University of
Nottingham

Electromechanical devices MM2EMD

Lecture 8 – Analog-to-digital and digitial-to analog converters.

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Outline of the lecture

- **No recap of last lecture :)**
- Recap of digital signals
- Converting between digital and analog
    - Digital to analog converters
    - Analog to digital converters
    - Flash converters for high speed video
- Summary

Outline of the lecture

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- **Recap of digital signals**
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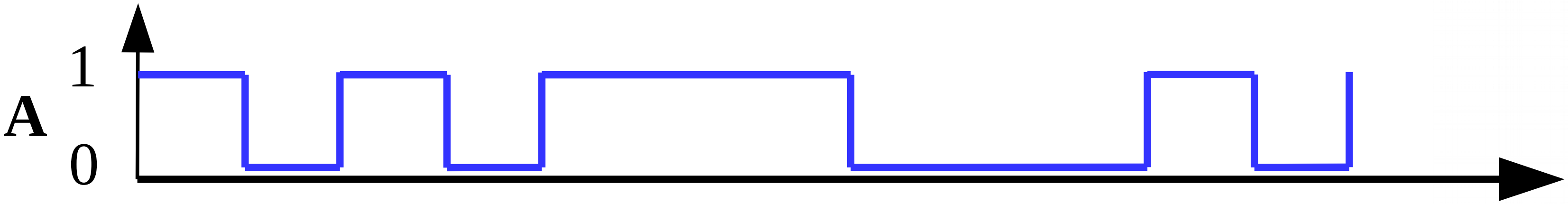
Digital signals recap

•In lectures 1-3 I taught you about digital electronic.

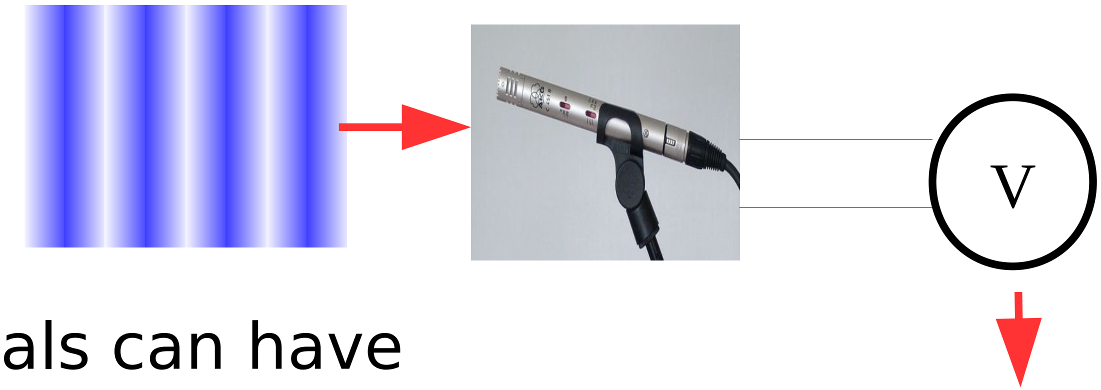
•In digital electronics signals can either be ***on*** (1) or ***off*** (0) and all information is transmitted and stored using binary numbers.



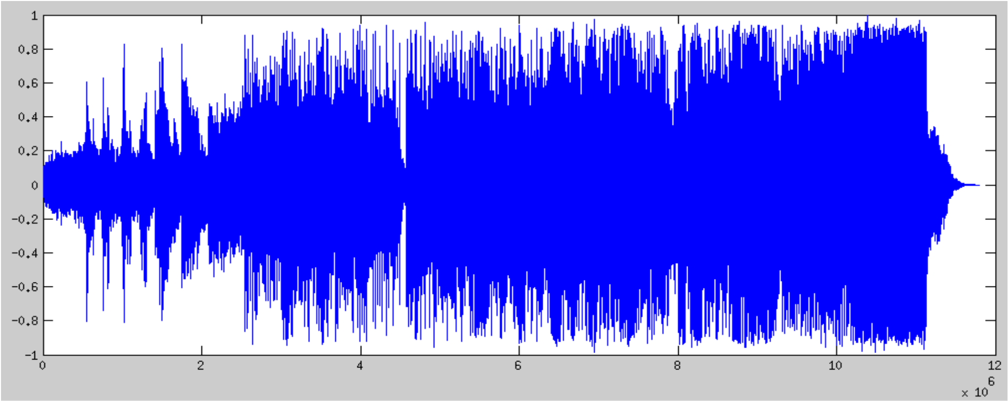
•In L4 we learnt that the **real world** is not binary......

Analog signals recap

•Your guitar produces compression waves in the air that a microphone can pick up.

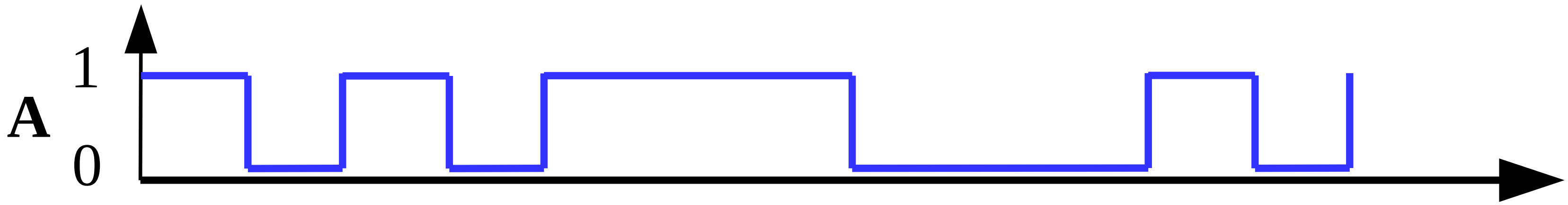


•These signals can have any value and are called **analog signals**.

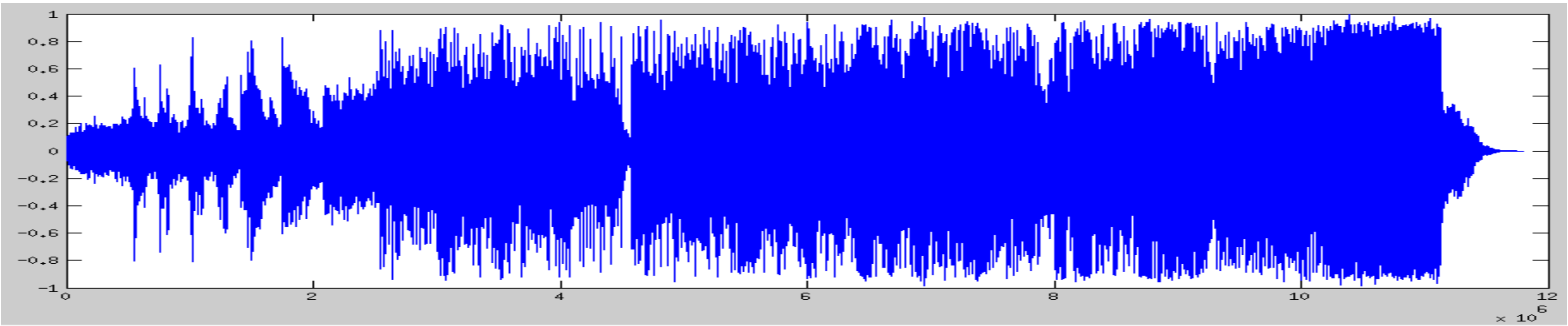


Digital v.s. analog signals

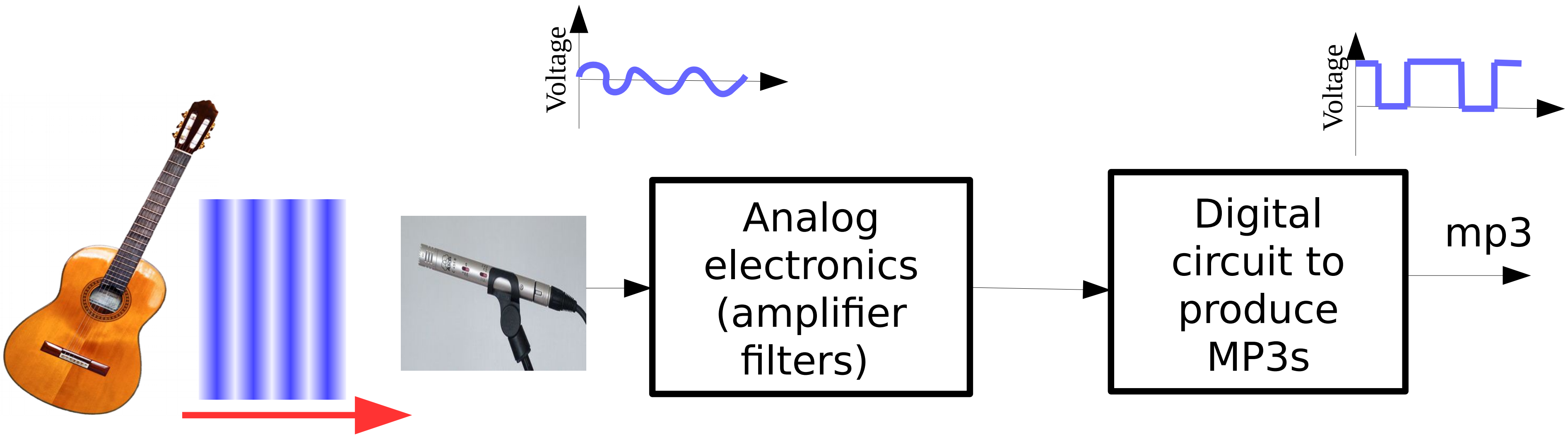
•A digital signal



•An analog signal

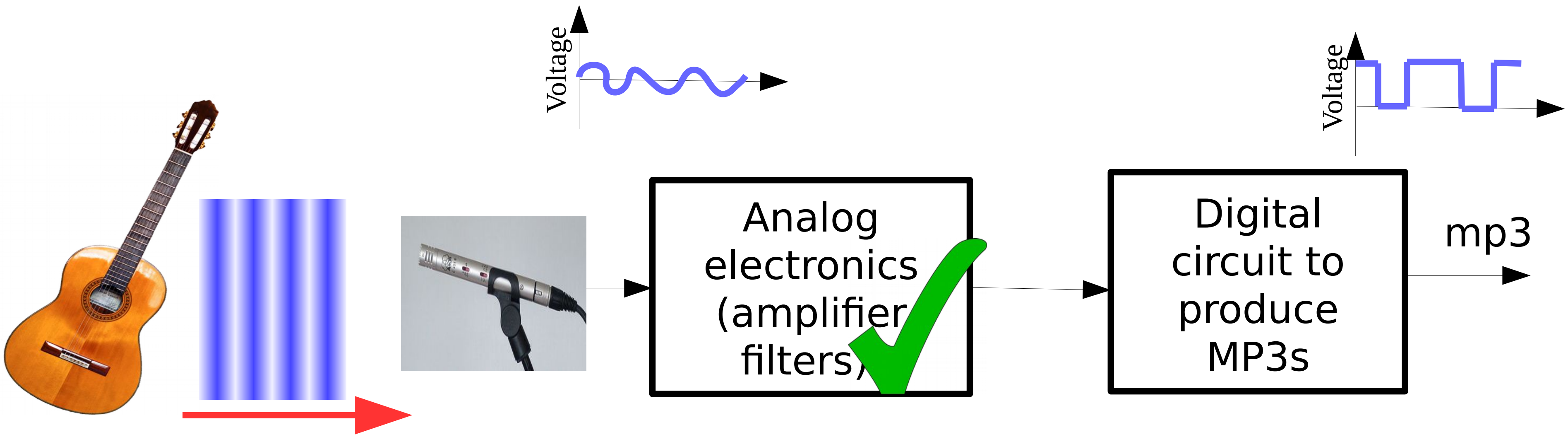


The MP3 recorder example



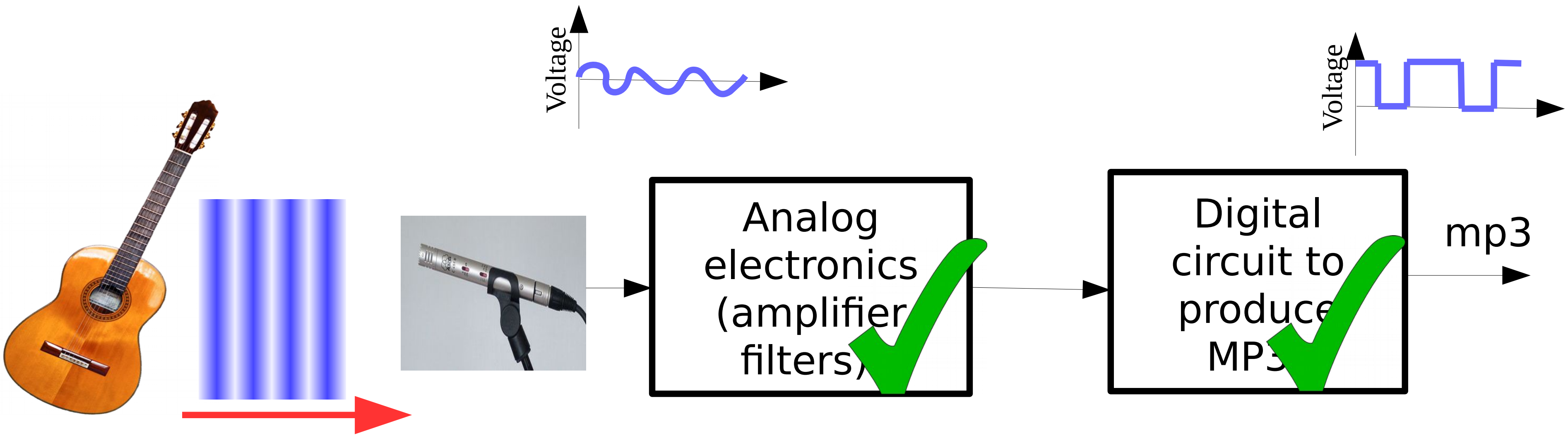
•An MP3 recorder as an example of a modern analog and digital electronics system.

The MP3 recorder example



•You now know all about digital electronics (well quite a lot anyway)

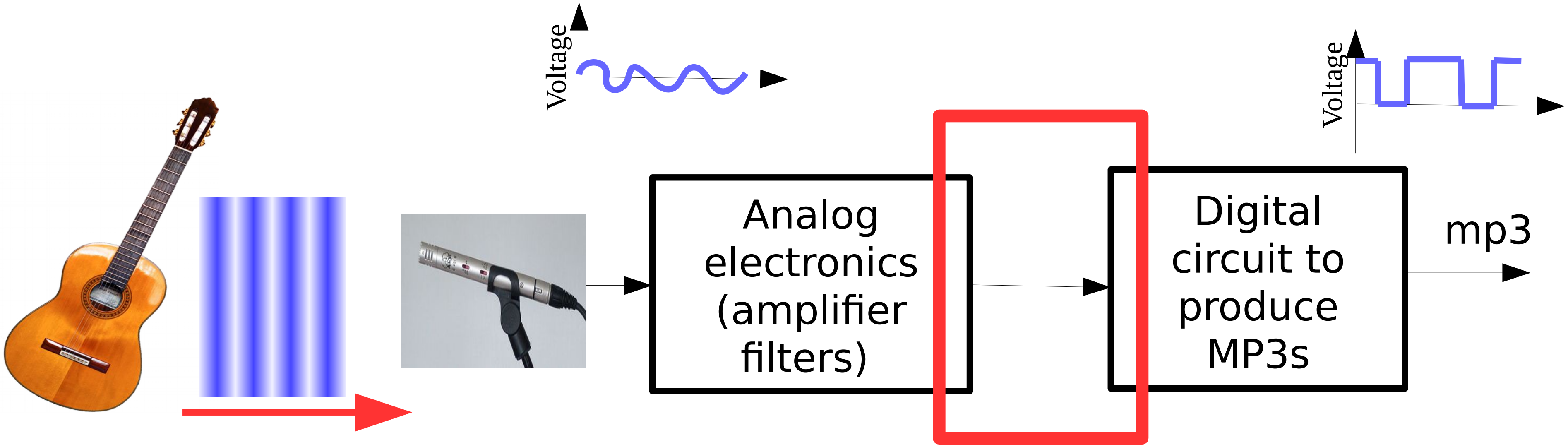
The MP3 recorder example



•You now know all about digital electronics

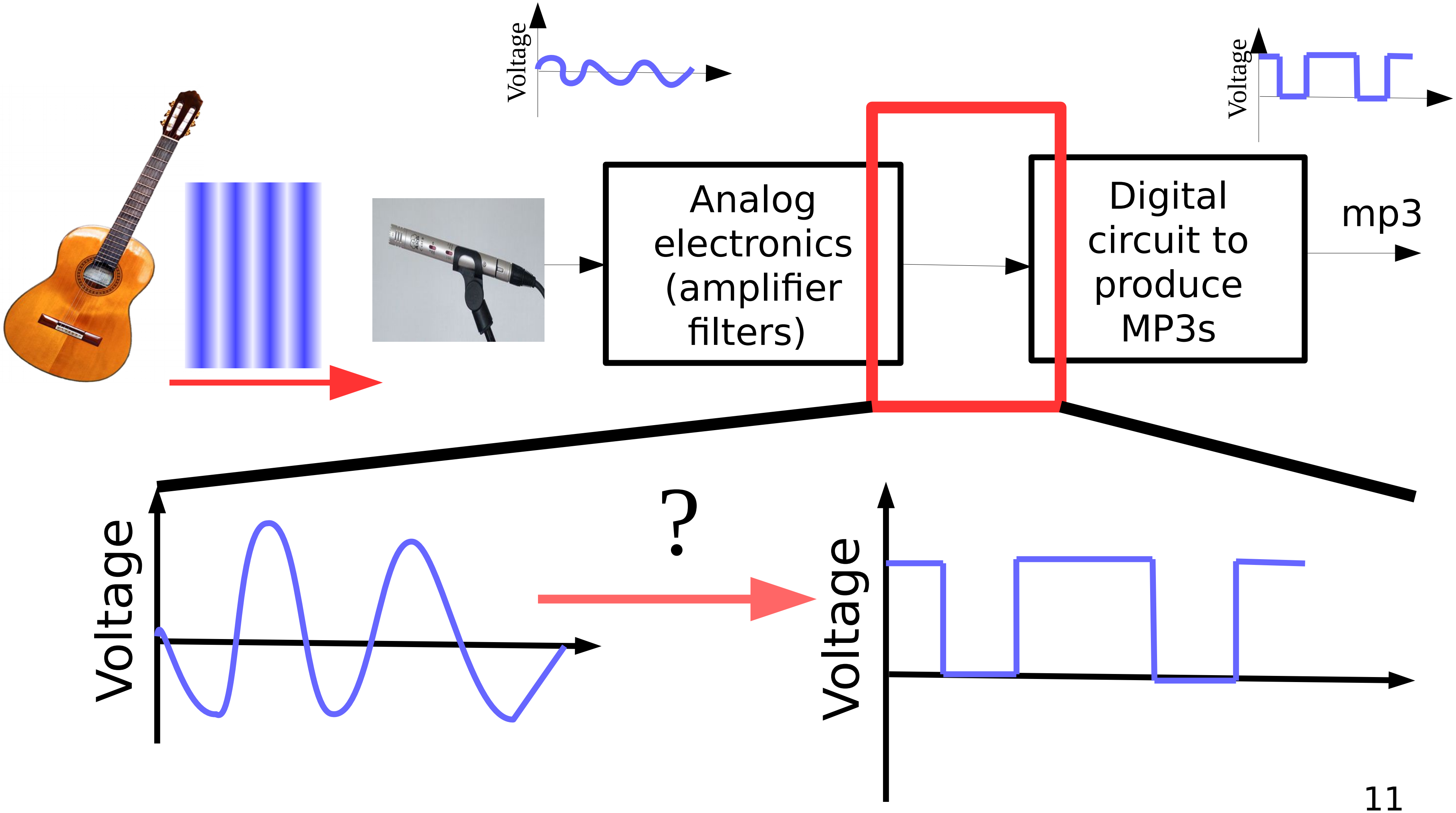
•You also know all about analog electronics. (well quite a lot anyway)

The analog/digital divide

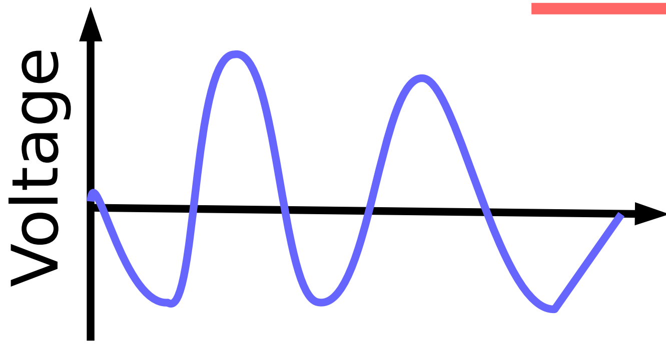


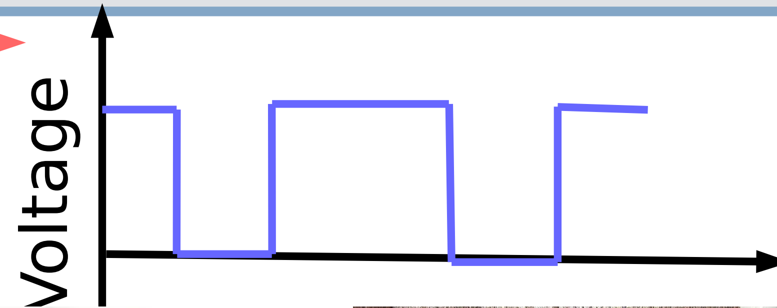
•But what you don't know yet is how to convert analog signals in to binary or digital codes.

Converting analog signals into binary signals.



Analog to digital converter





Andre Karwath

Xell

•Every time you want a computer to interact with the real word you will need a analog to digital converter.

Outline of the lecture

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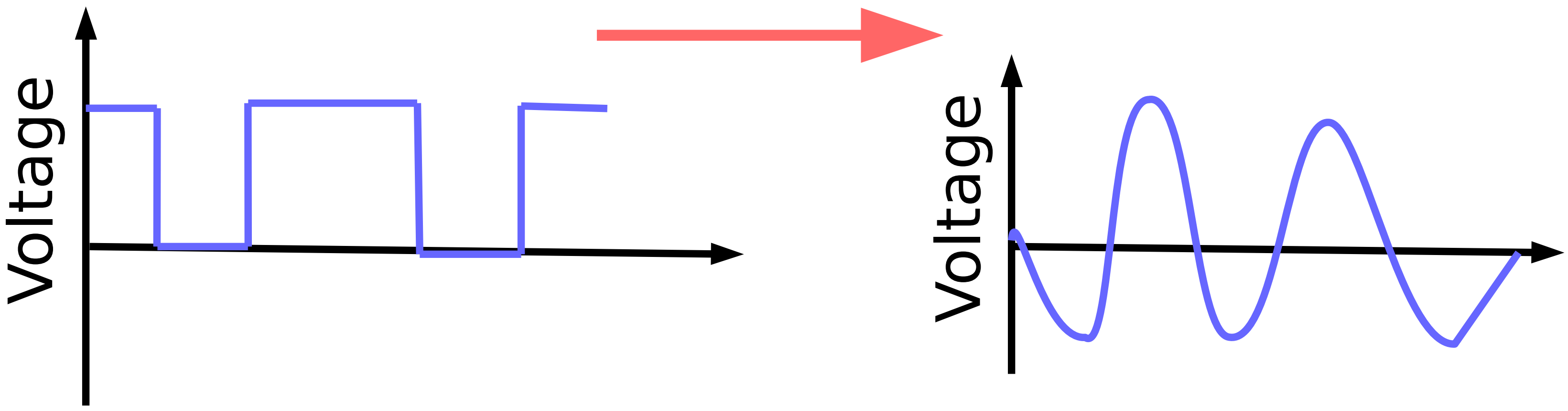
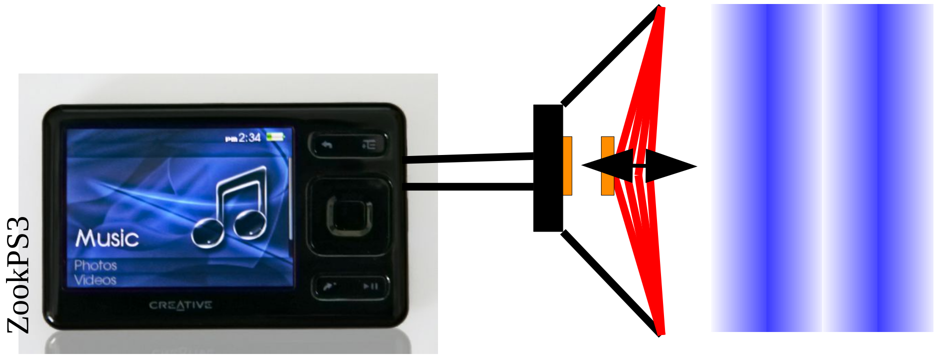
Digital to analog converter





Digital to analog converter

- Before we look at something complex like music, let's look at just converting on number.

