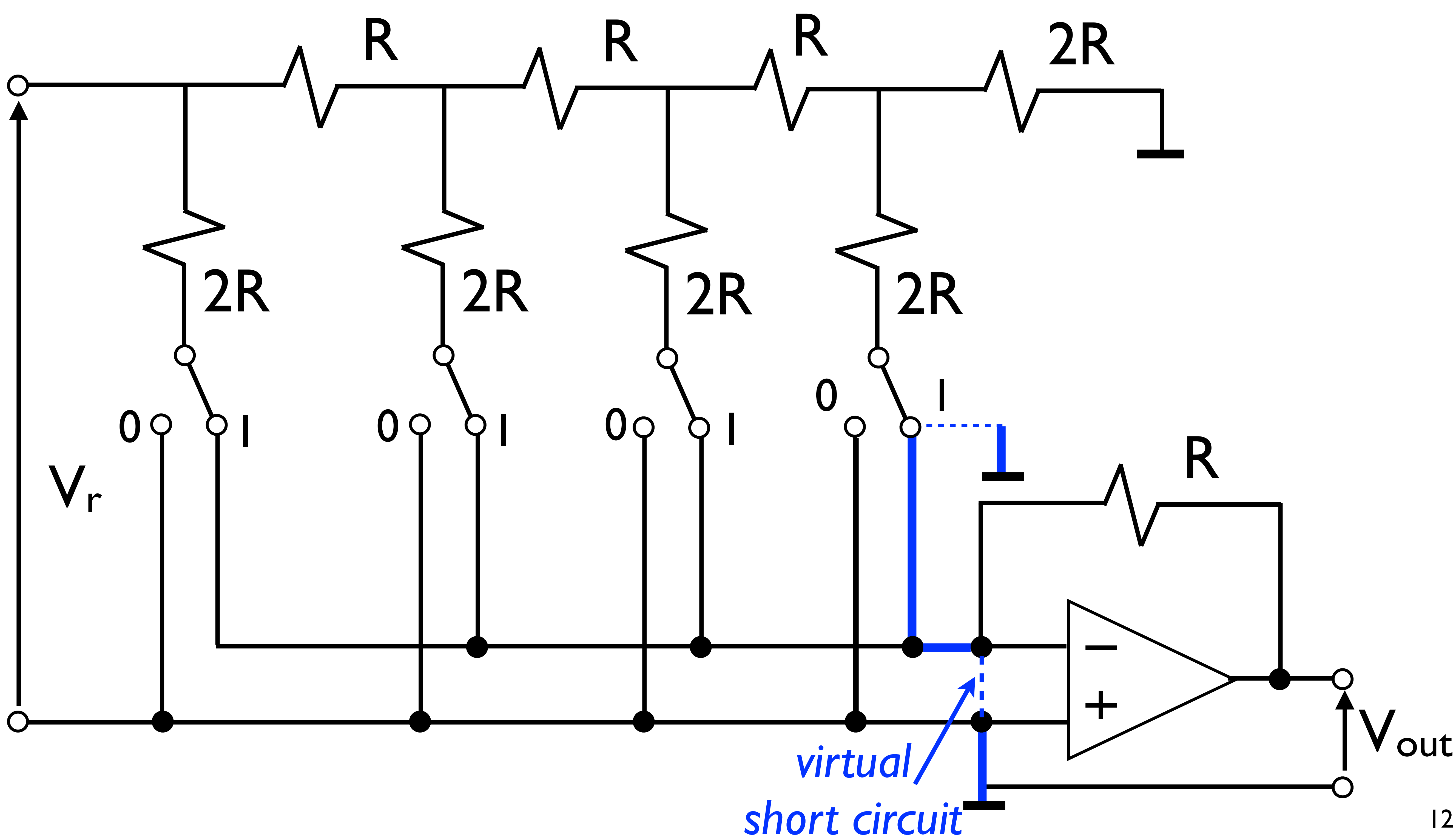
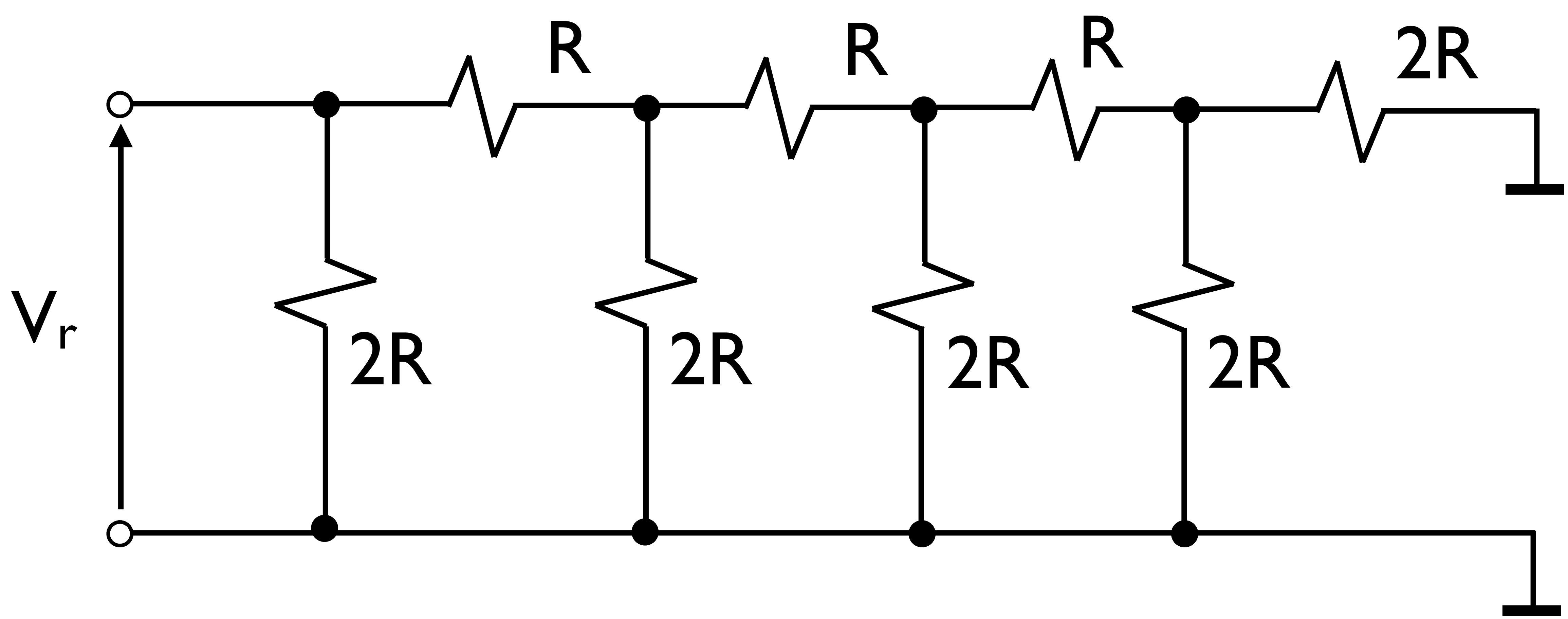


2 - DAC using R-2R Resistance ladder

Equivalent circuit resistive ladder



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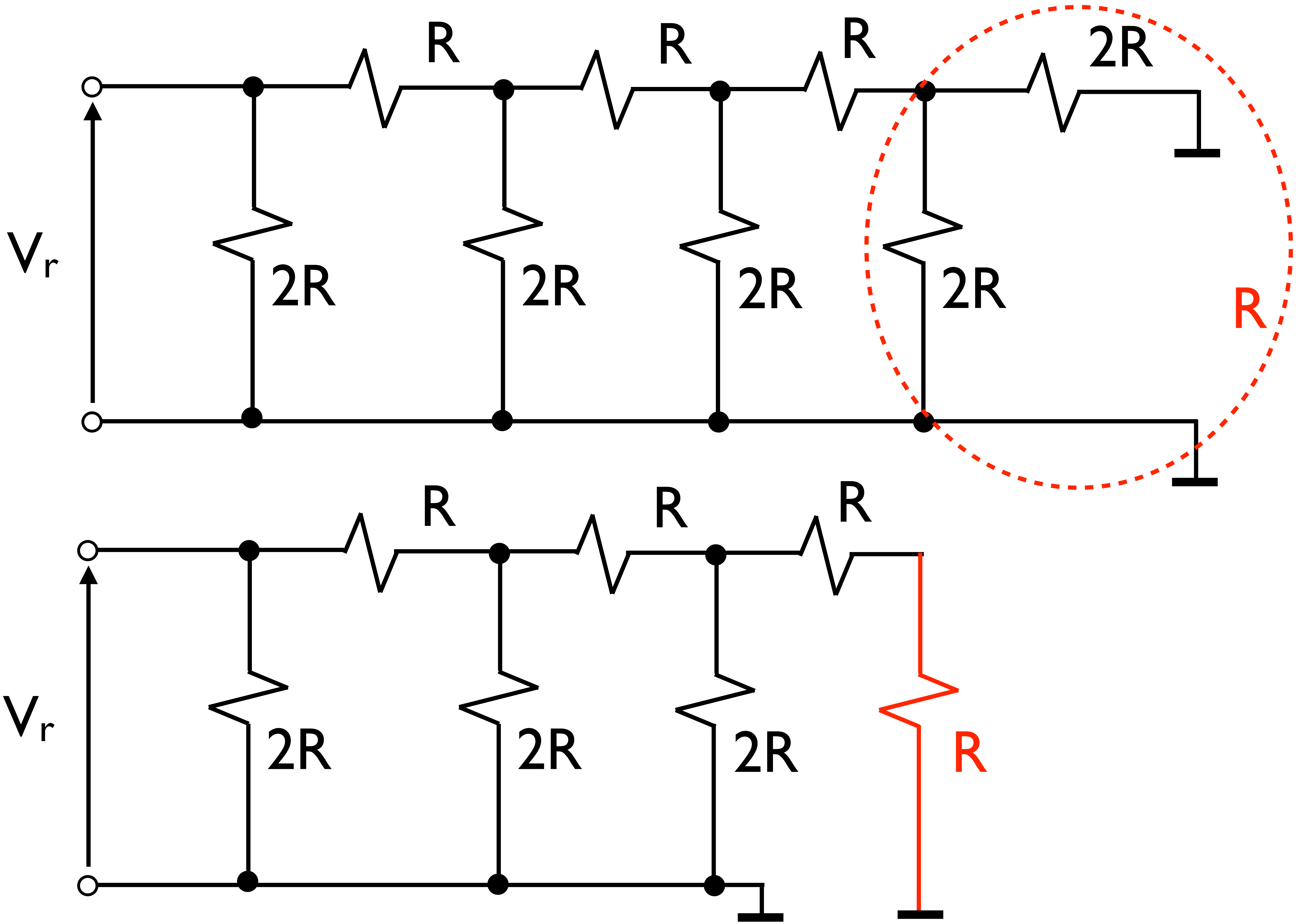

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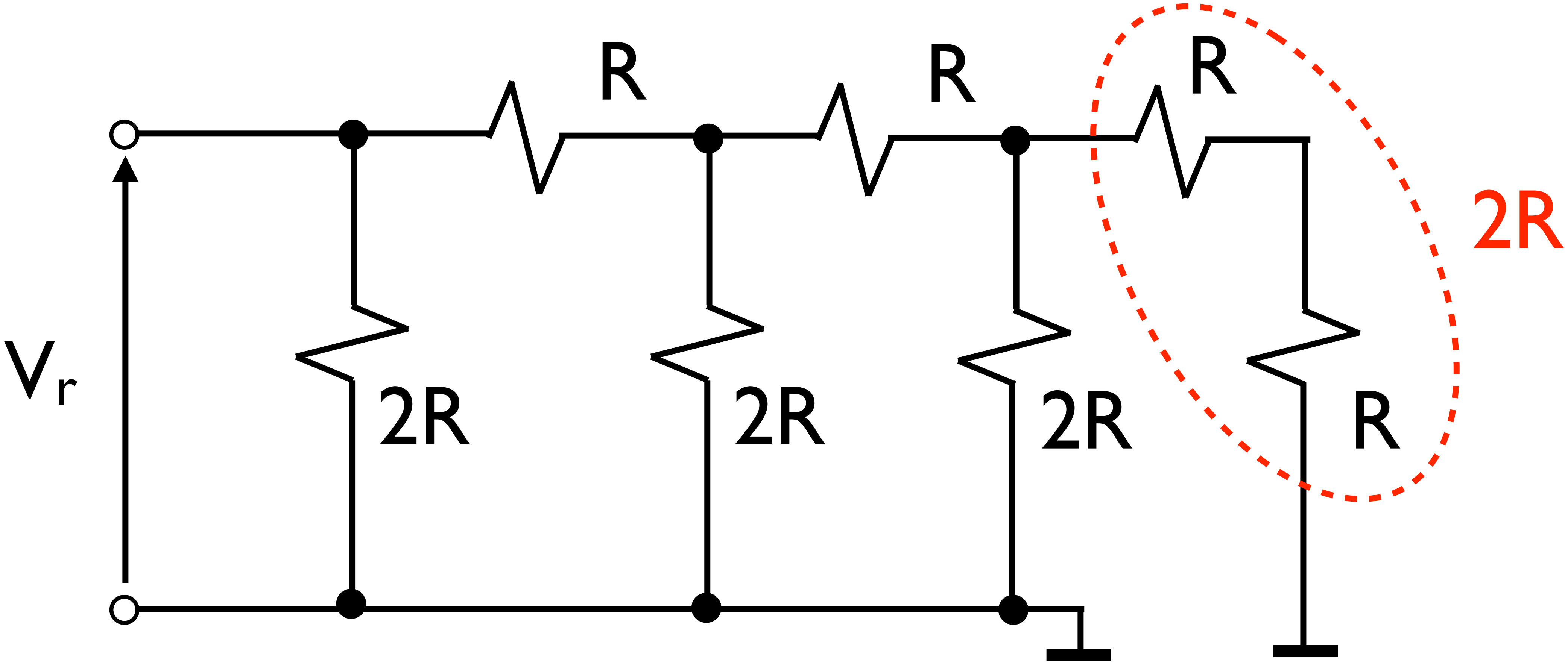

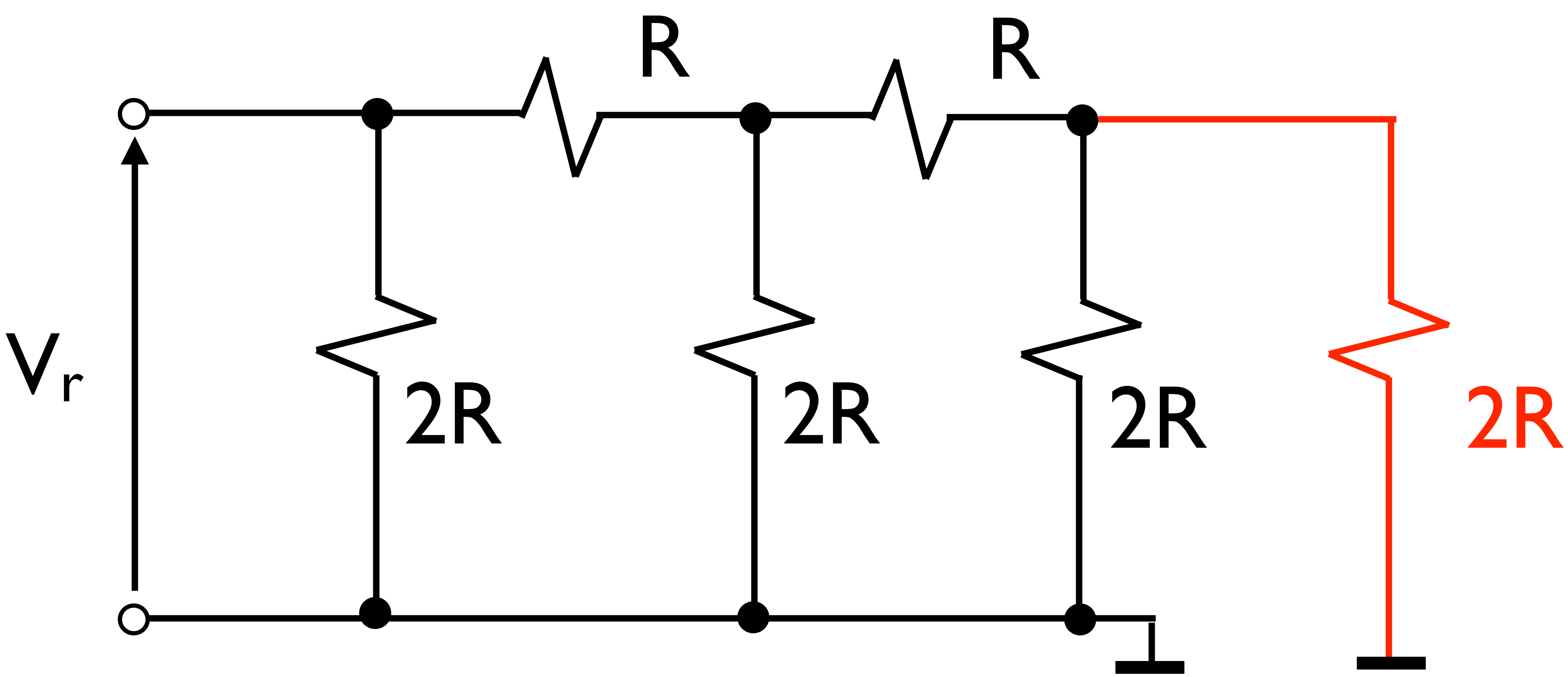

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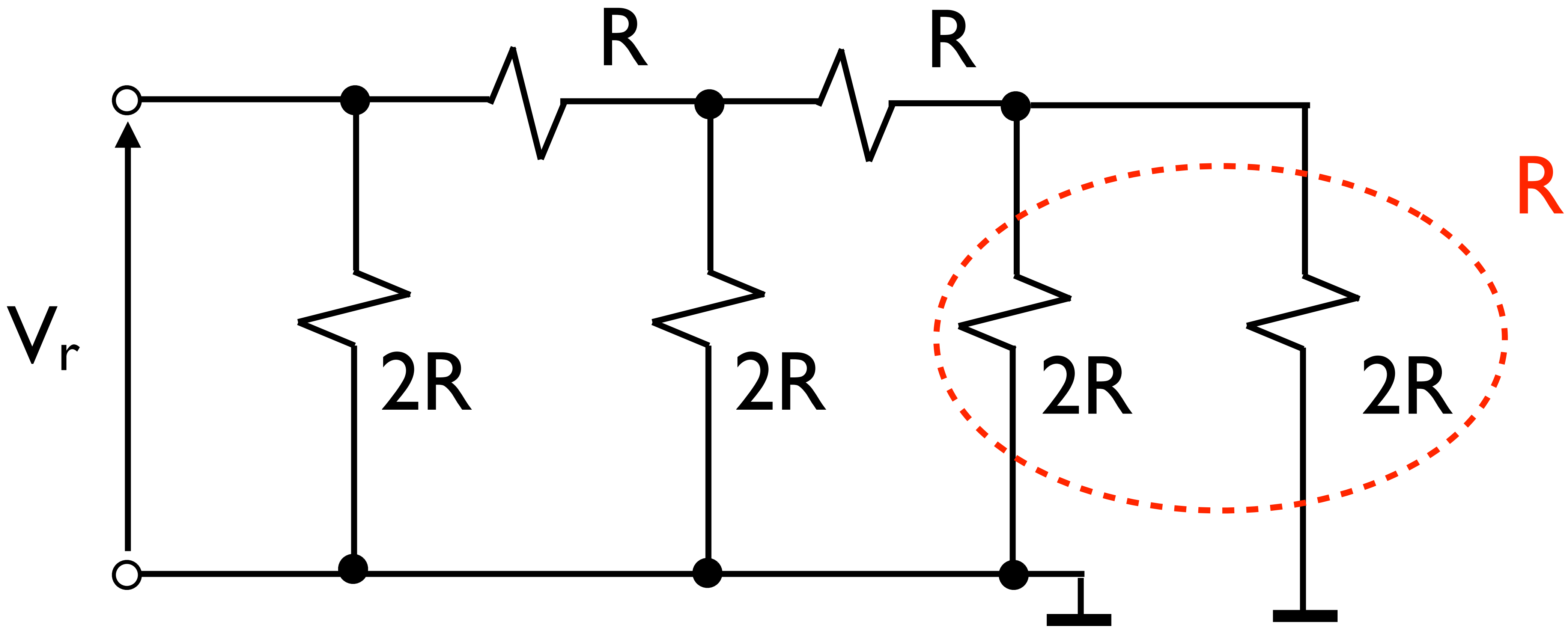

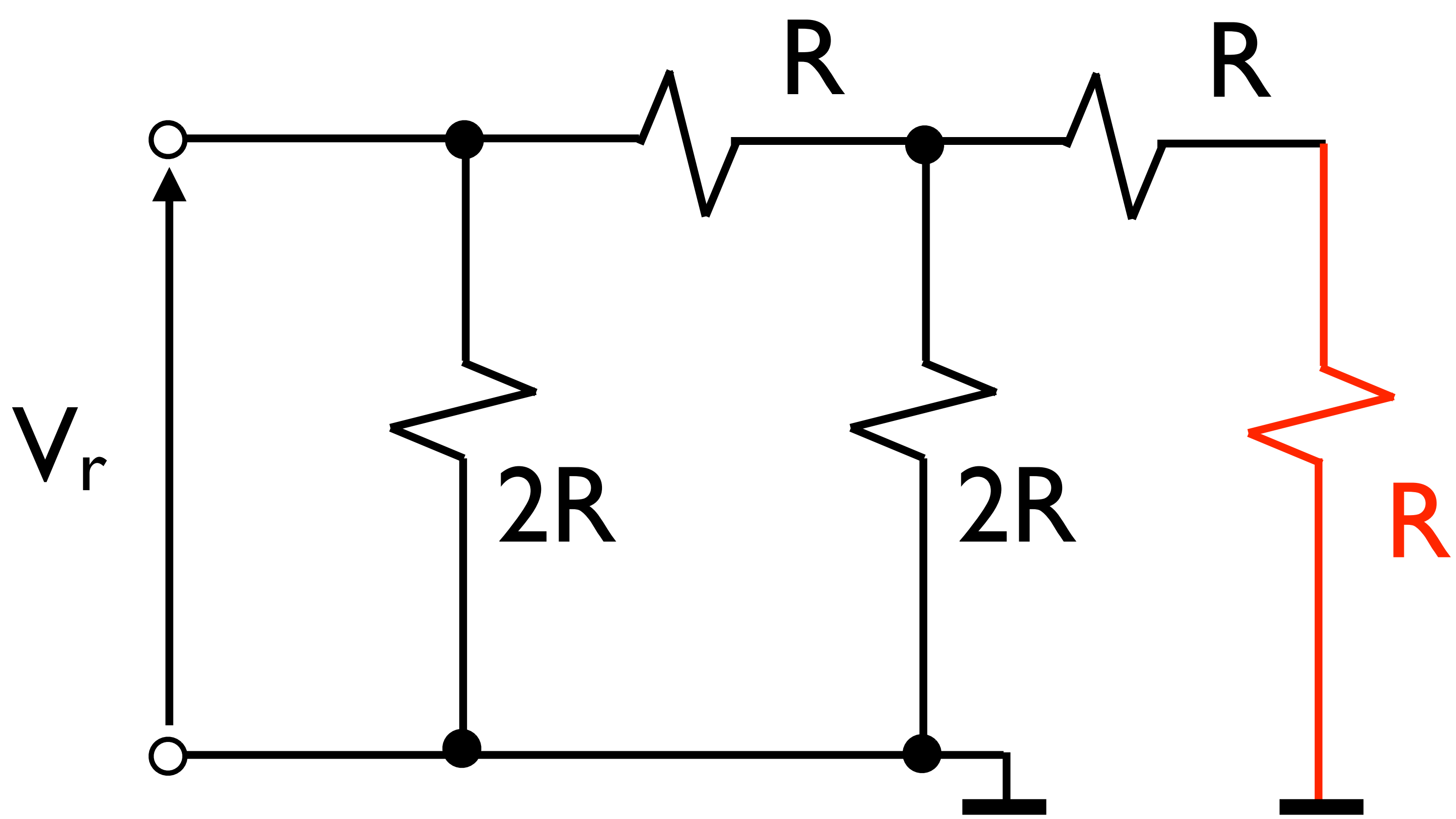

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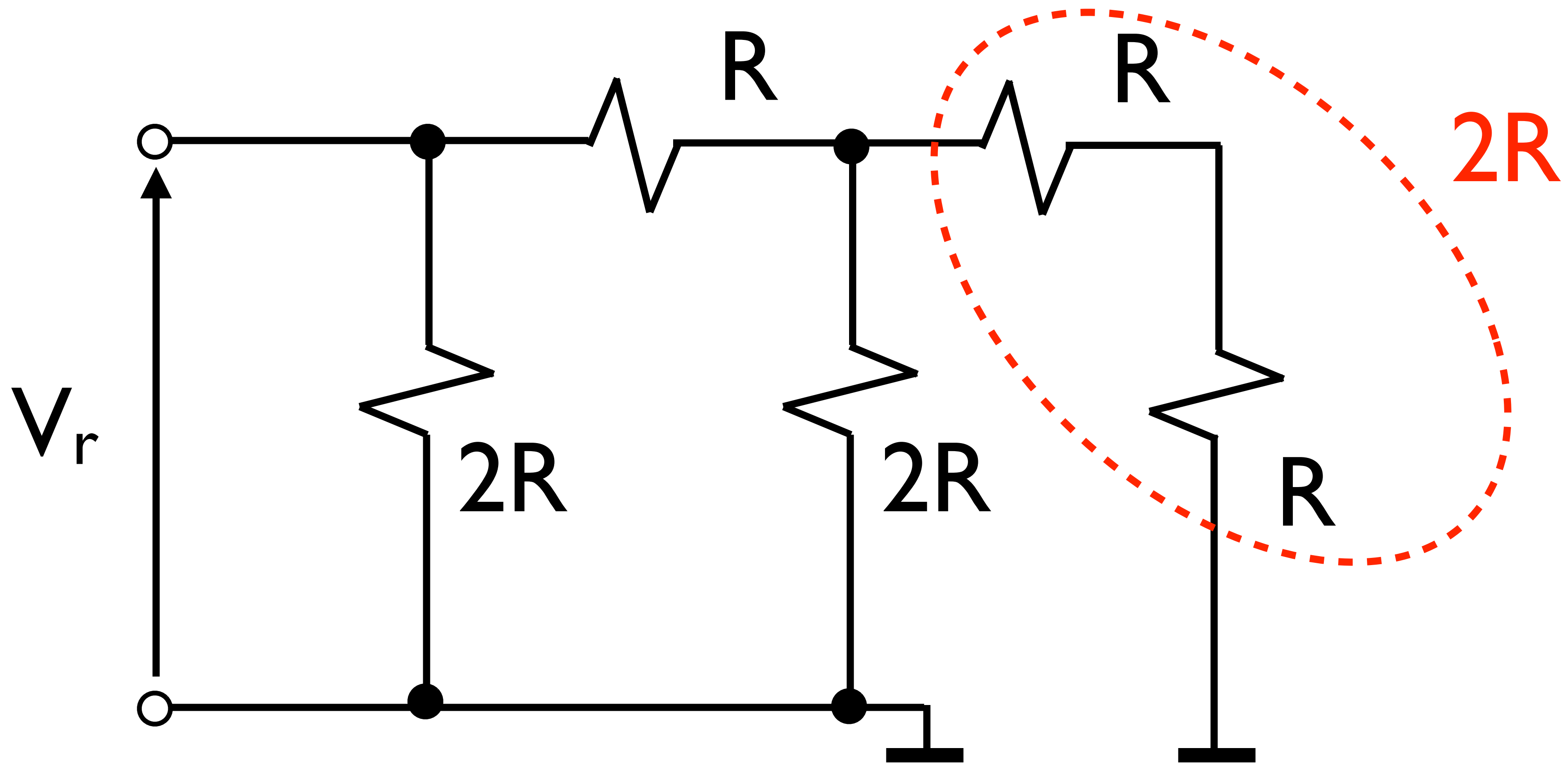
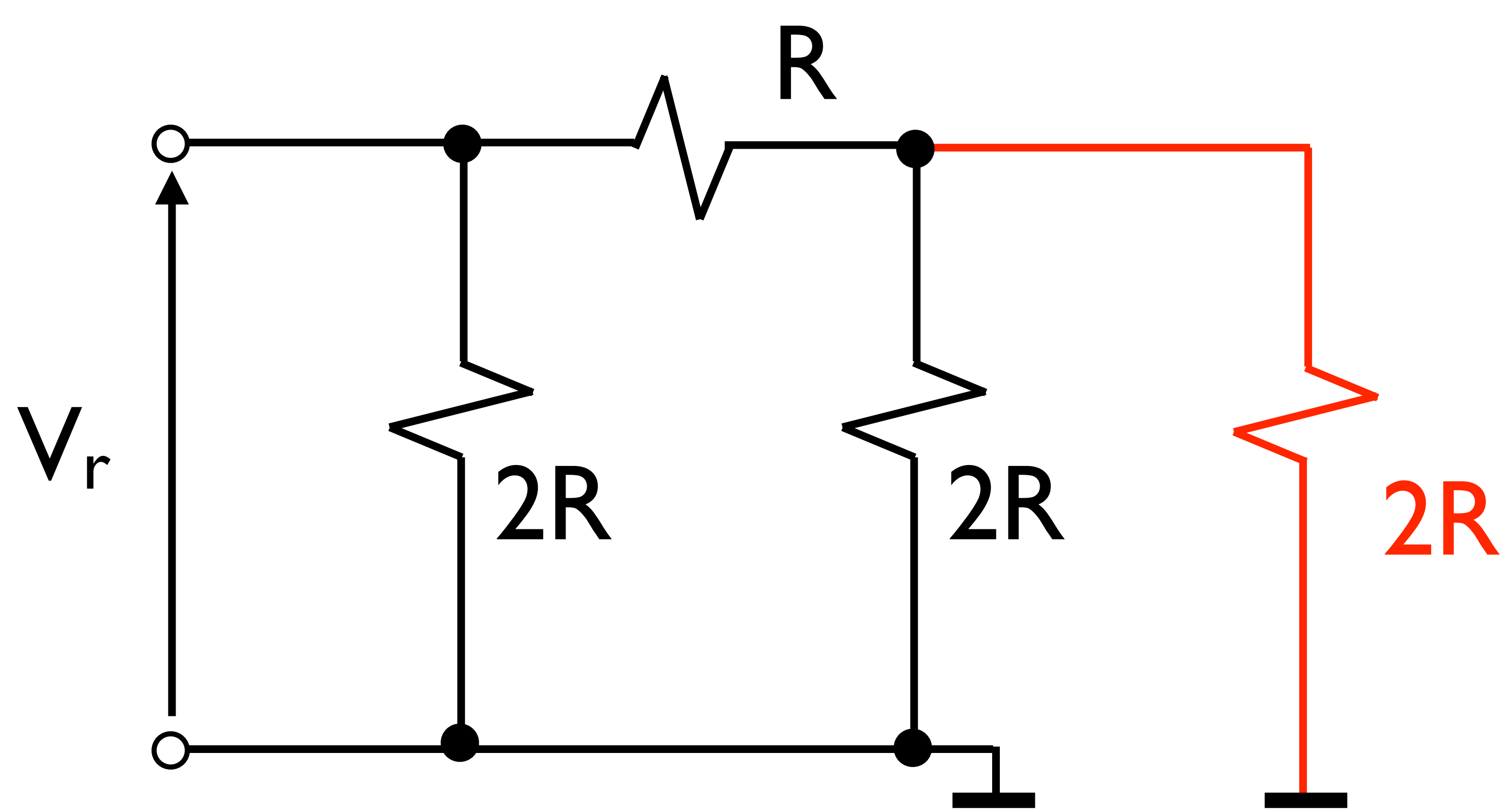
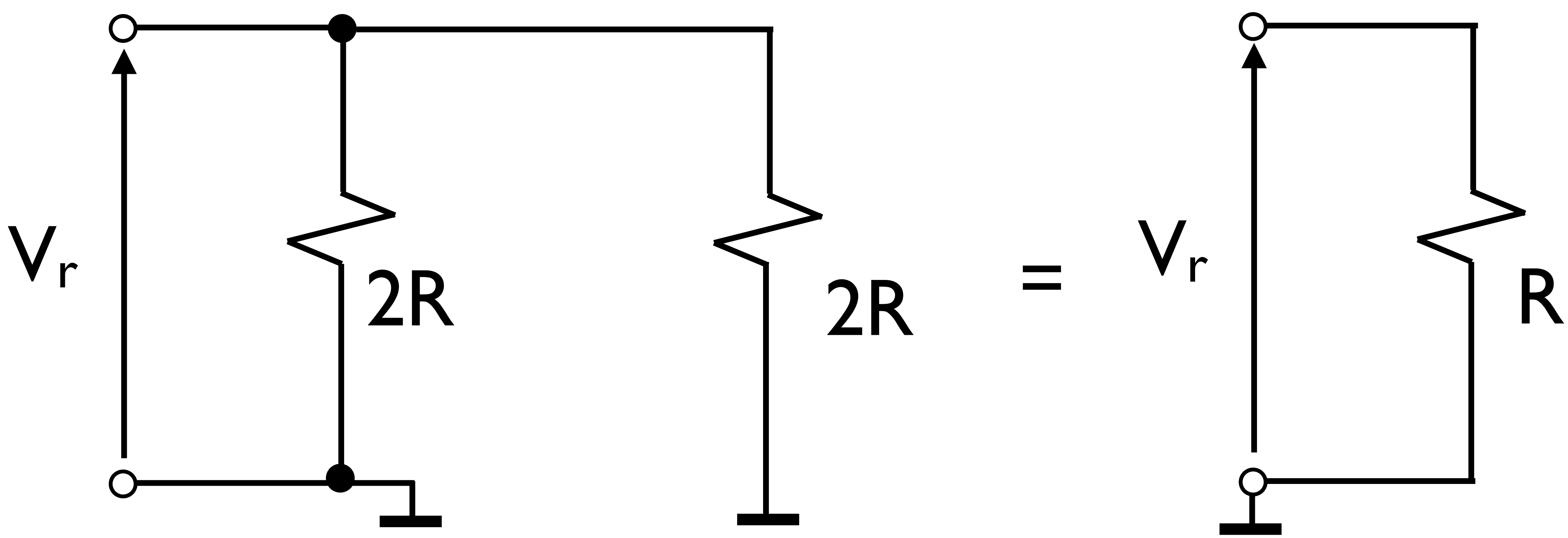




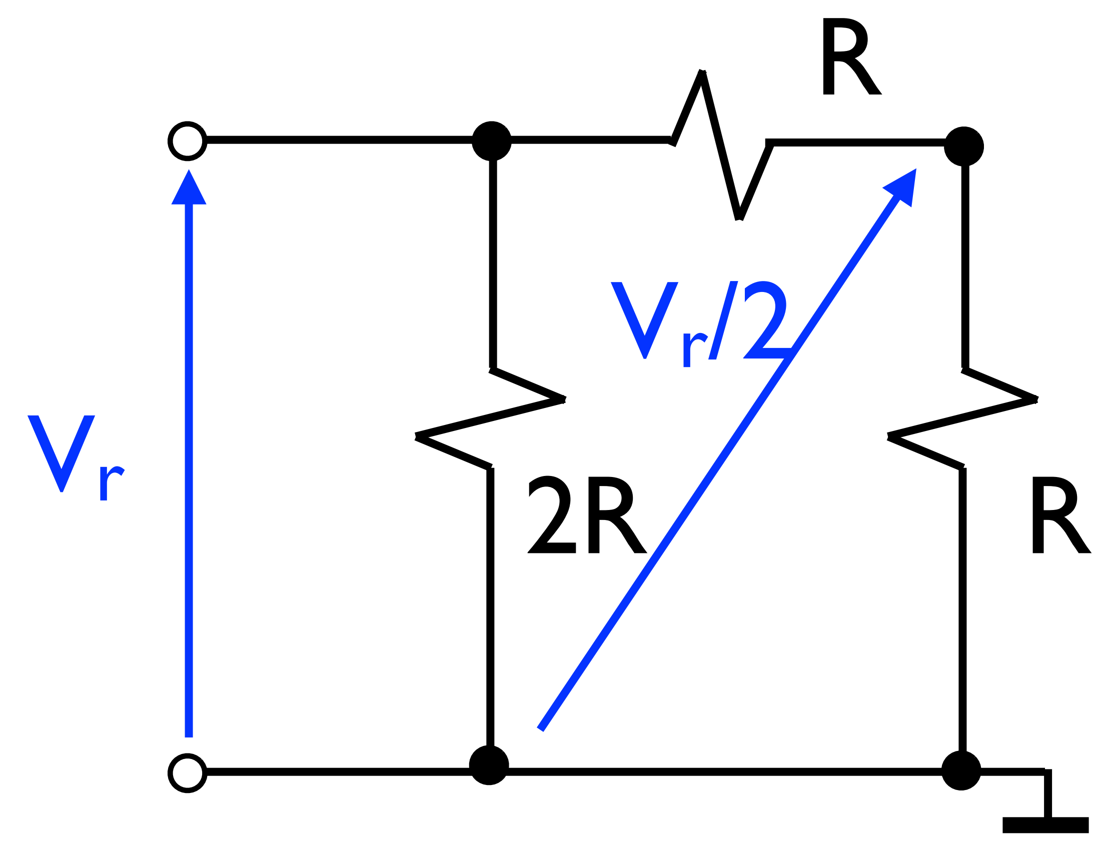
2 - DAC using R-2R Resistance ladder

The reference voltage is applied to R



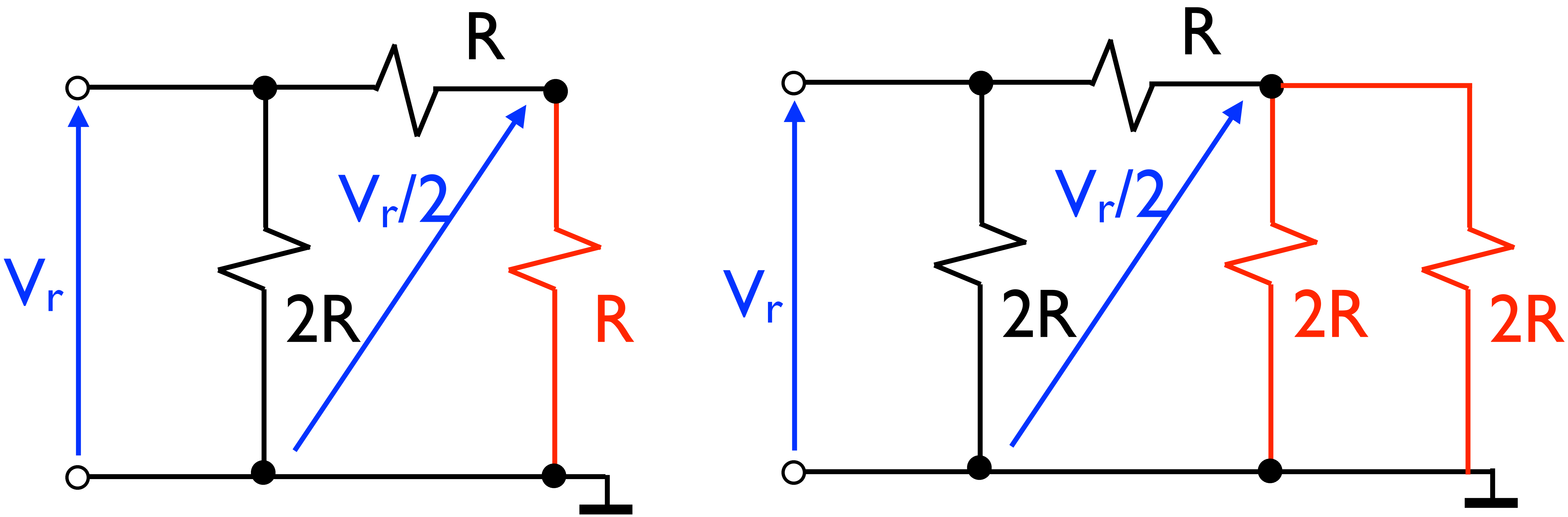
2 - DAC using R-2R Resistance ladder

at each stage the voltage is divided by 2



2 - DAC using R-2R Resistance ladder

at each stage the voltage is divided by 2



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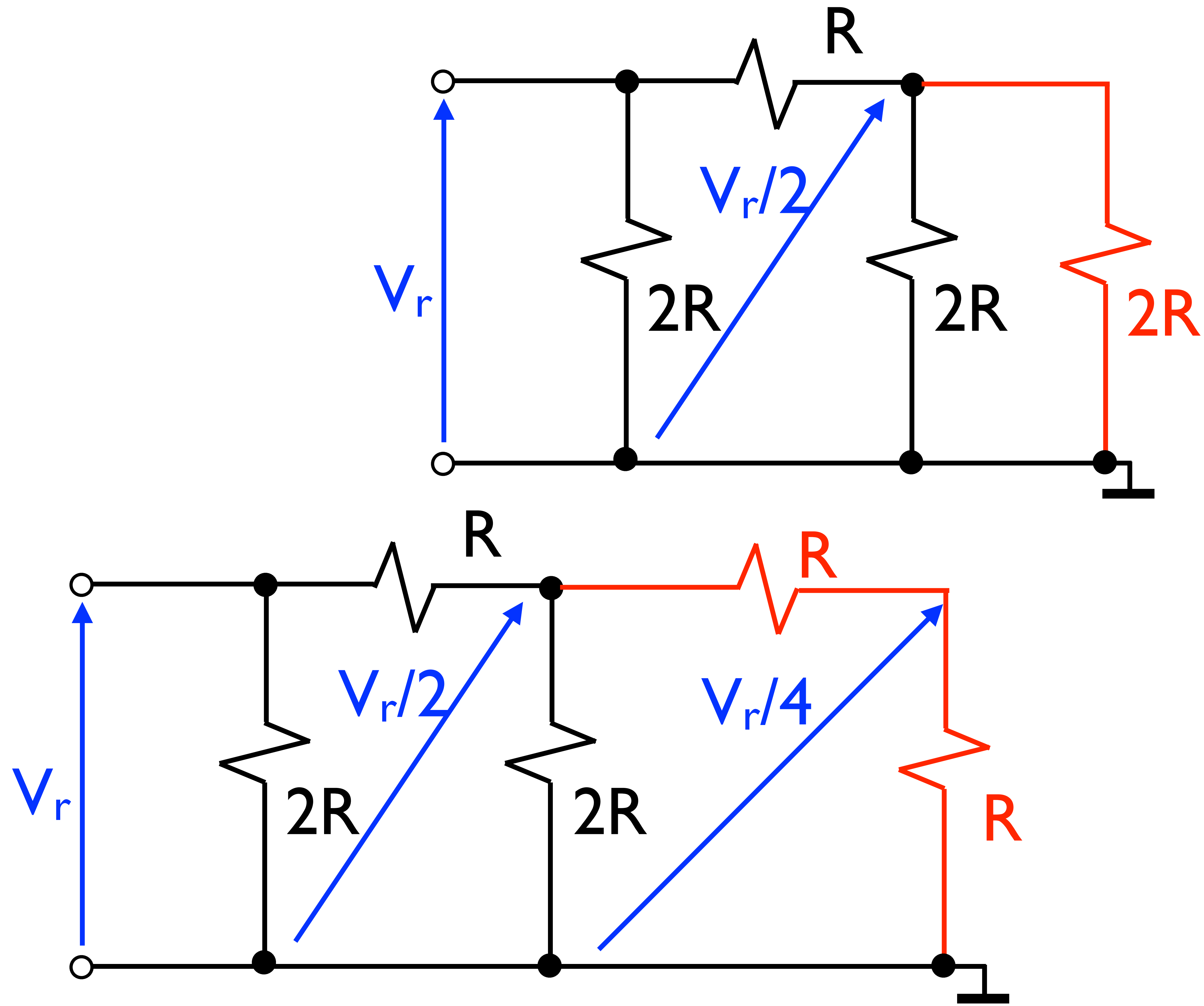
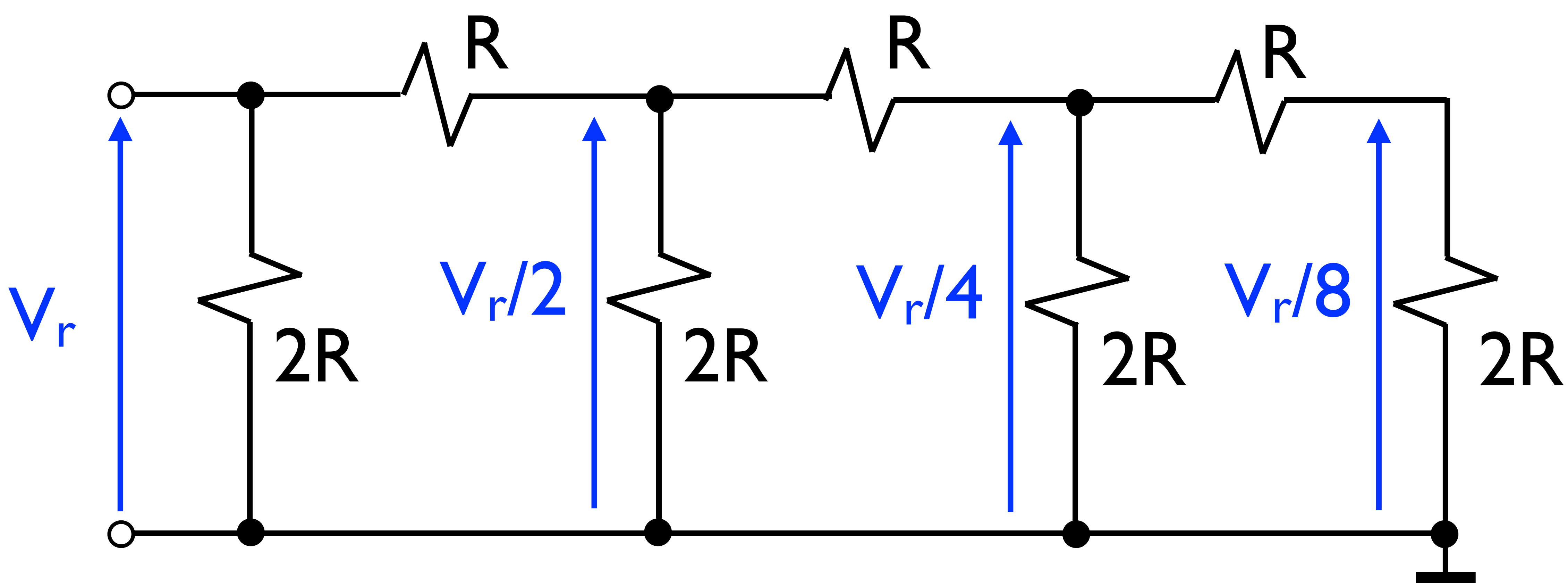


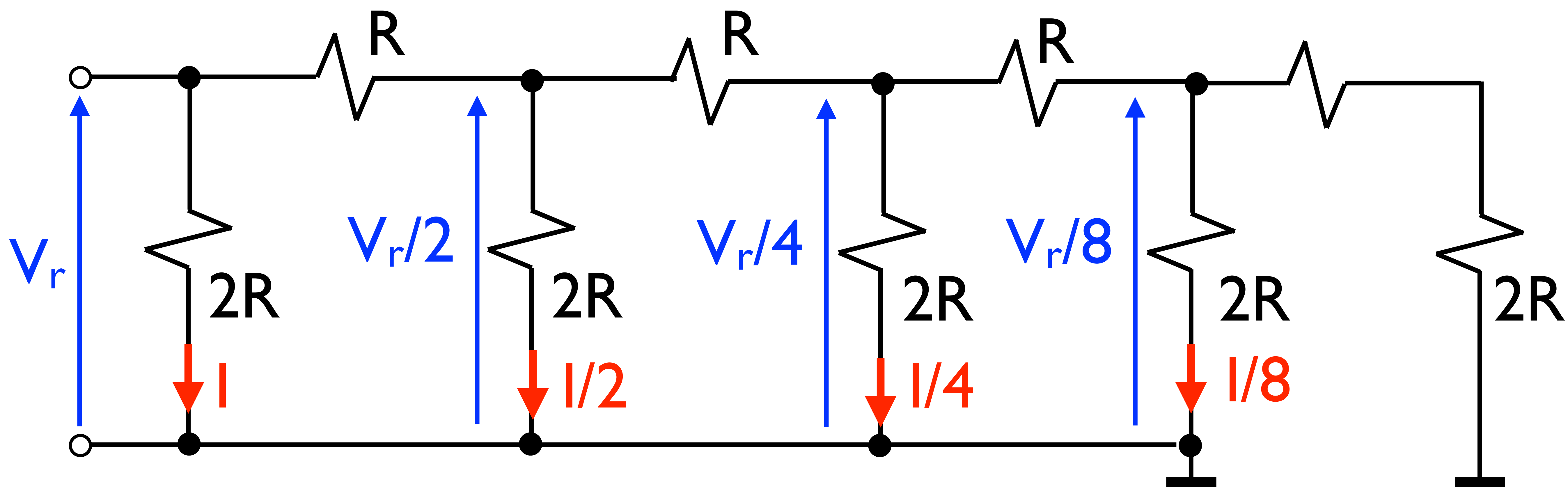
2 - DAC using R-2R Resistance ladder

at each stage the voltage is divided by 2

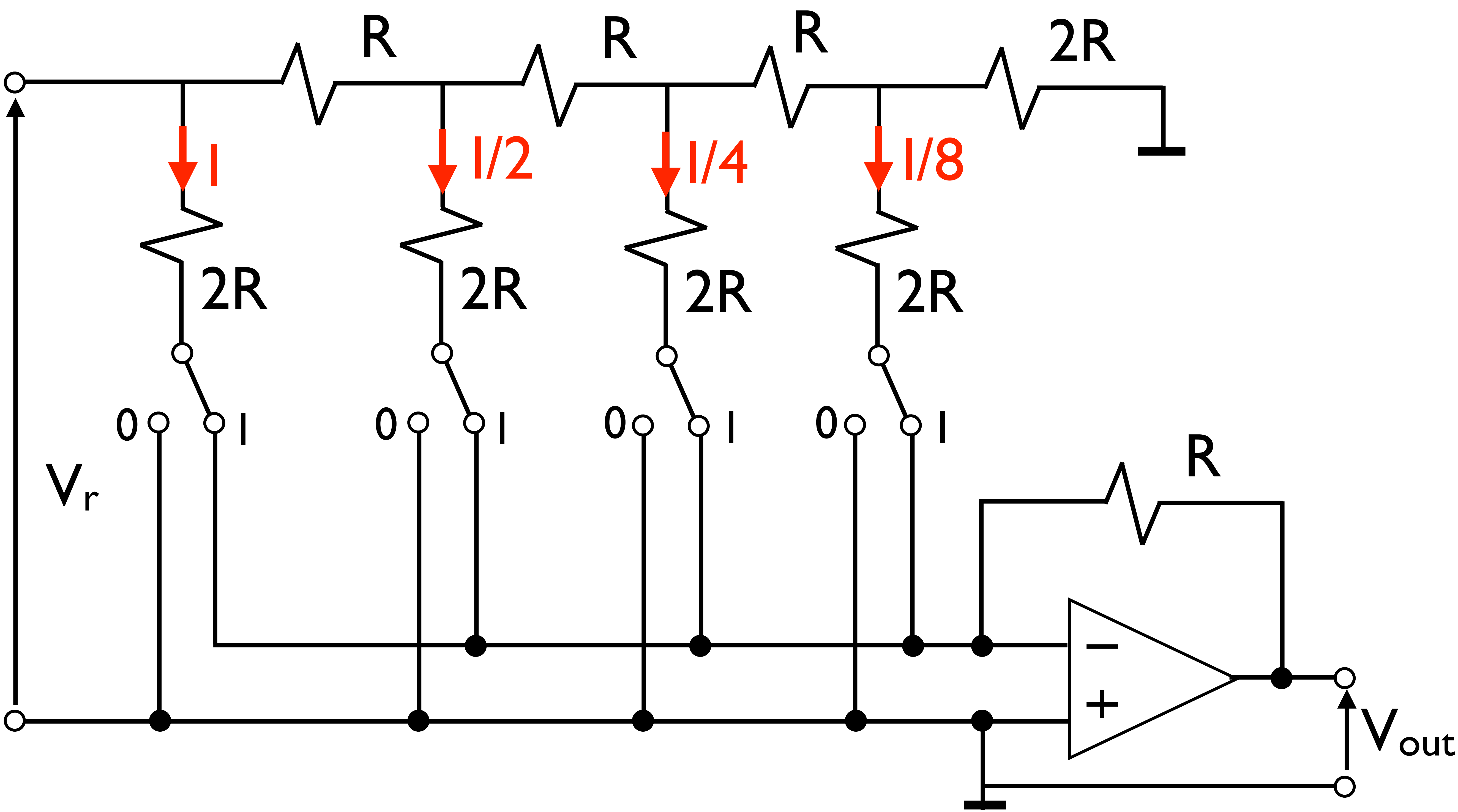


2 - DAC using R-2R Resistance ladder

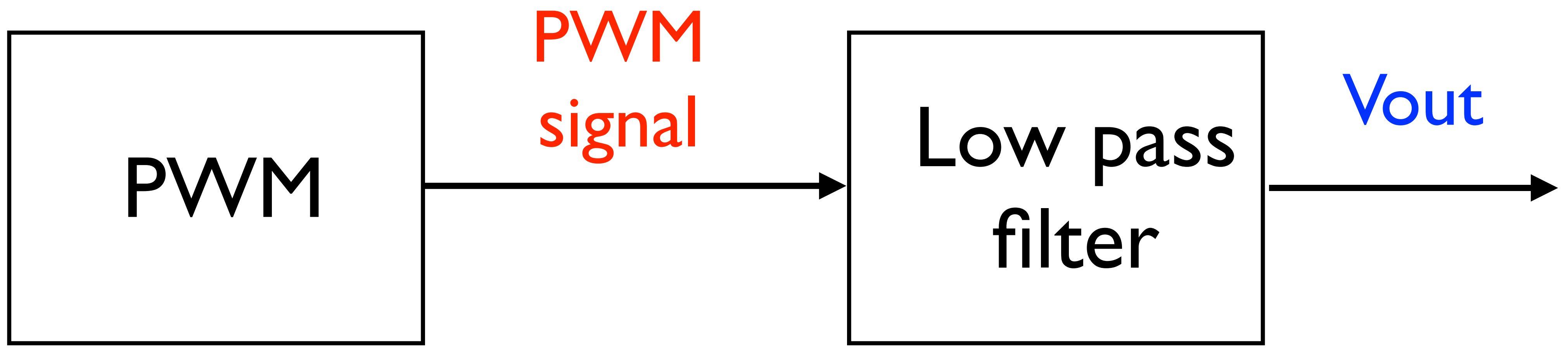
Each current flowing through each resistor is half of the previous current

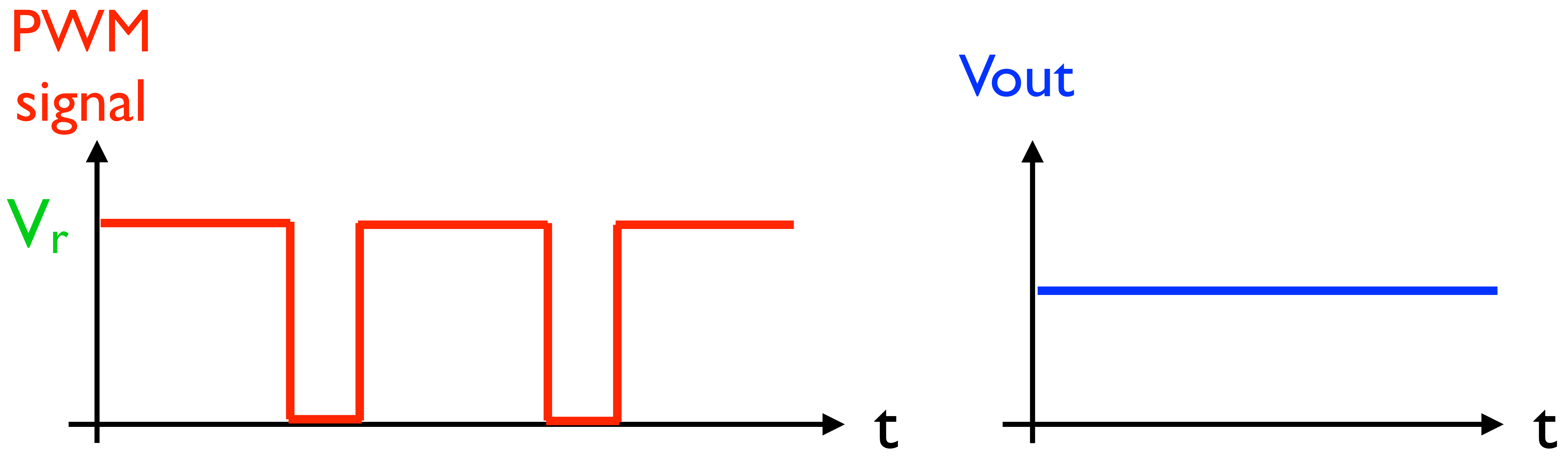


2 - DAC using R-2R Resistance ladder



3 - DAC based on PWM





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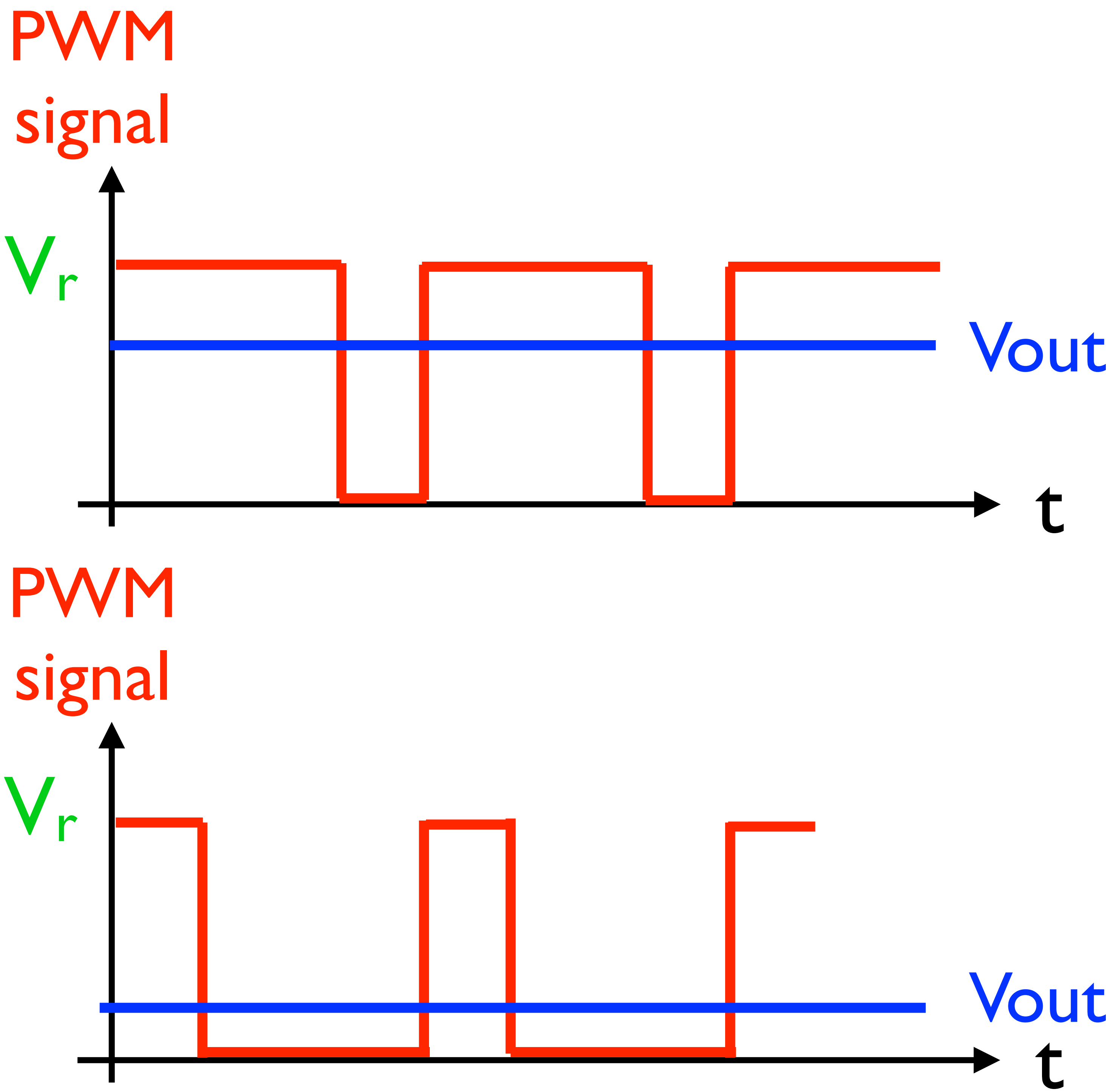

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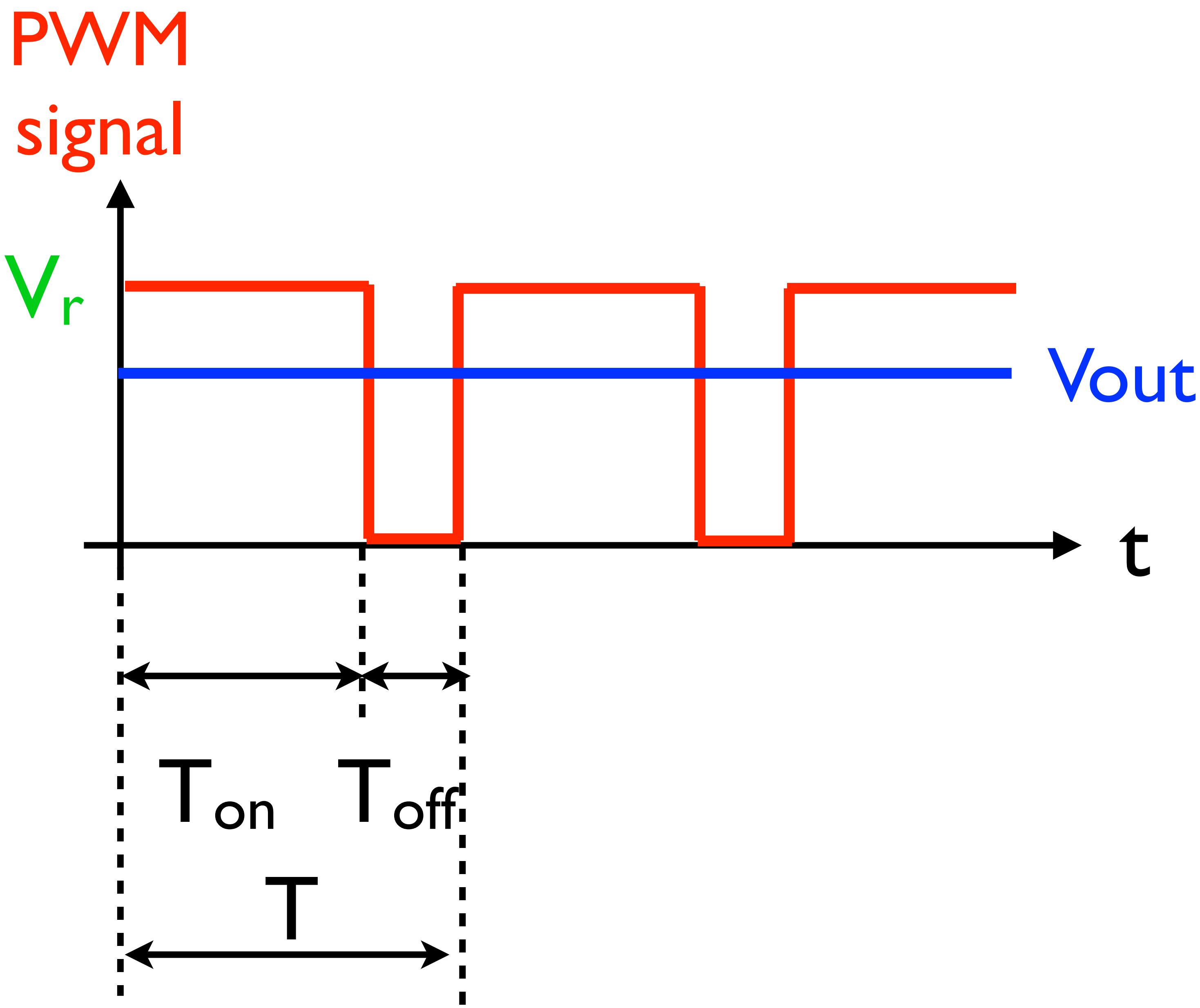