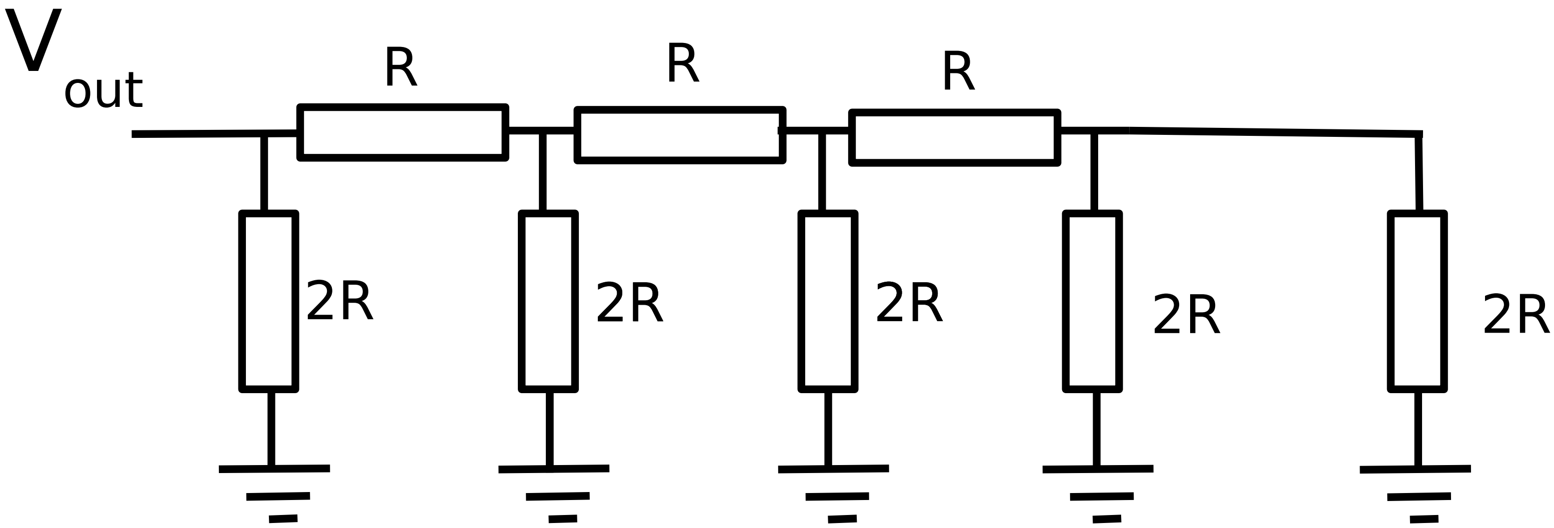
10000 → 0.5 V

01000 → 0.25 V

- And this is the circuit we use to do this convert one binary number to a analog number....

The R2R ladder

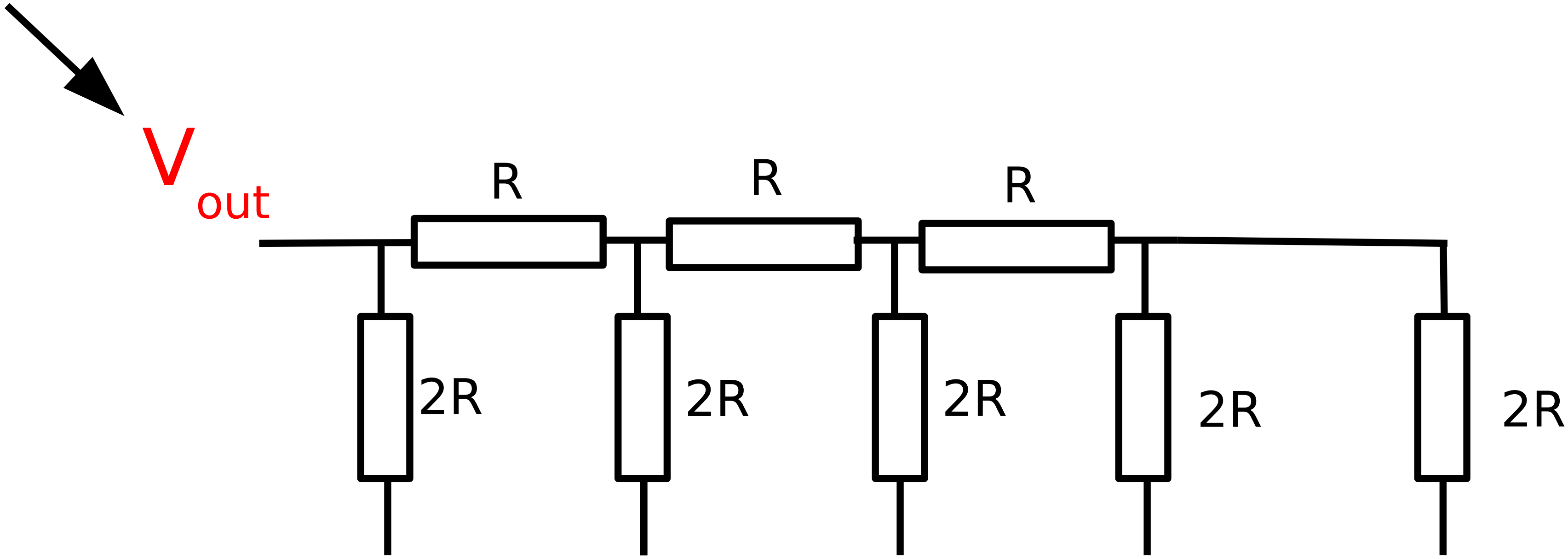
- This is THE circuit used to convert all digital signals to analog signals.



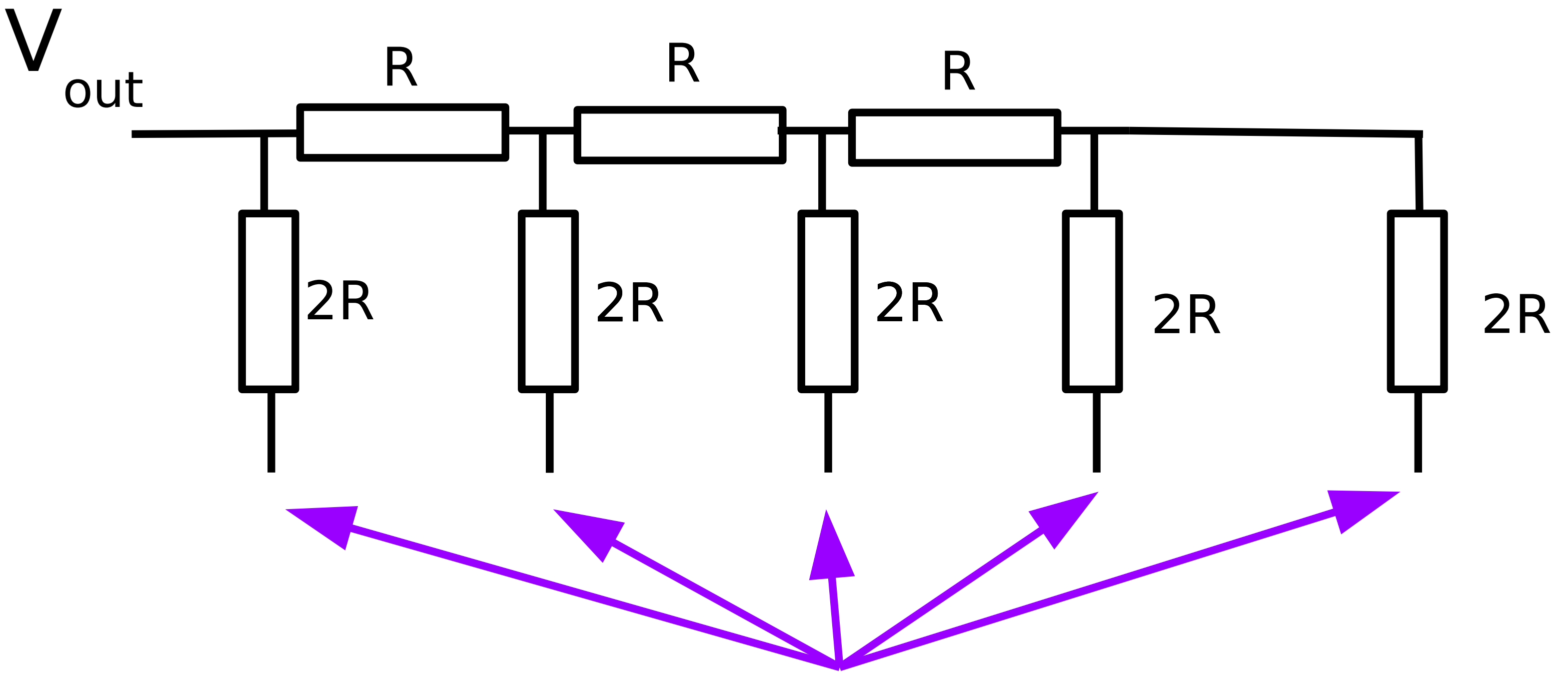
- It is also very elegant

The R2R ladder

•This is the analog output of the circuit.

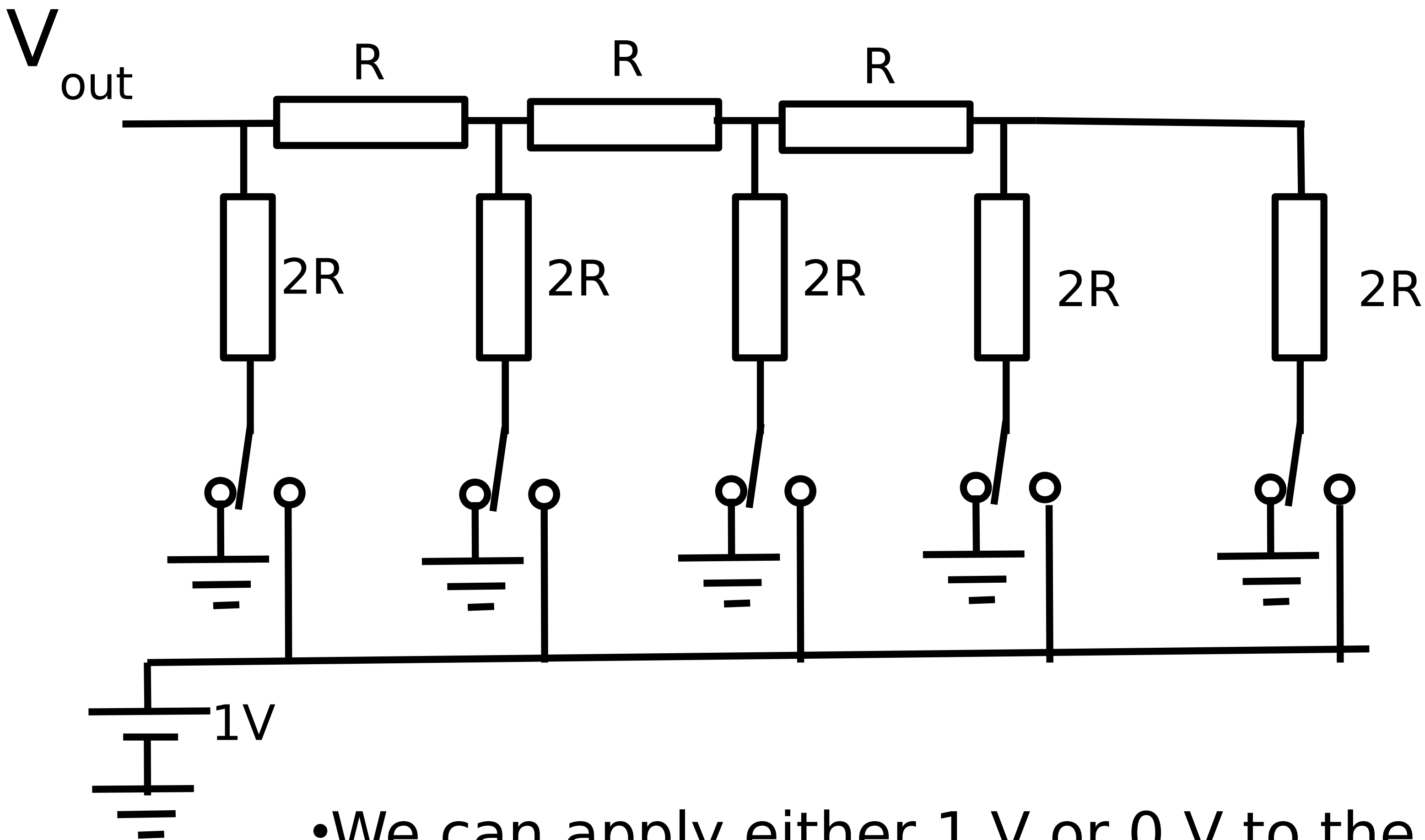


The R2R ladder



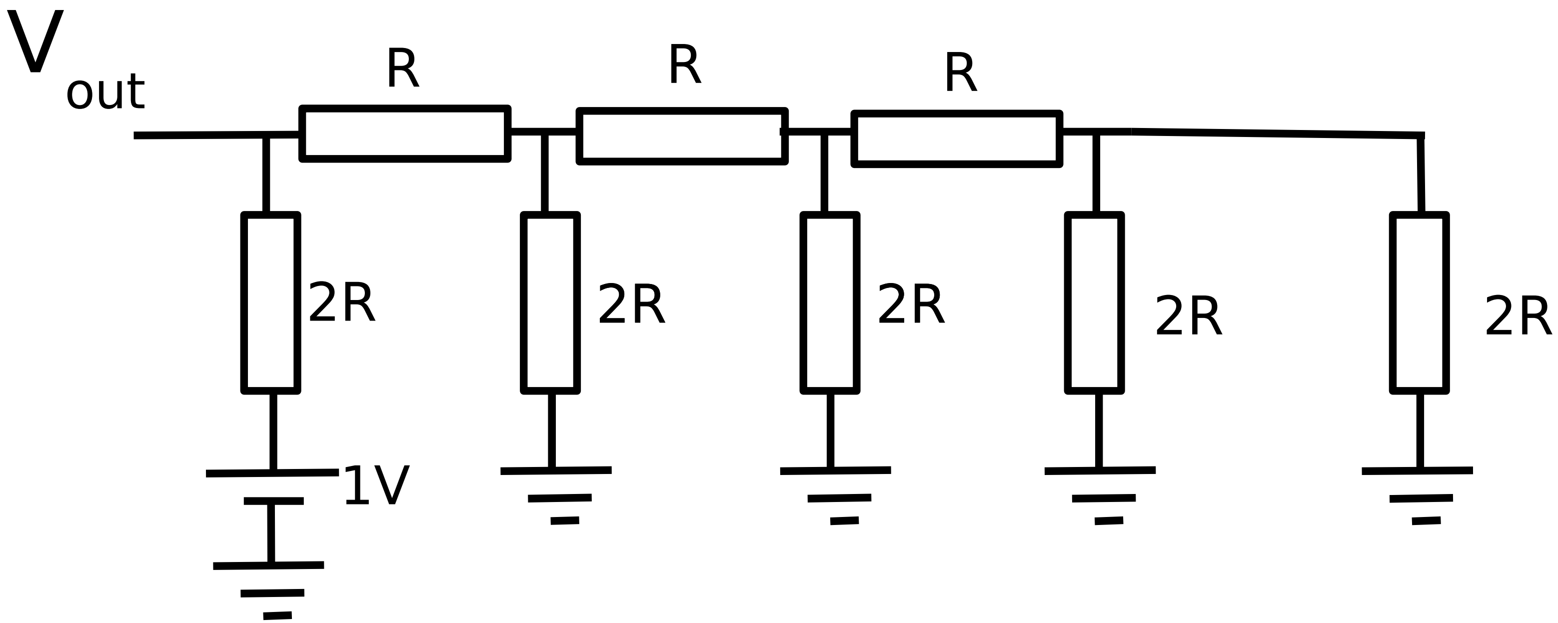
These are the digital inputs to the circuit.

The R2R ladder



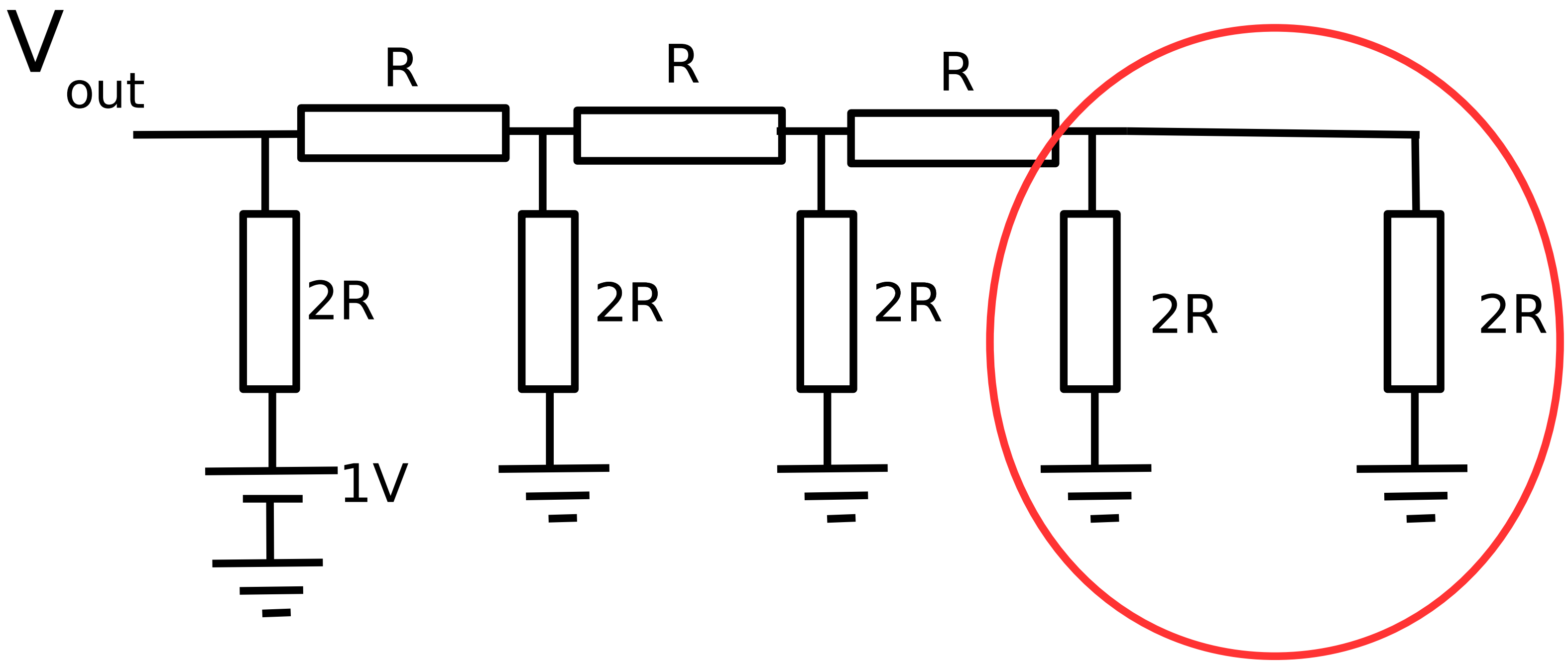
•We can apply either 1 V or 0 V to the inputs.
•This would represent 00000

Let's look at pin 1



- Let's apply 1V to the first input and see what output we get at V_{out}.
- This would represent the binary number 10000
- To do this we need to analyze the circuit.

Analyze the last two resistors

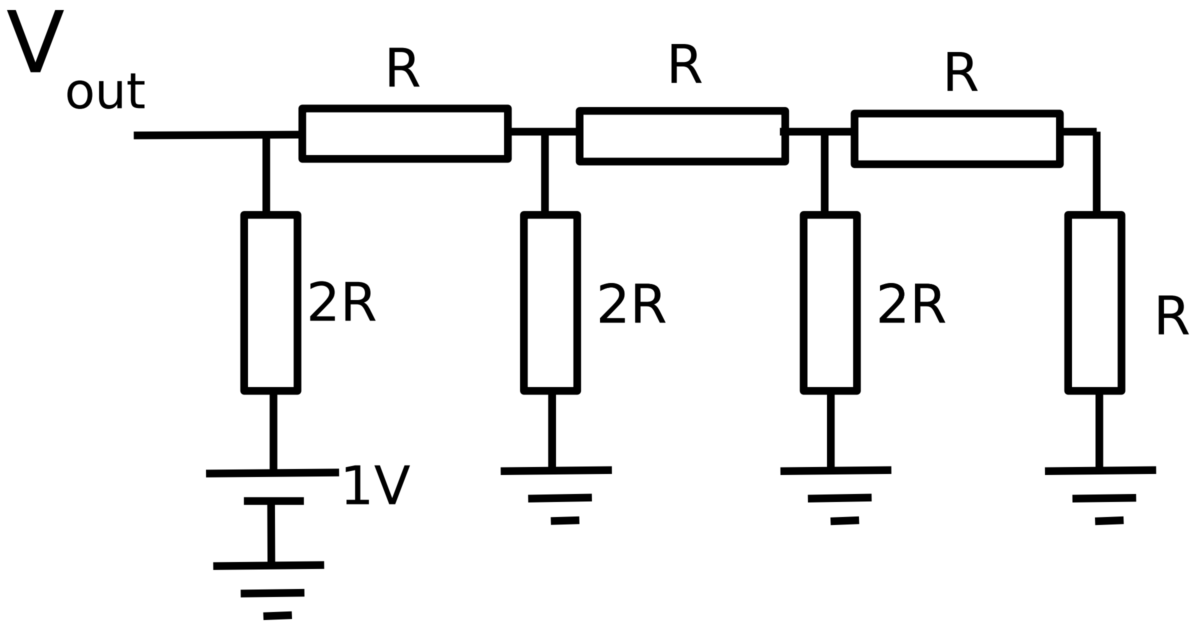


•They are in parallel so...