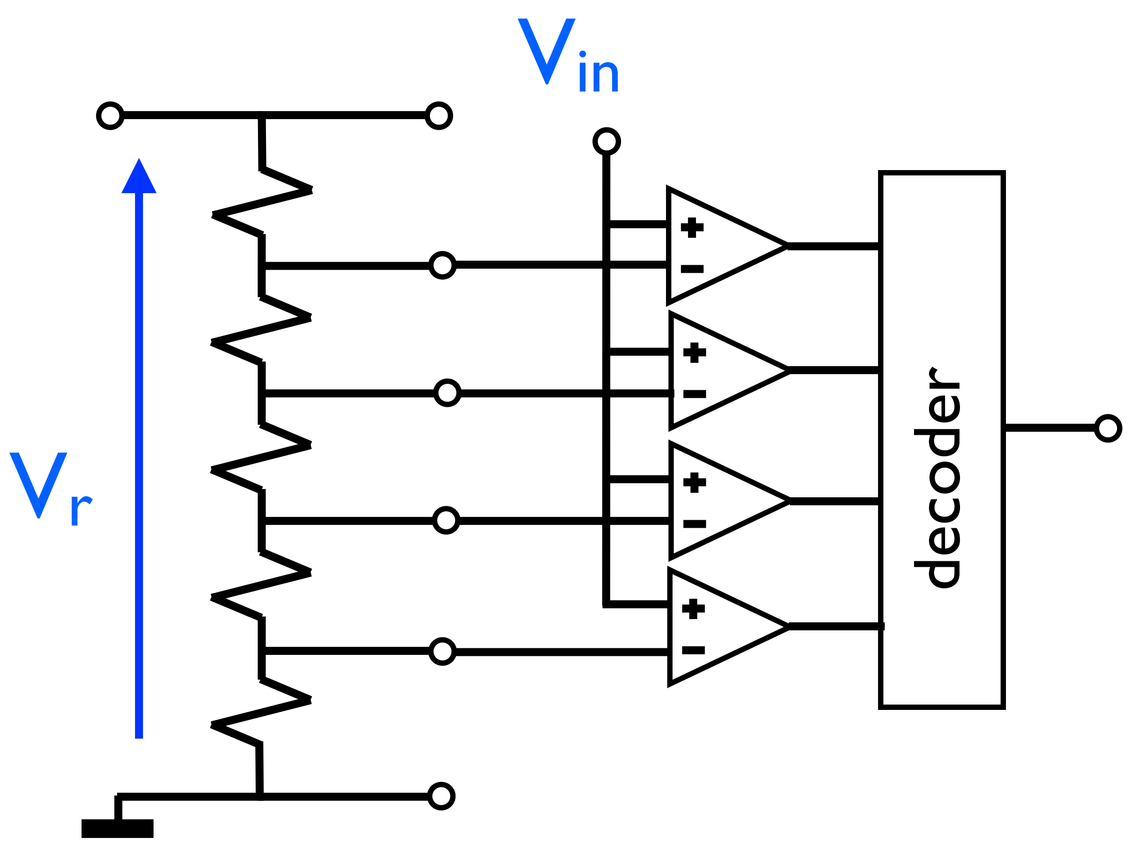
$$V_{out} = V_r \cdot T_{on}/T$$

$$T = T_{on} + T_{off}$$

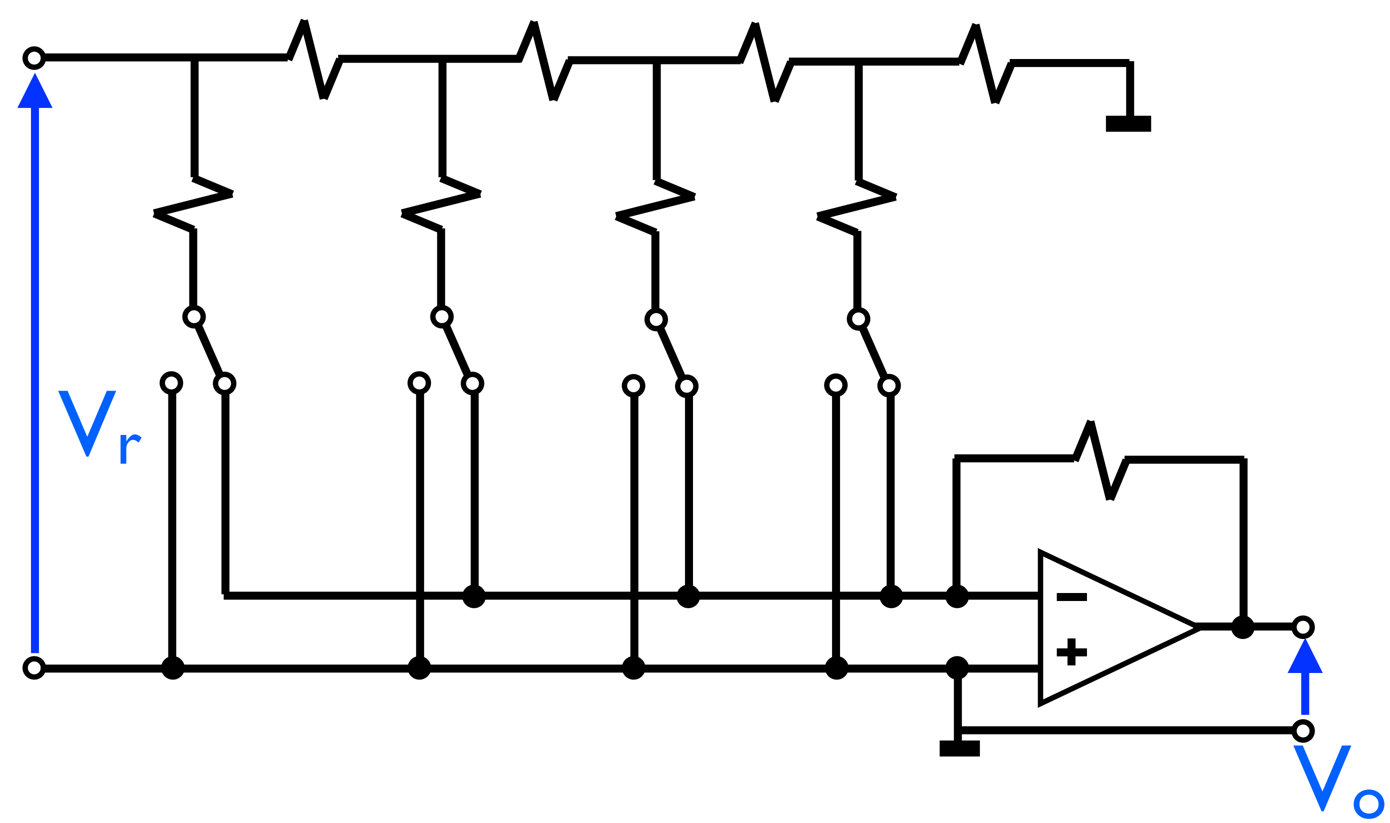
VOLTAGE REFERENCES

- necessary for both ADCs and DACs
- they must provide constant voltage, independent on time and temperature

ADC



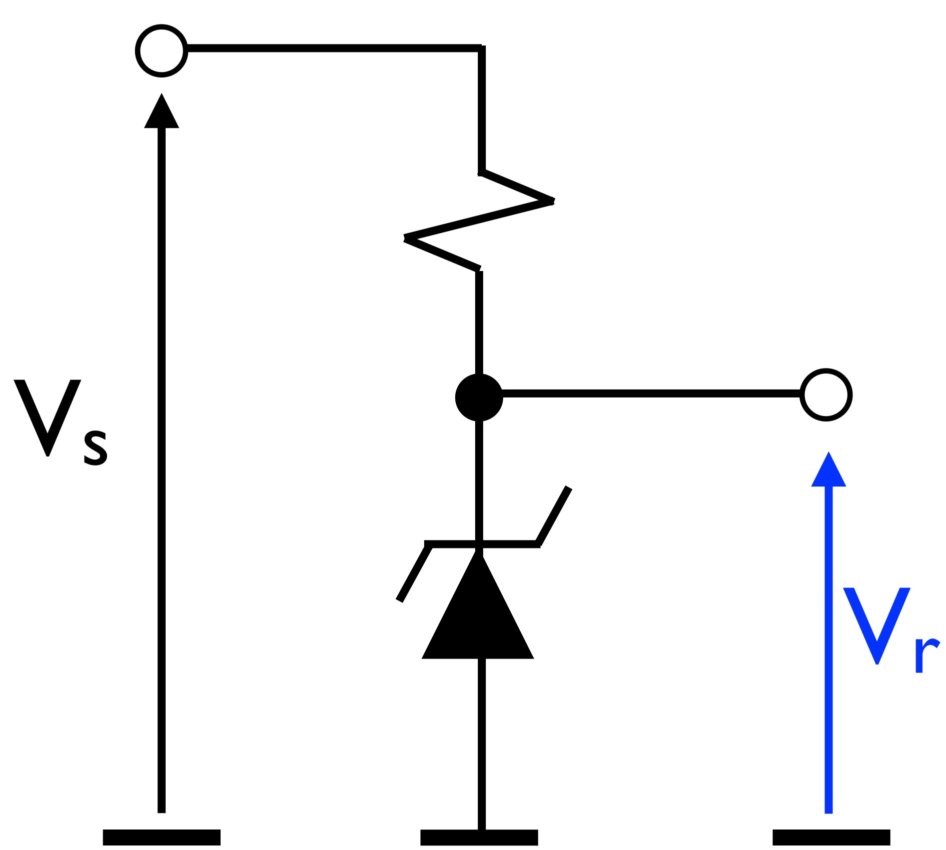
DAC



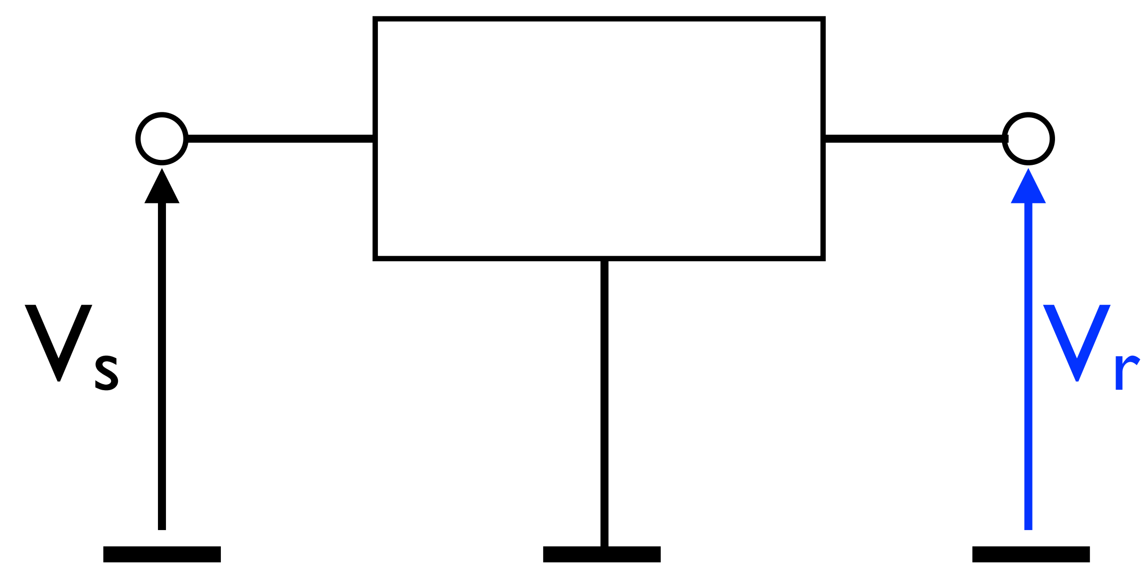
VOLTAGE REFERENCES

Two basic structures

SHUNT



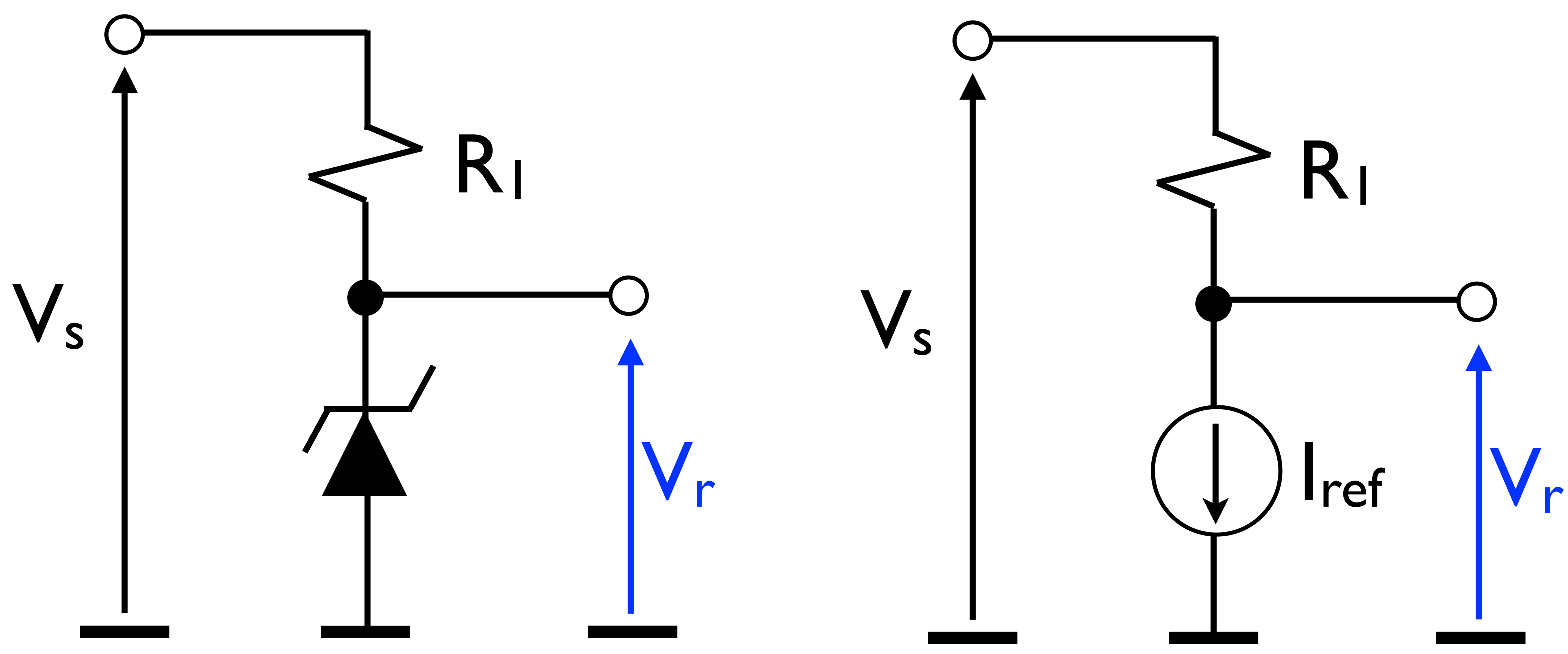
SERIES



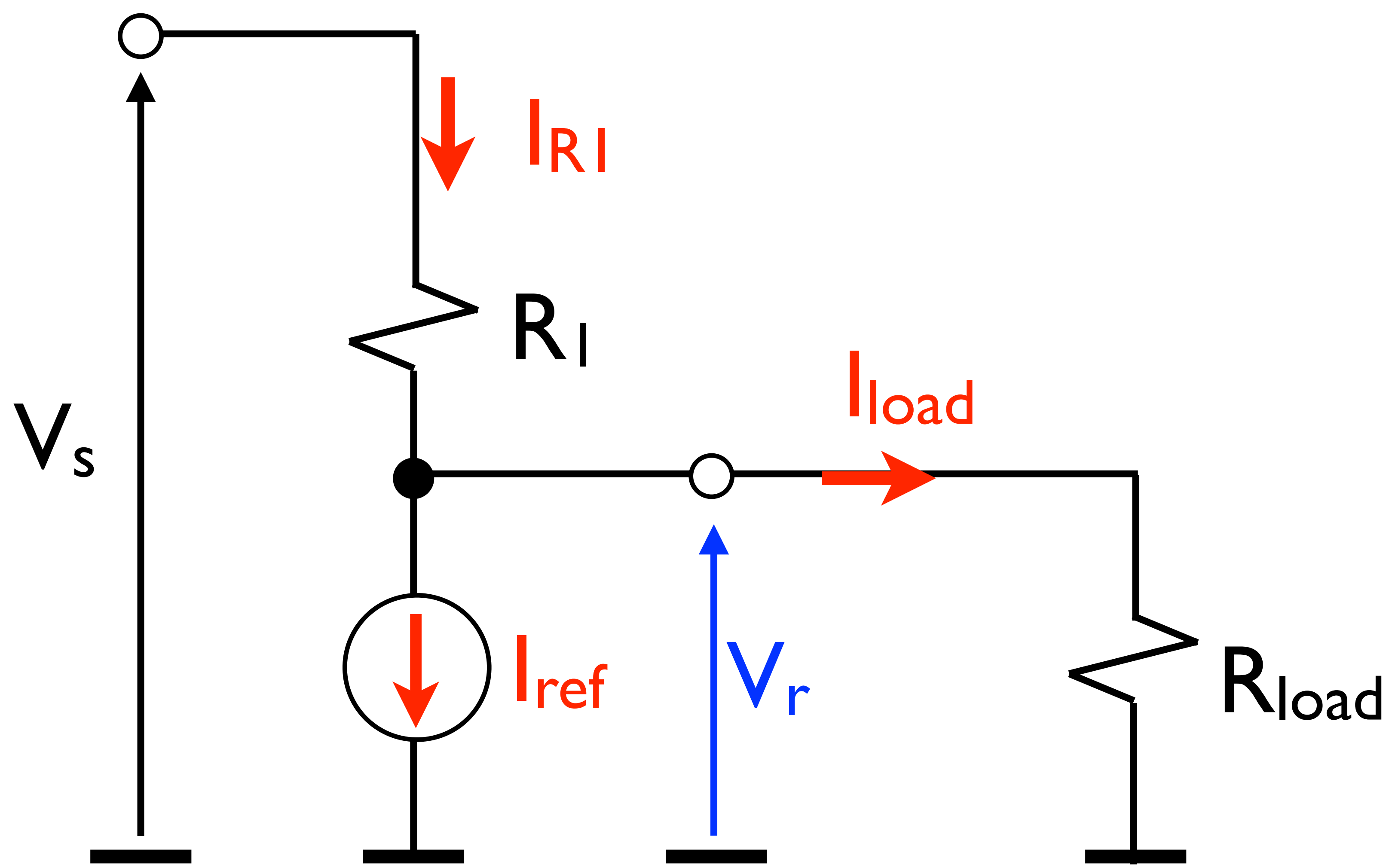
SHUNT VOLTAGE REFERENCE

Working principle:

You can see it as a current source which adjust the current level in order to have constant V_r



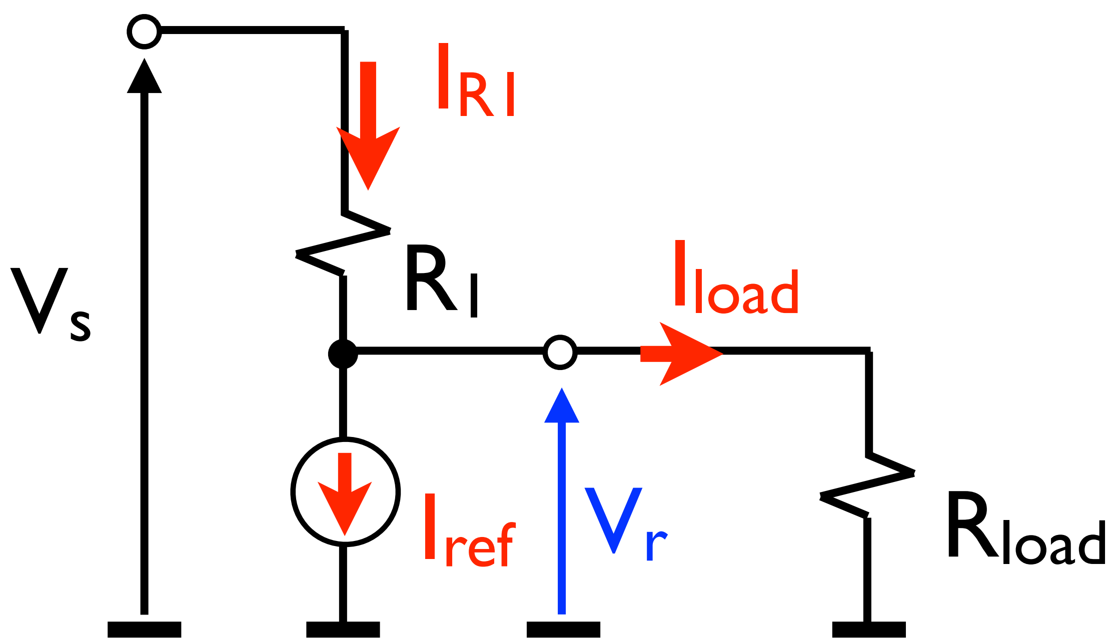
SHUNT VOLTAGE REFERENCE



$$V_r = V_s - R_1 \cdot I_{R1}$$
$$= V_s - R_1 \cdot (I_{ref} + I_{load})$$

I_{ref} is automatically adjusted so that I_{R1} is constant whatever is the load

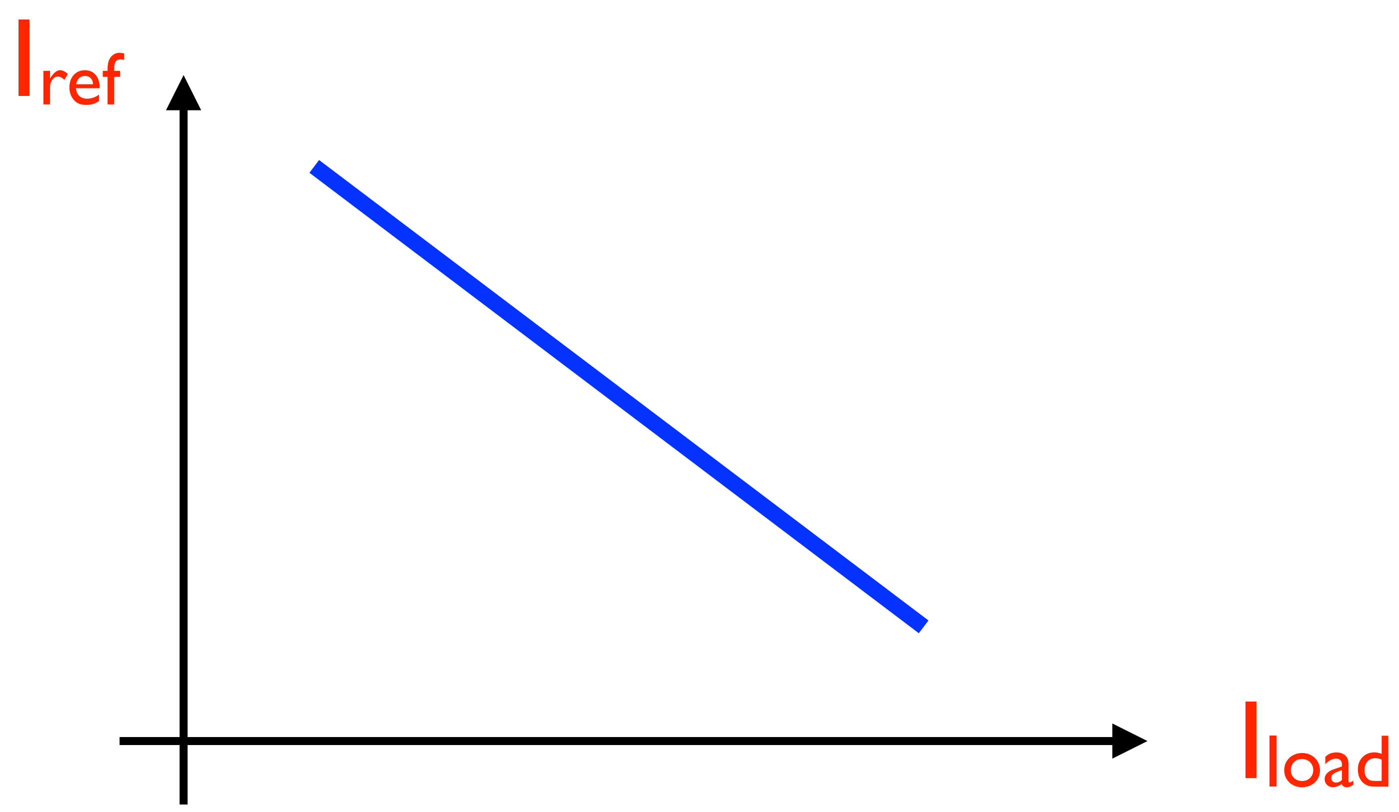
SHUNT VOLTAGE REFERENCE



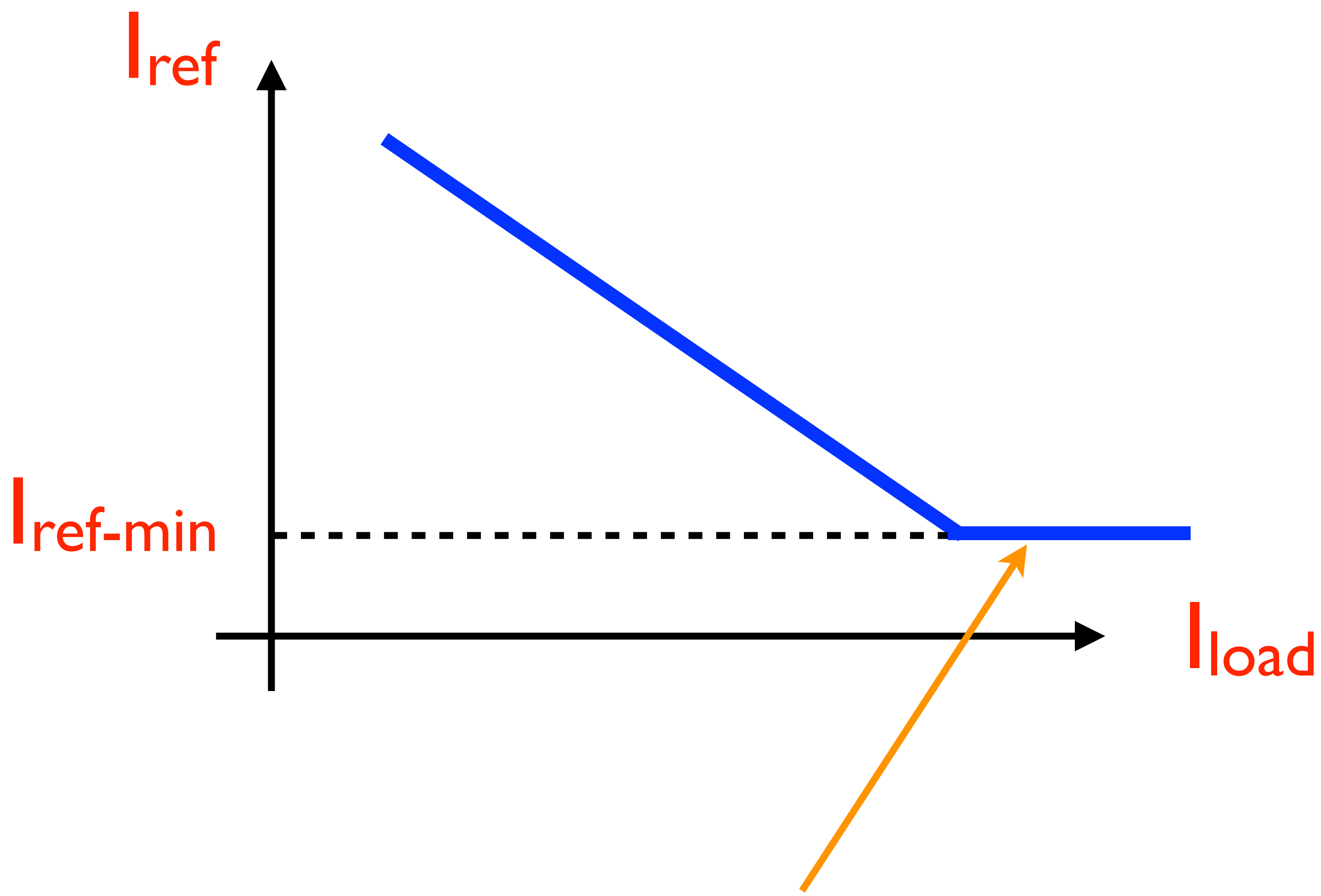
$$V_r = V_s - R_1 \cdot (I_{ref} + I_{load})$$

$(I_{ref} + I_{load})$ must be constant

if I_{load} increases I_{ref} decreases

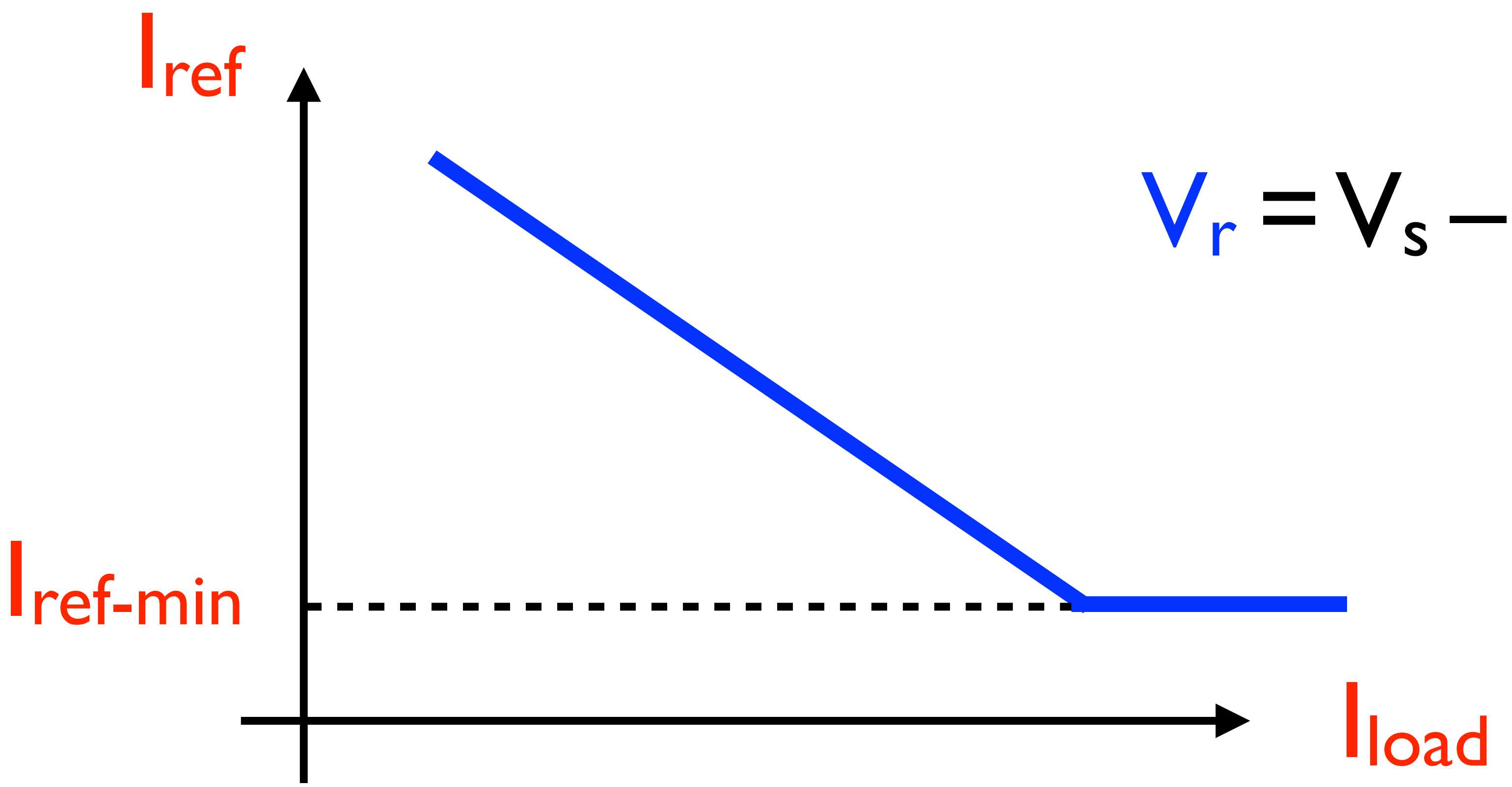


Problem 1: I cannot decrease indefinitely. There is a minimum value $I_{ref\text{-}min}$



here (I_{ref} + I_{load}) will be larger than required, therefore the voltage drop on R_l will be higher and V_r will fall down

Problem 1: I cannot decrease indefinitely. There is a minimum value $I_{ref\text{-}min}$