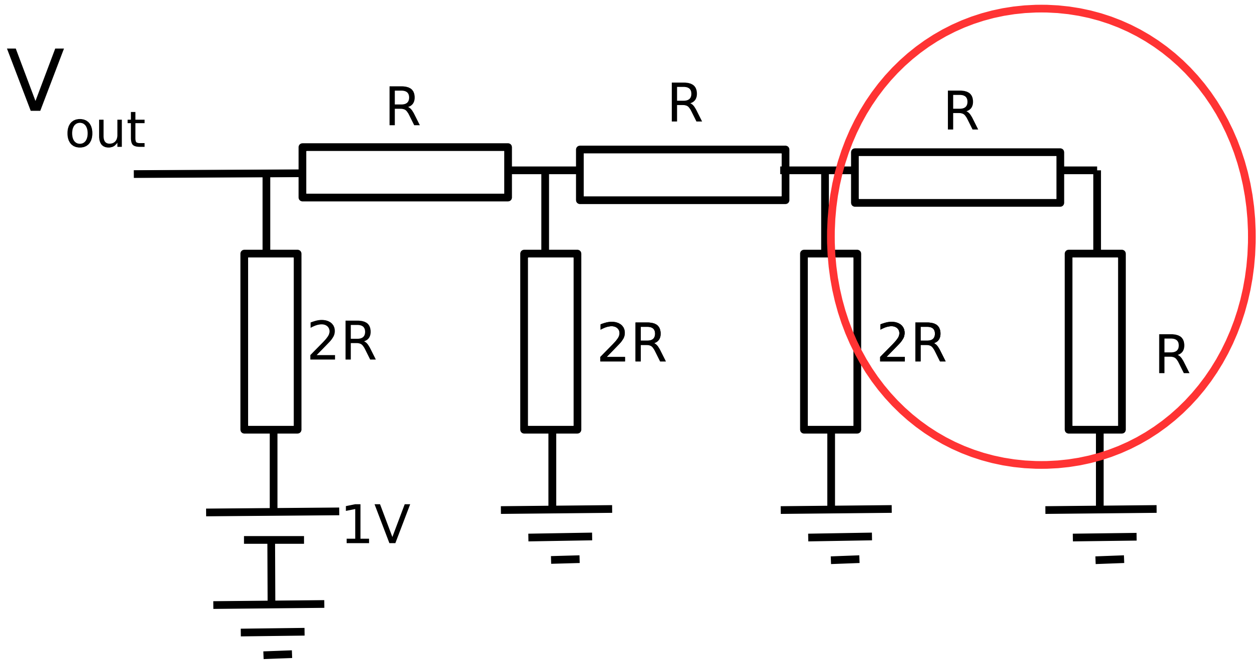
$$\frac{1}{R_{new}} = \frac{1}{2R} + \frac{1}{2R}$$

$$R_{new} = R$$

We can represent them using one resistor with value R

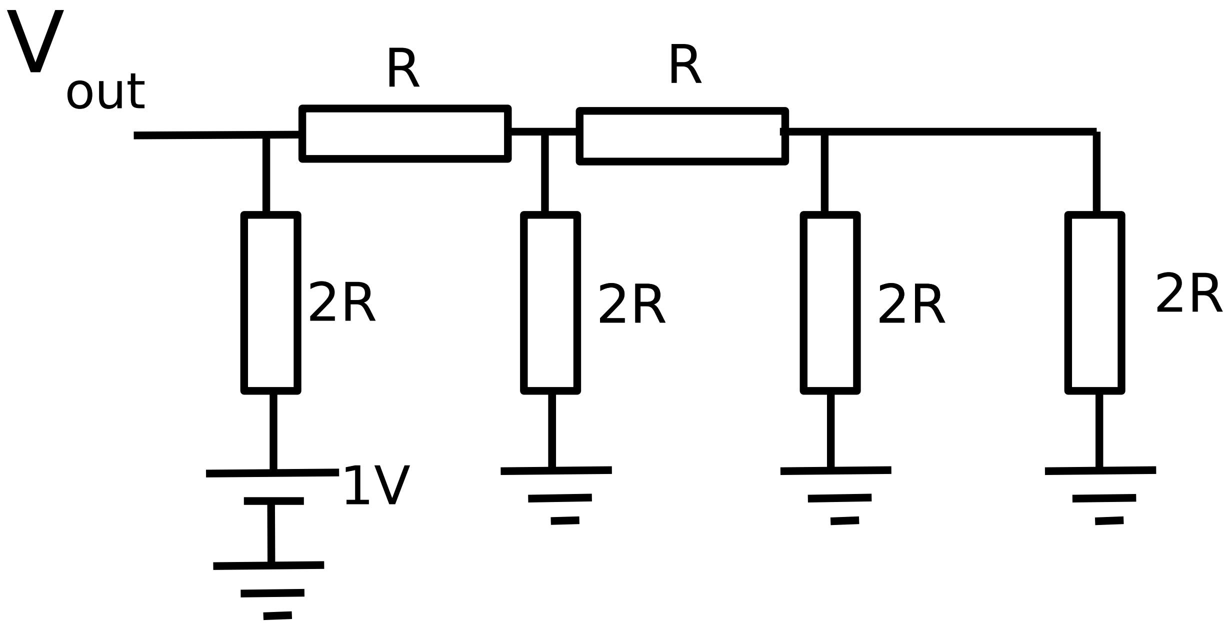


Now look at these two resistors on the end.

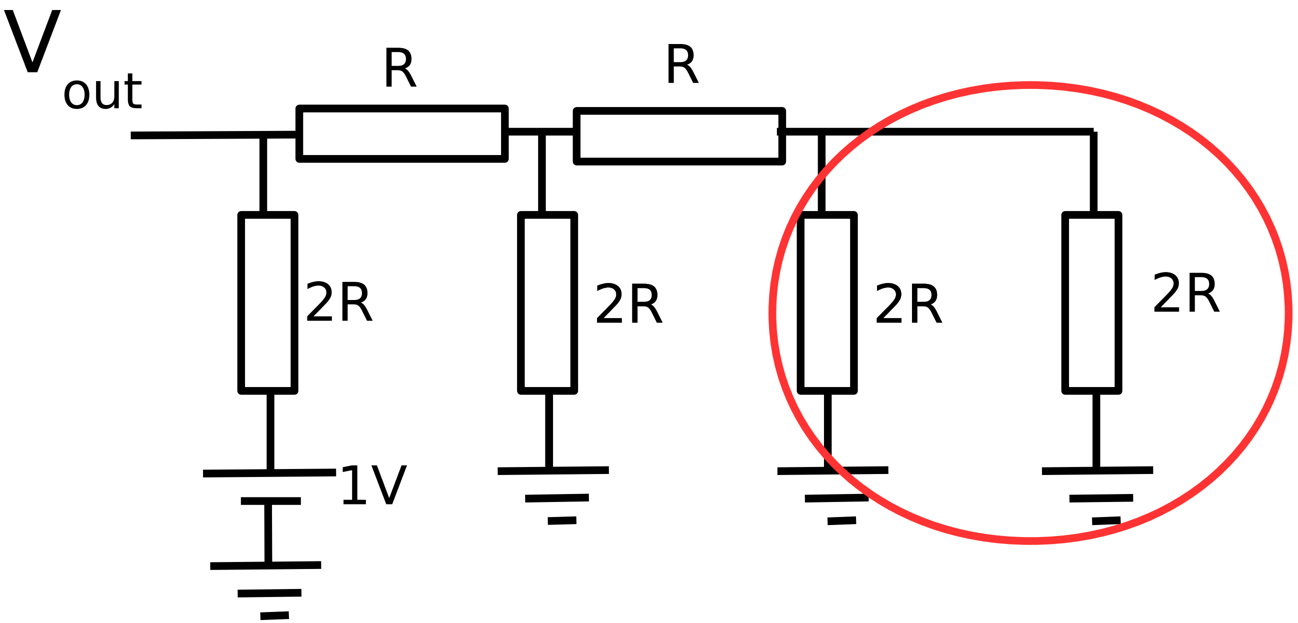


- We can turn them into one resistor with value 2R

Giving...



Another two parallel resistors...

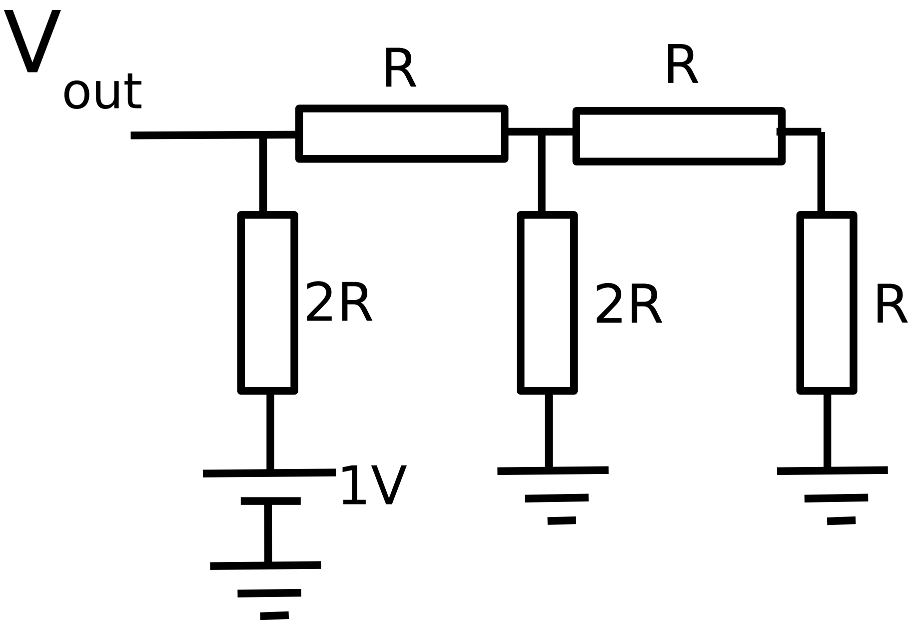


•Now let's turn these two parallel resistors into one resistor.

$$\frac{1}{R_{\text{new}}}=\frac{1}{2R}+\frac{1}{2R}$$

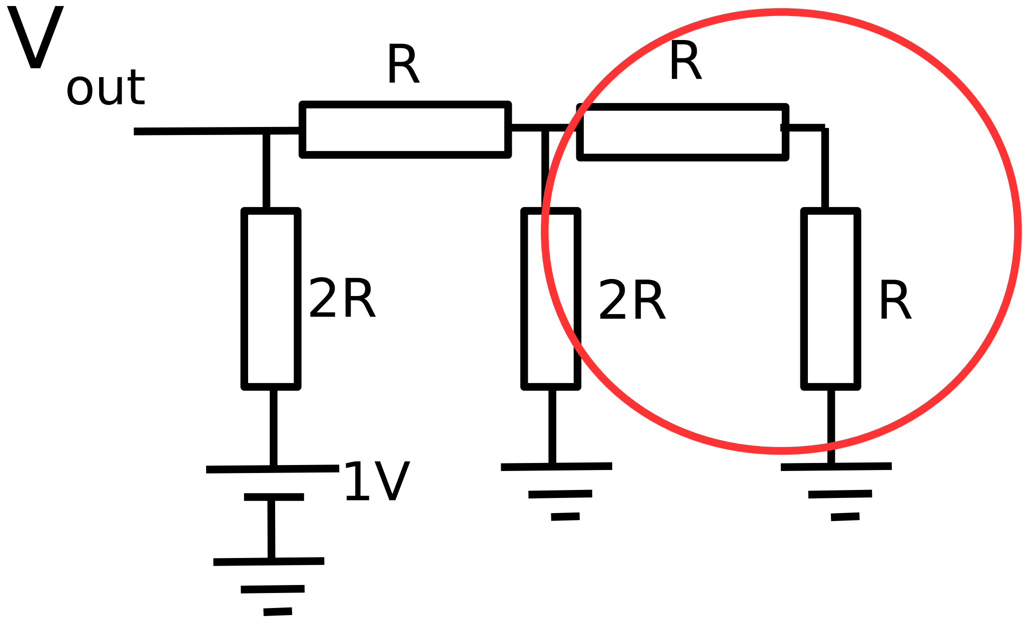
$$R_{\text{new}}=R$$

Gives...



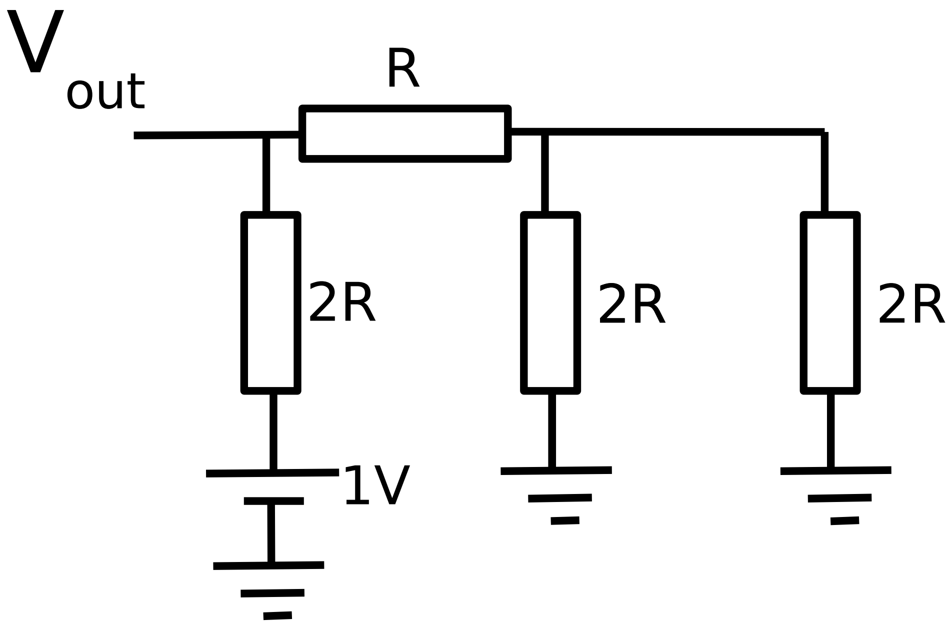
- Which can be converted into one resistor....

Two resistors in series..

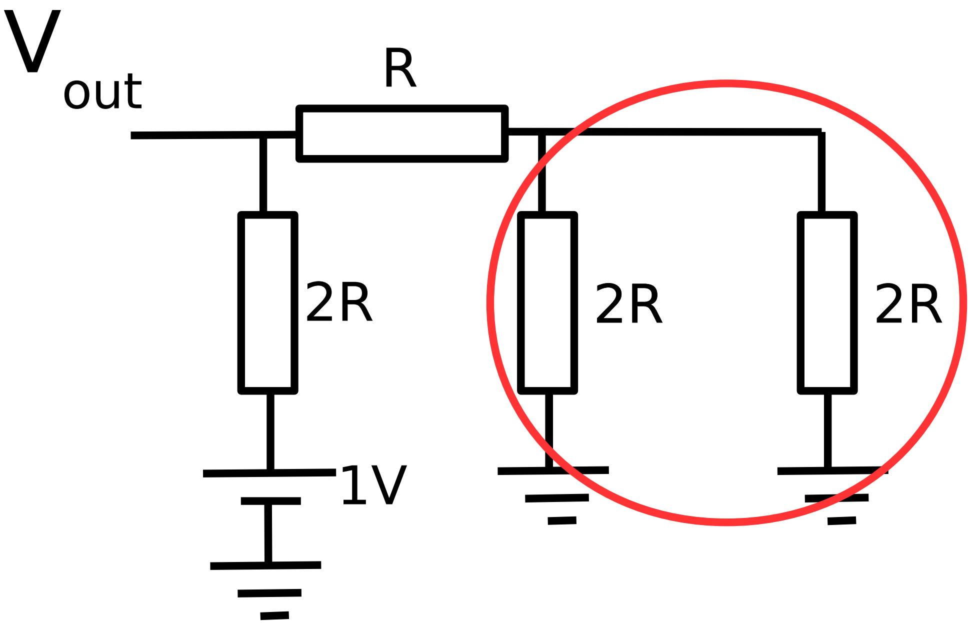


•Which can be converted into one resistor....

What voltage will we get if we put



Another two resistors in parallel

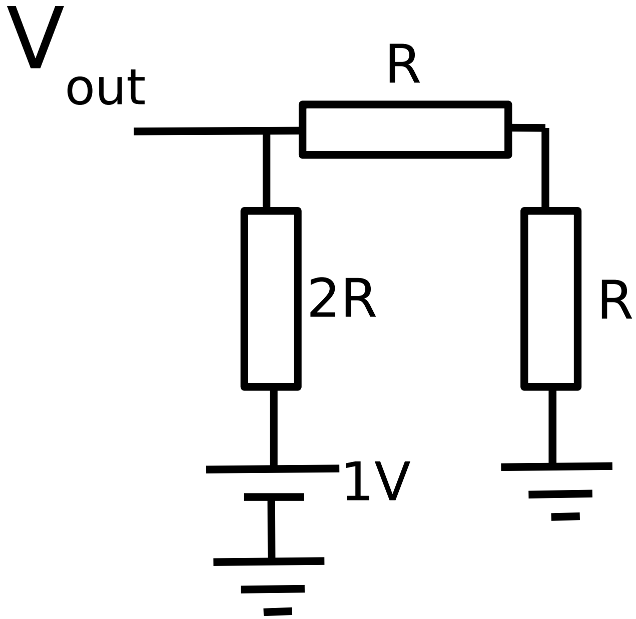


•Which again gives one resistor with a value of R.

$$\frac{1}{R_{\mathrm{new}}}=\frac{1}{2R}+\frac{1}{2R}$$

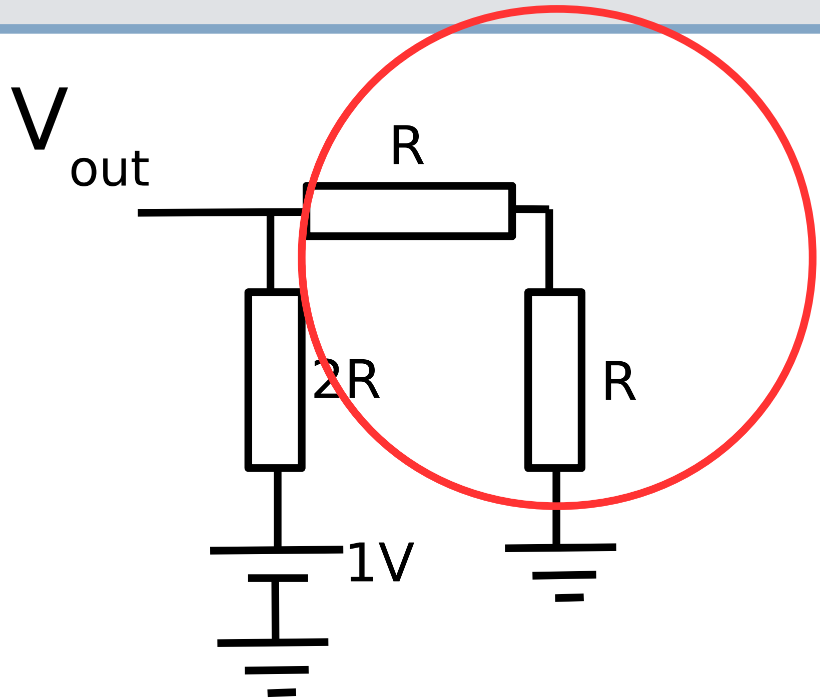
$$R_{\mathrm{new}}=R$$

Leaving us with.....



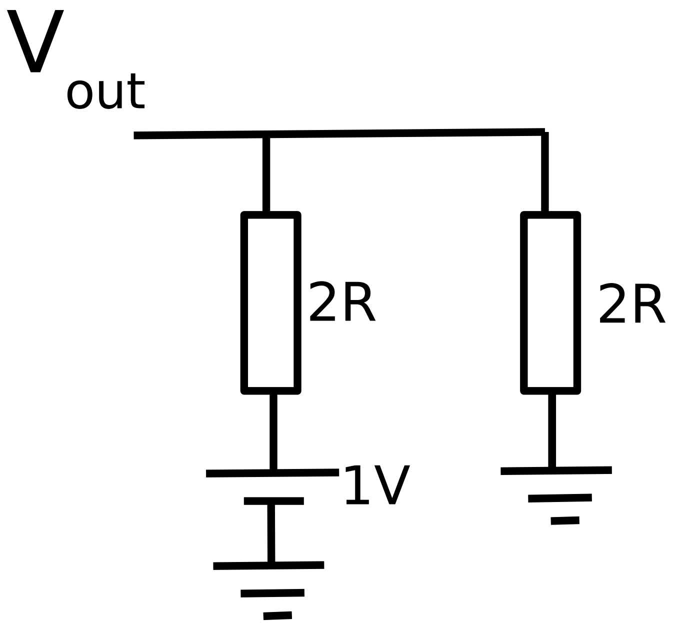
- What can we do now??

Leaving us with.....



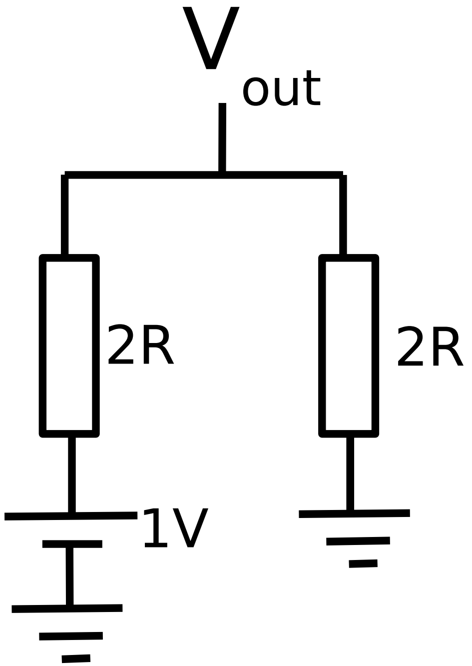
- Join these two resistors together.

And we now have...



- This looks complicated so let's just move things around to make them less scary.

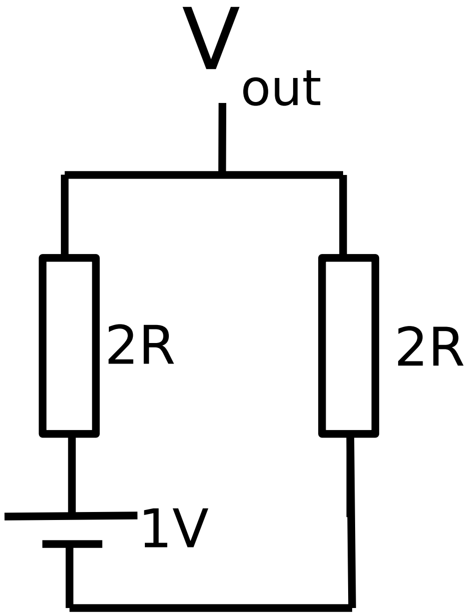
Move V_{out} to the top – why not?



•Looking a bit like a potential divider now.

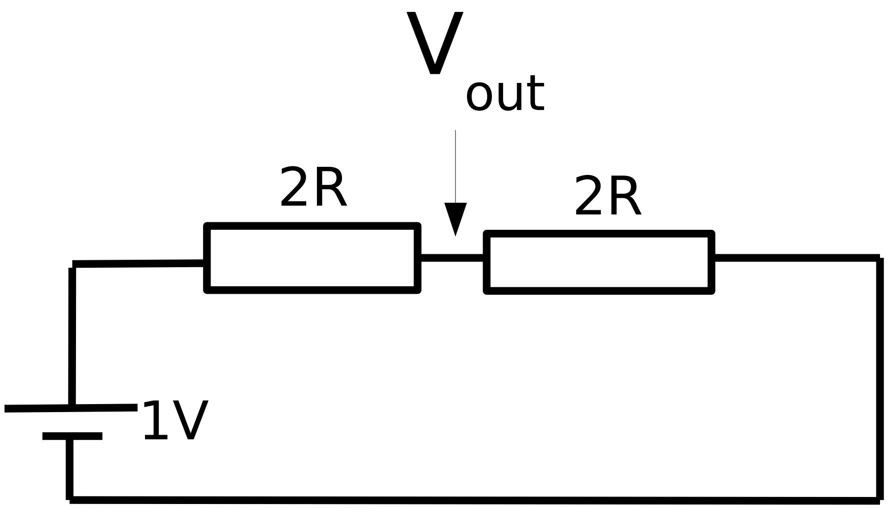
•Let' get rid of the grounds.

A more simple circuit

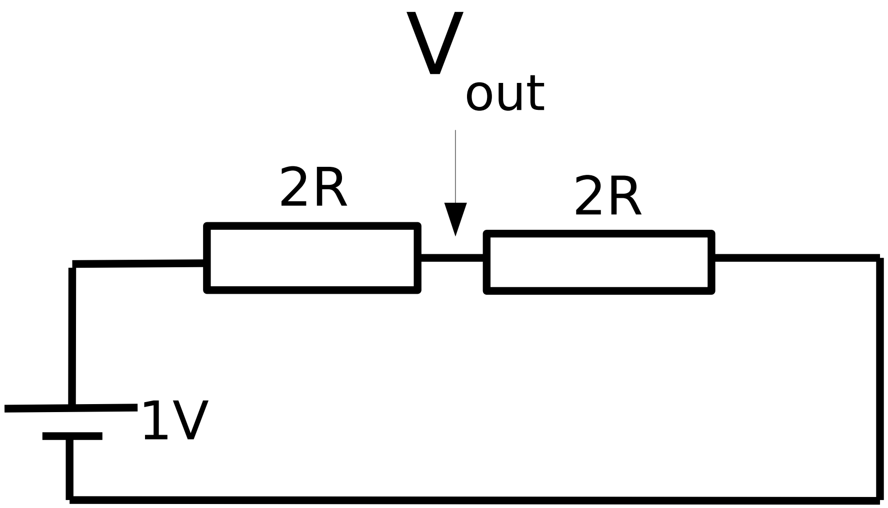


Now let's rearrange this circuit to make it look like something we may understand.

What does this remind you of?