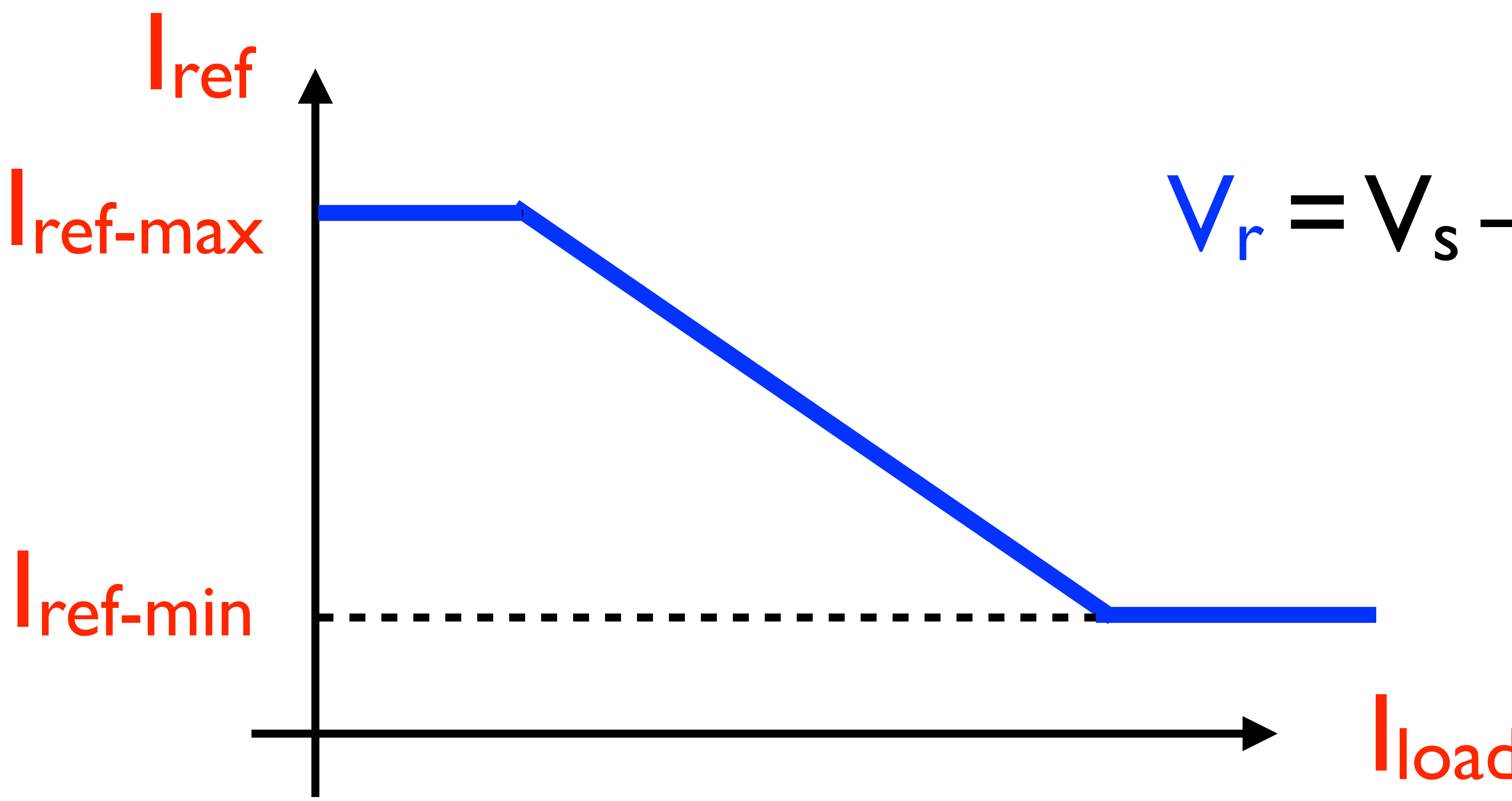
$$V_r = V_s - R_l \cdot (I_{ref} + I_{load})$$

$$R_l = \frac{V_s - V_r}{I_{ref\text{-}min} + I_{load\text{-}max}}$$ limit condition

It's better a larger resistance so that $I_{ref} > I_{ref\text{-}min}$

$$R_l > \frac{V_s - V_r}{I_{ref\text{-}min} + I_{load\text{-}max}}$$

Problem 2: cannot increase indefinitely. There is a maximum value $I_{ref\text{-}max}$



$$V_r = V_s - R_l \cdot (I_{ref} + I_{load})$$

$$R_l = \frac{V_s - V_r}{I_{ref\text{-}max} + I_{load\text{-}min}}$$ limit condition

It's better a lower resistance so that $I_{ref} < I_{ref\text{-}max}$

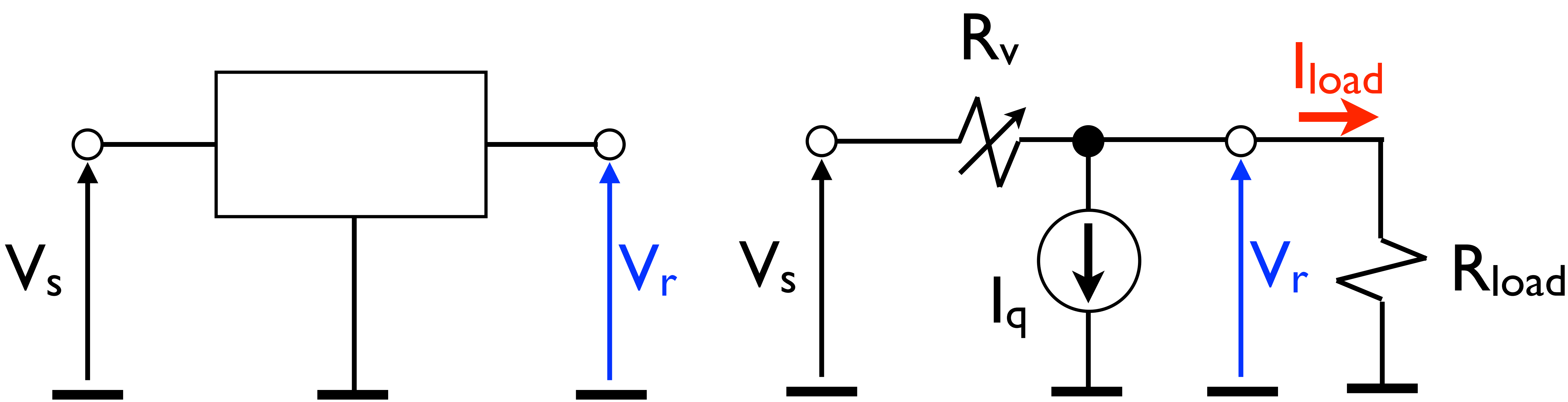
$$R_l < \frac{V_s - V_r}{I_{ref\text{-}max} + I_{load\text{-}min}}$$

Joining both conditions we can find the range of resistance

$$\frac{V_s - V_r}{I_{ref\text{-}min} + I_{load\text{-}max}} < R_l < \frac{V_s - V_r}{I_{ref\text{-}max} + I_{load\text{-}min}}$$

SERIES VOLTAGE REFERENCE

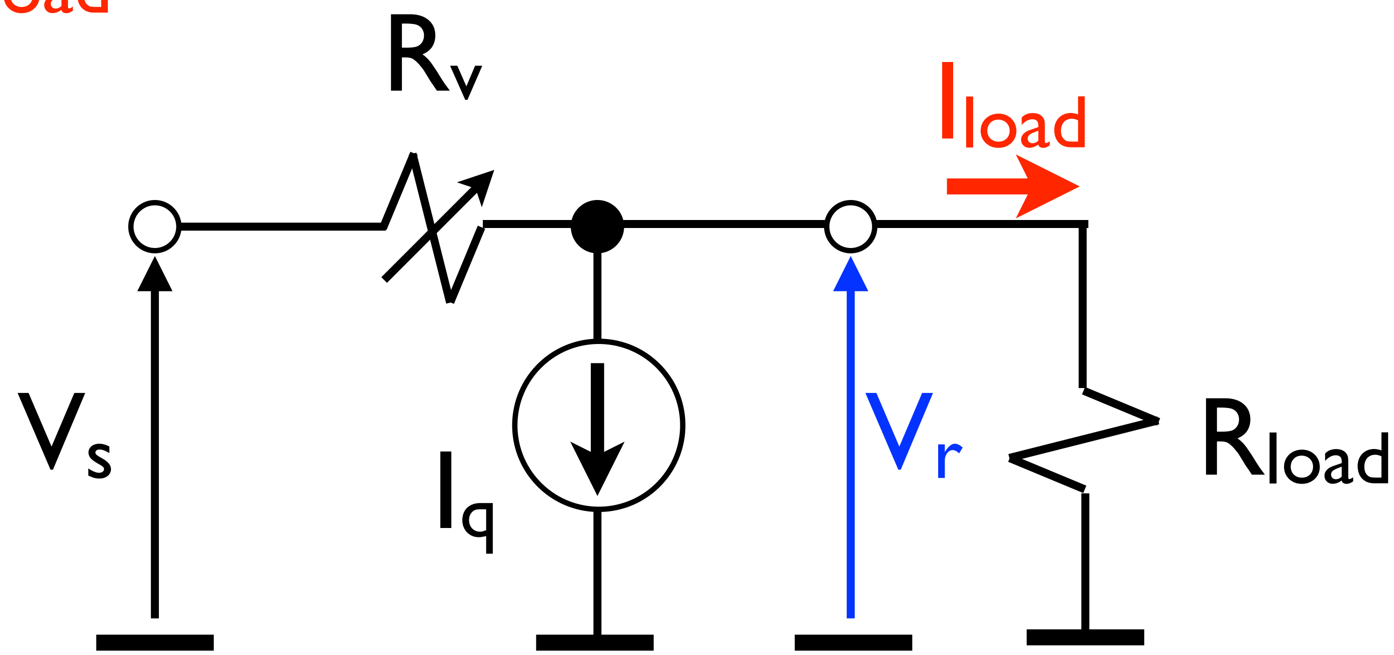
Working principle: it can be seen as a variable resistor in series to the load. The value of the resistor is regulated to have proper voltage drop according whatever is the load

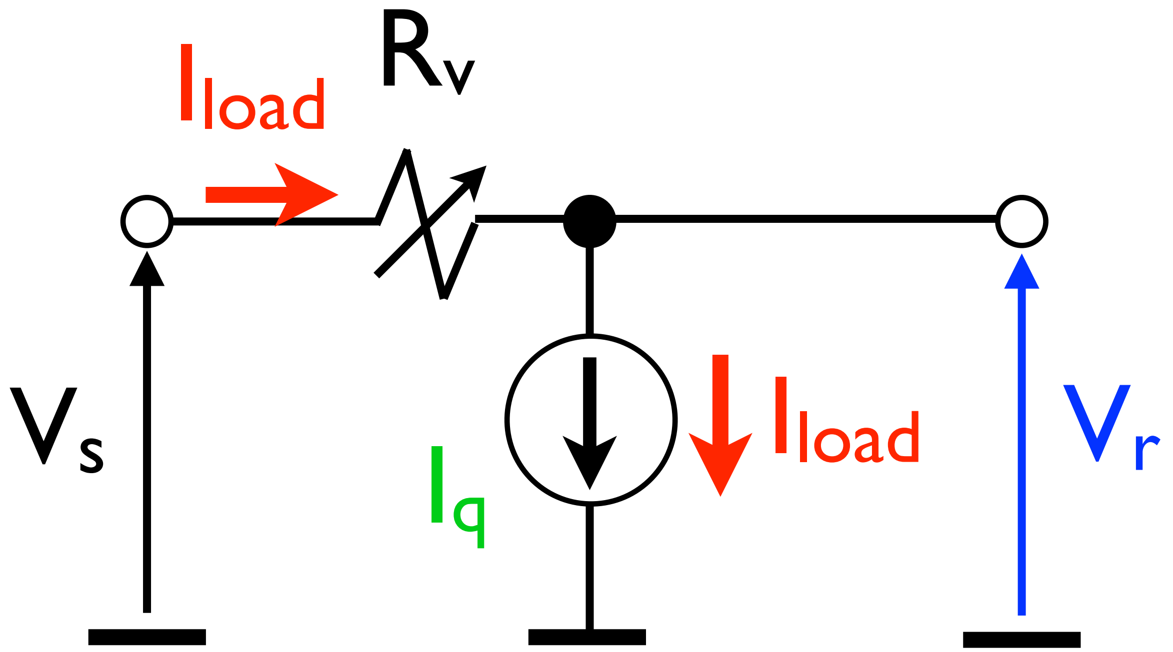


$$V_r = V_s - R_v \cdot I_{load}$$

SERIES VOLTAGE REFERENCE

$$V_r = V_s - R_v \cdot I_{load}$$





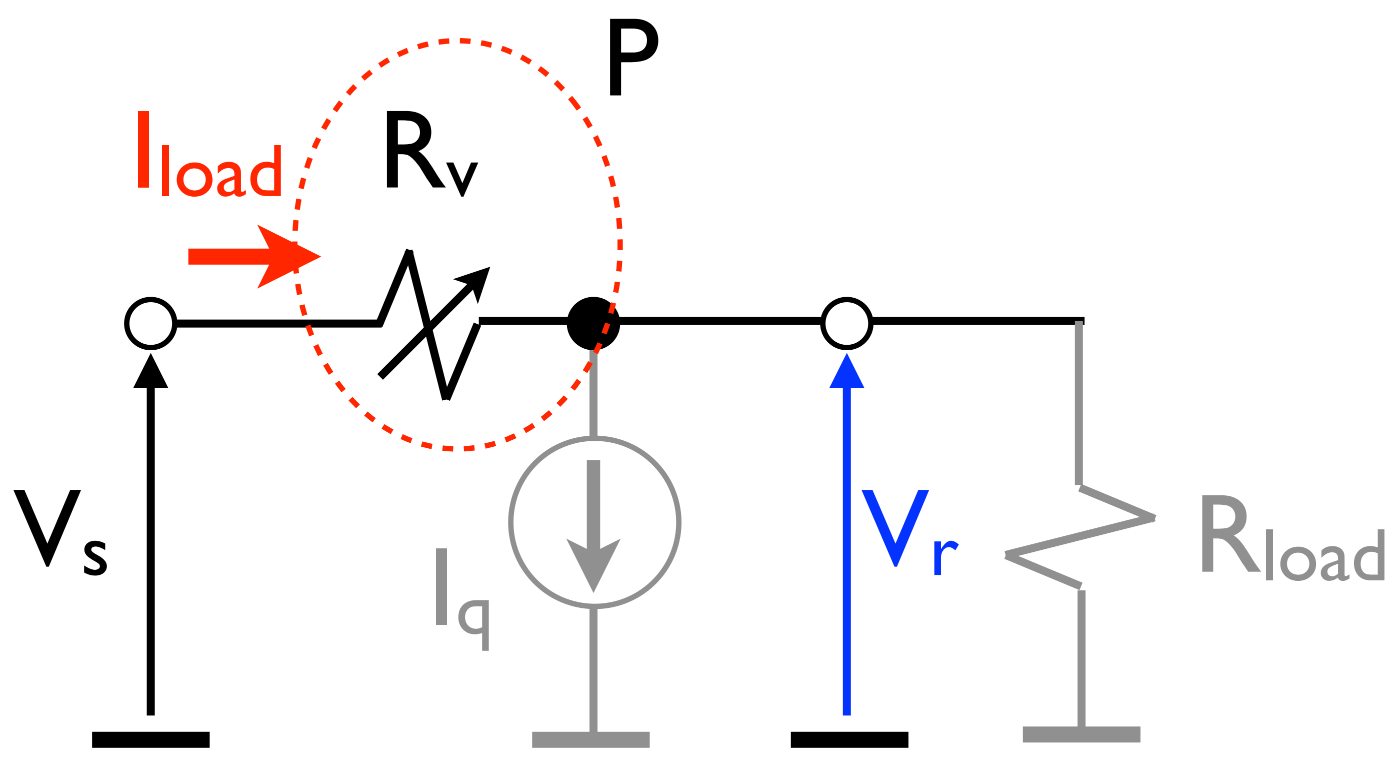
I_q is a quiescent current, necessary to have a voltage drop on R_v even if no load is applied

SERIES VOLTAGE REFERENCE

IMPORTANT!

A power is lost on the resistor R_v.

$$P = (V_r - V_s) \cdot I_{load}$$



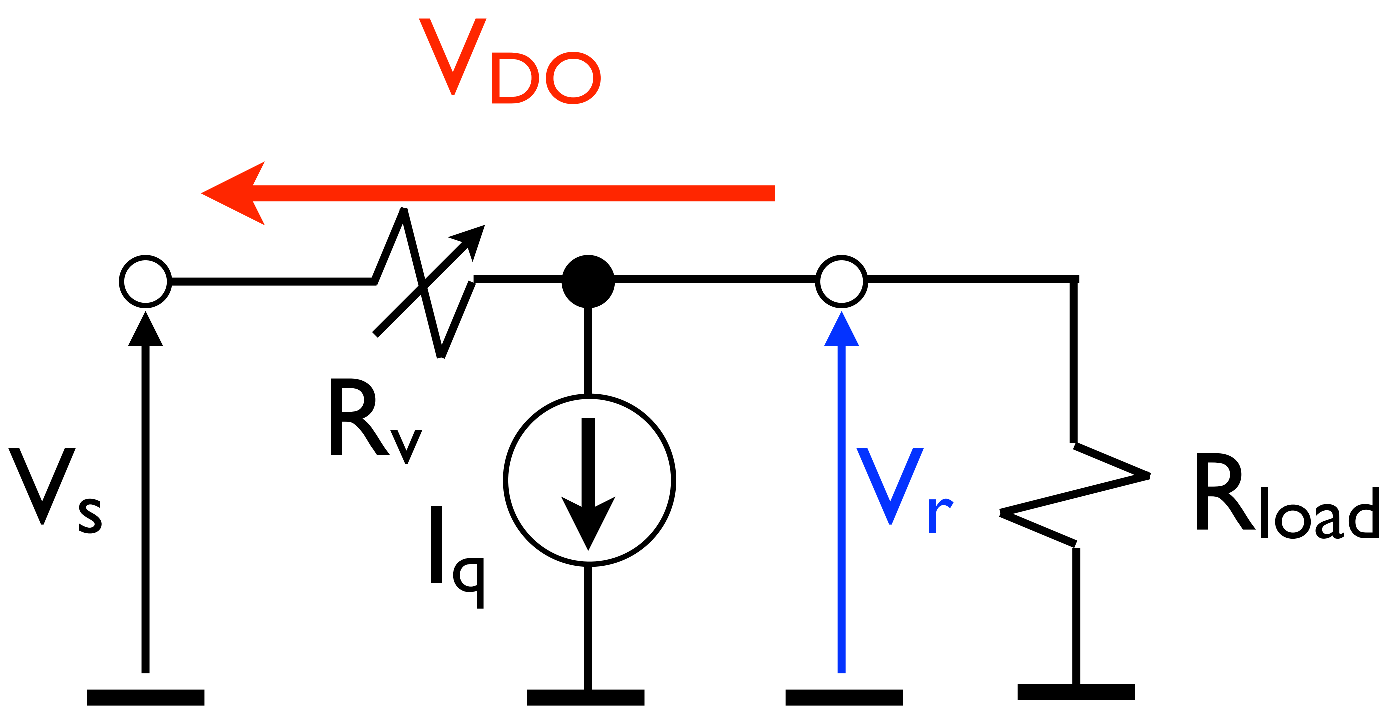
You must take into account the lost power to avoid overheating

SERIES VOLTAGE REFERENCE

ALSO VERY IMPORTANT!

The difference between the supply voltage and the reference voltage must be higher than dropout voltage

$$(V_r - V_s) > V_{DO}$$



IMPORTANT PARAMETERS

Initial accuracy

from 1% to 0.02%

E.g.:

if $V_r = 5\,V$ and initial accuracy is 0.5%, the actual V_r is :

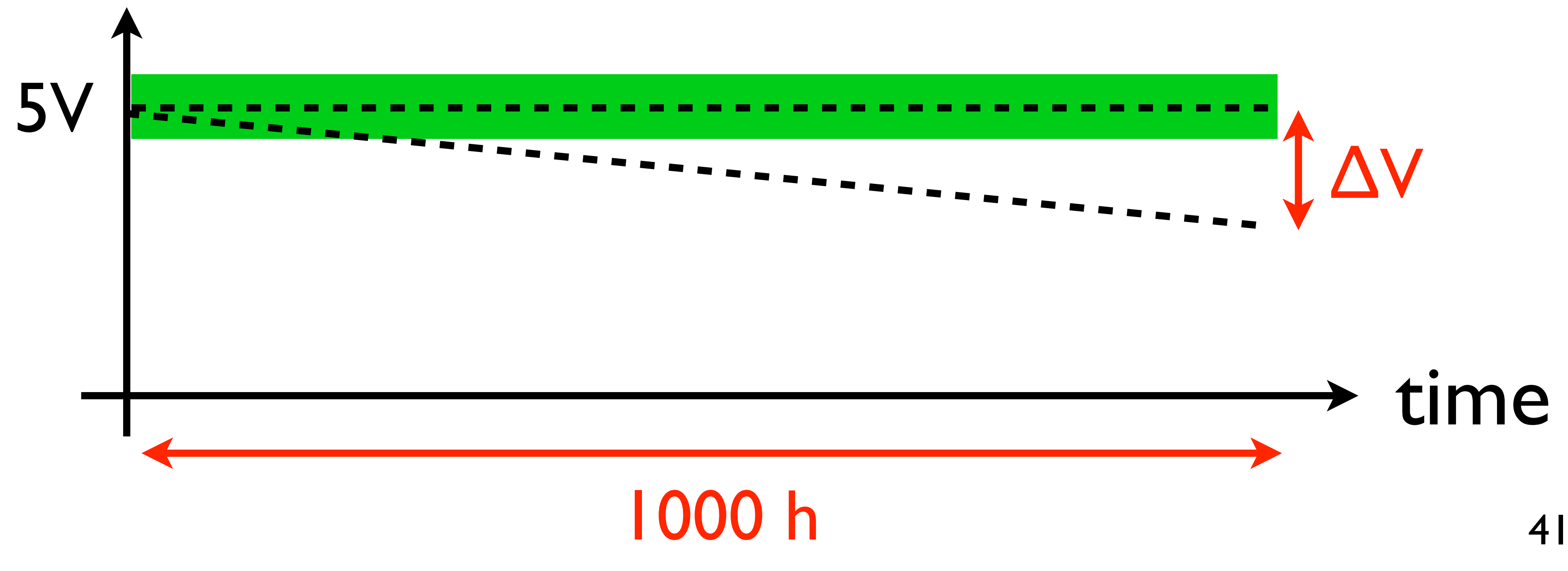
$$5 - 5 \cdot 0.005 < V_r < 5 + 5 \cdot 0.005 \quad [V]$$

$$5 - 0.025 < V_r < 5 + 0.025 \quad [V]$$

$$4.975 < V_r < 5.025 \quad [V]$$

Long term stability

in ppm/1000 h

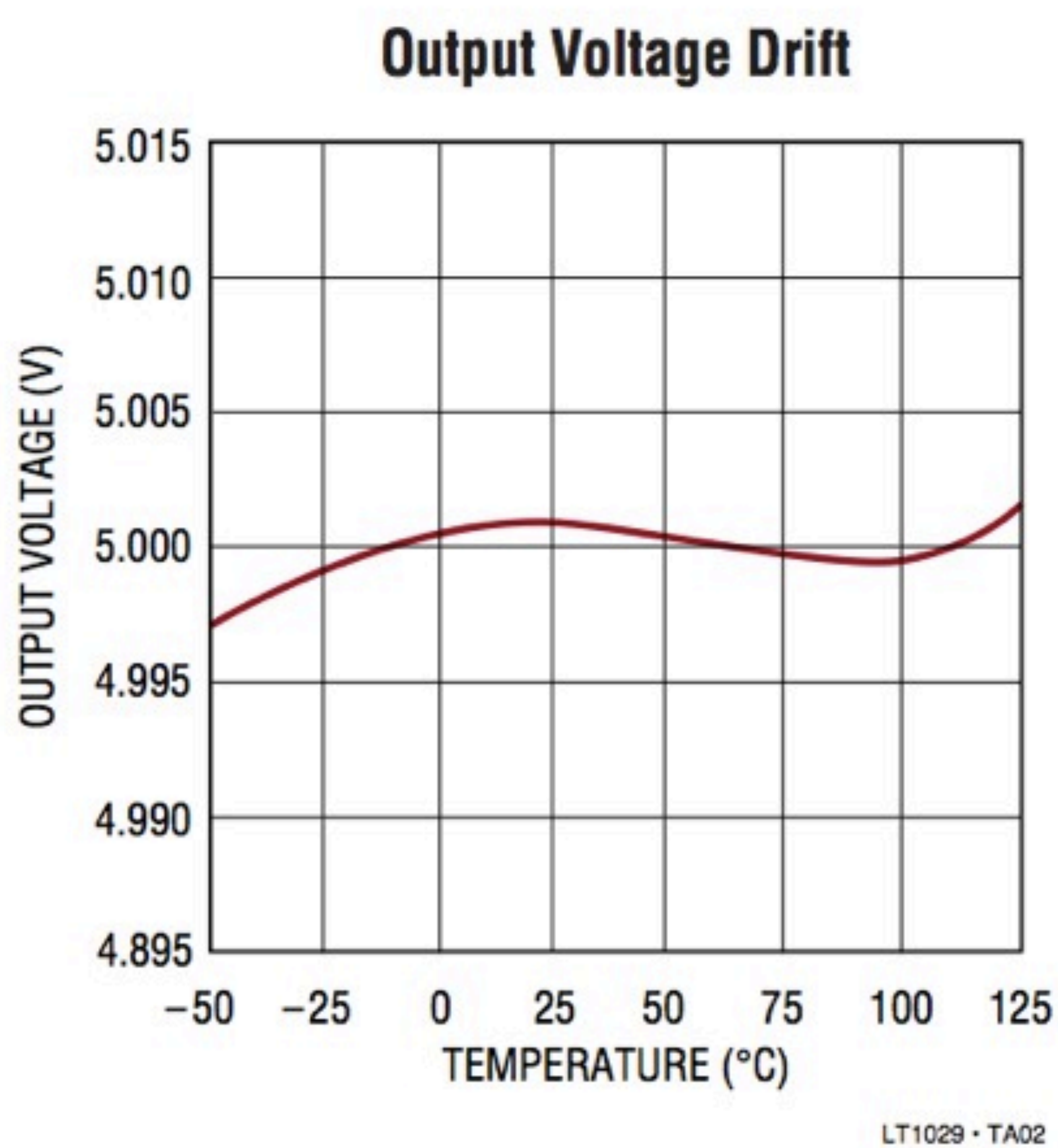


IMPORTANT PARAMETERS

Temperature coefficient (tempco)

Usually given in ppm/°C... but it is NOT linear!

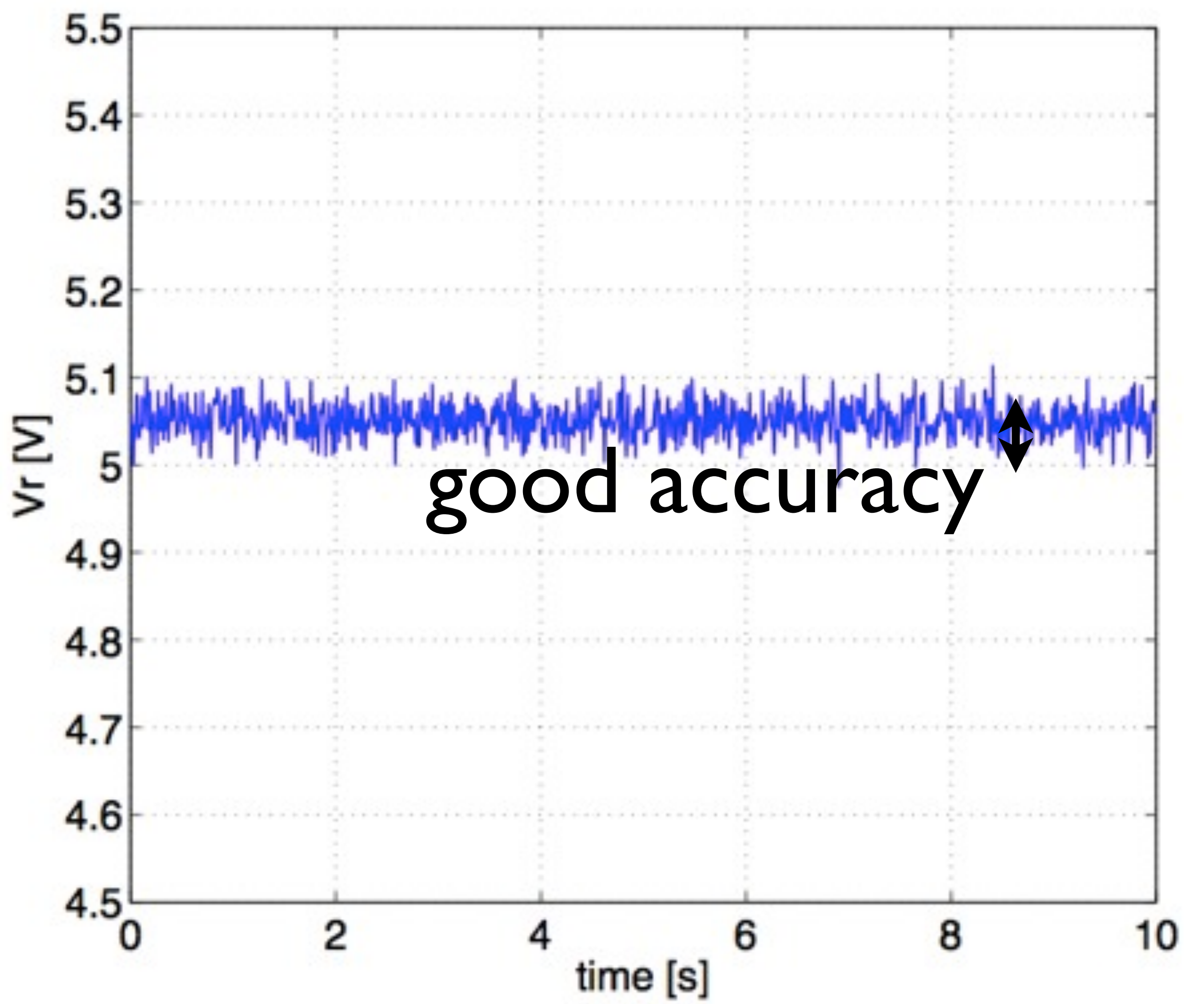
E.g.: LT1029 - Linear Technologies

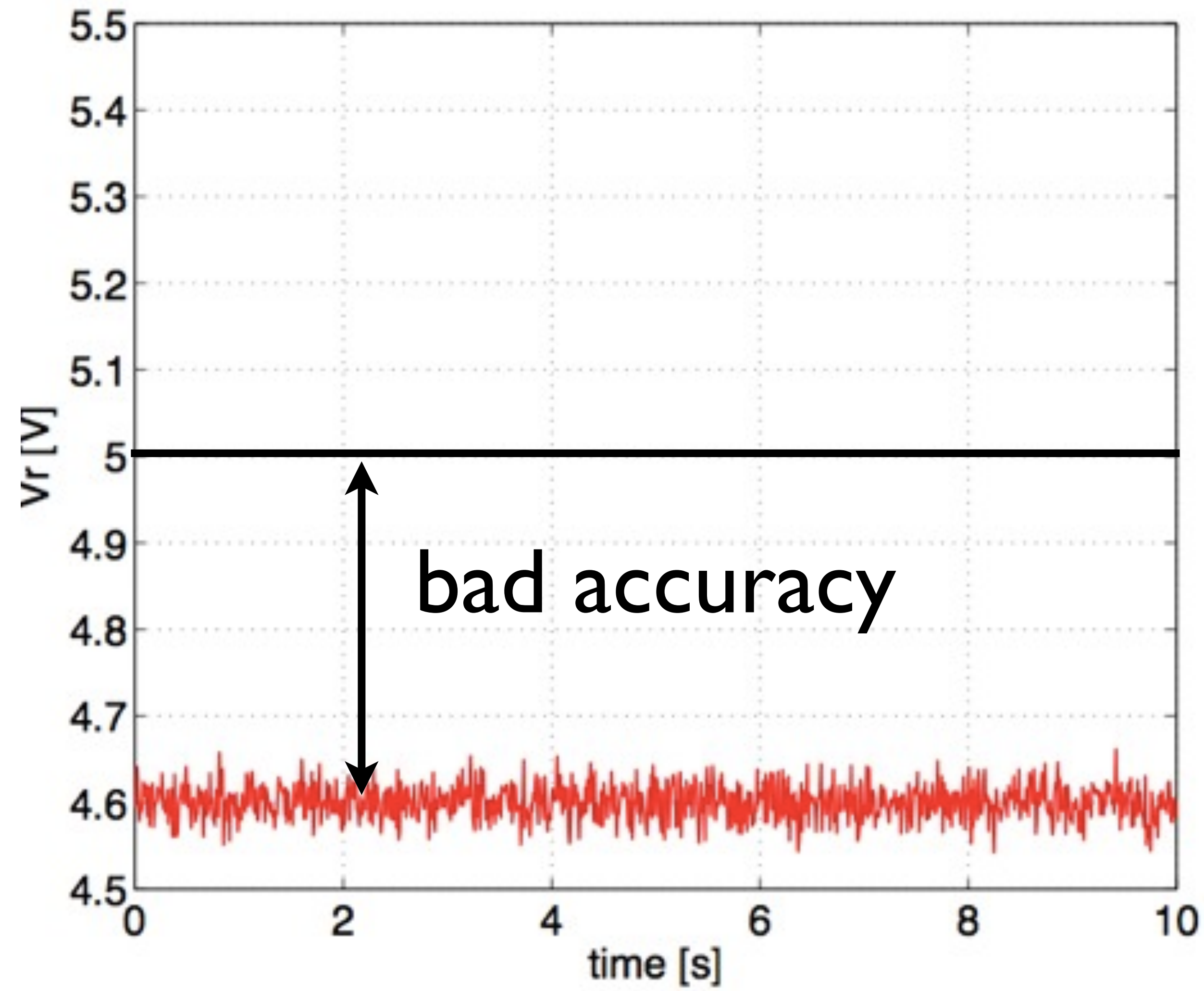


IMPORTANT PARAMETERS

Noise

The accuracy only tells you how "precise" is the average value of V_r. It does not tell you how much "swings" around it