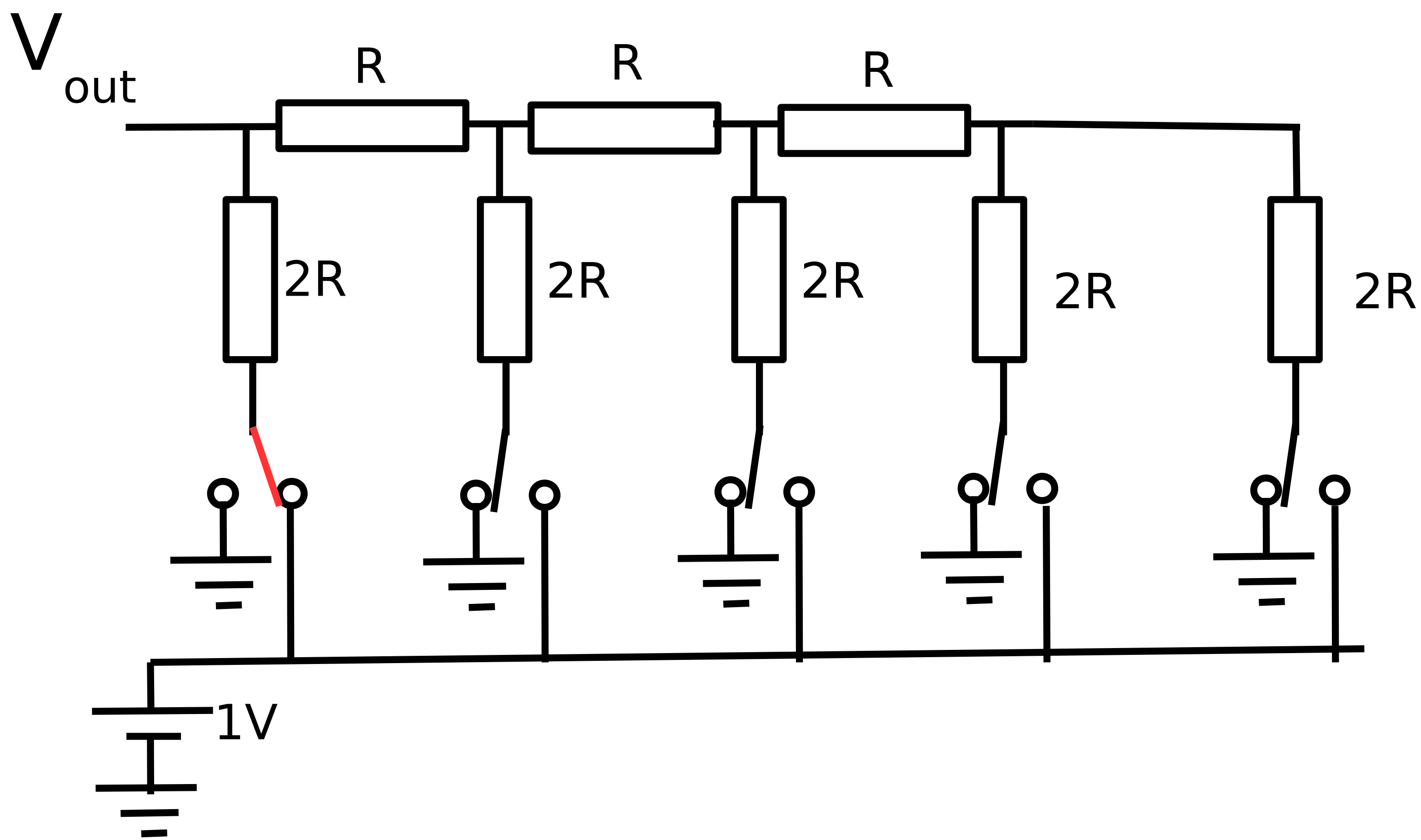
It's a potential divider



$$V_{out}=1V*\frac{2R}{2R+2R}$$

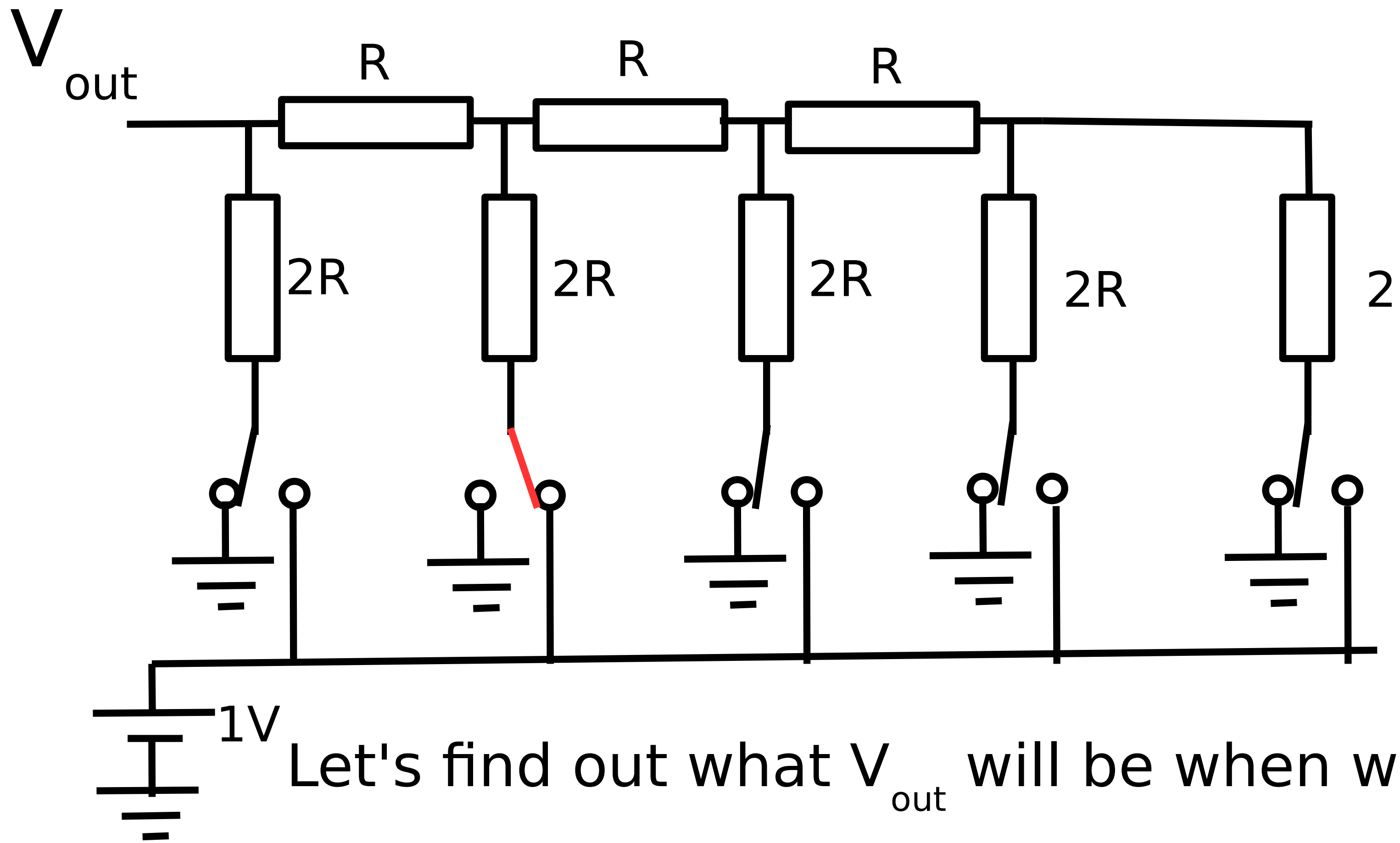
Therefore, V_{out} =0.5 V

If the first resistor is switched on we get V_{out}=0.5 on the output.



$V_{out}=0.5$ <-Remember this at least for the next 15 min

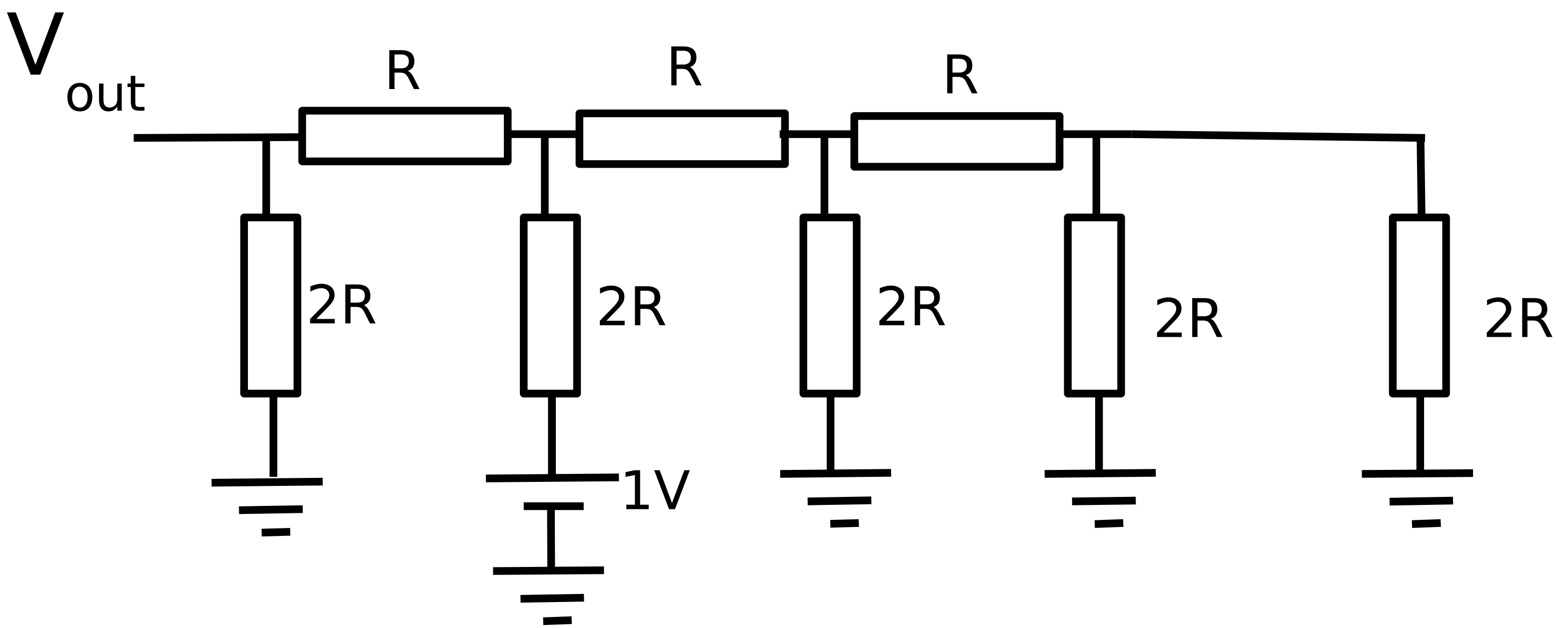
Now lets look at the second digital input.



Let's find out what V_{out} will be when we turn this on.

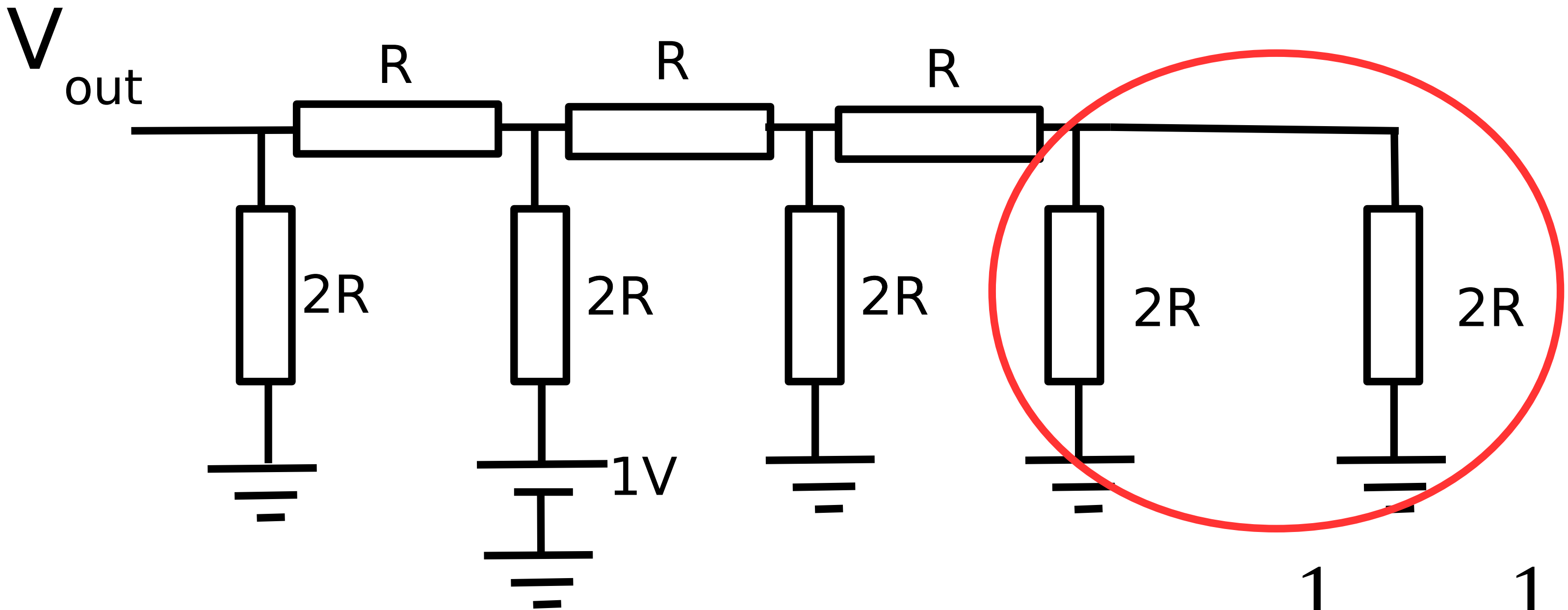
- This would represent the binary number 01000

Let's look at input 2 (This is the last pin we will examine)



Starting from the right hand side again.

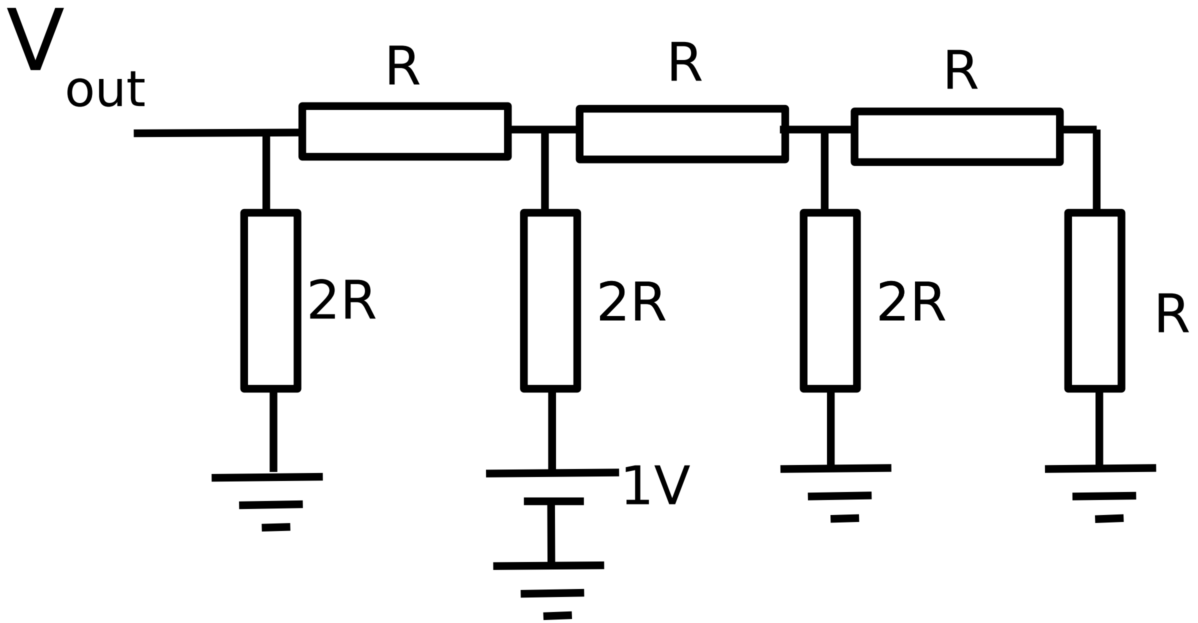
Two resistors in parallel



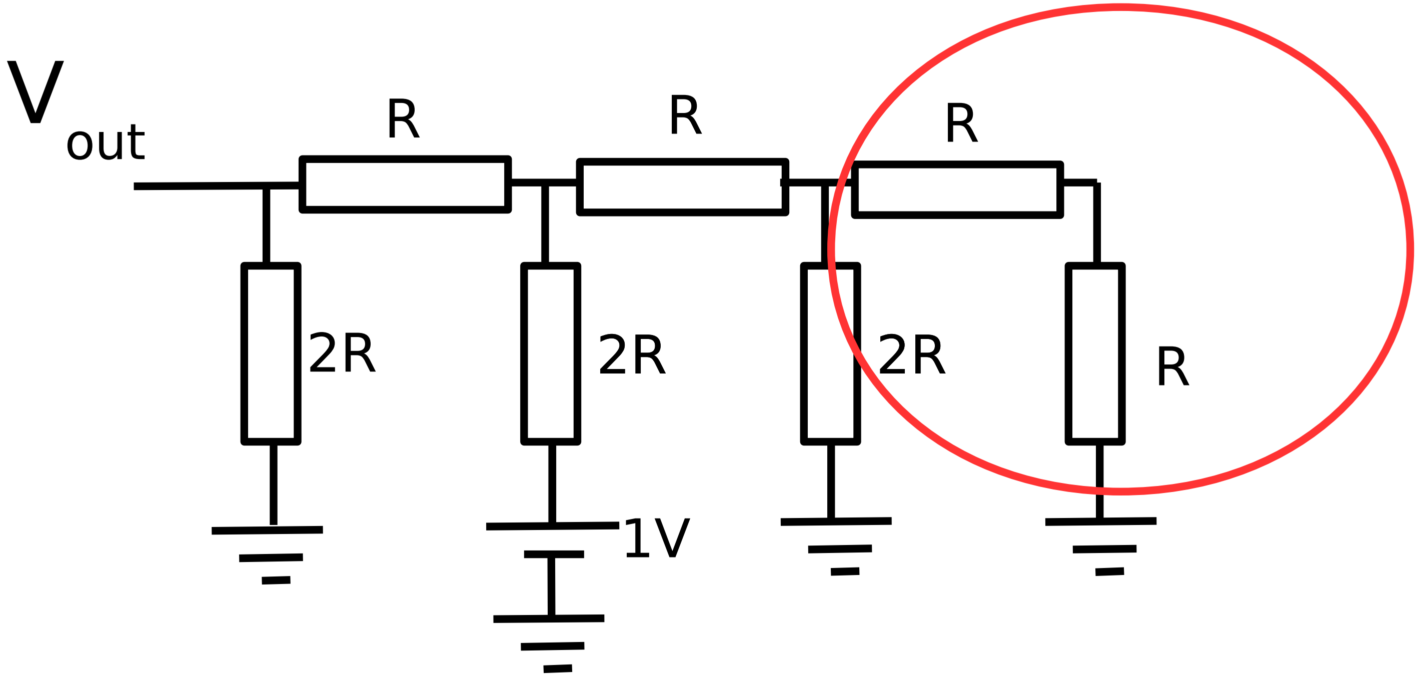
$$\frac{1}{R_{\text{new}}}=\frac{1}{2R}+\frac{1}{2R}$$

$$R_{\text{new}}=R$$

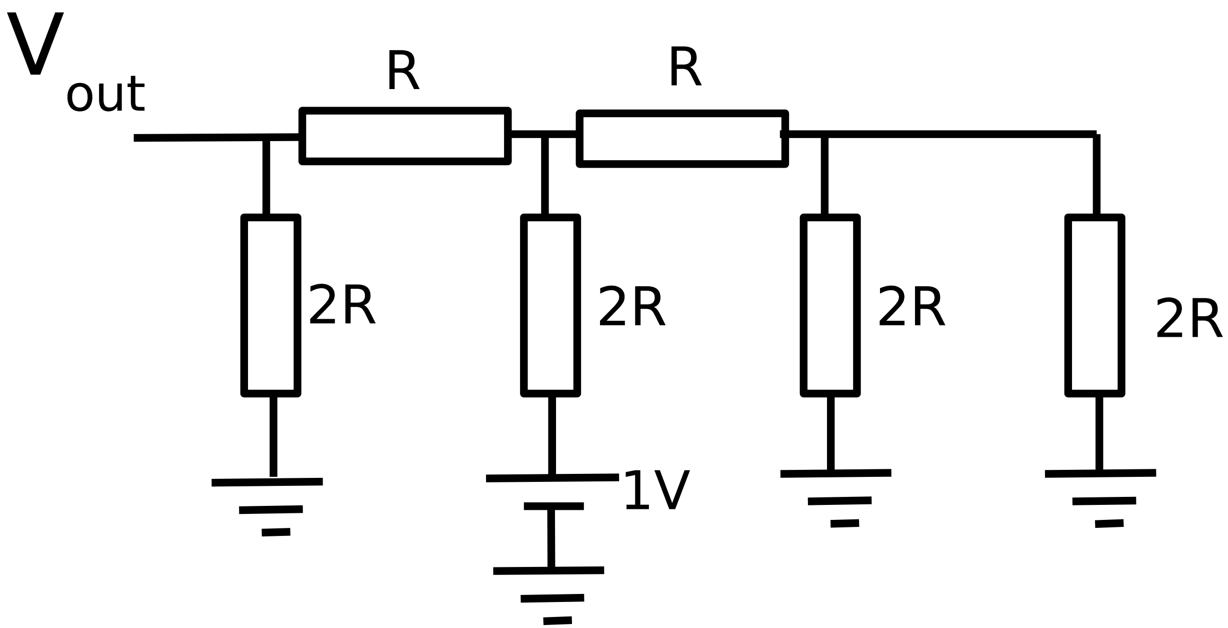
Gives....



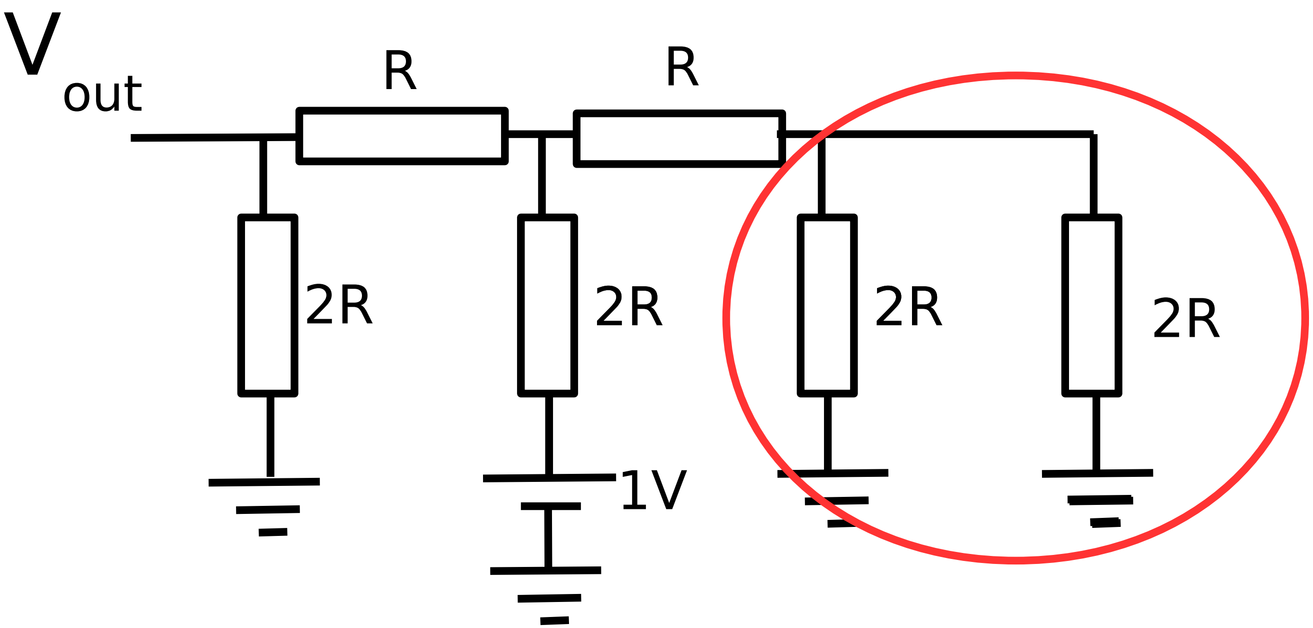
R + in series gives..