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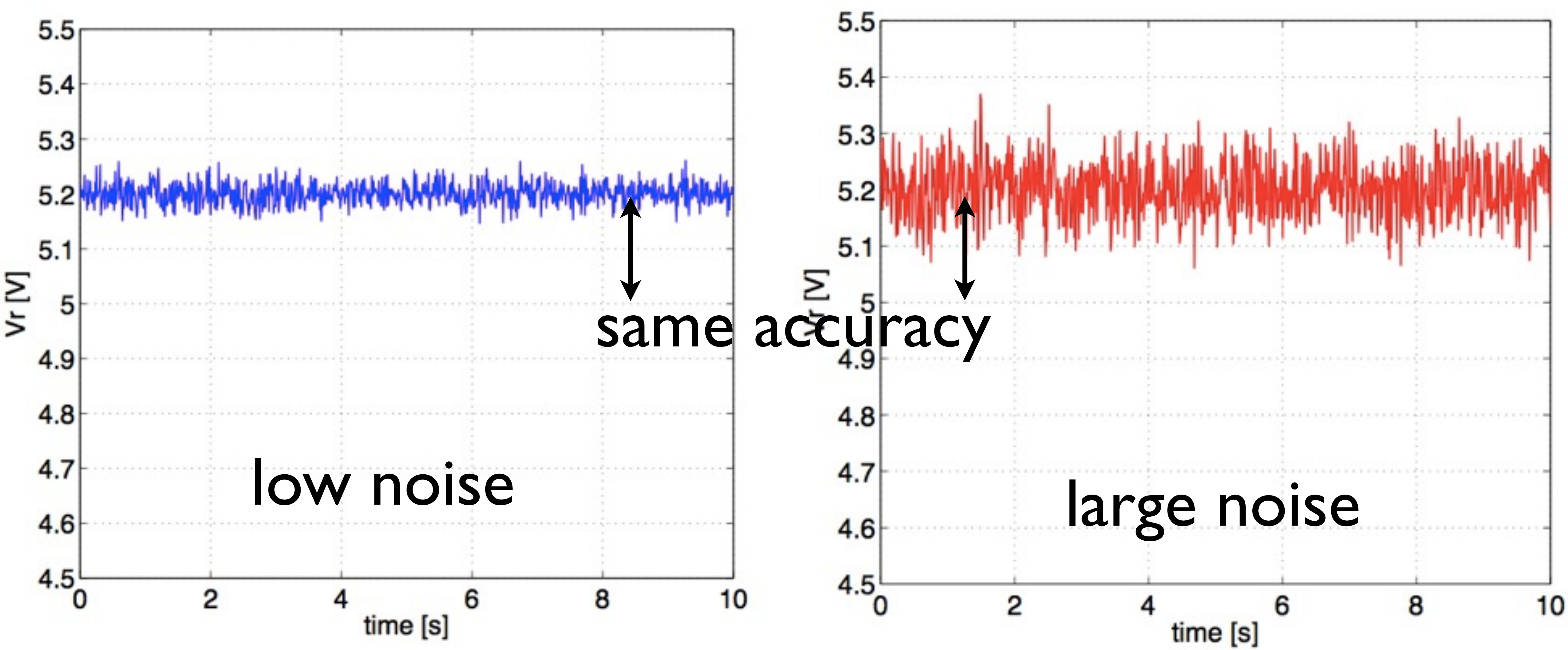
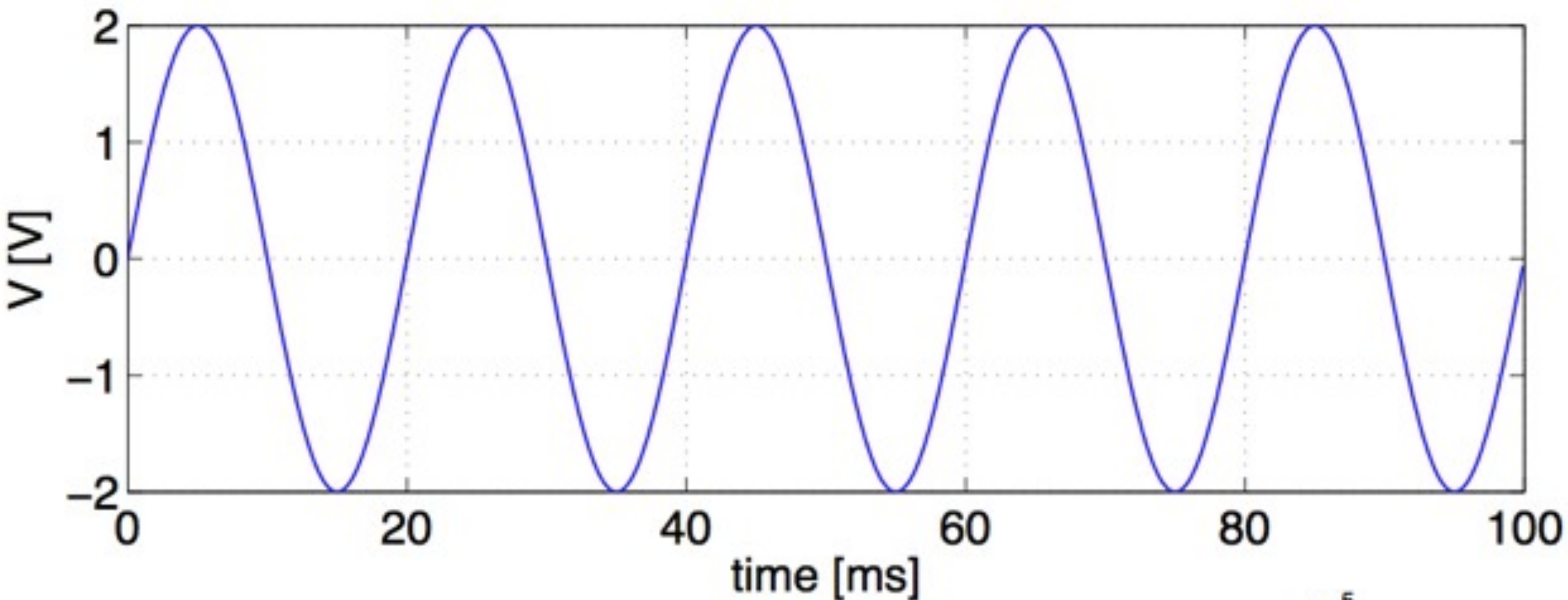
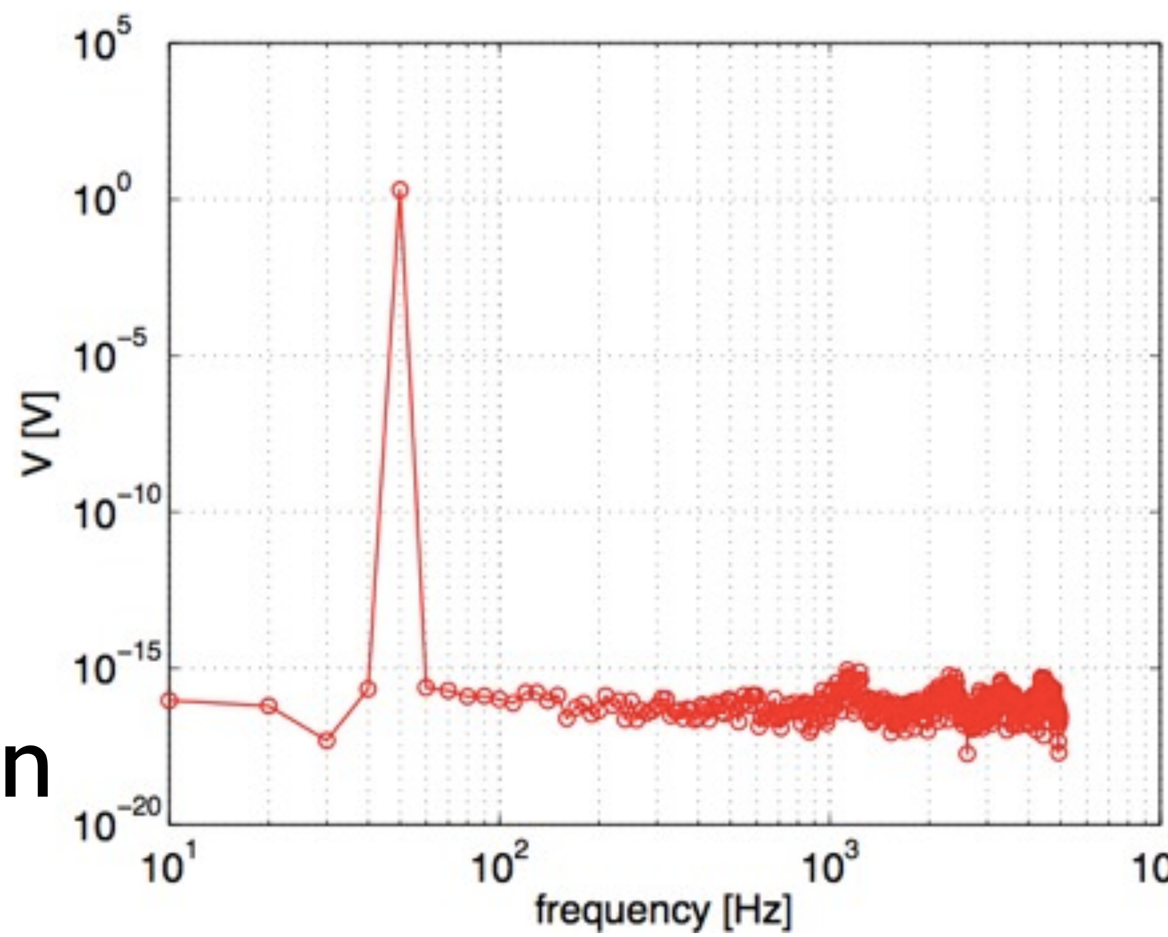


SPECTRUM ANALYZER

The same signal can be viewed in



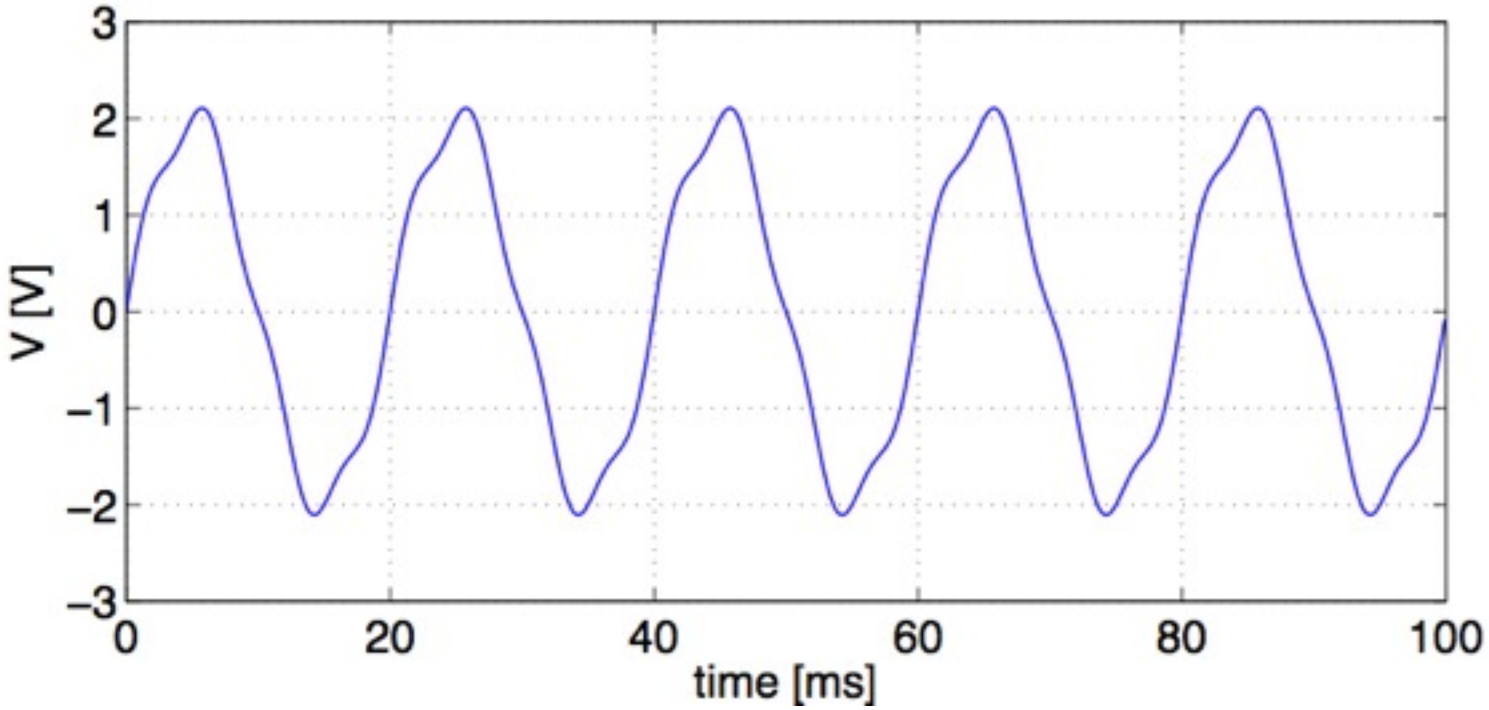
time domain



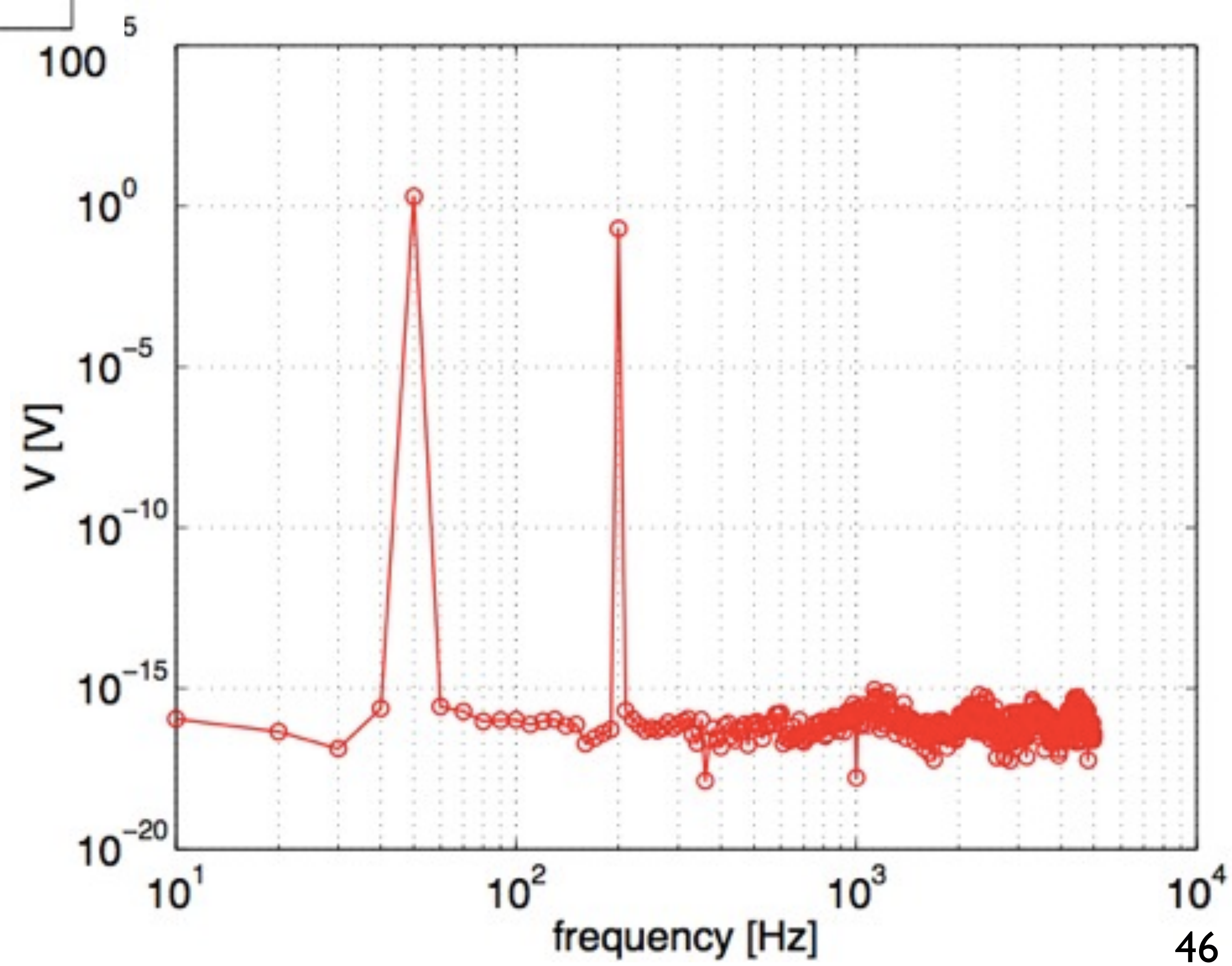
frequency domain

SPECTRUM ANALYZER

The same signal can be viewed in



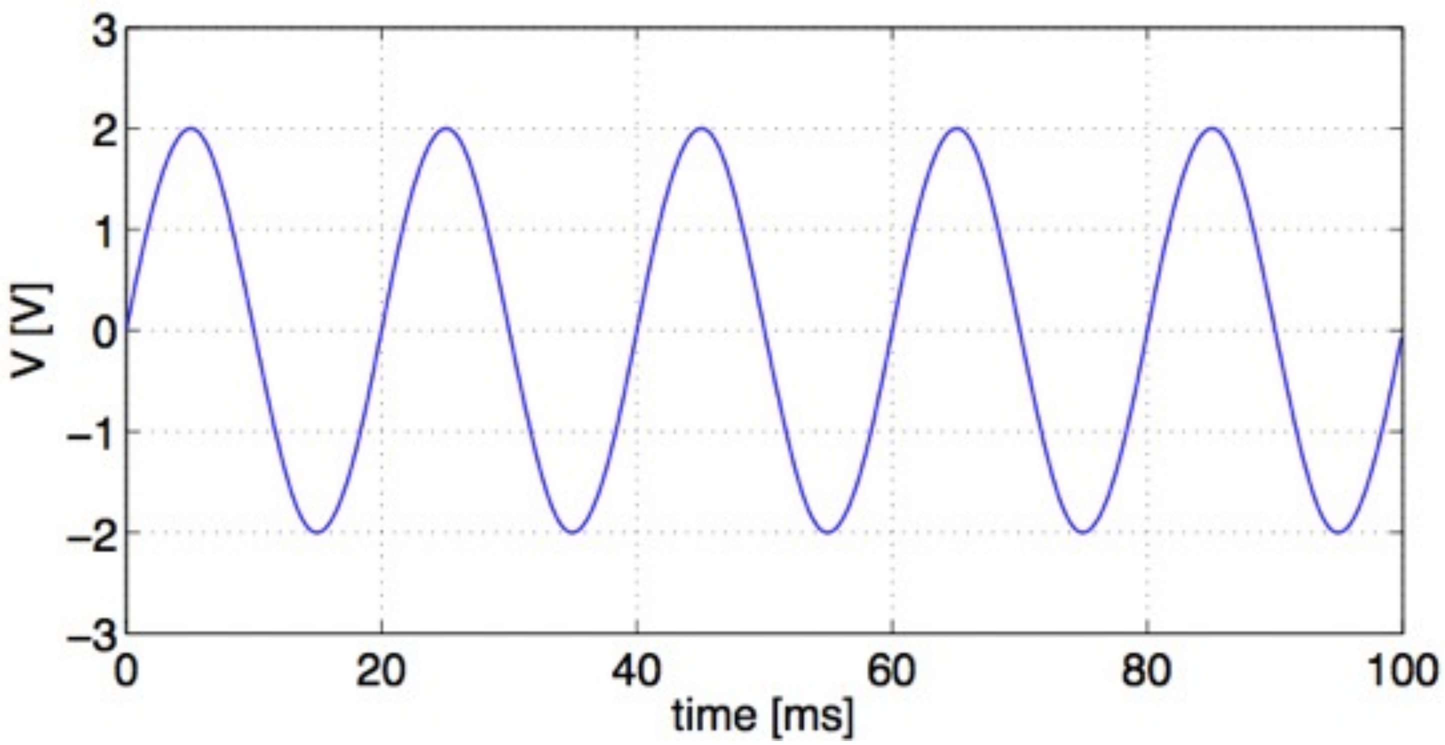
time domain



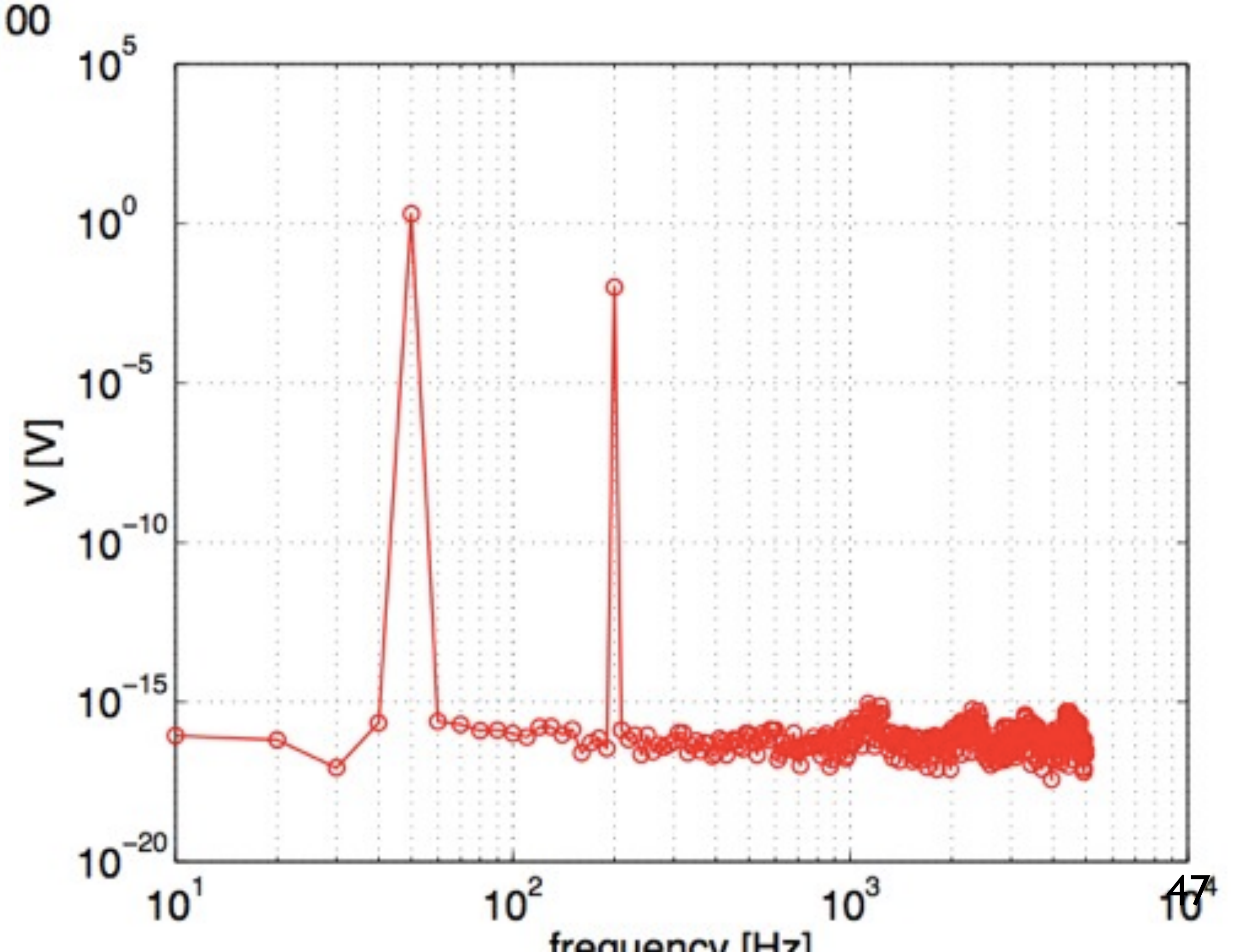
frequency domain

SPECTRUM ANALYZER

It can be useful to observe harmonics we can't see in time domain

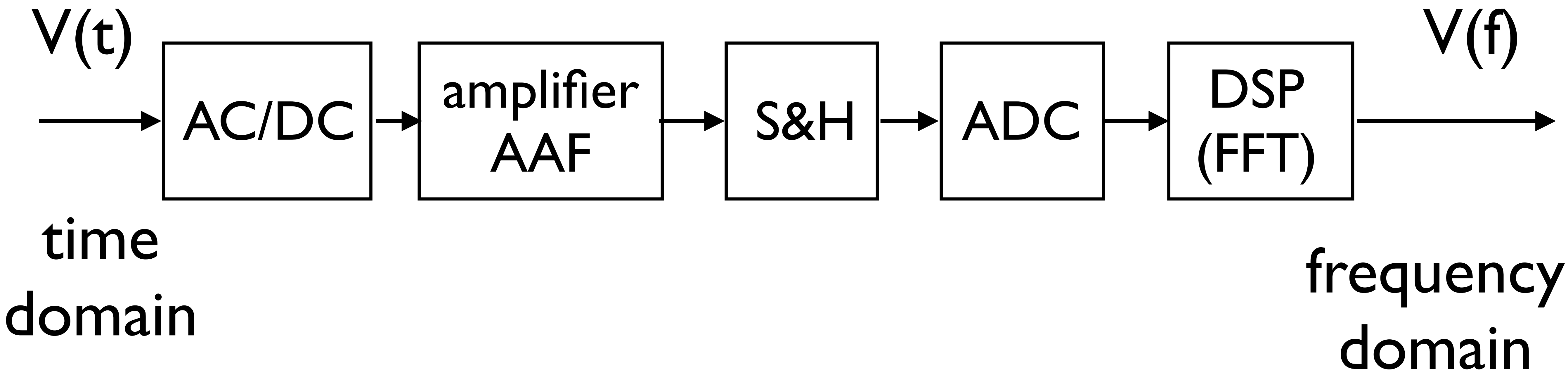


time domain



frequency domain

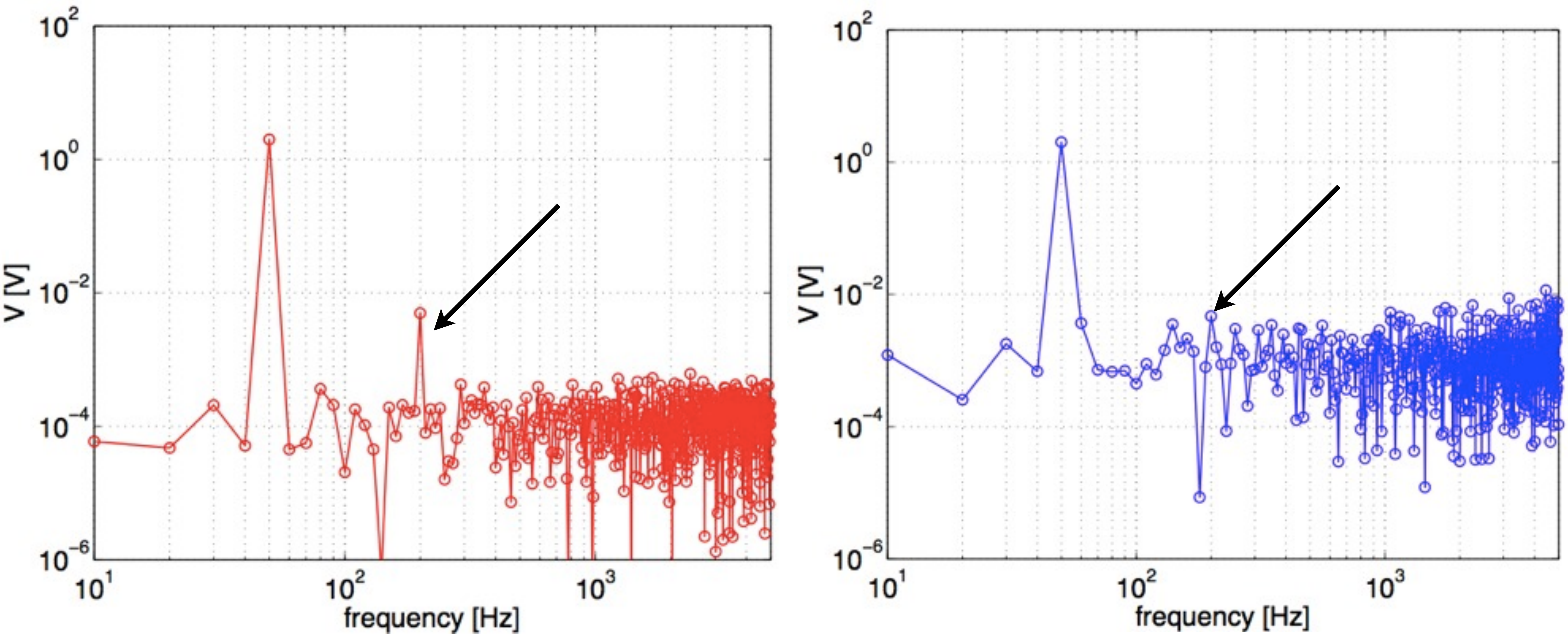
FFT SPECTRUM ANALYZER



AAF=anti-aliasing filter

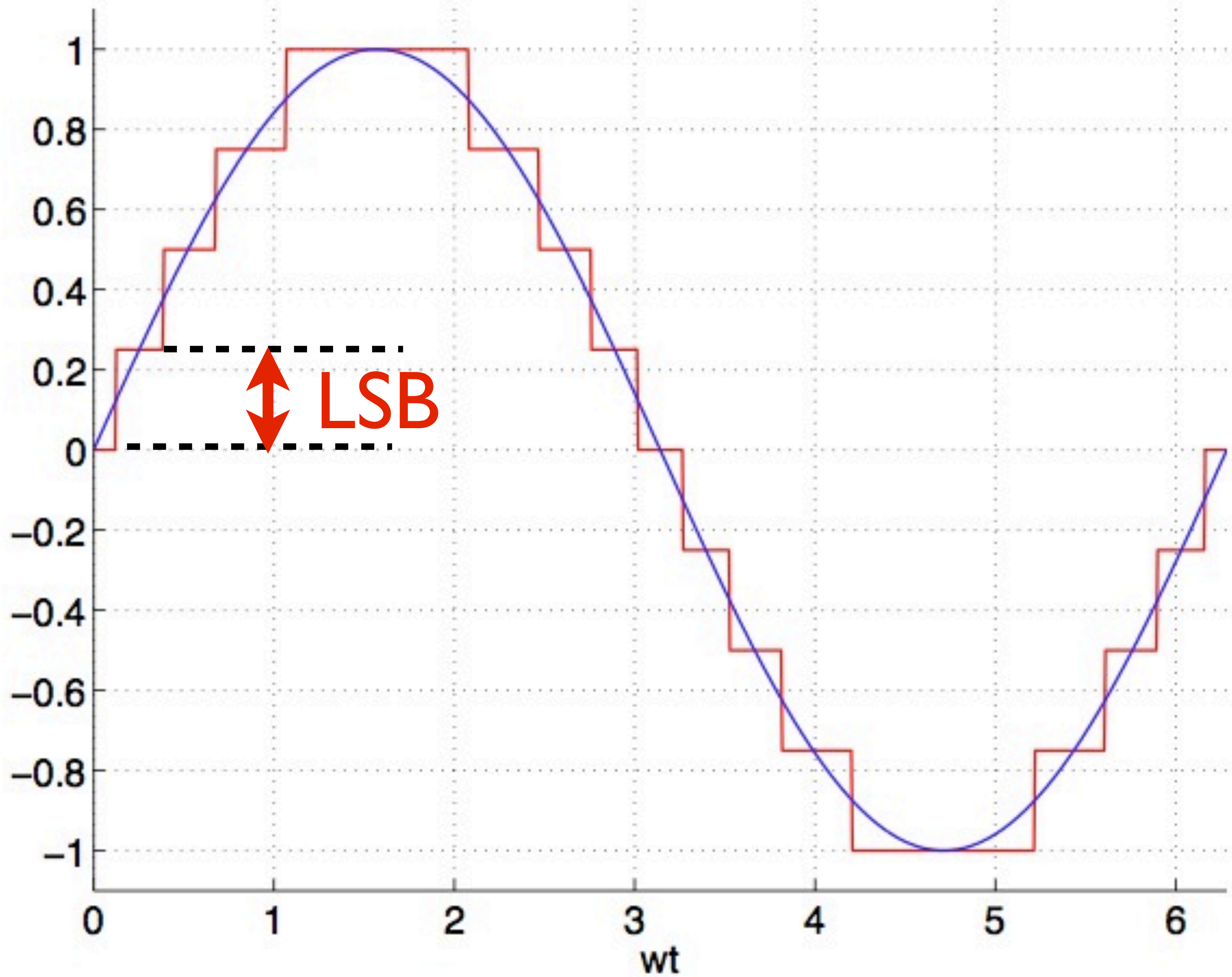
The noise floor is important!