Gives 2R



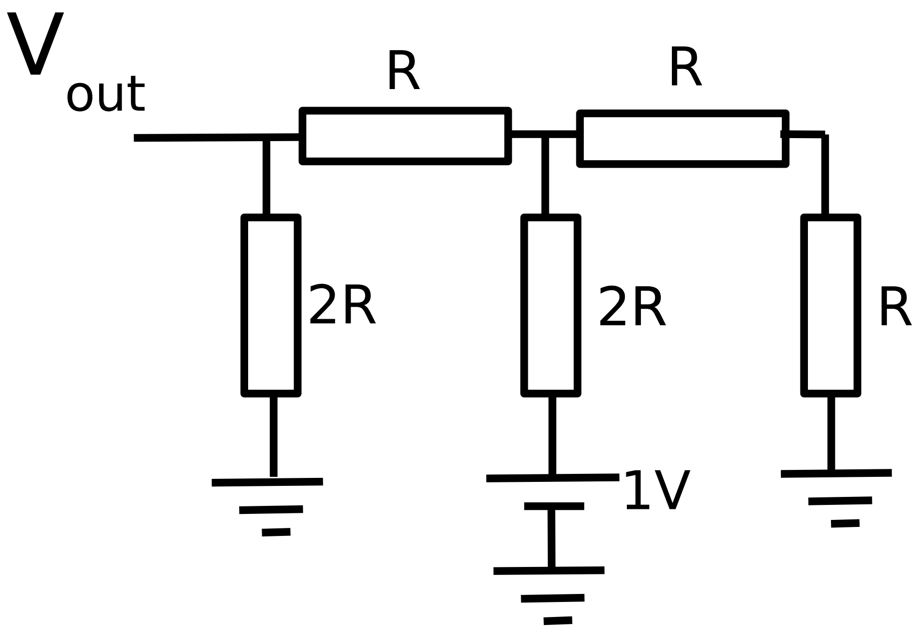
2R and 2R in parallel gives



$$\frac{1}{R_{new}} = \frac{1}{2R} + \frac{1}{2R}$$

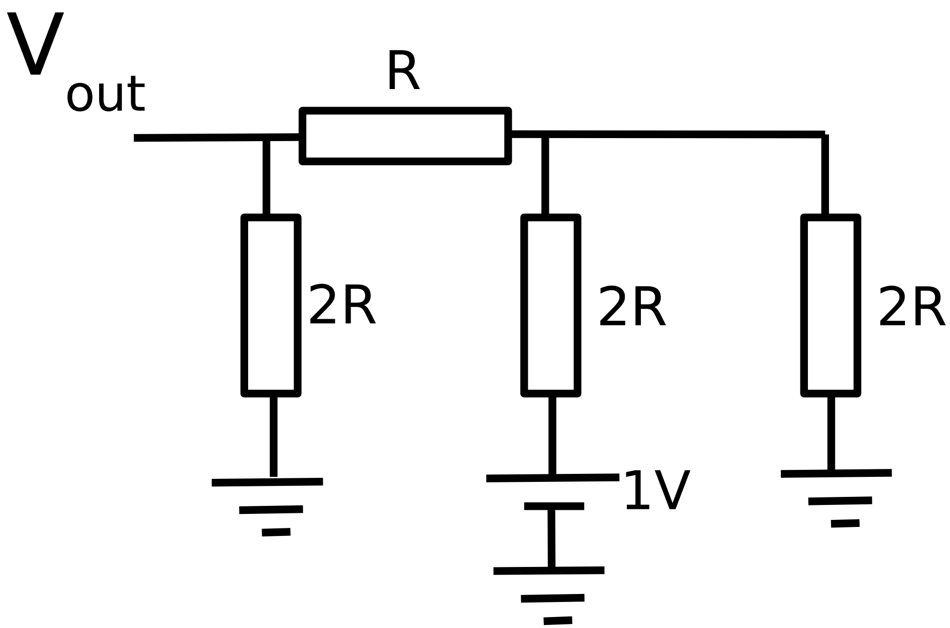
$$R_{new} = R$$

This gives R



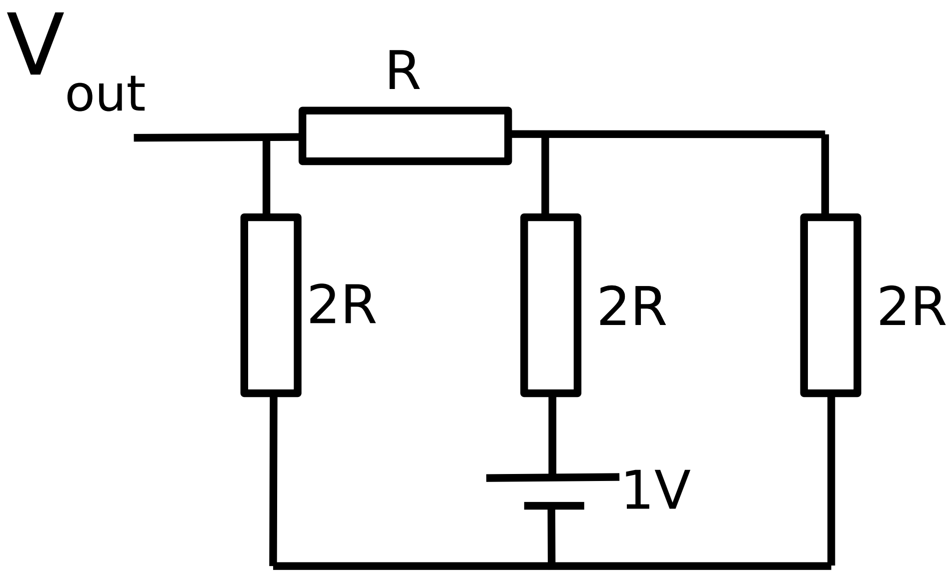
Tidying up R+R..

We are left with this circuit



Let's get rid of the ground signs because they are confusing.

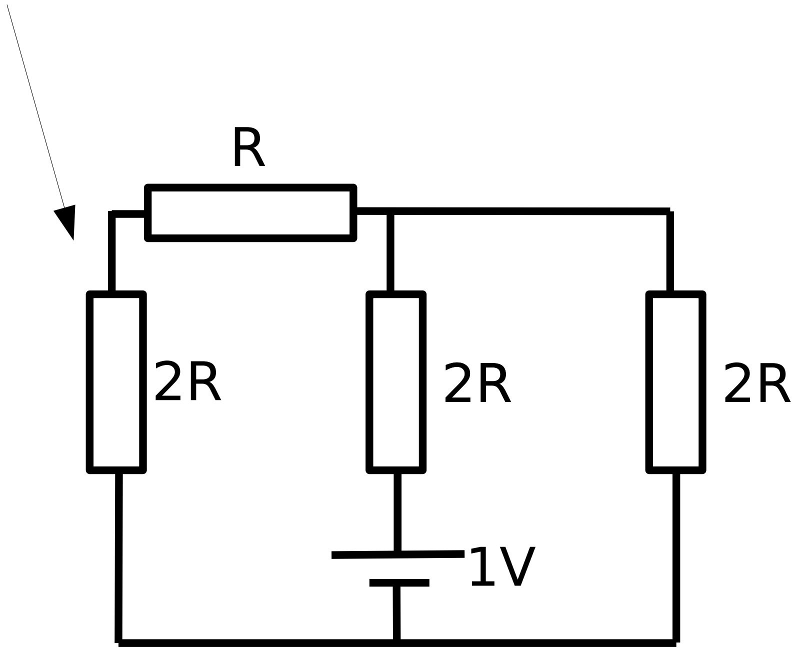
That's better



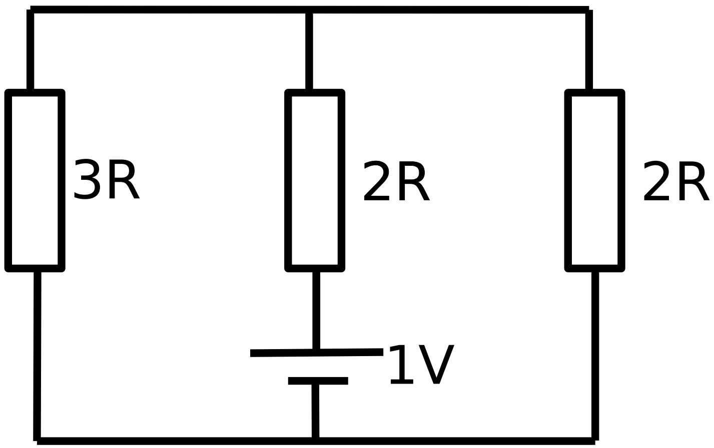
For the moment let's also get rid of V_{out}.

This is looking more simple

Join R and 2R together.

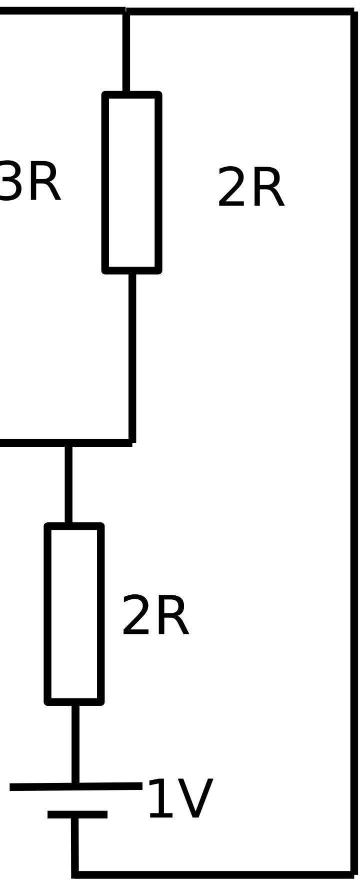


Even more manageable



Let's redraw this in a more easy to understand form..

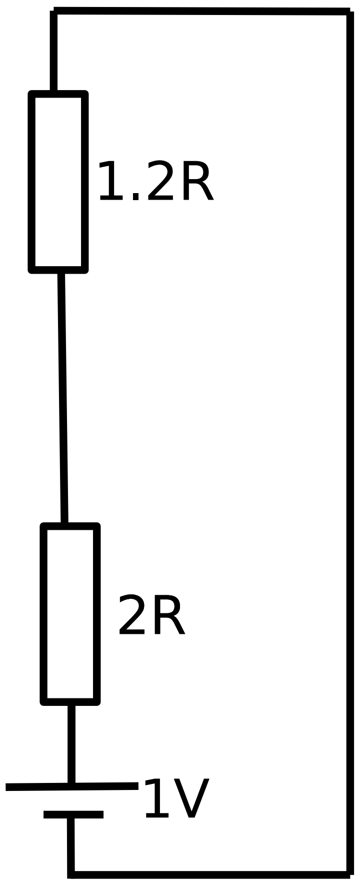
Two resistors in parallel.



$$\frac{1}{R_{\mathrm{new}}}=\frac{1}{3R}+\frac{1}{2R}$$

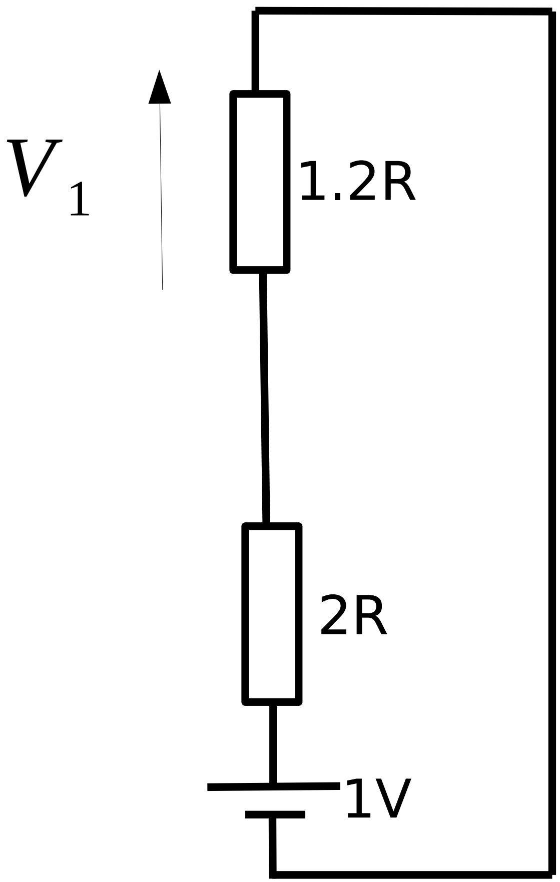
$$R_{\mathrm{new}}=1.2R$$

Now we just have a potential divider



What's this circuit?

Now we just have a potential divider

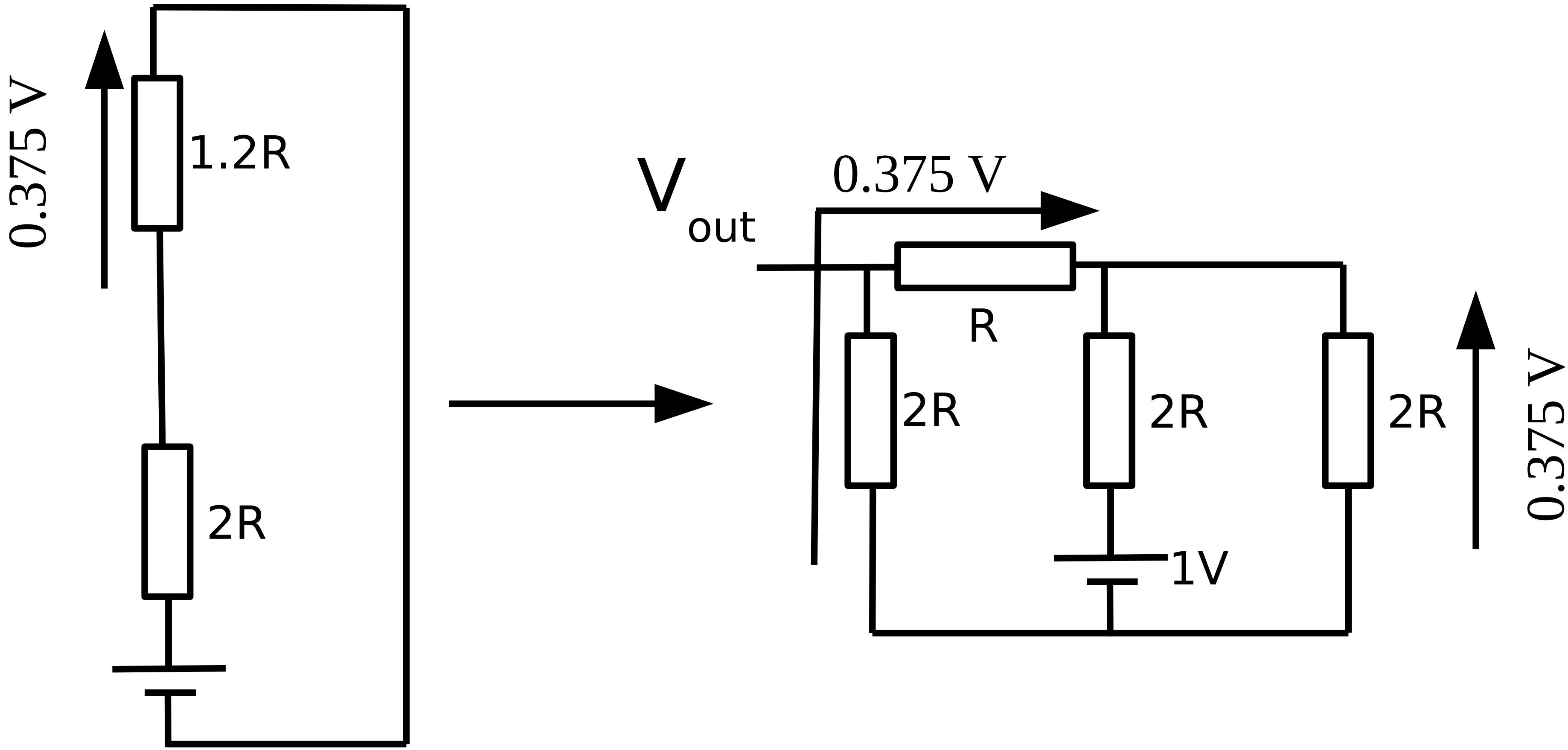


The voltage across 1.2 R is.

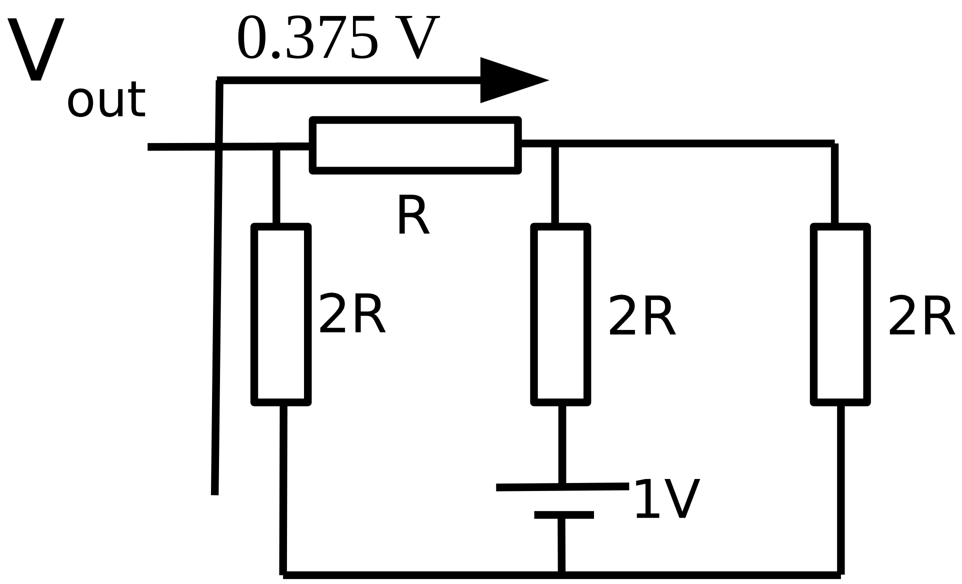
$$V_1 = 1V \frac{1.2R}{2R + 1.2R}$$

$$0.375V$$

Superimposing this voltage on our original circuit.

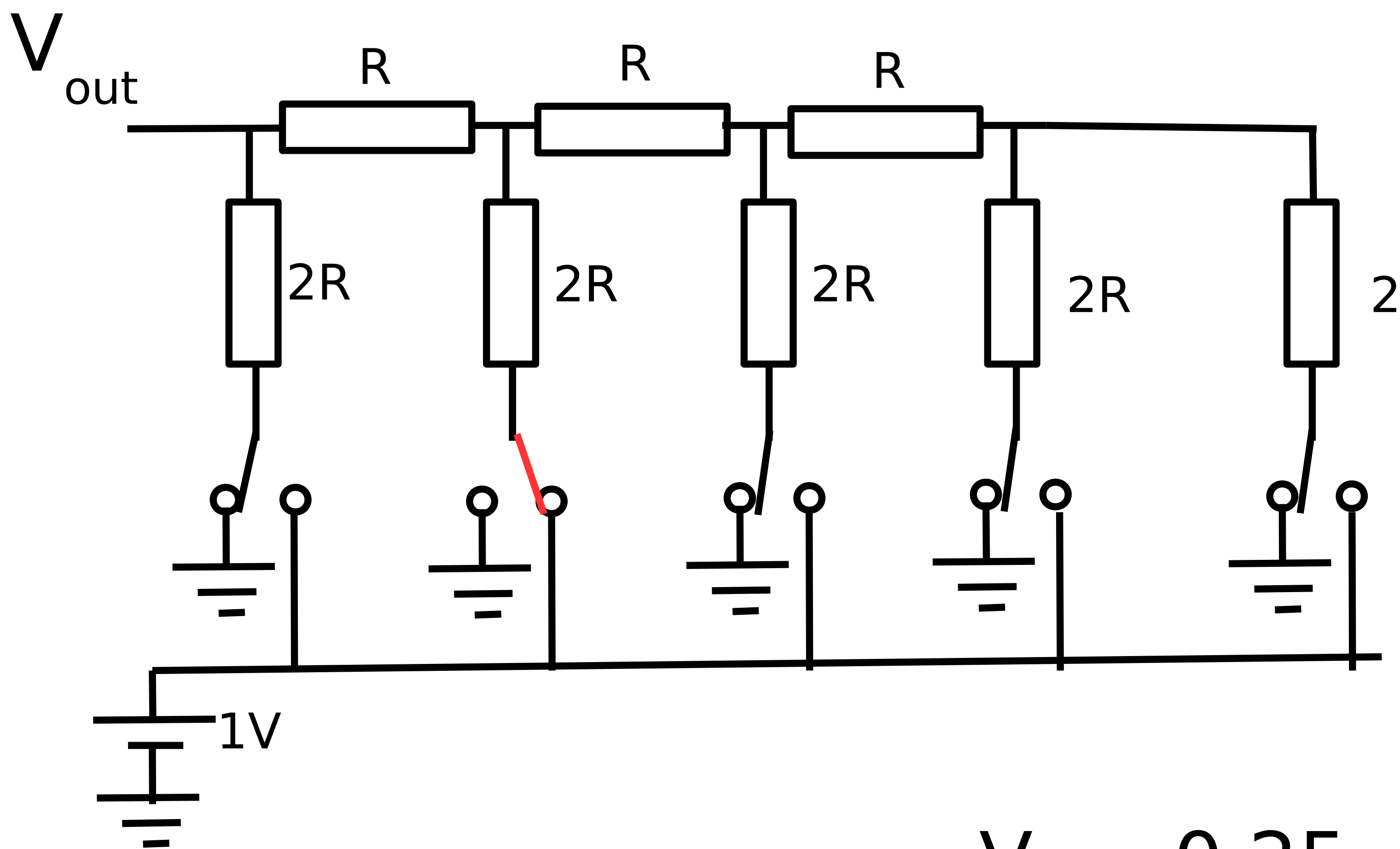


Another potential divider



$$V_{out} = 0.375 \frac{2R}{R+2R} = 0.25\,V$$

If the **second** resistor is switched on we get V_{out}=0.25 on the output.