If the noise floor is too high we can't see tiny harmonics



Back to lesson 1...

How does LSB affect the digital signal?



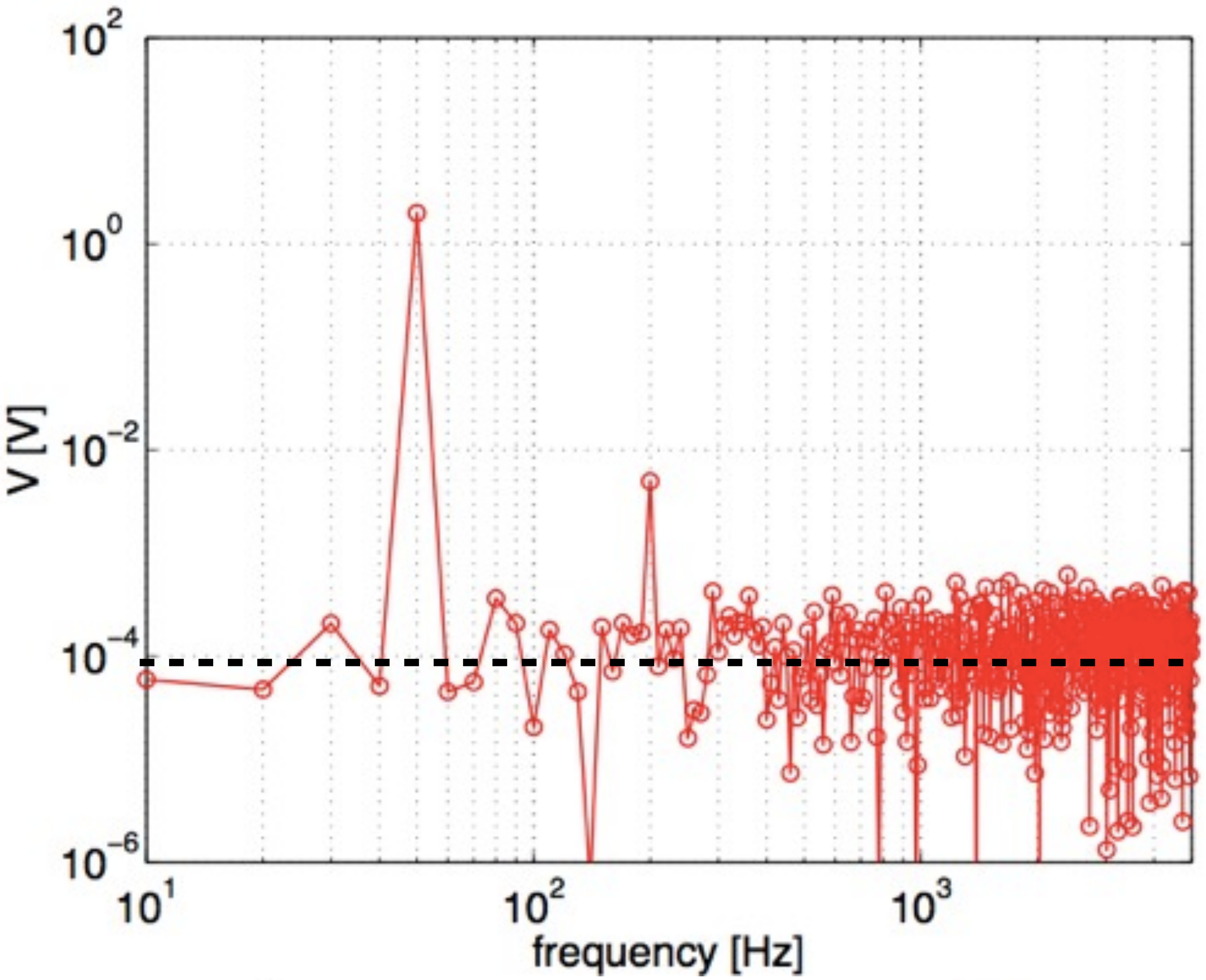
3 bits ADC

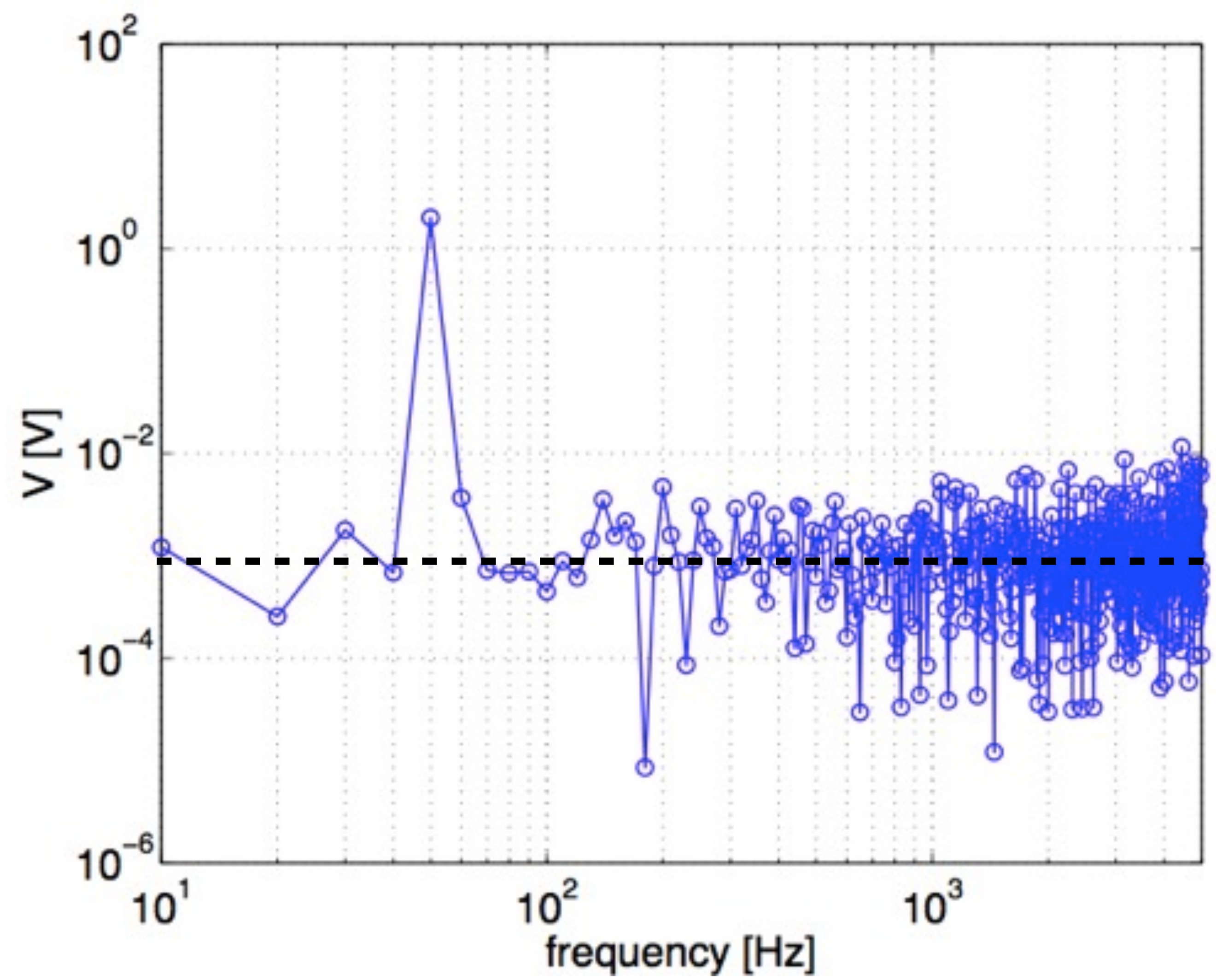
$2^3=8$

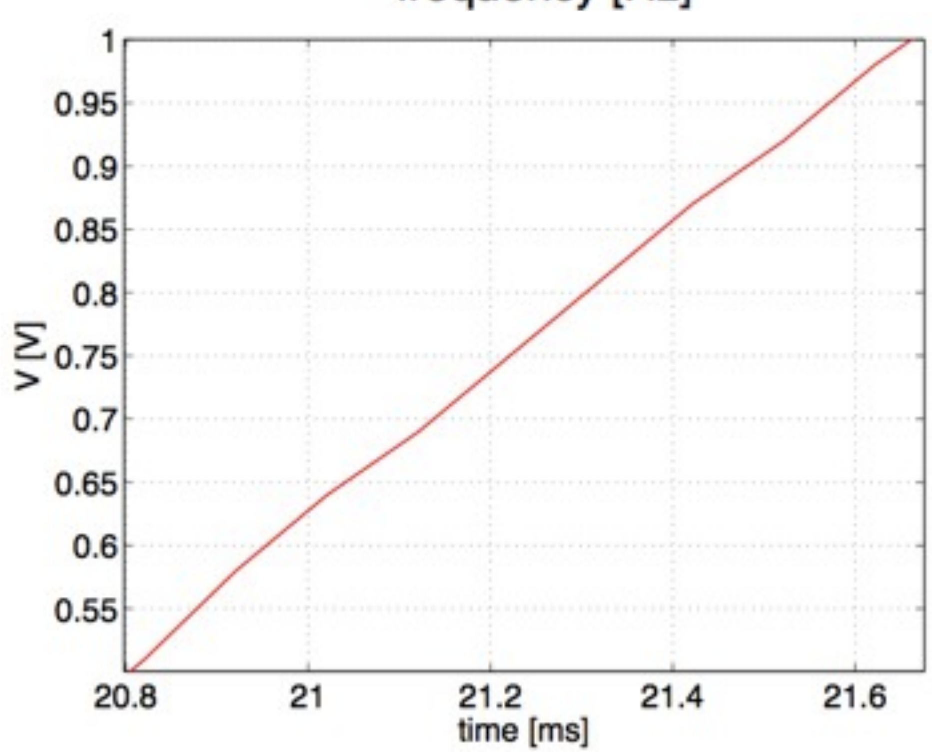
Maximum voltage range 2V

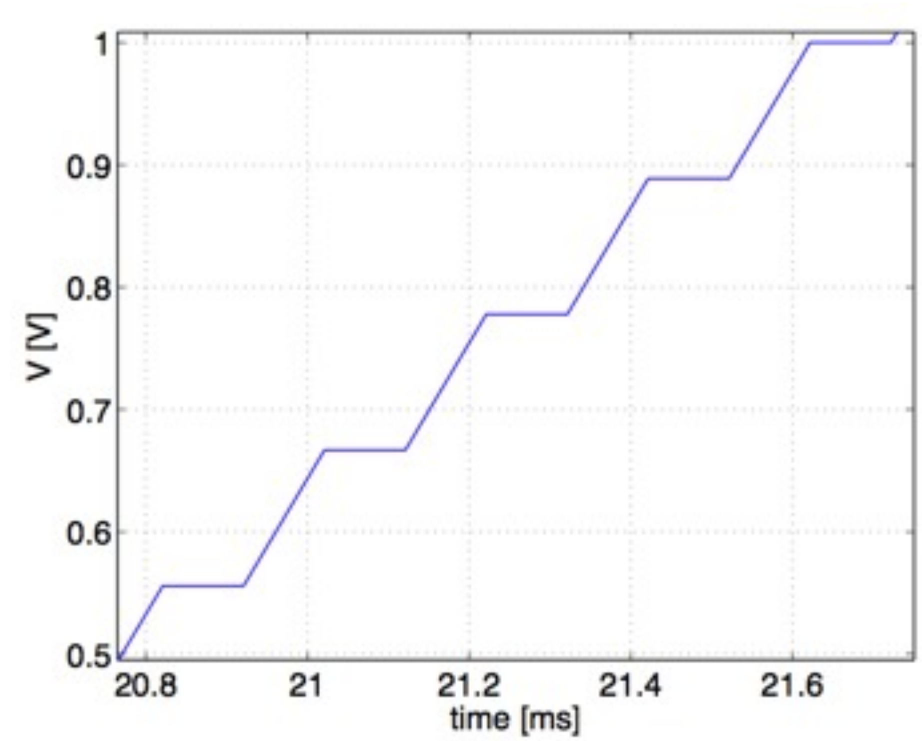
LSB = 2V/8 = 0.25 V

Poor resolution (large LSB) makes the noise floor larger

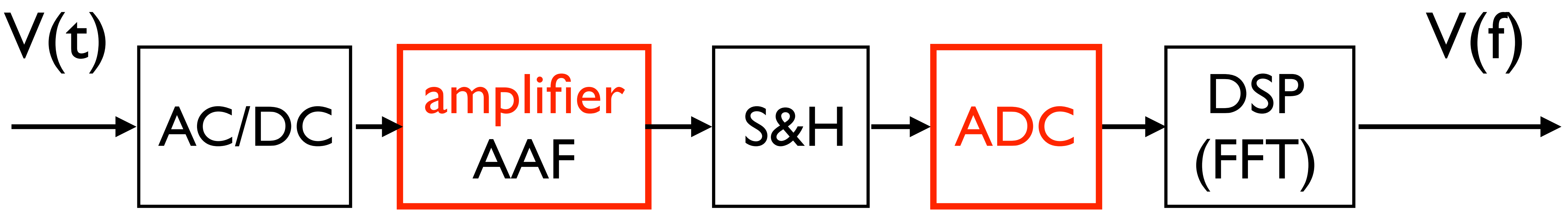






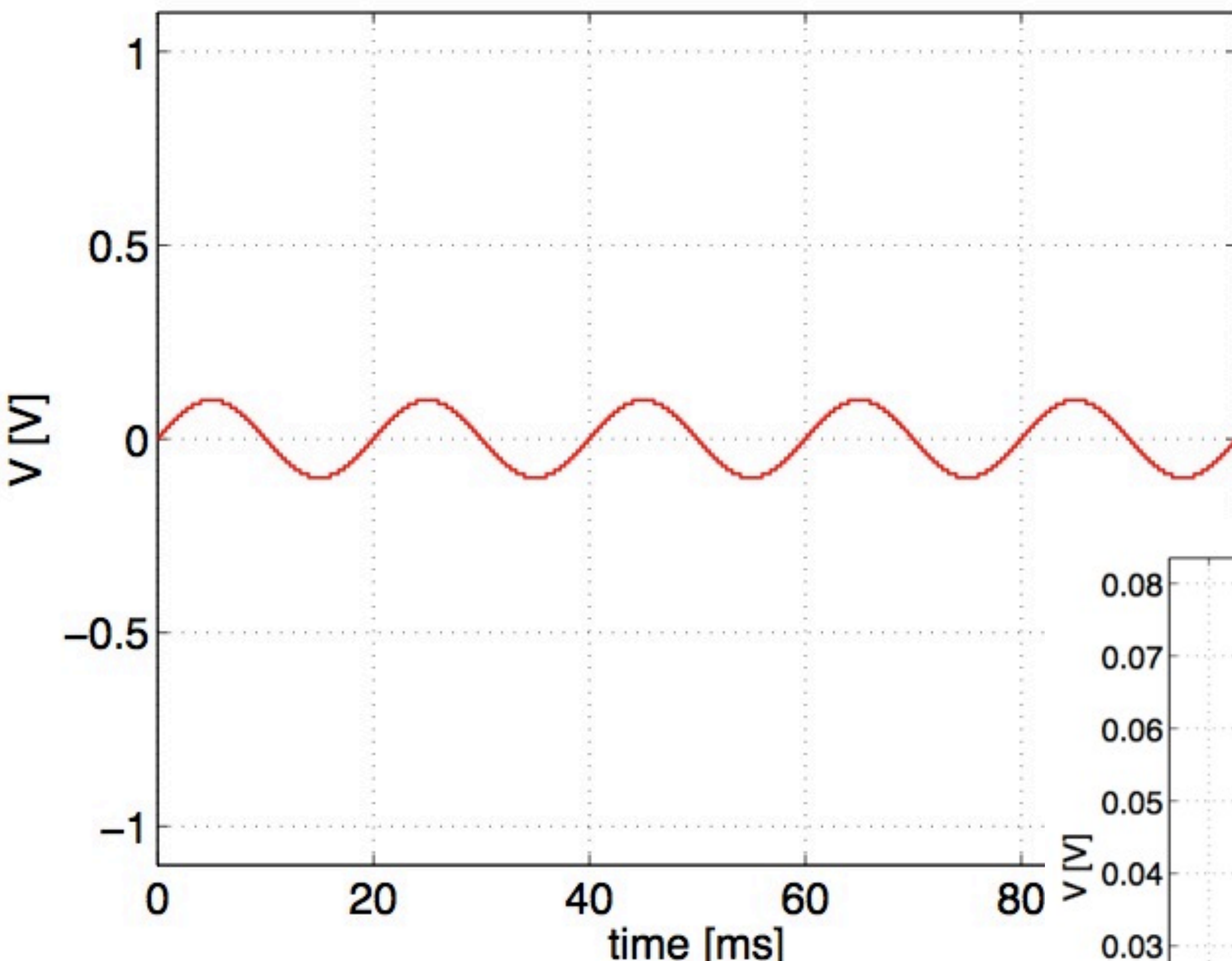


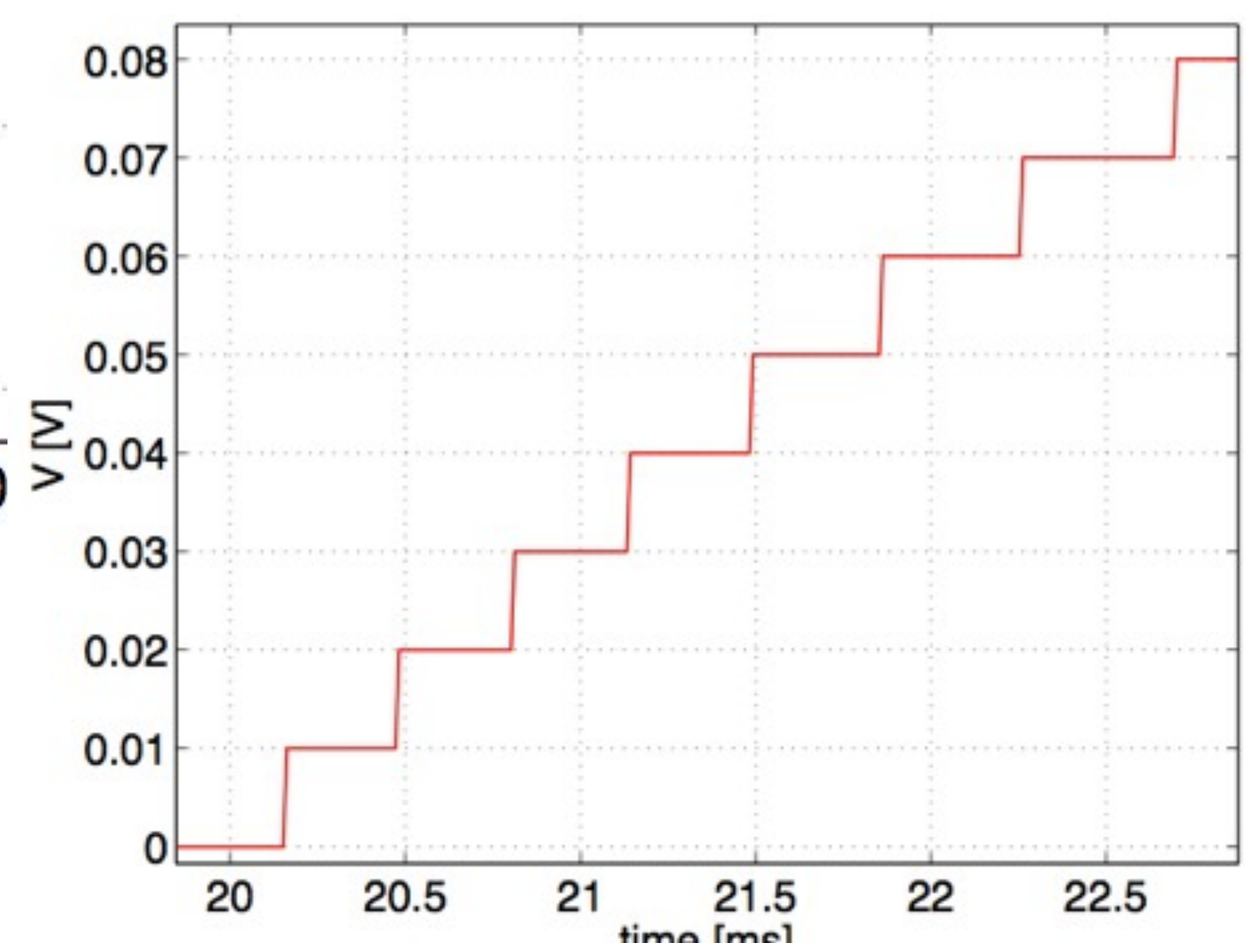
We need LSB as low as possible



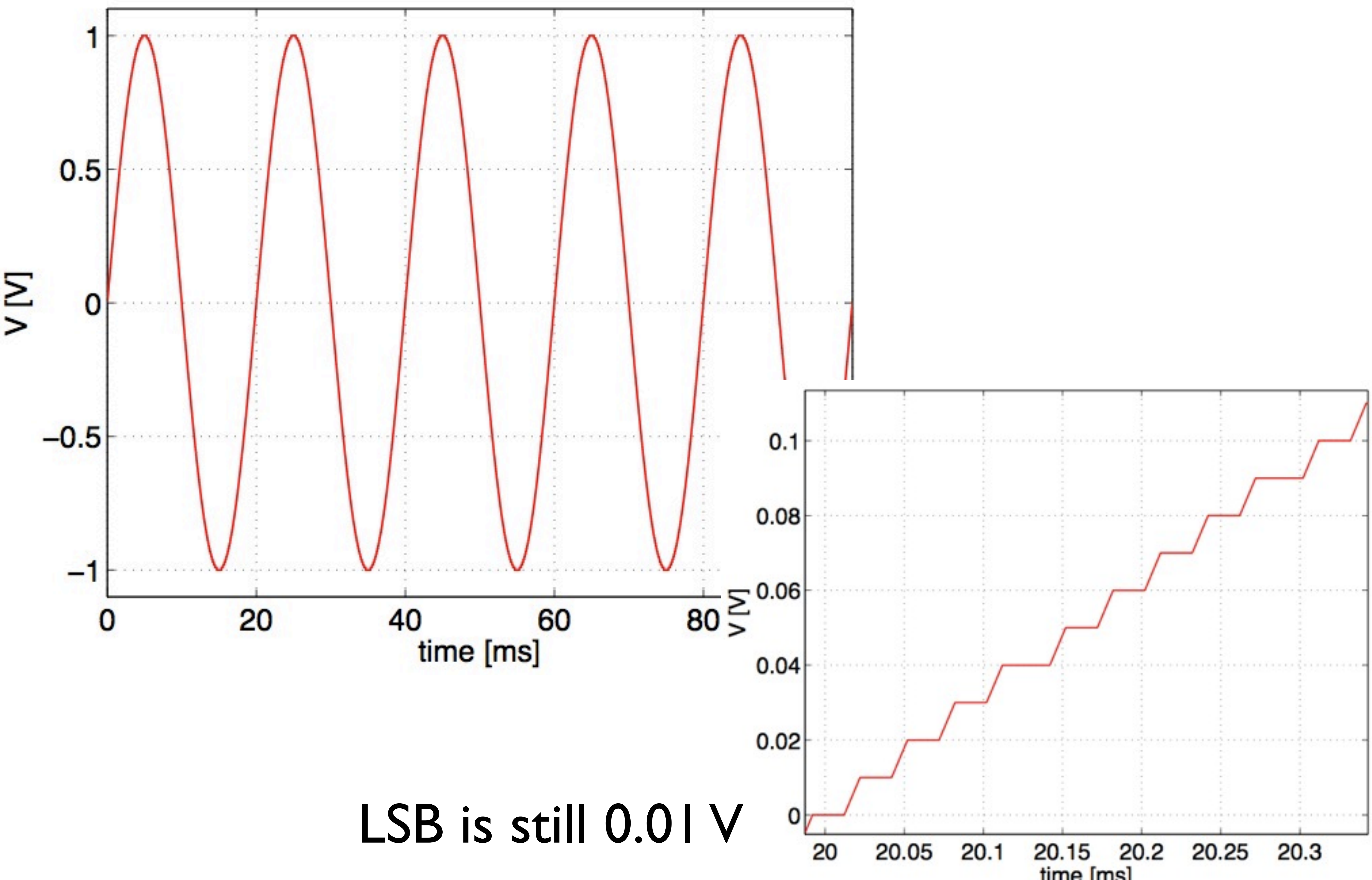
In fact the ADC does not change. We amplify the voltage before ADC so that the LSB will be *proportionally* lower

Example: the signal span is from -0.1V to 0.1V
LSB =0.01 V



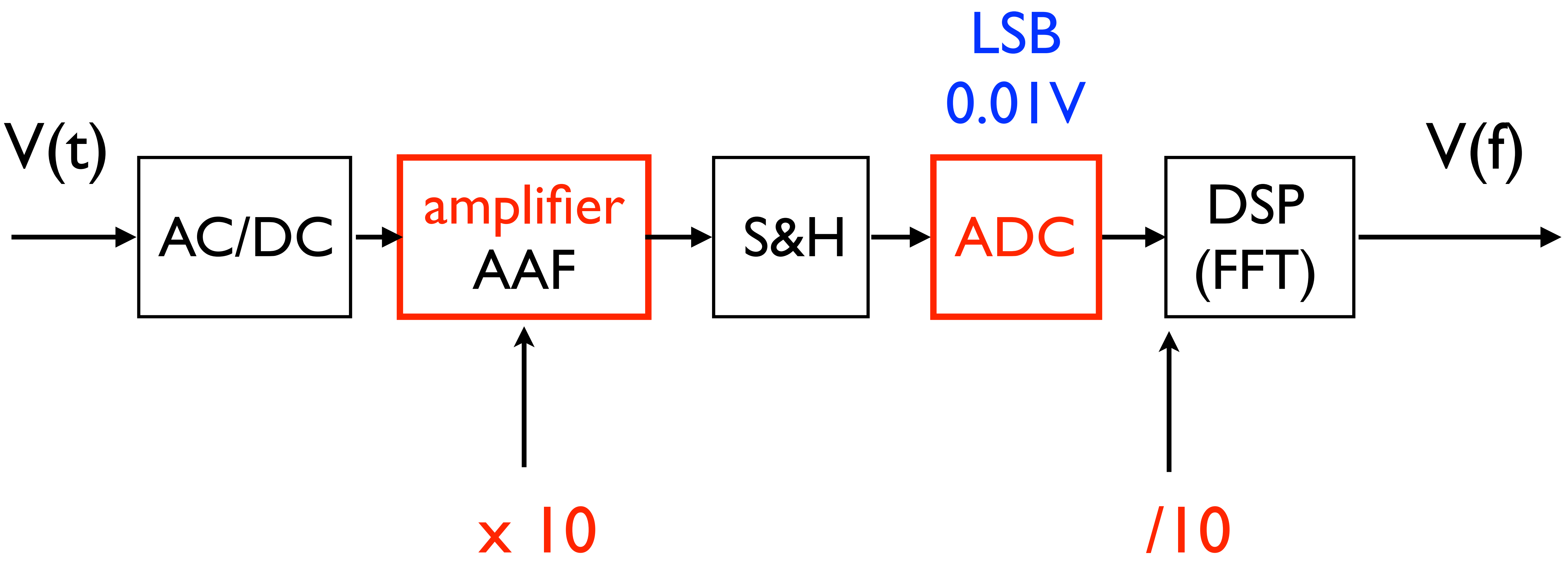


I amplify the signal 10 times before the quantization

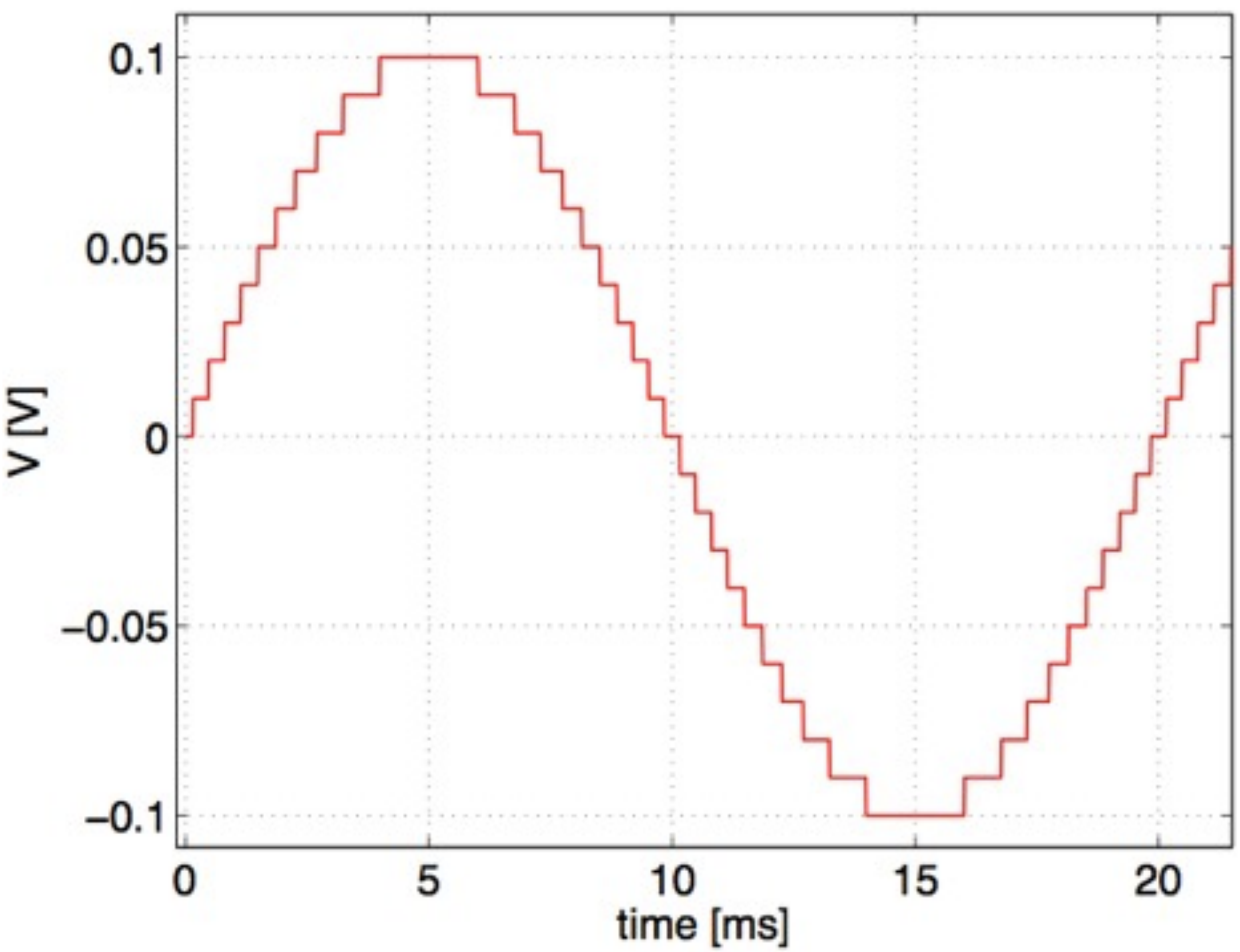


LSB is still 0.01 V

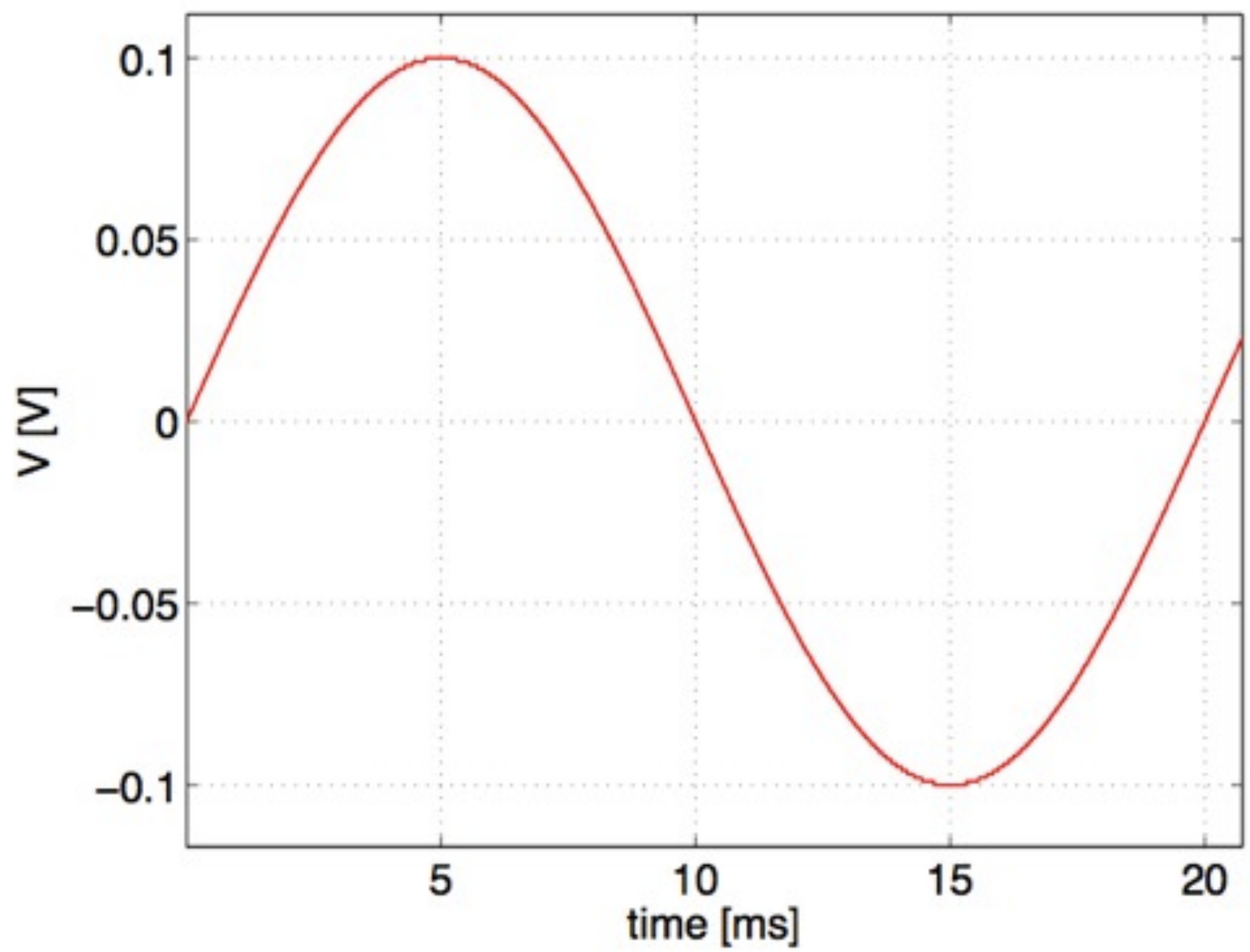
After Analog to digital conversion the signal in quantized.
I have to *numerically* divide it by 10 to obtain the correct gain.
Therefore also the LSB will be divided by 10



The quantized signal has lower quantization if we amplify it before ADC and then divide it numerically

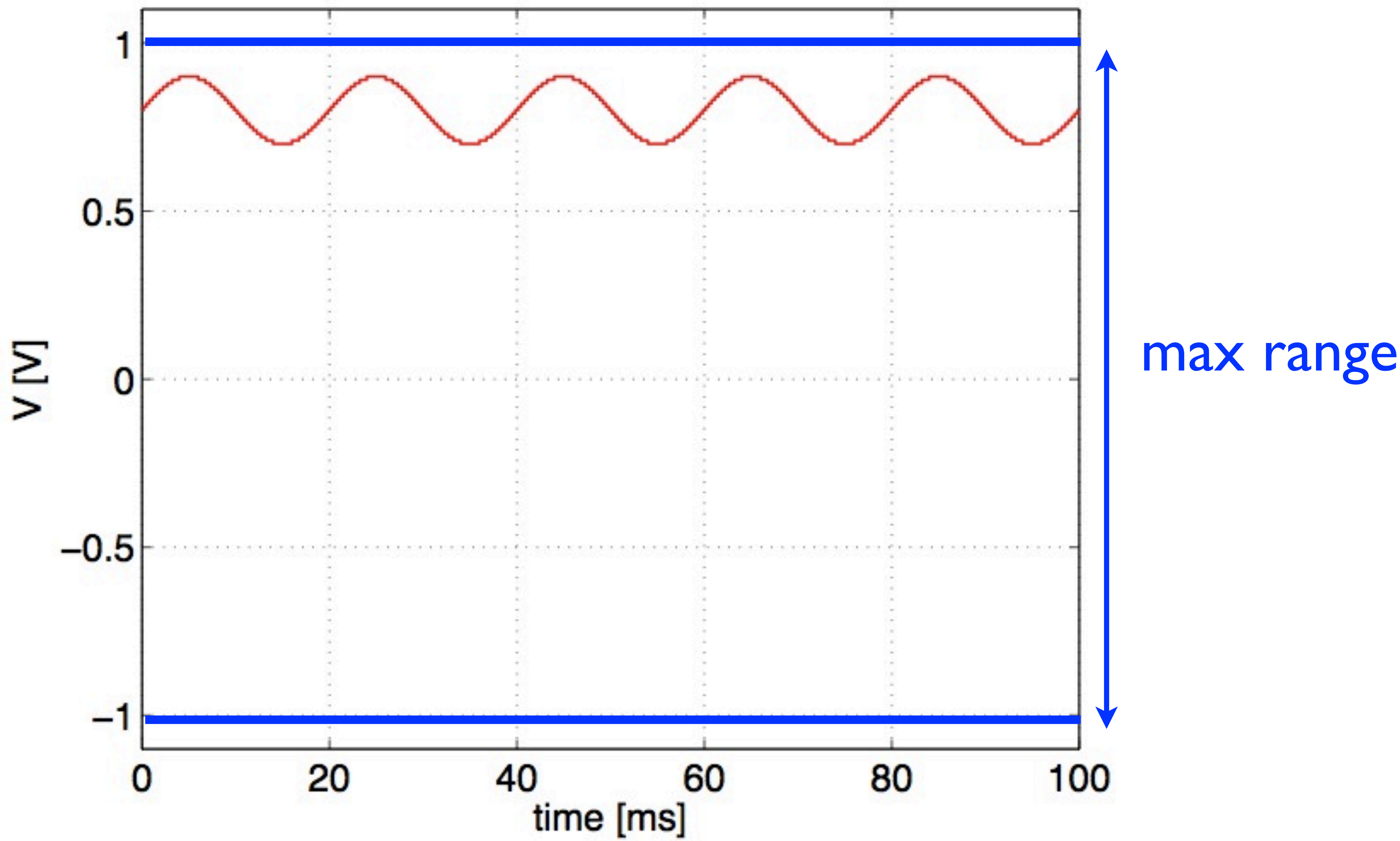


without amplification



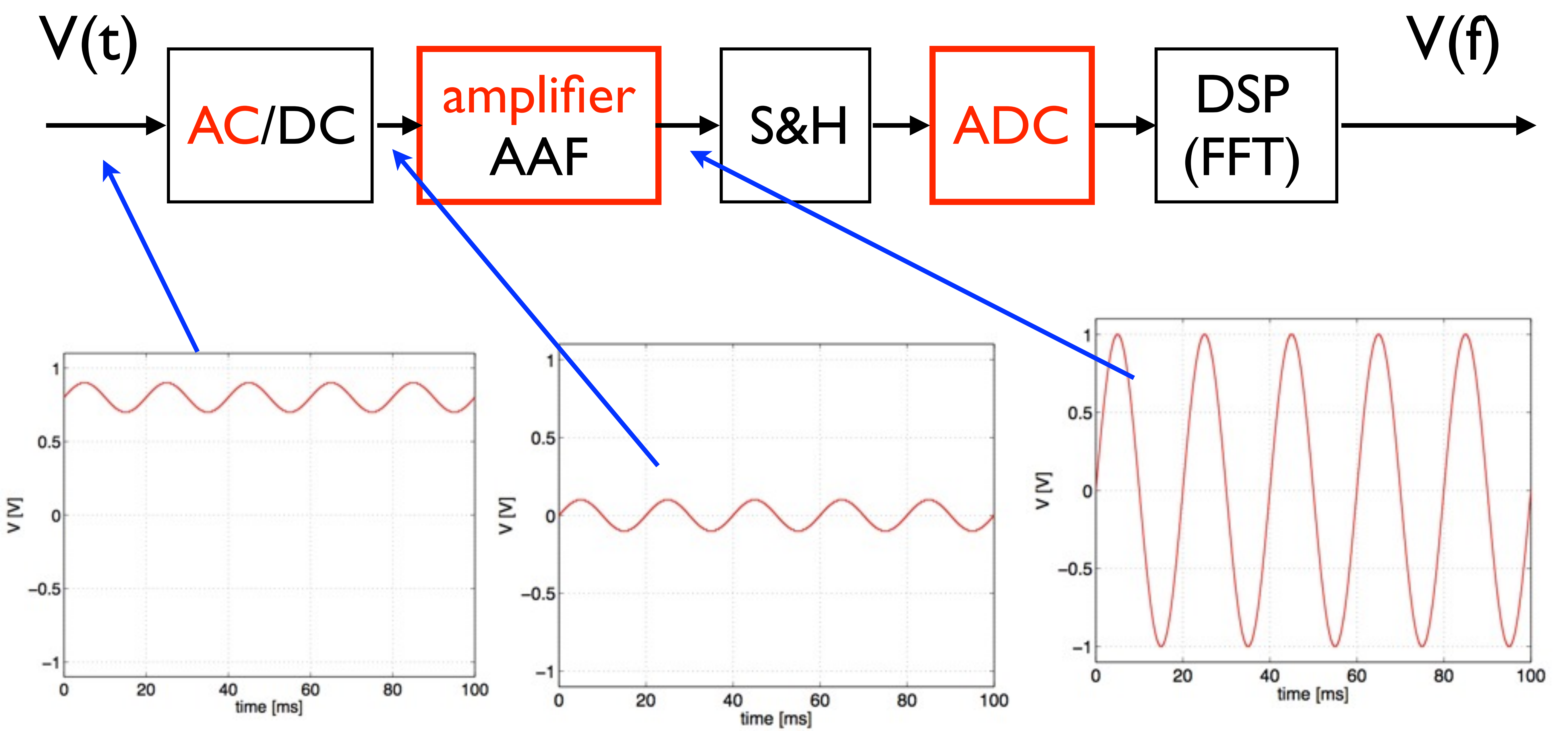
with amplification

Unfortunately is not always possible to amplify.
For instance is the average value is large.

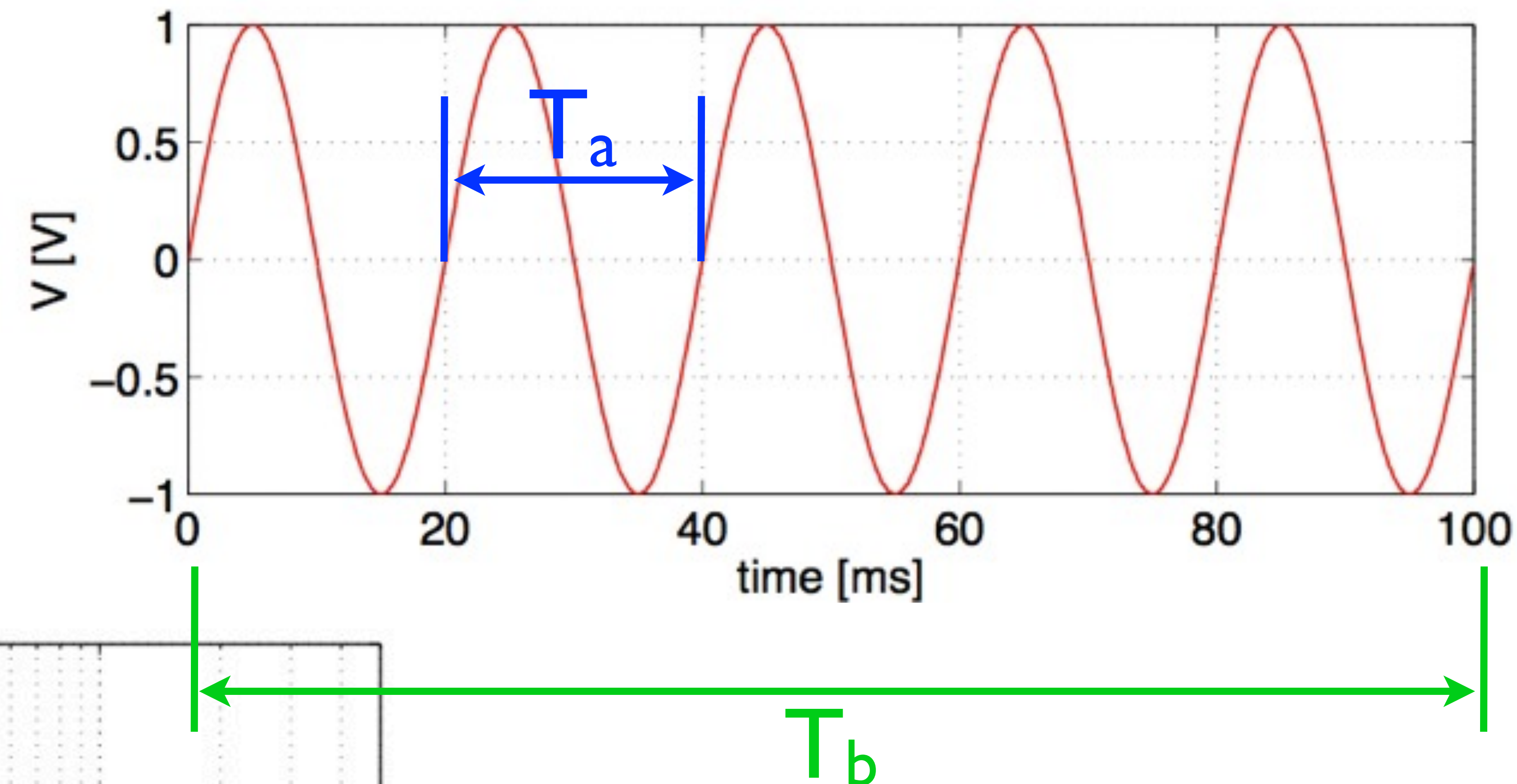


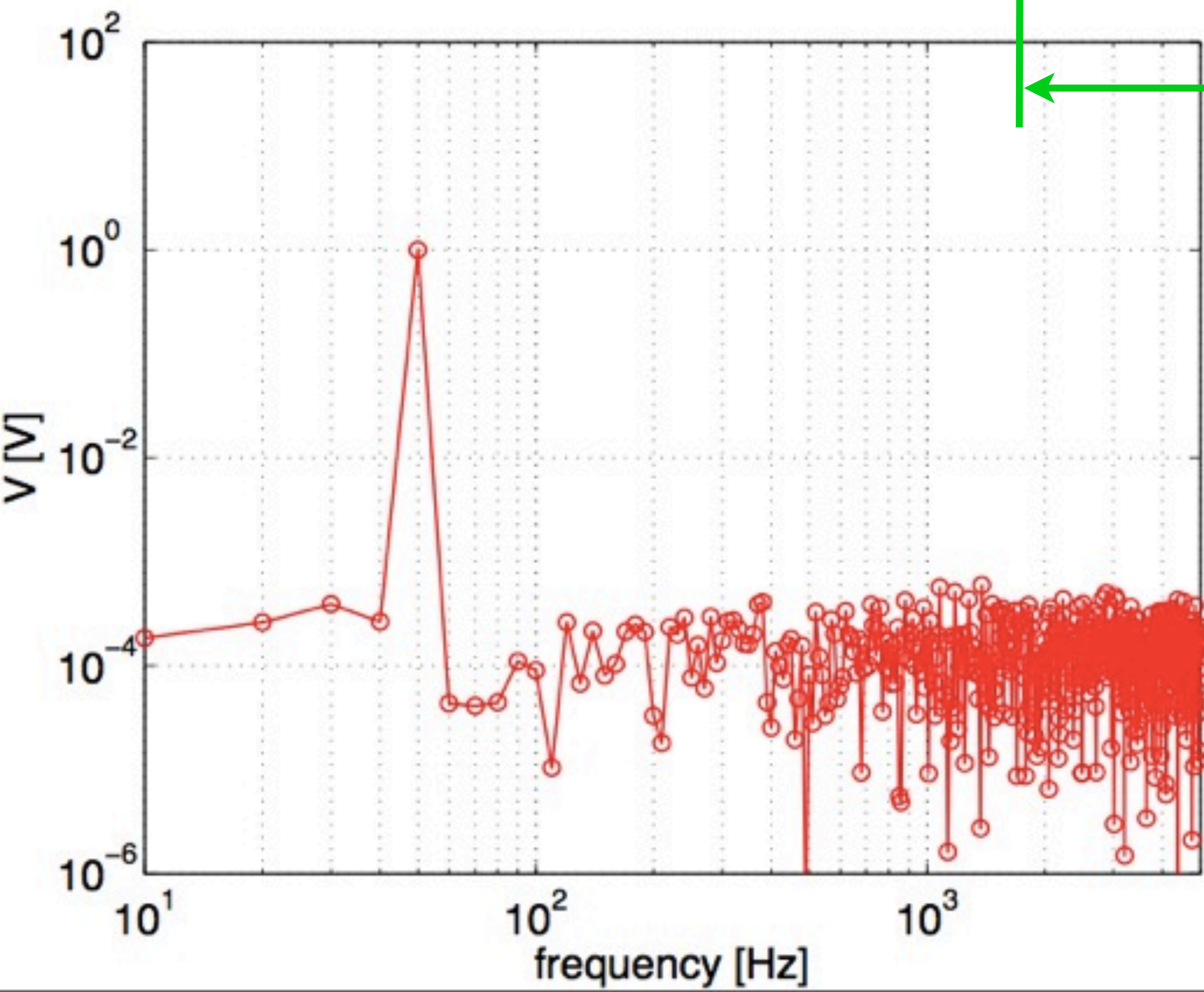
if I amplify I will get into saturation!

In this case, if you are not interested in the average value of the signal you can use AC input to cut it off



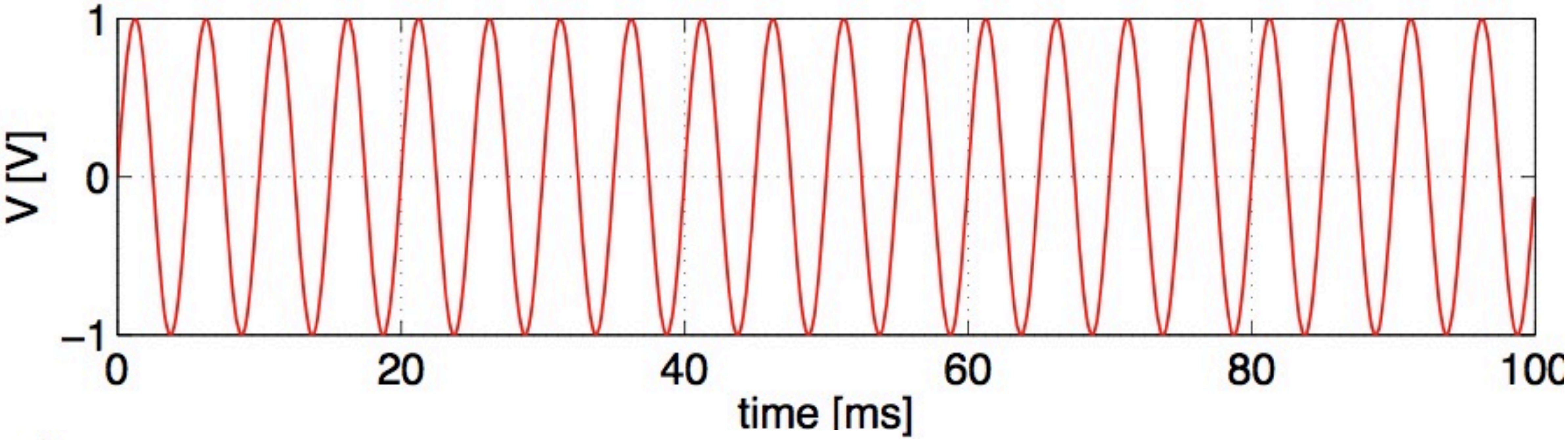
So far we considered only synchronous harmonics.

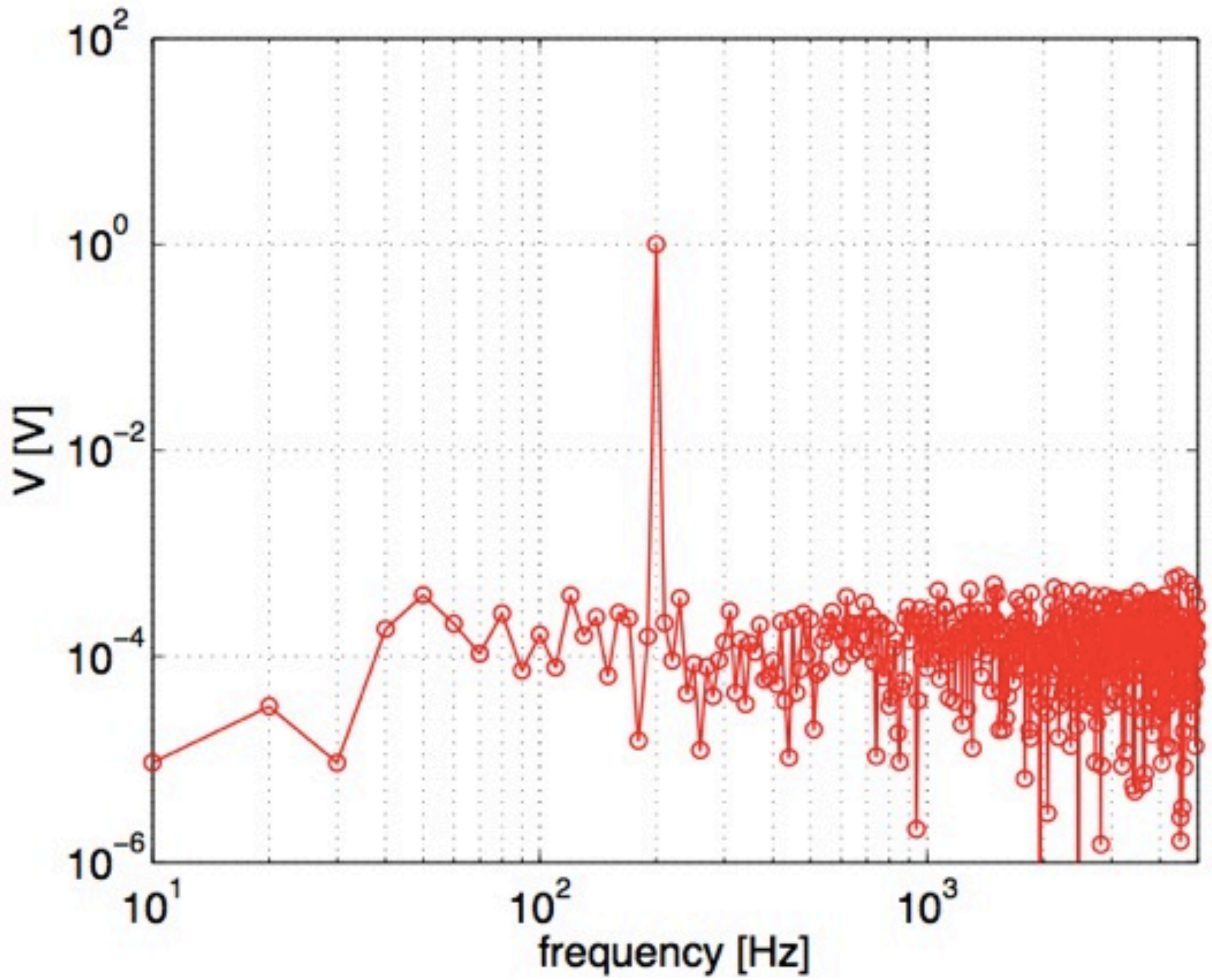




T_b/T_a is integer

So far we considered only synchronous harmonics.



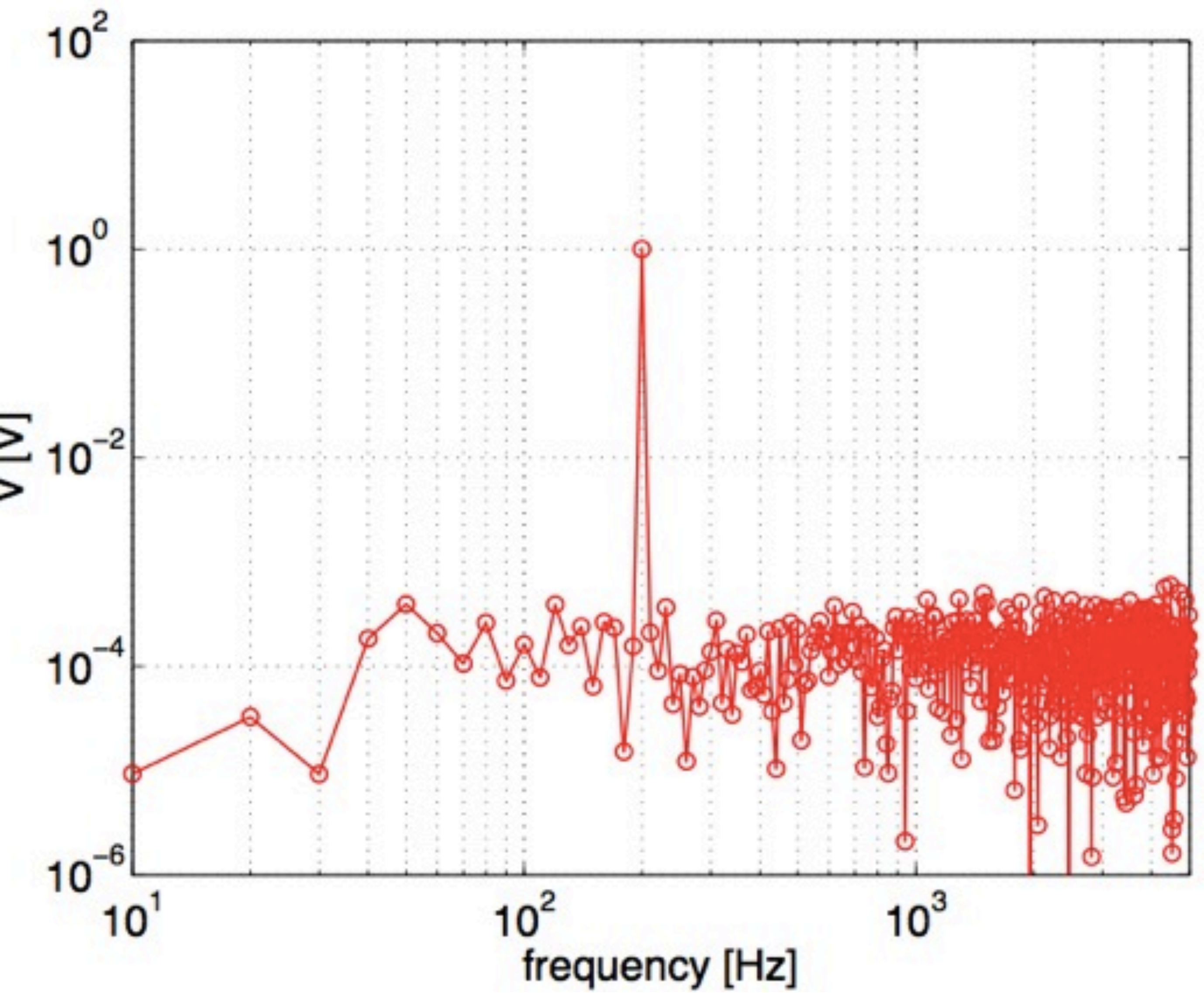


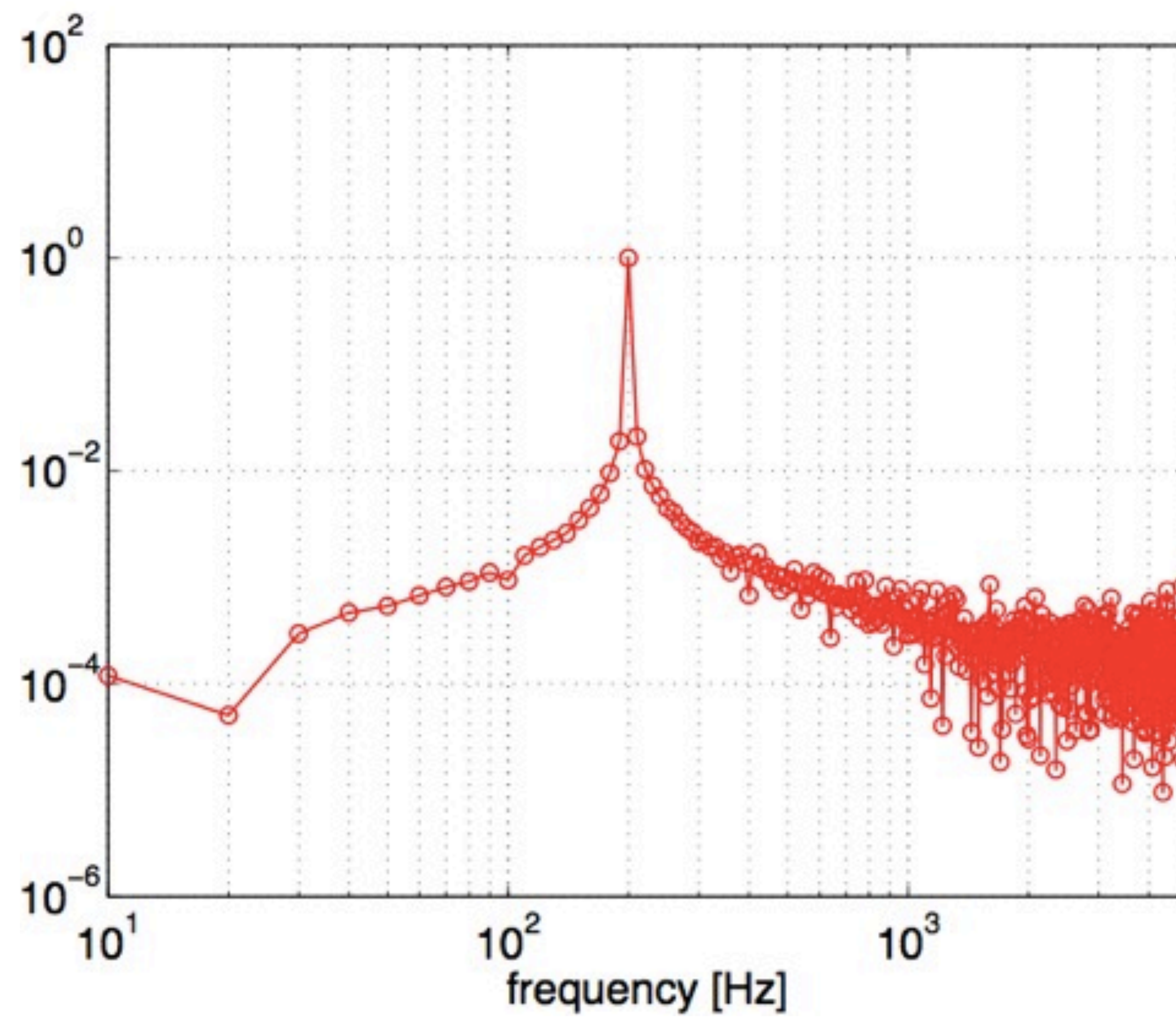
If the frequency is not synchronous it does not match any of the available frequencies in the spectrum