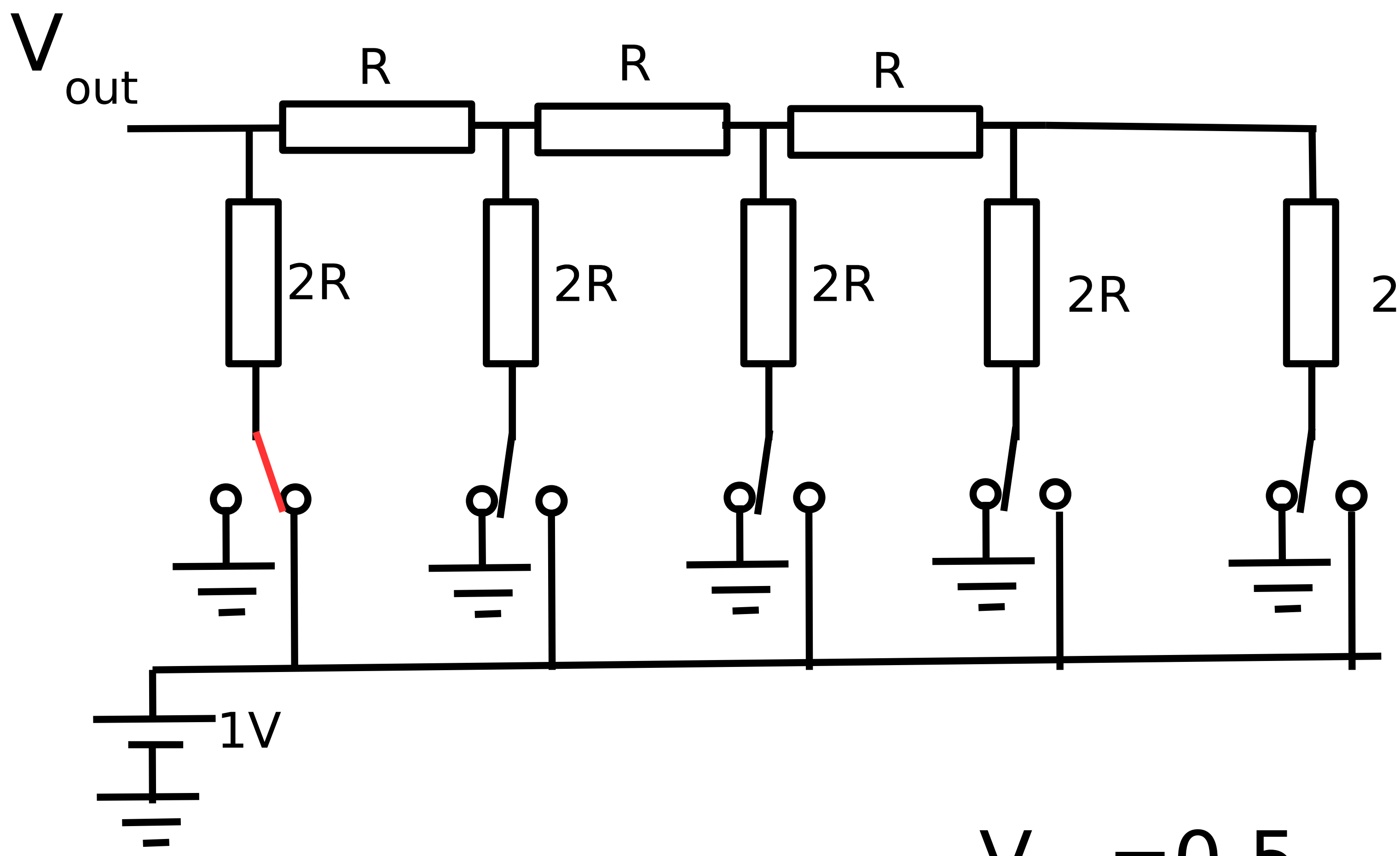


$V_{out}=0.25$

Life is short – so we won't look at any more pins

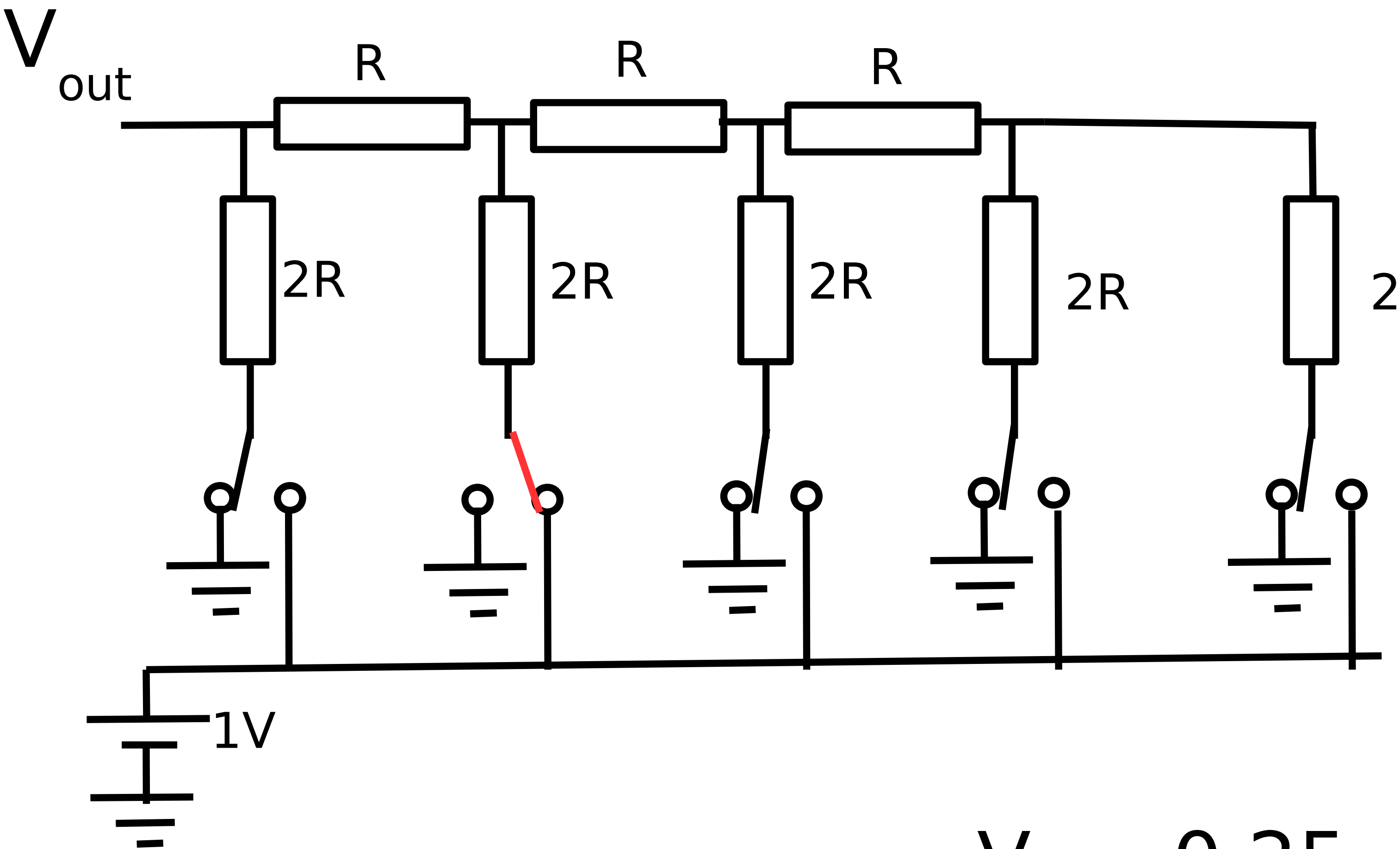
- I will just tell you what happens for the rest of the pins now.

Input 1 representing binary 10000



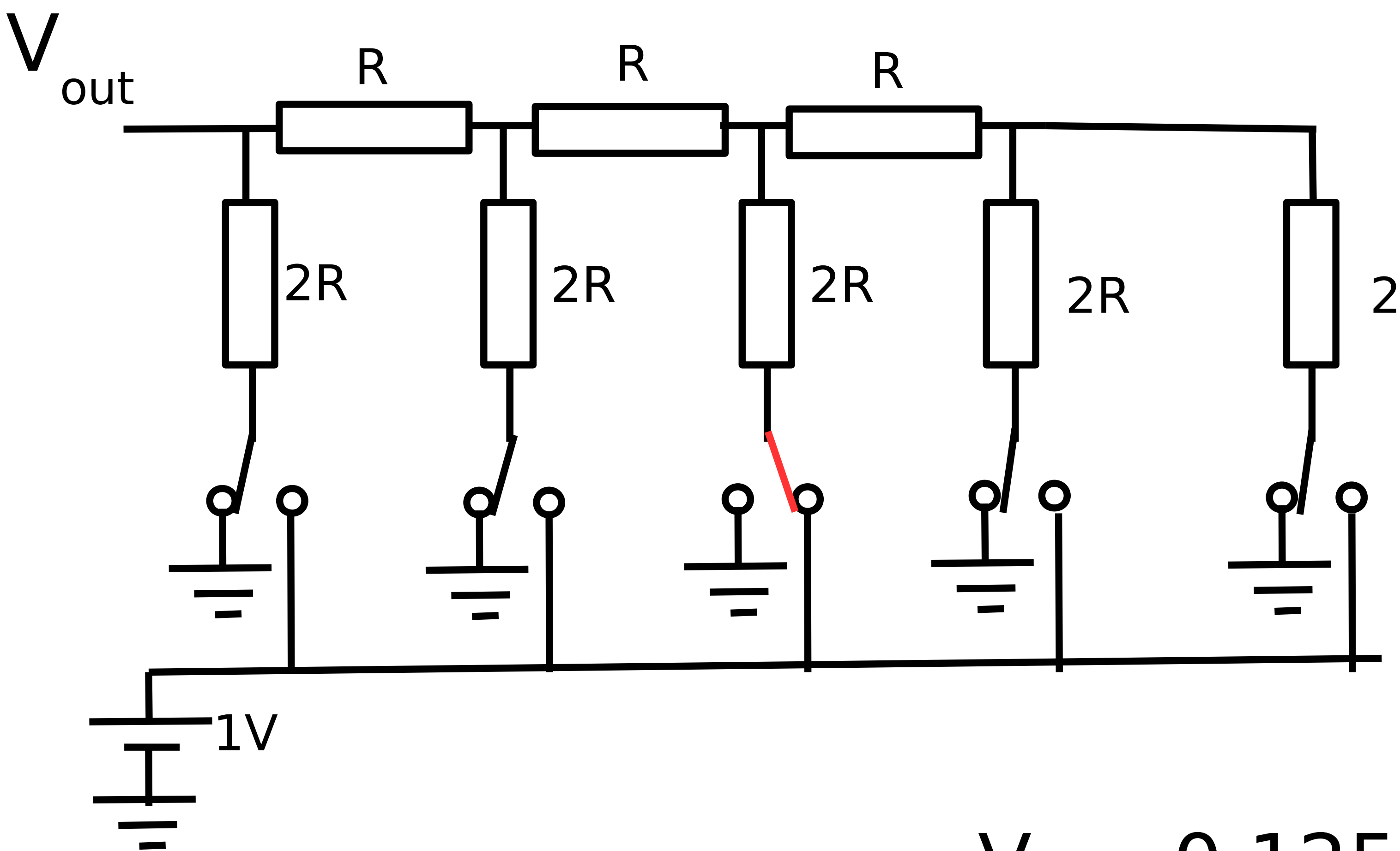
V_{out}=0.5

Input 2 representing binary 01000



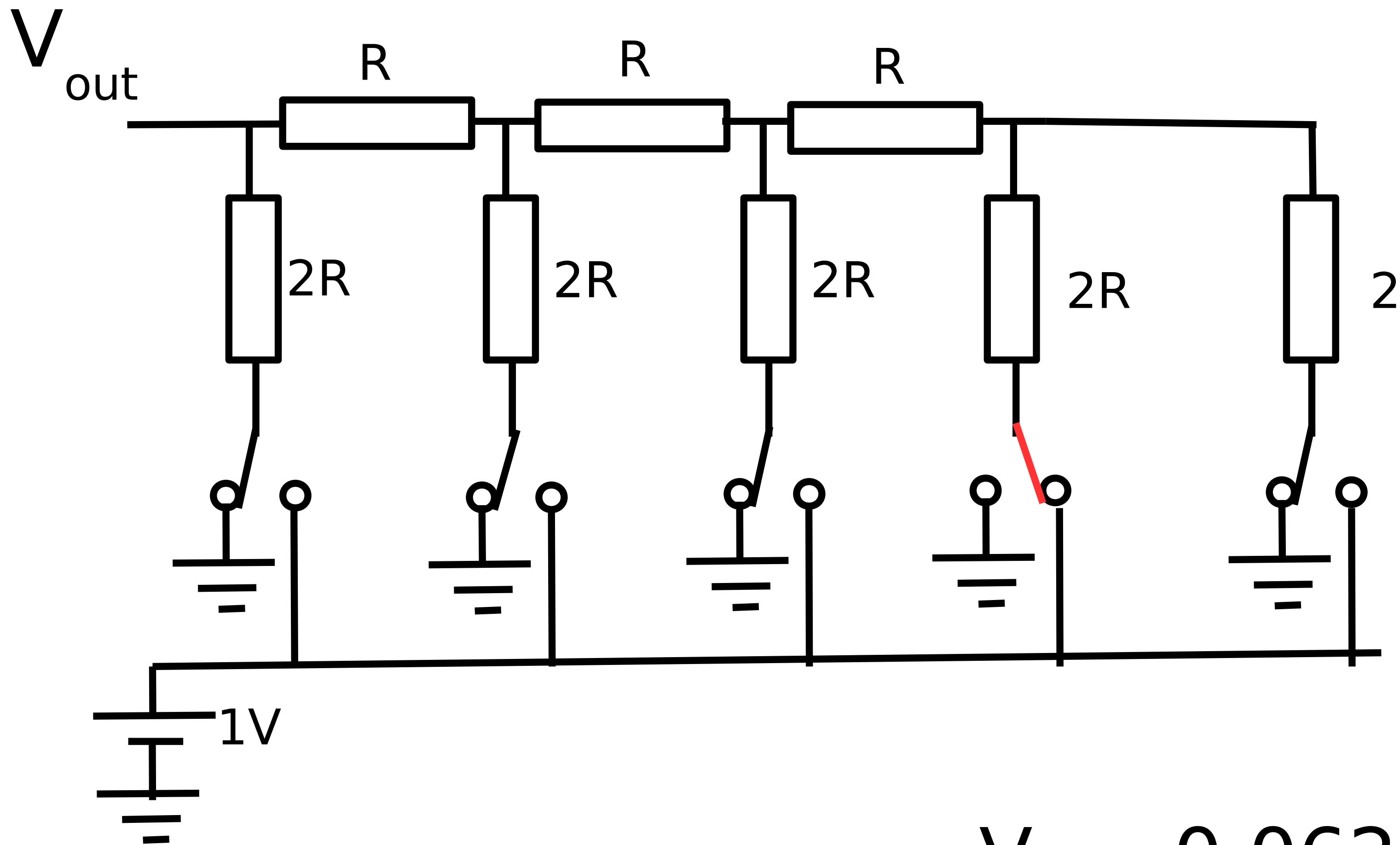
V_{out}=0.25

Input 3 representing binary 00100



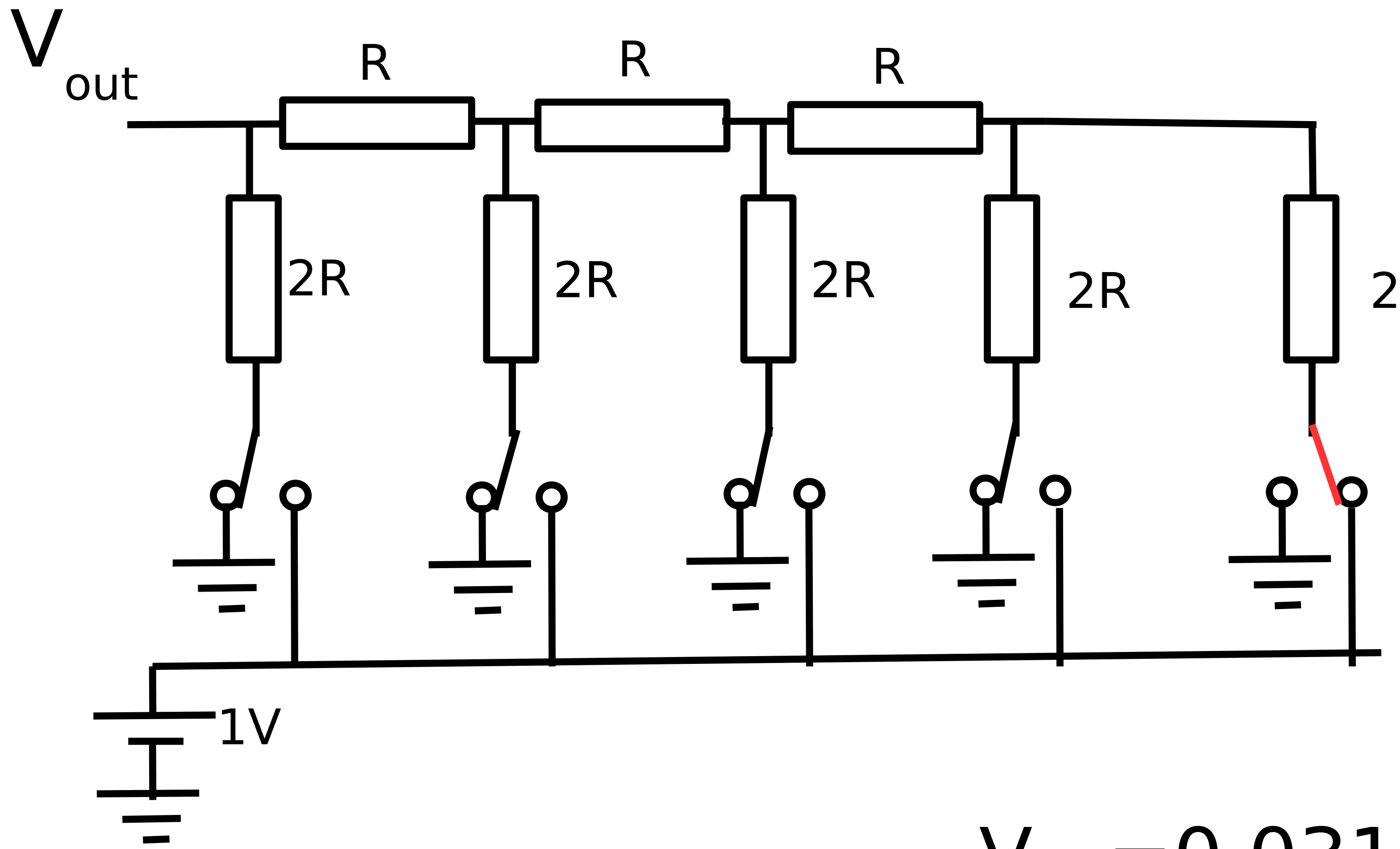
V_{out}=0.125 V

Input 4 representing binary 00010



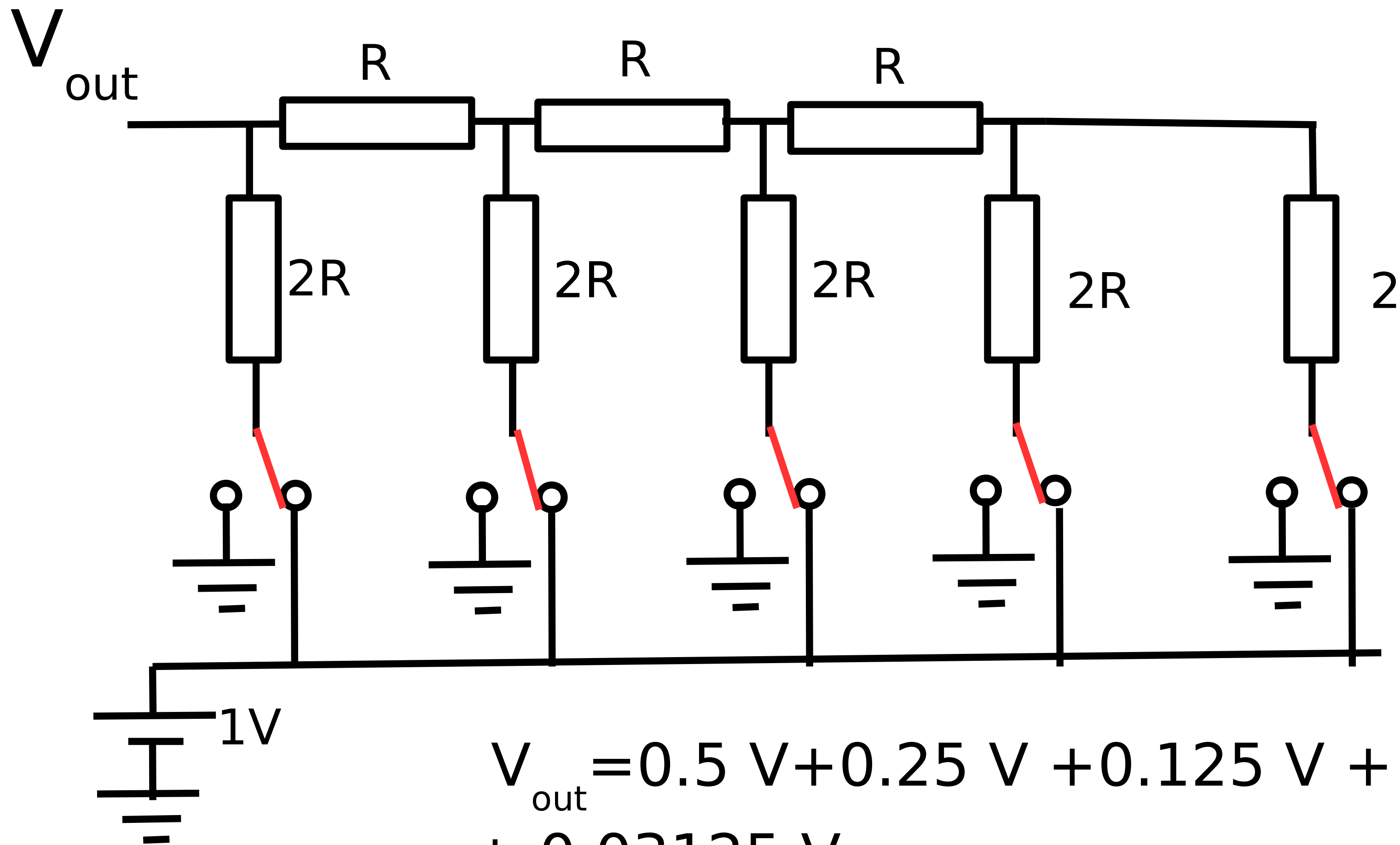
V_{out}=0.0625 V

Input 5 representing binary 00001



V_{out}=0.03125 V

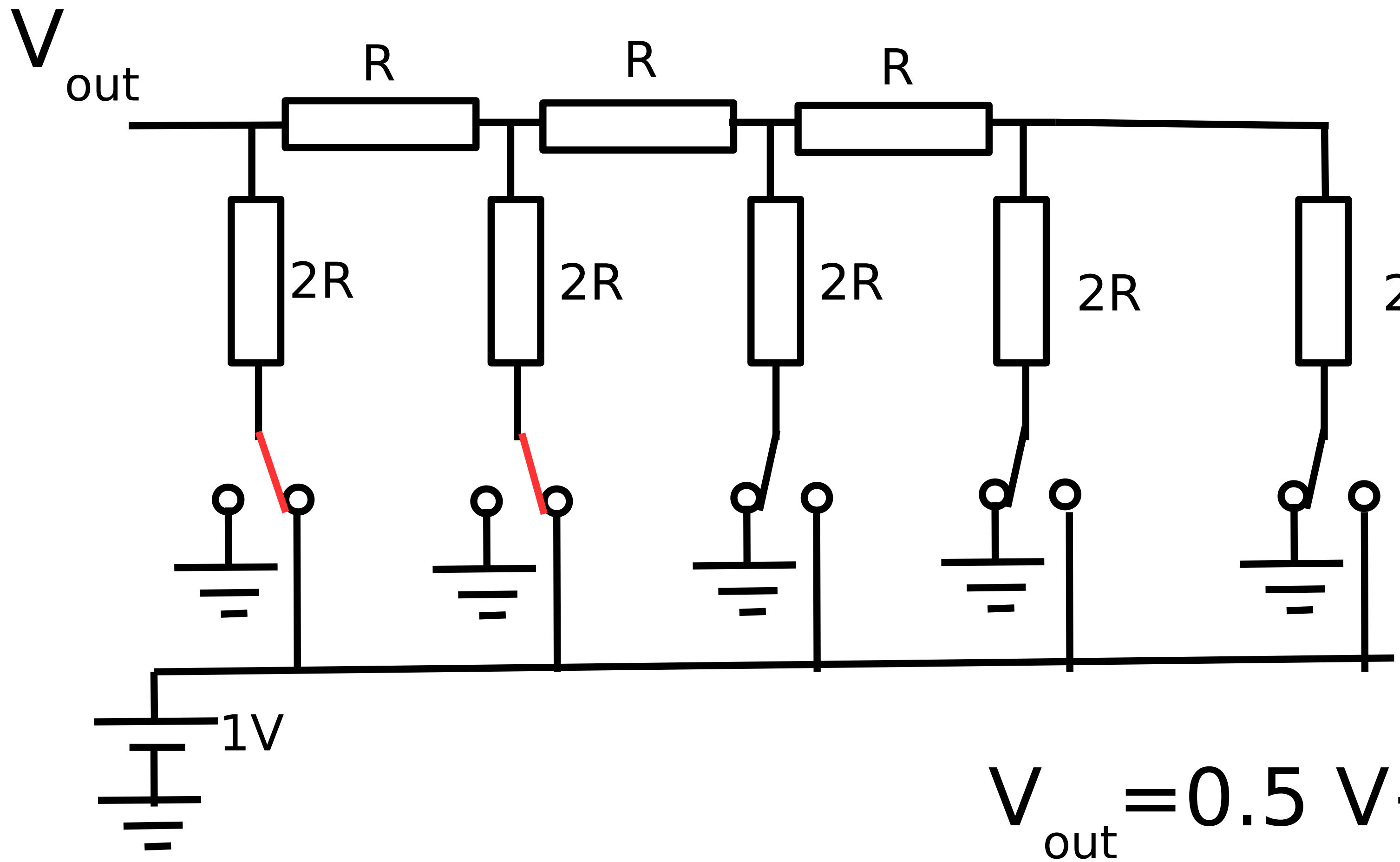
Inputs 1, 2, 3, 4, and 5 - (11111)



V_{out}=0.5 V+0.25 V +0.125 V + 0.0625 V + 0.03125 V

V_{out}=1 V

We can turn on any combination on i.e. 11000



V_{out}=0.5 V+0.25 V

V_{out}=0.75 V

Question

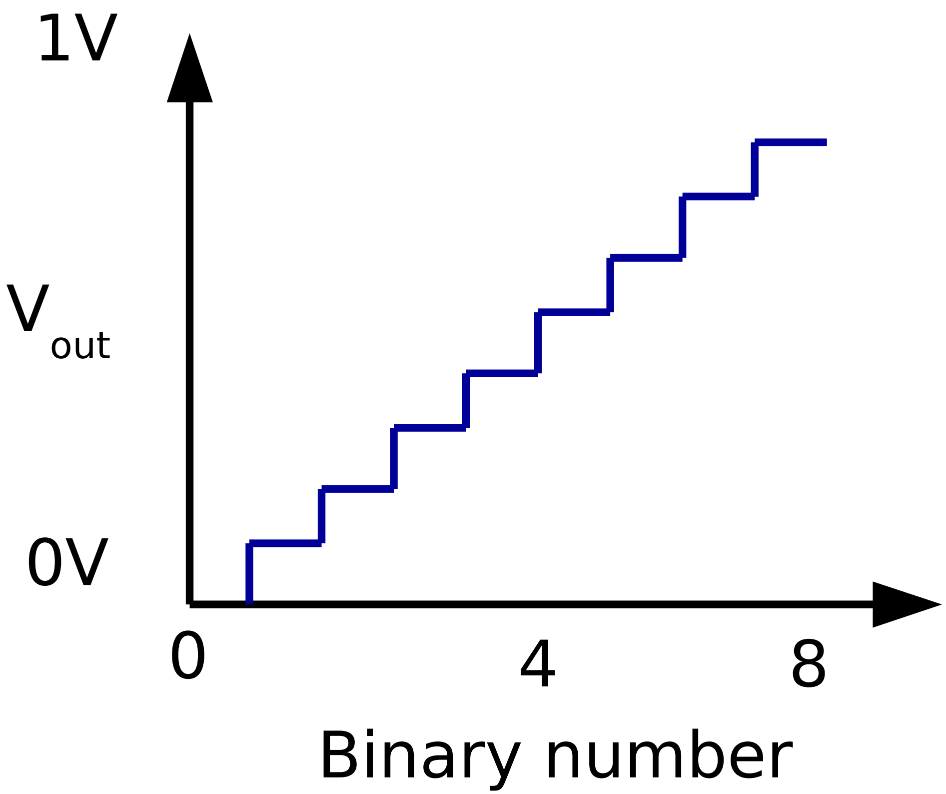
- Does this remind you of anything?

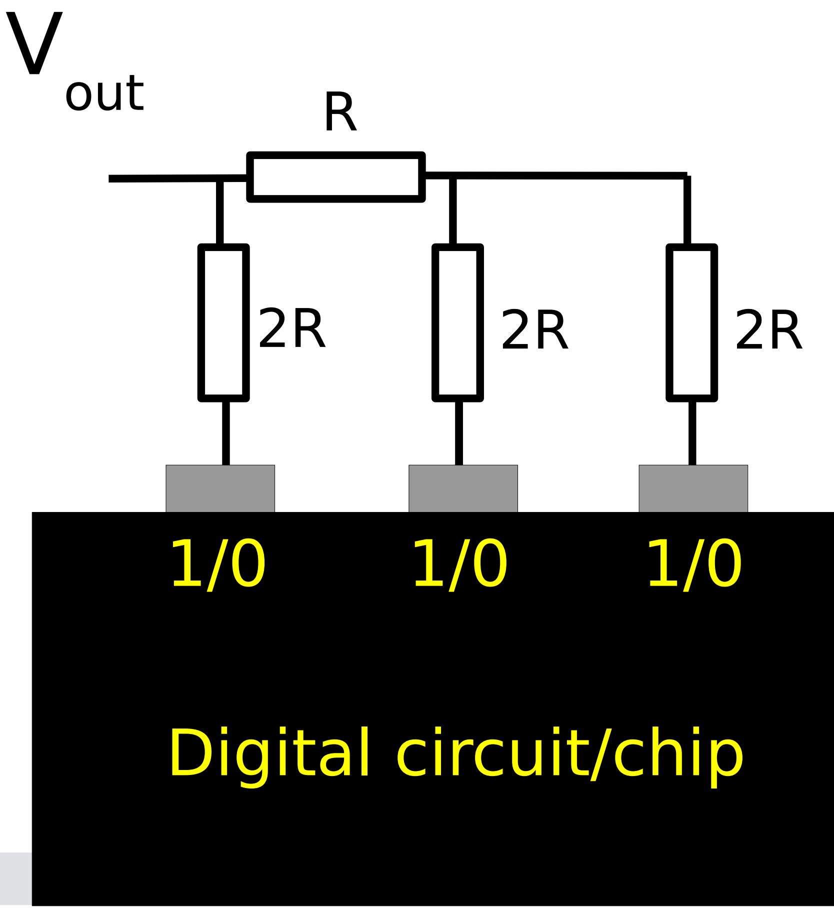
Answer

- Sort of counting in binary...

If we connect the R2R ladder to the binary output from a chip...

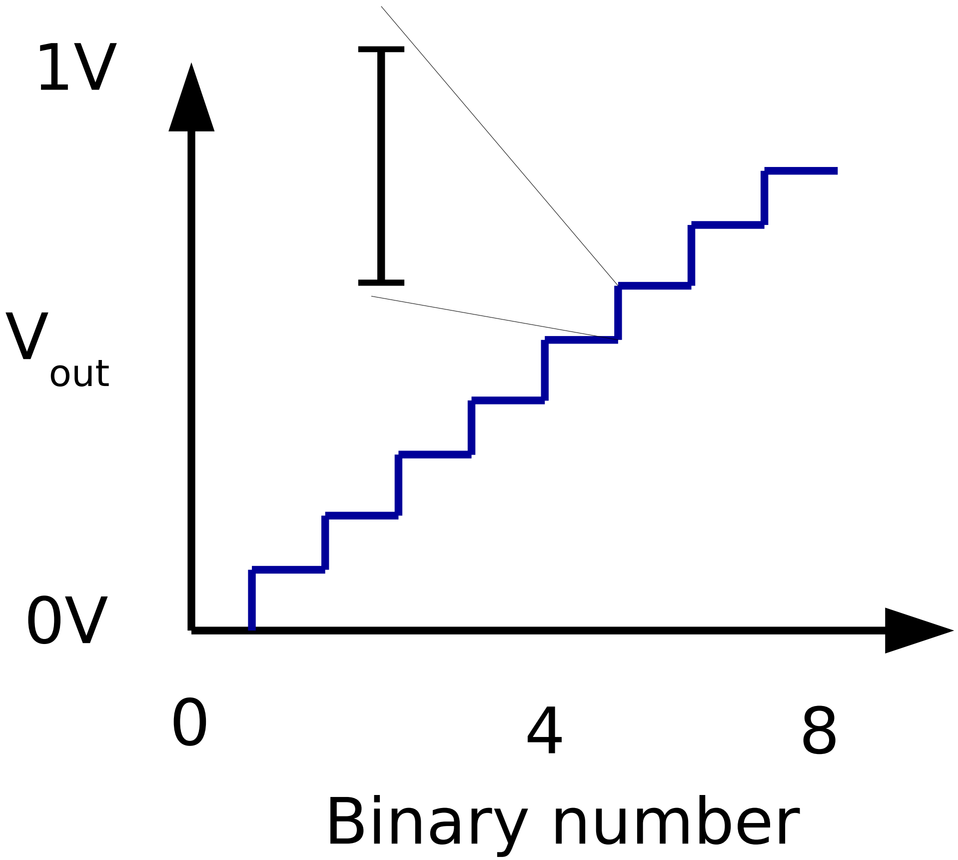
•We can generate any voltage between 0 V and 1 V

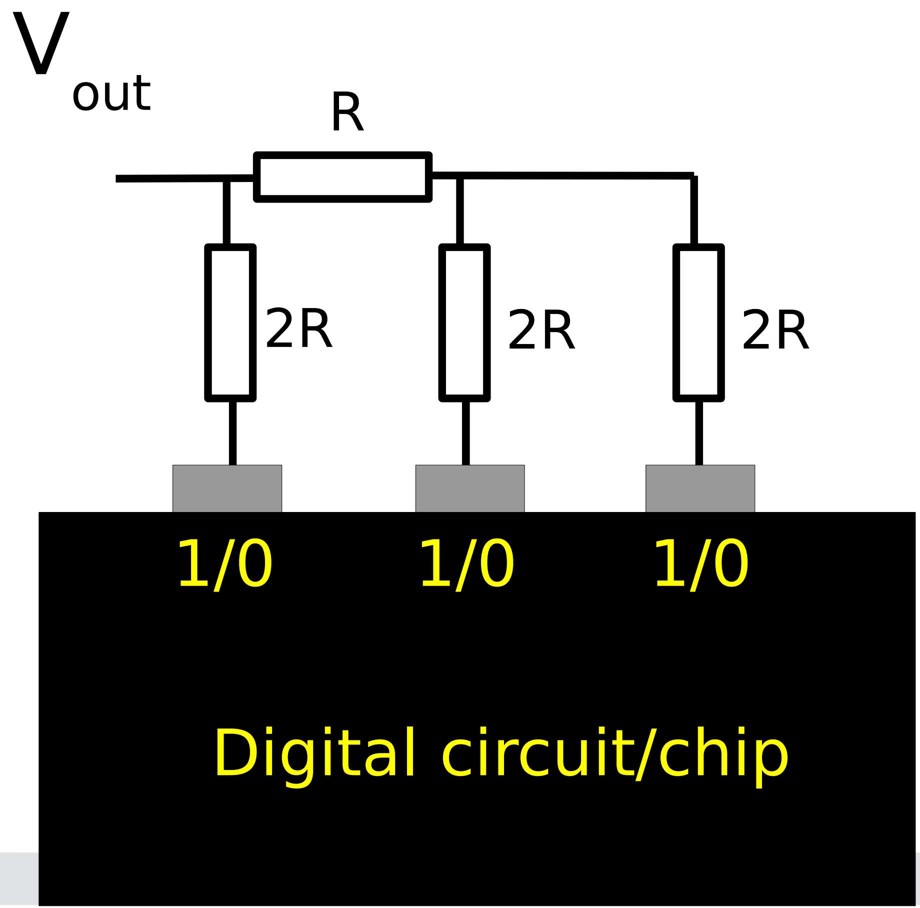




R2R ladder resolution

$$resolution = \frac{\text{Maximum output voltage}}{\text{number of combinations}}$$

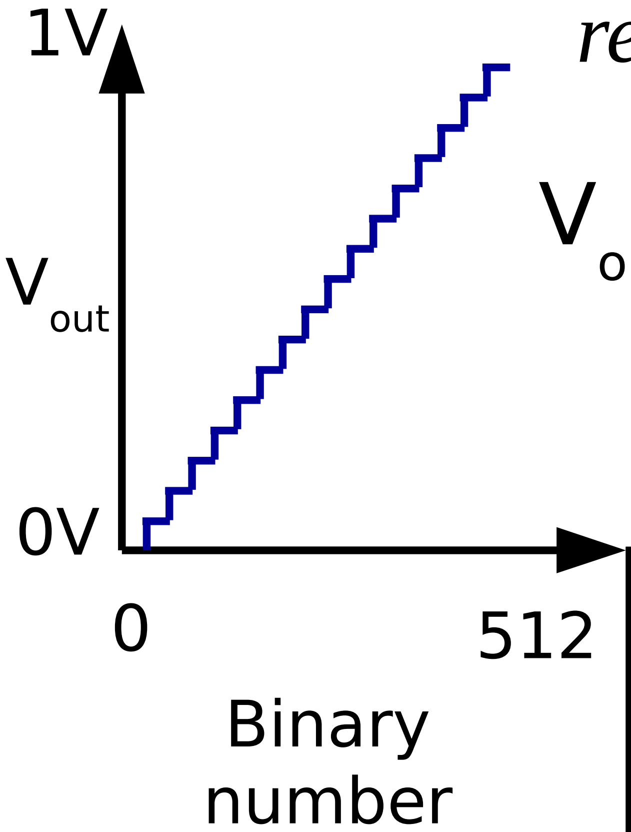


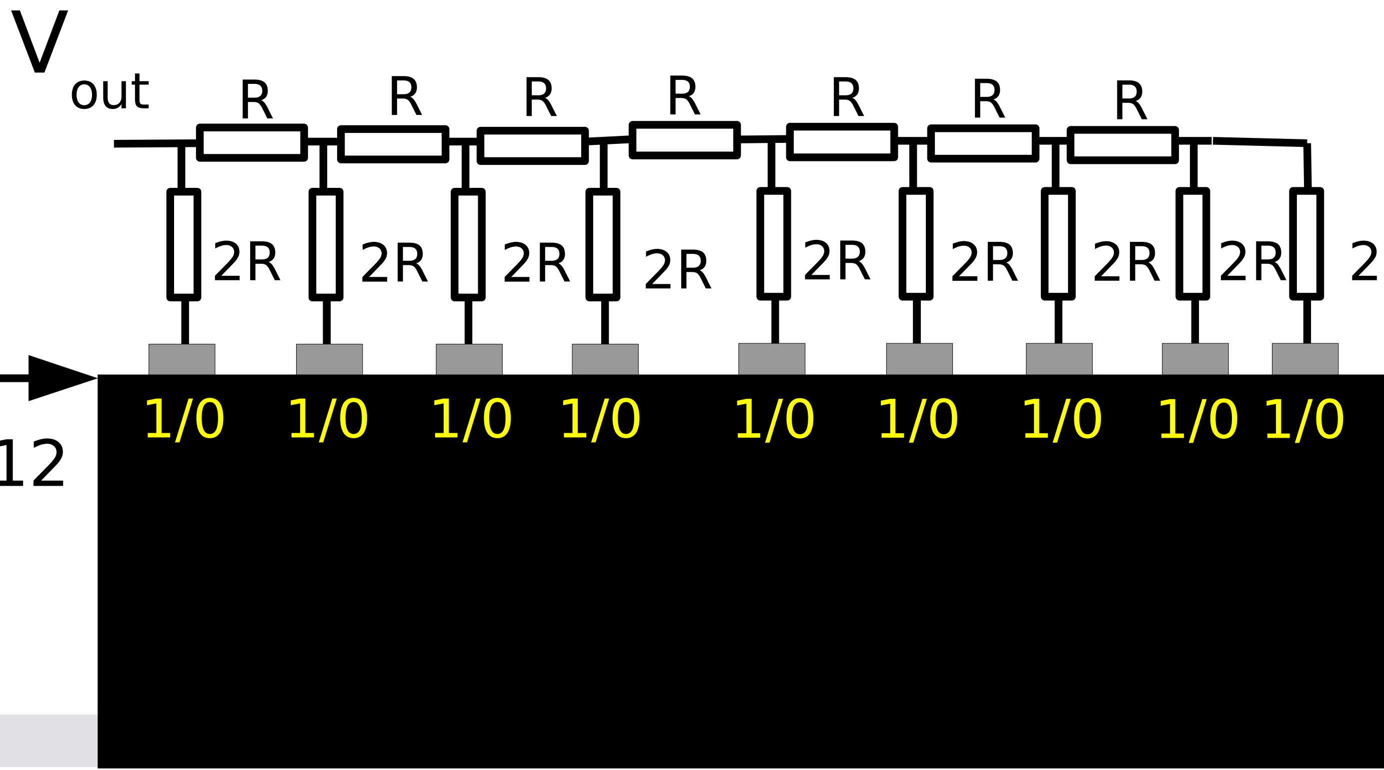


The more pins we have

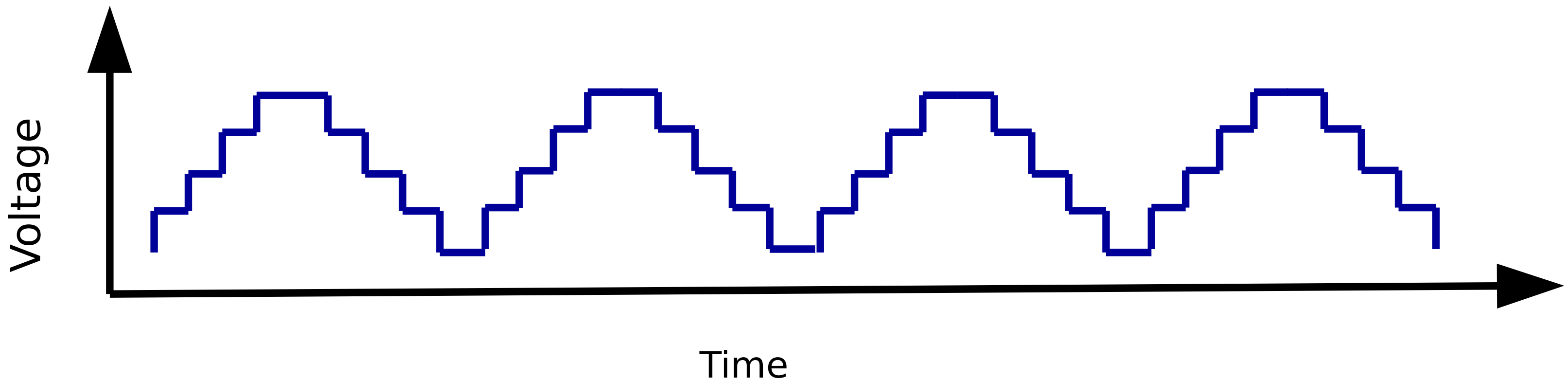
- The finer the resolution we get.

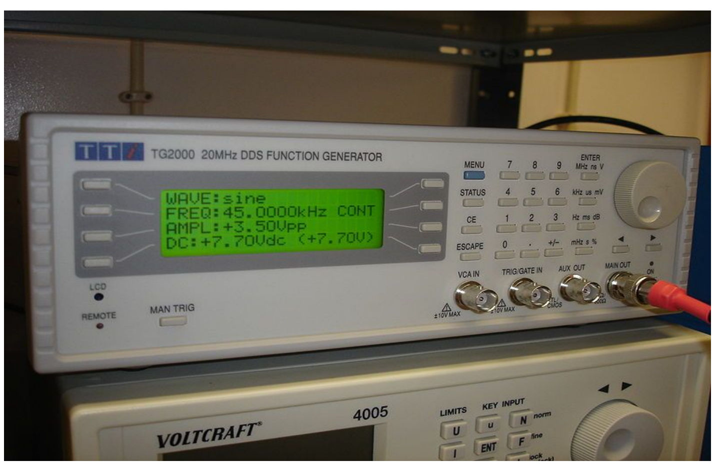
$$resolution = \frac{\text{Maximum output voltage}}{\text{number of combinations}}$$





We can now make any shape analog signal we want.





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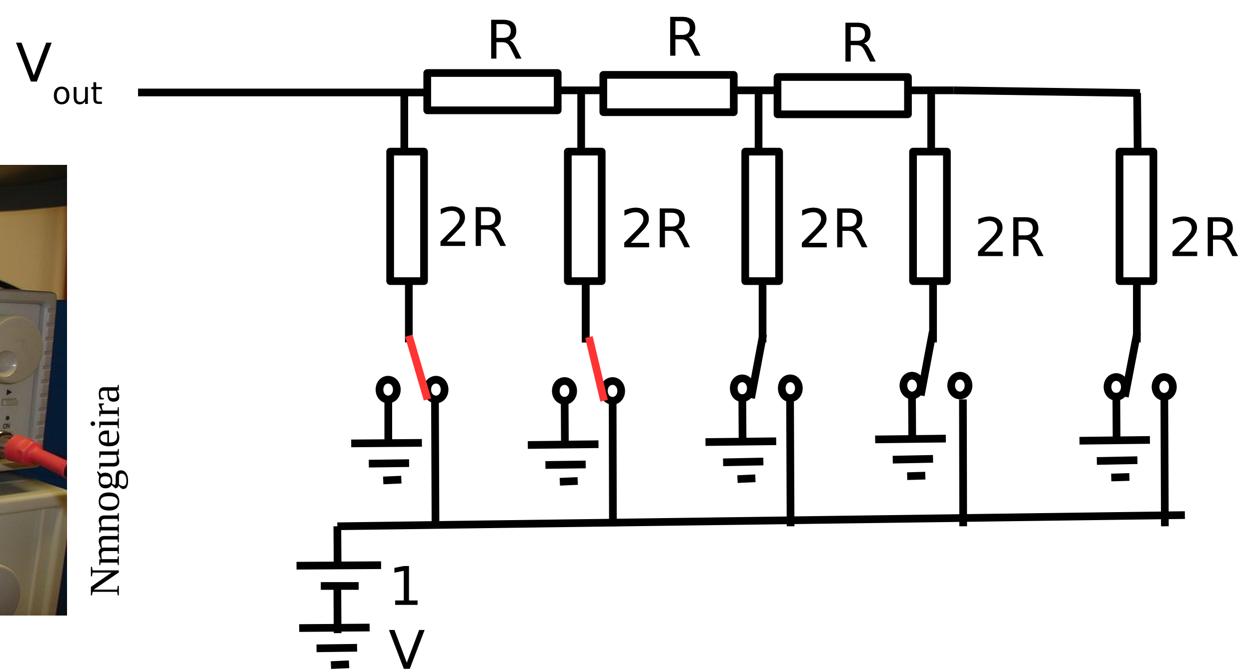
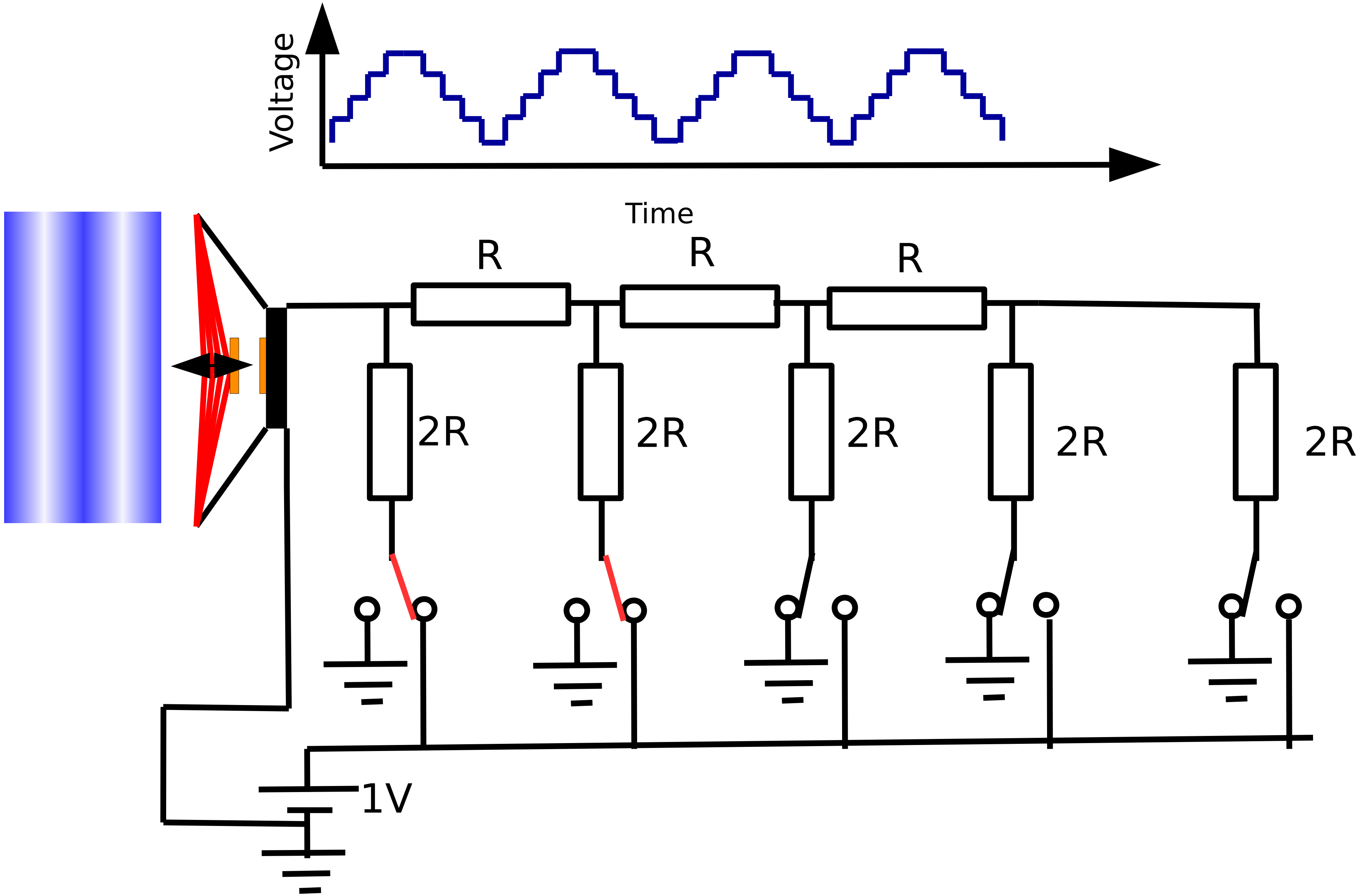


If we attach a speaker we get a tone.