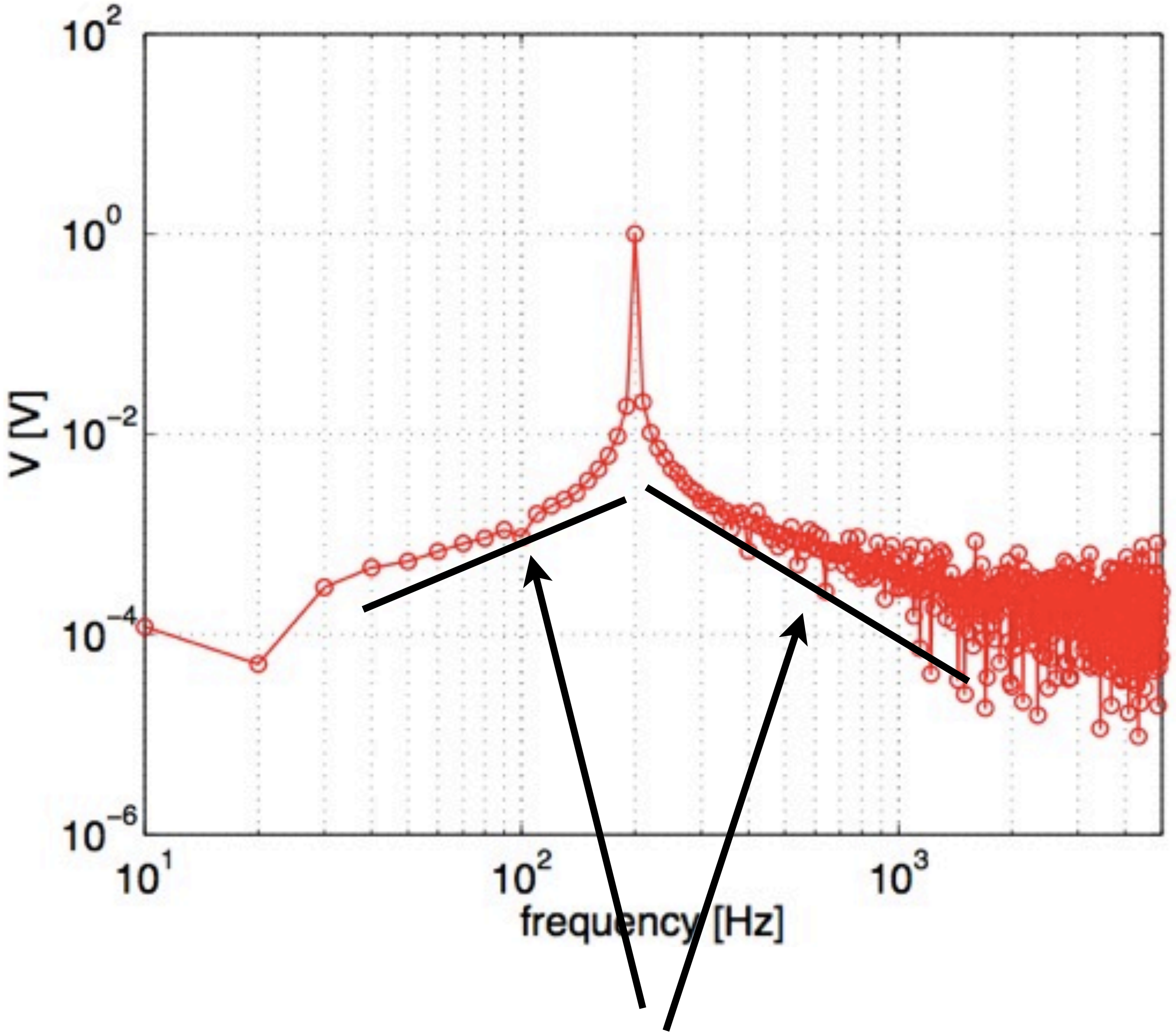
f=200 Hz

f=200.2 Hz

200< <210



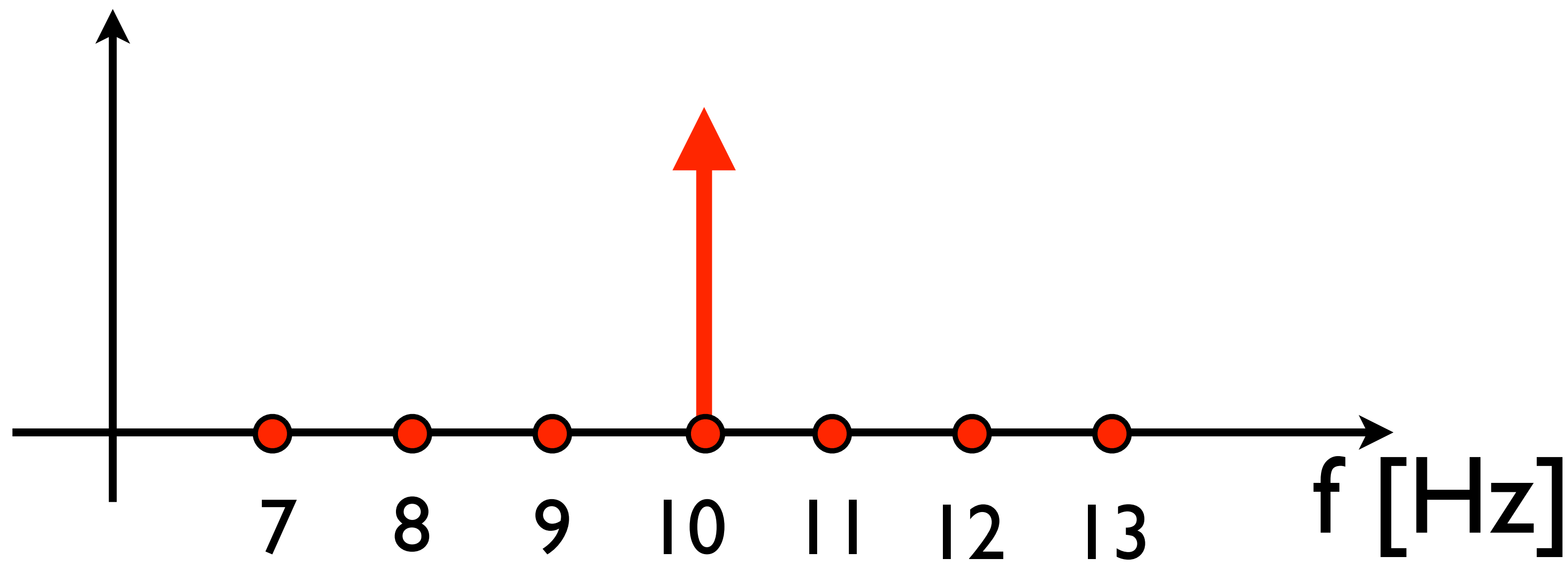




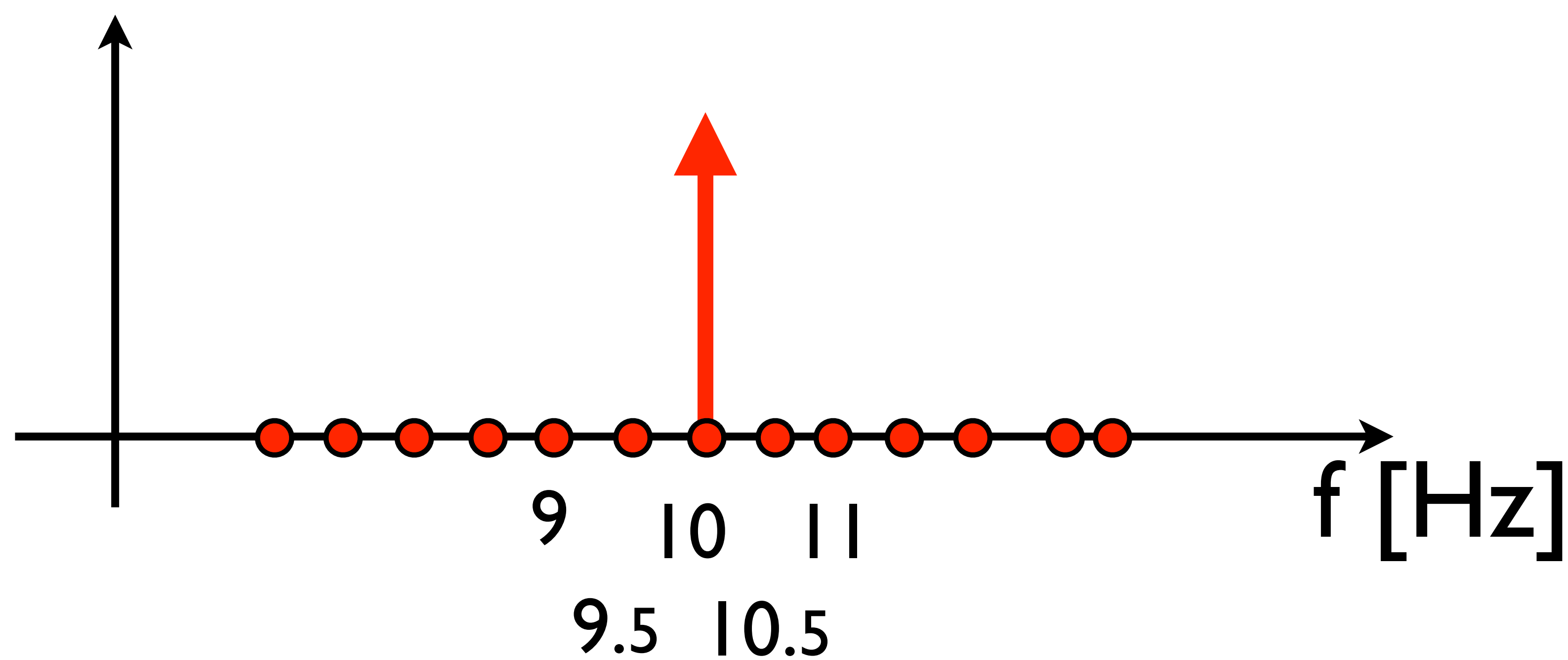
These components in the spectrum do NOT exist!
They are just artifacts.

In order to avoid this problem on the spectrum analyzer you must use proper WINDOW

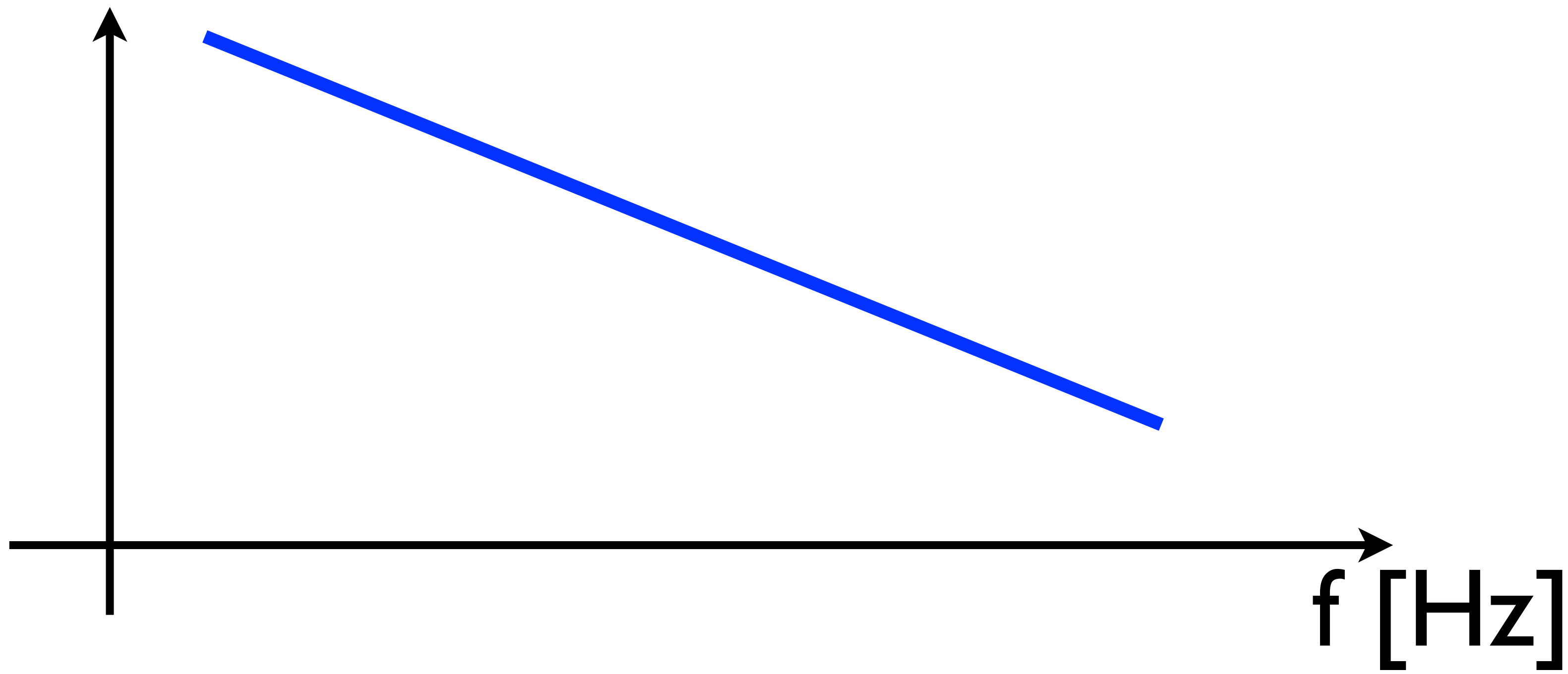
Some signal are “concentrated” in a single frequency



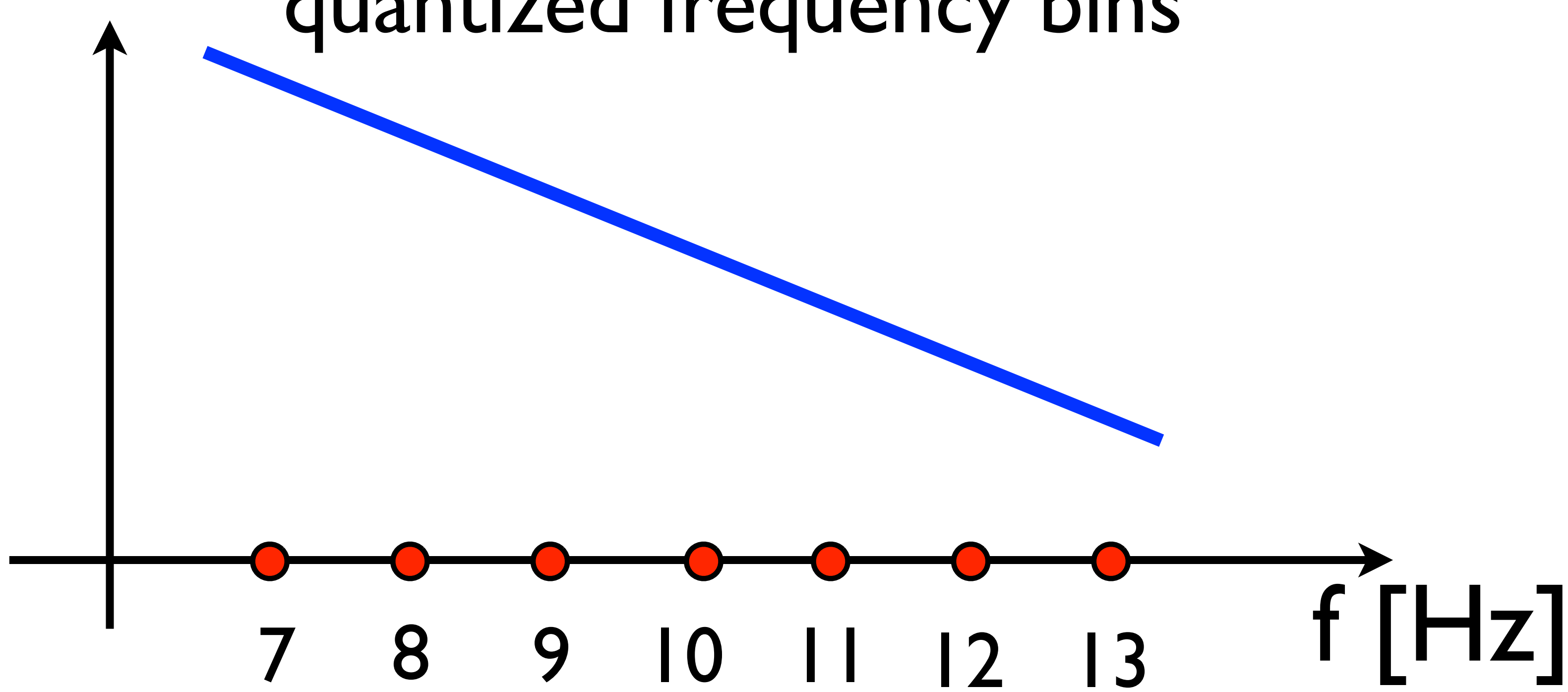
Even if we have better frequency resolution nothing changes

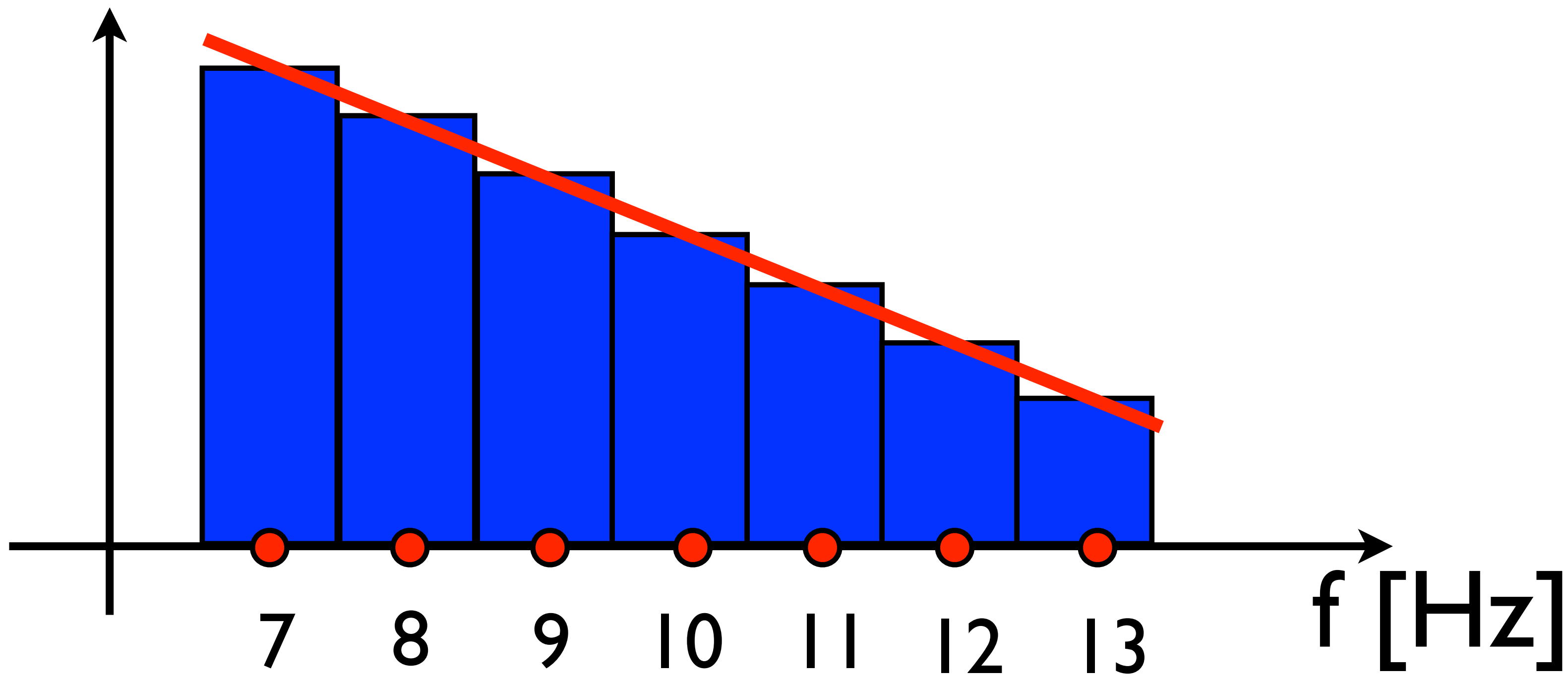


Other signals have a spectrum with continuous frequency components

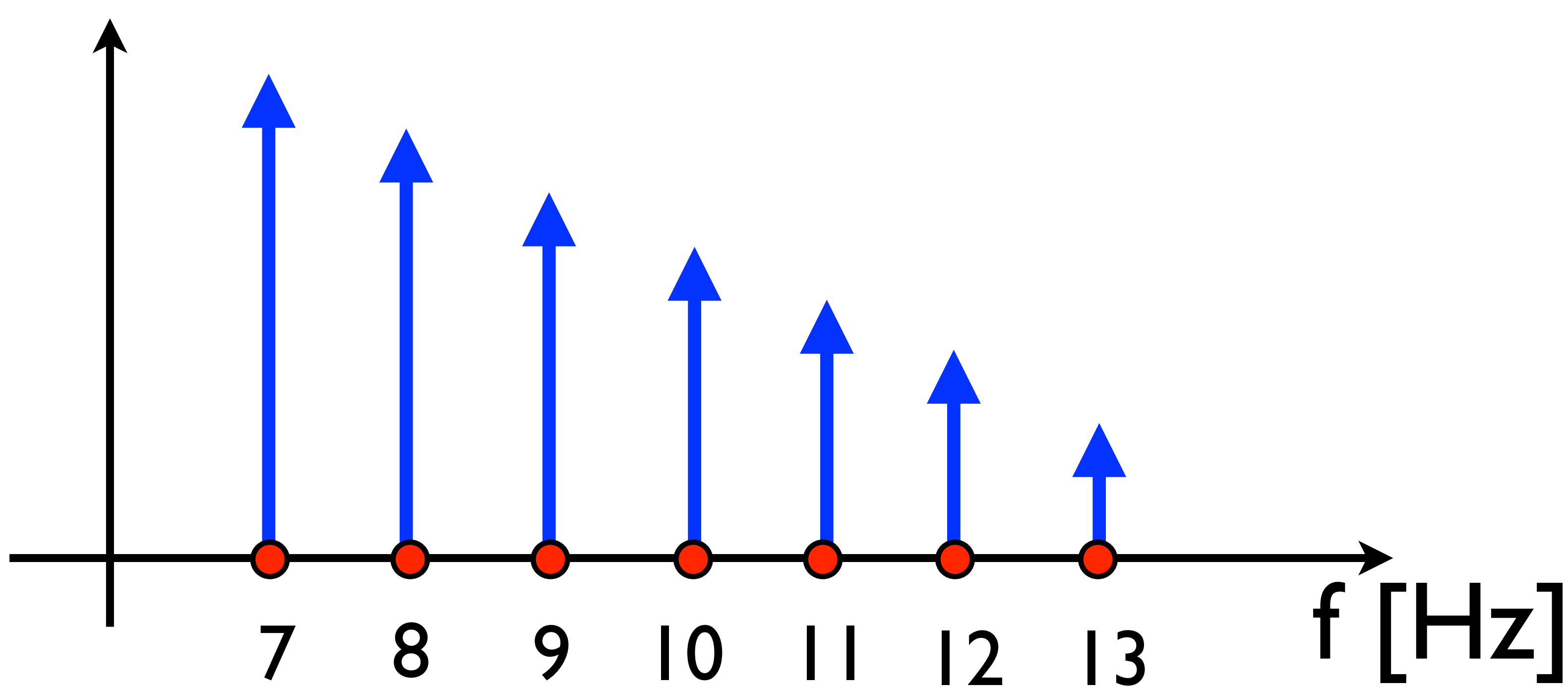


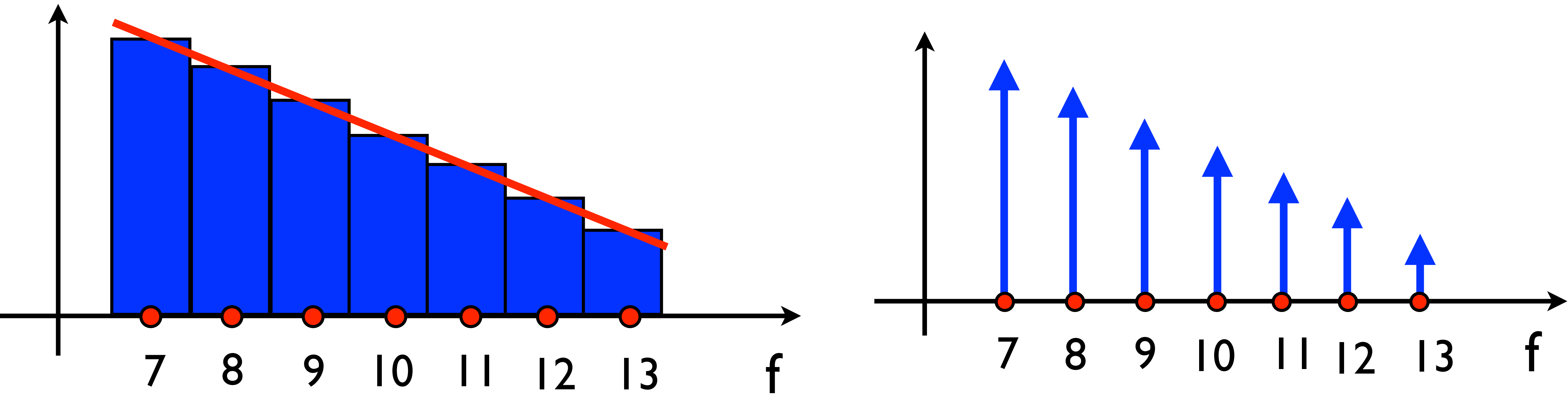
When you calculate the spectrum from the digitized data you have quantized frequency bins



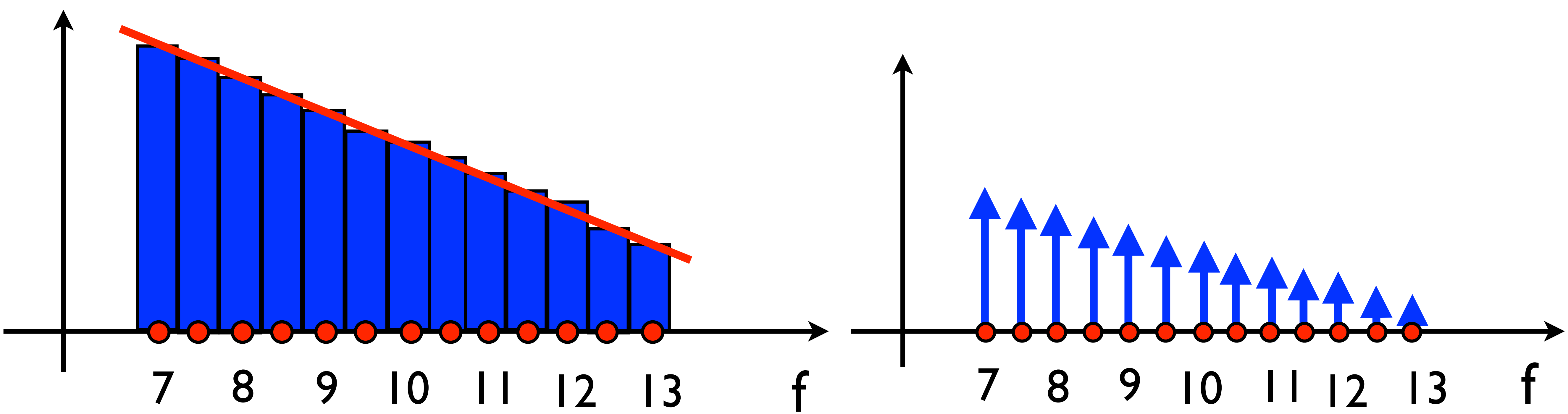


The computed spectrum will have discrete frequency lines, but each of them in fact represent a bin with a frequency width

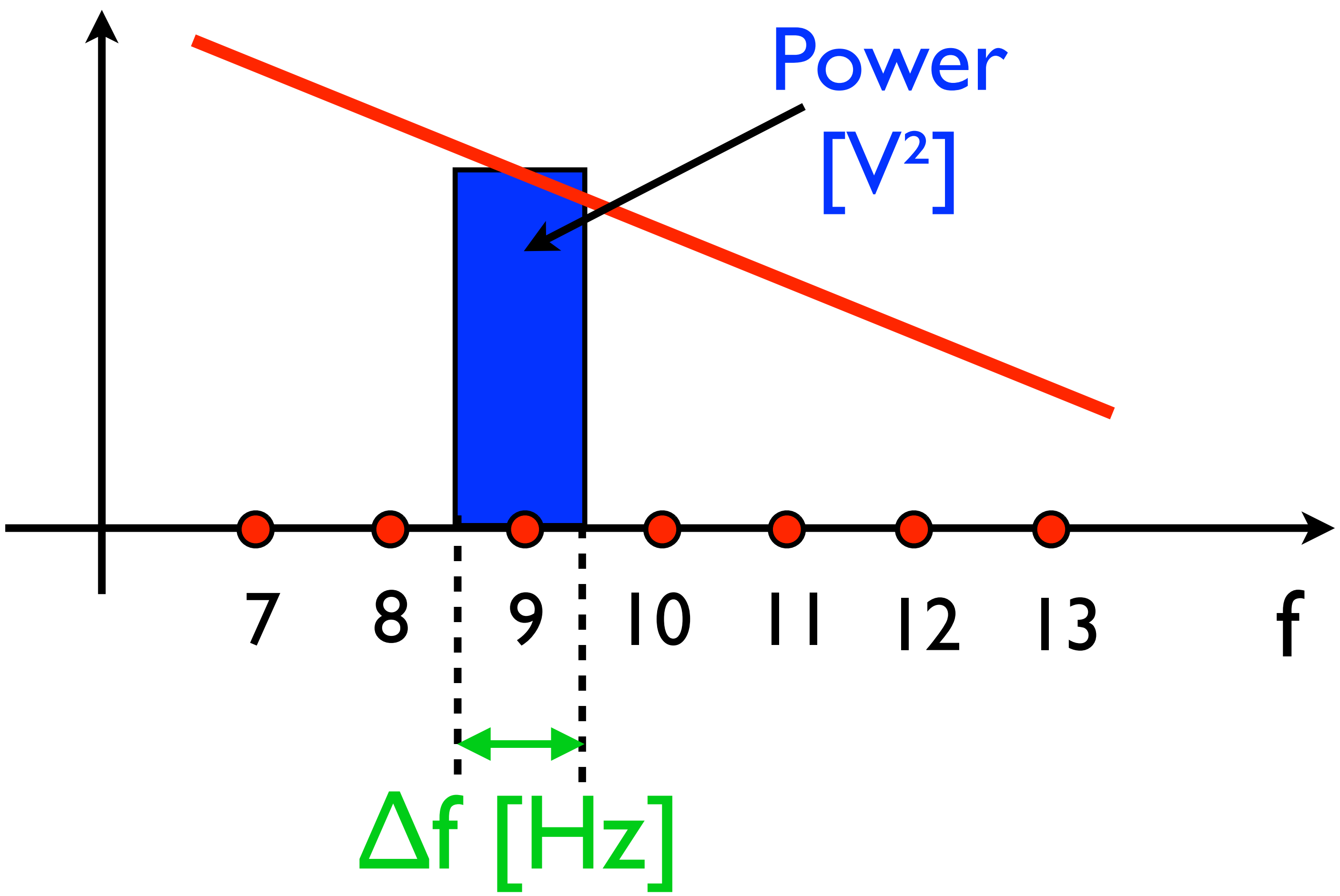




If you increase the frequency resolution you have a larger number of bins. Then, the area of each bin will be lower.



In this case you should set the spectrum analyzer to display PSD (power spectral density)



PSD= Power/Δf

= [V²] /[Hz]

More typically it is shown in [V]/√[Hz]

The PSD does NOT depend on the number of frequency bins!

The spectrum analyzer calculates it taking into account the width of the bins

WAVEFORM GENERATORS

Analog

- Sinewave generators (based on RC or LC oscillators)

-Function generators

Digital

- Arbitrary waveform generators

Arbitrary waveform generators