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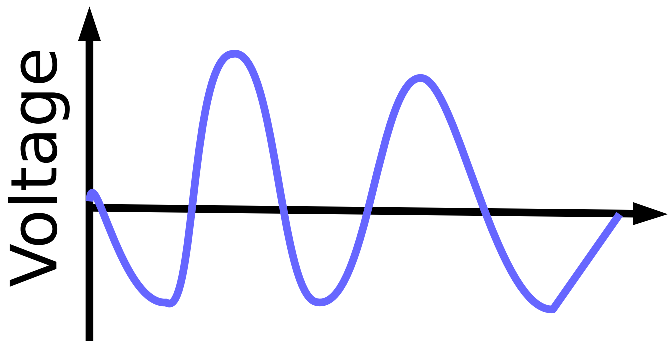
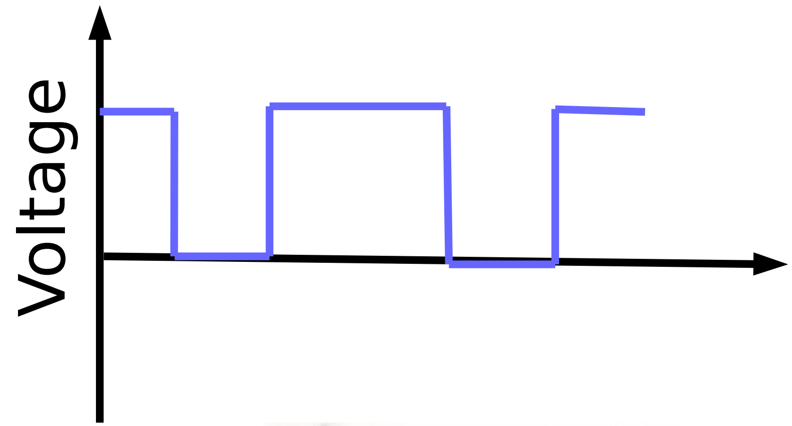
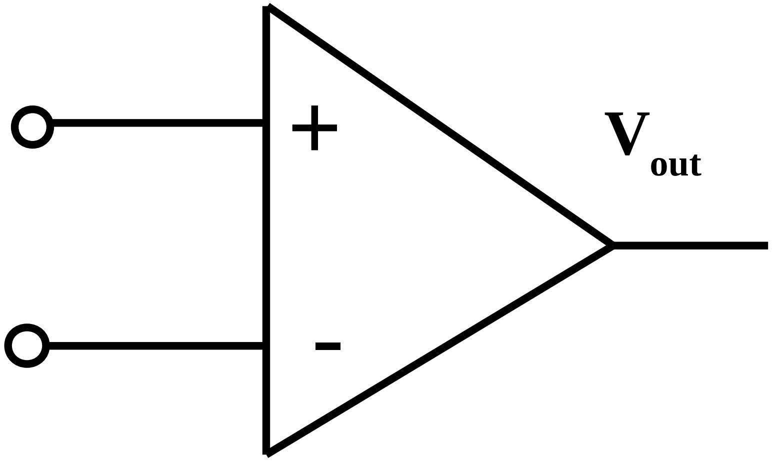
Analog to digital converter

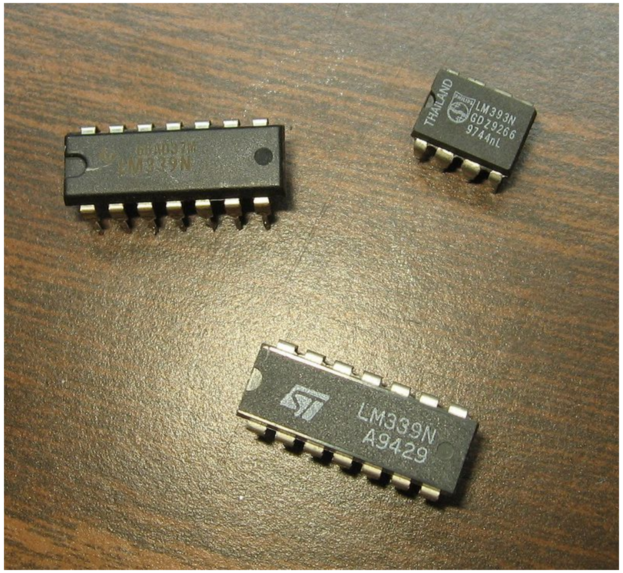




Comparators basics

•Before we can learn about A2D converters we need to learn about comparators.



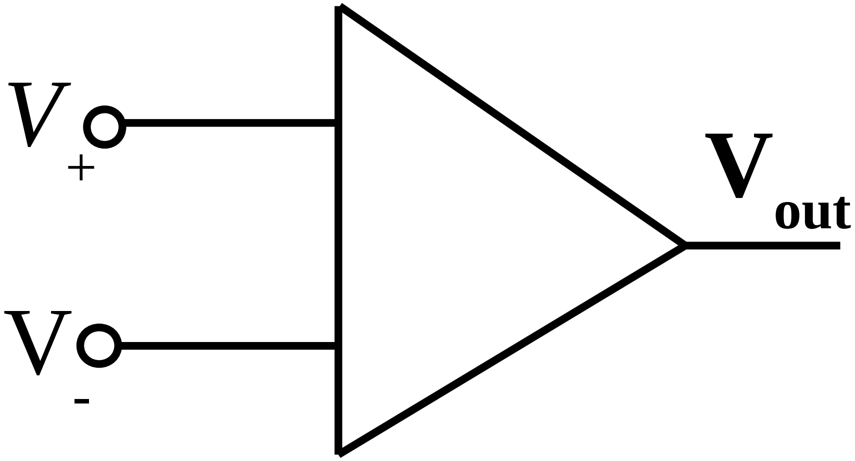


Stuuf

•Comparators look ***just like*** an ***op-amp***, in fact you can use an op-amp as a low performance comparitor, but you are better off getting a specially designed chip like the LM393.

Comparators basics

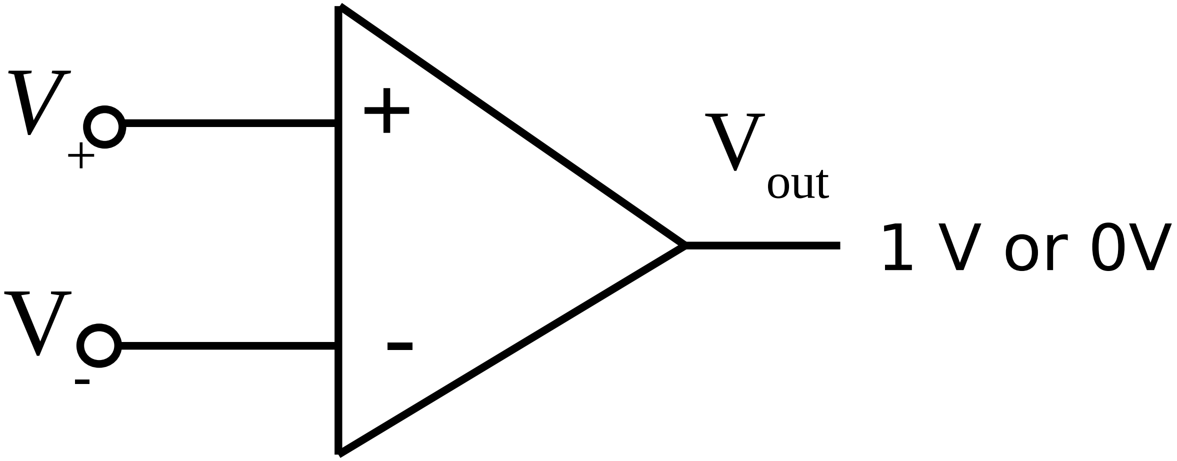
- Comparators compare two voltages:



- For example...

Compactors basics

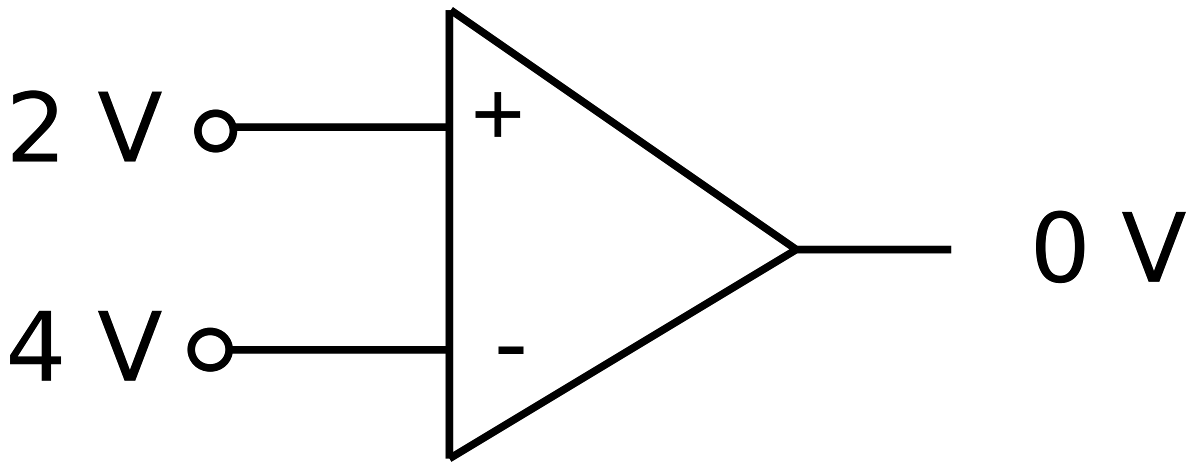
- If **V_+** is **BIGGER** than **V_-** it will output a **1 V**
- If **V_+** is **SMALLER** than **V_-** it will output a **0 V**



- For example…

Comparators

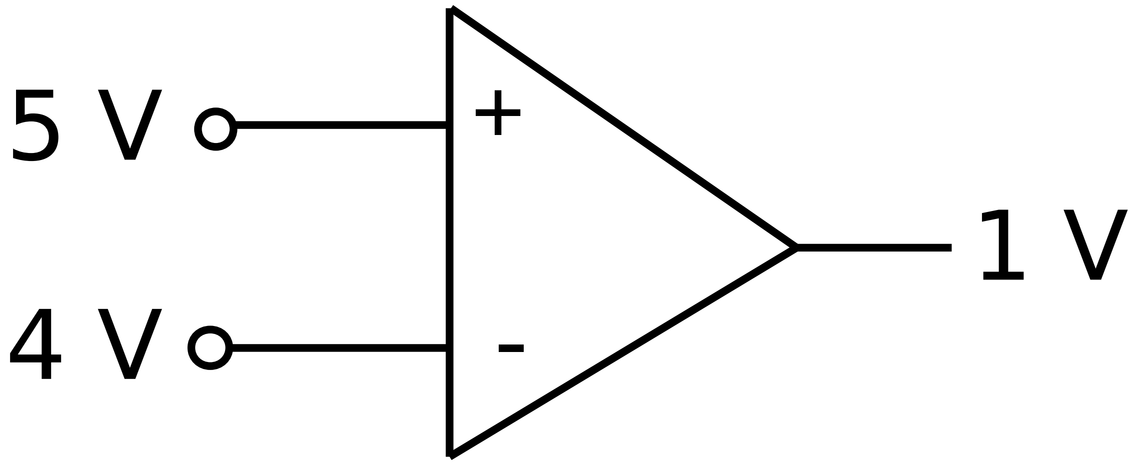
- If V_-=4 V and V_+=2 V it will output 0 V.



- For example...

Comparators

- If V_-=4 V and V_+= 5 V it will output V 1.

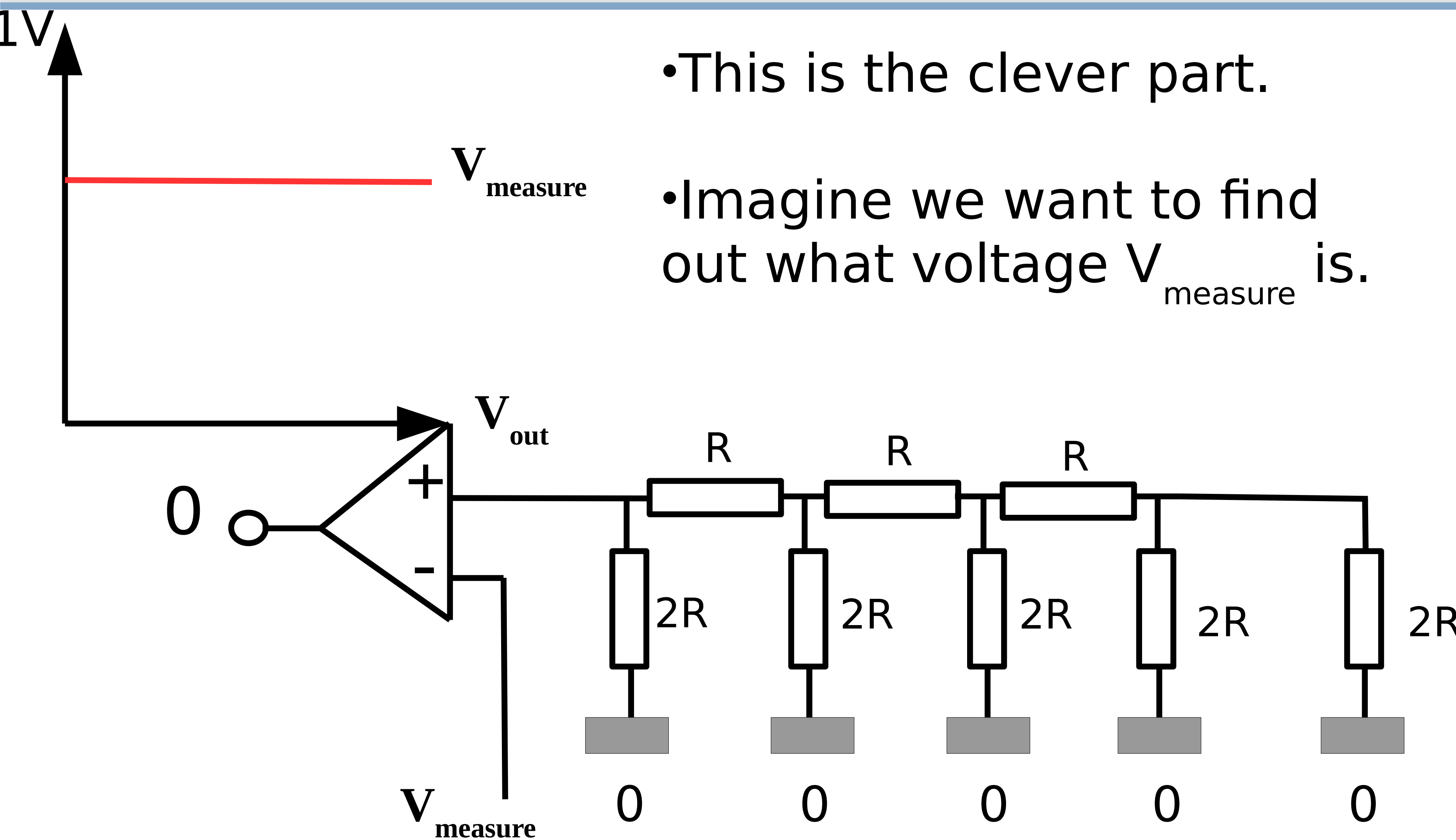


- We now know everything we need to implement an analog to digital converter.

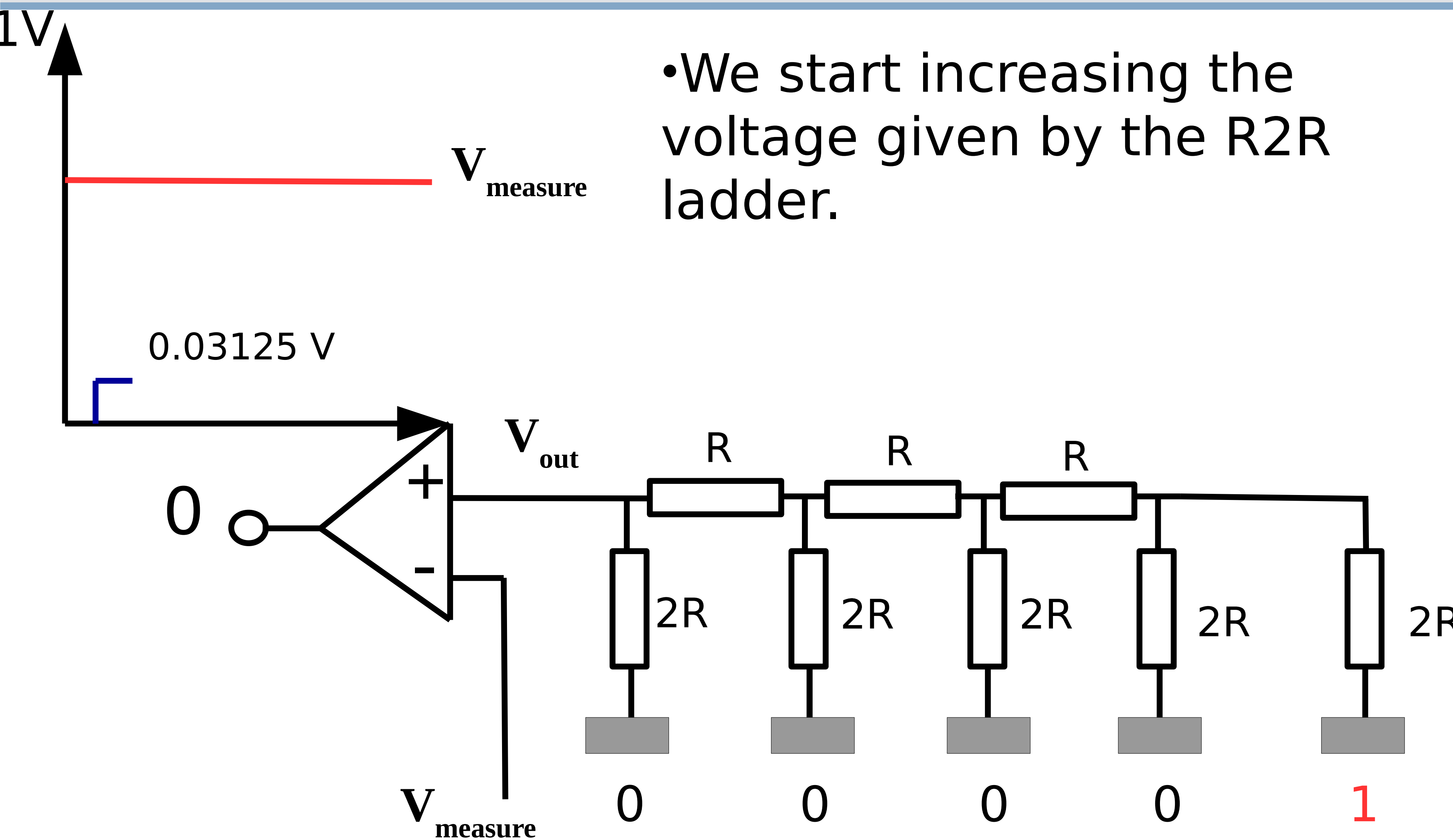
Stick our comparator on the output of and R2R ladder

•This is the clever part.

•Imagine we want to find out what voltage $V_{measure}$ is.

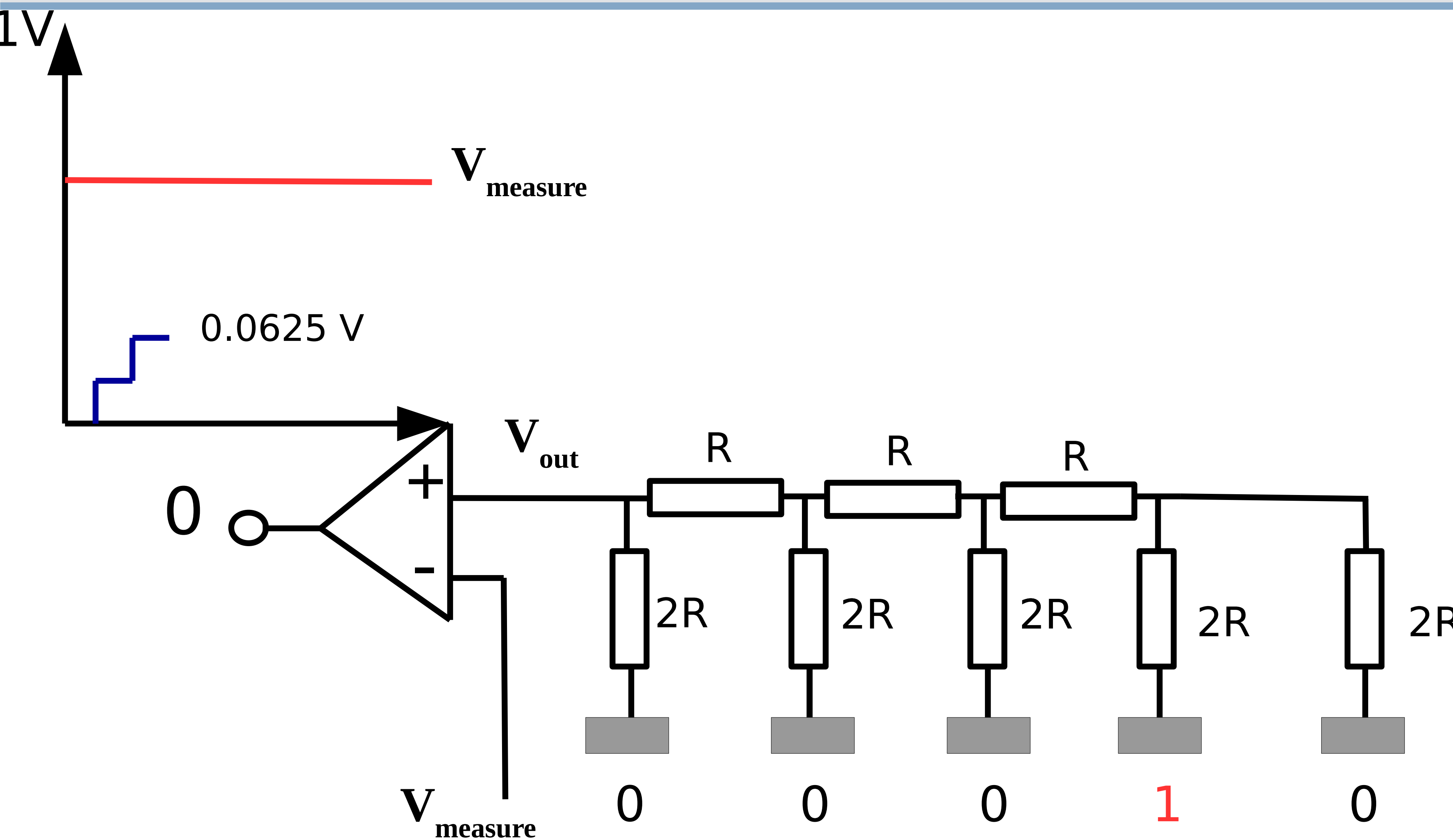


Binary 1

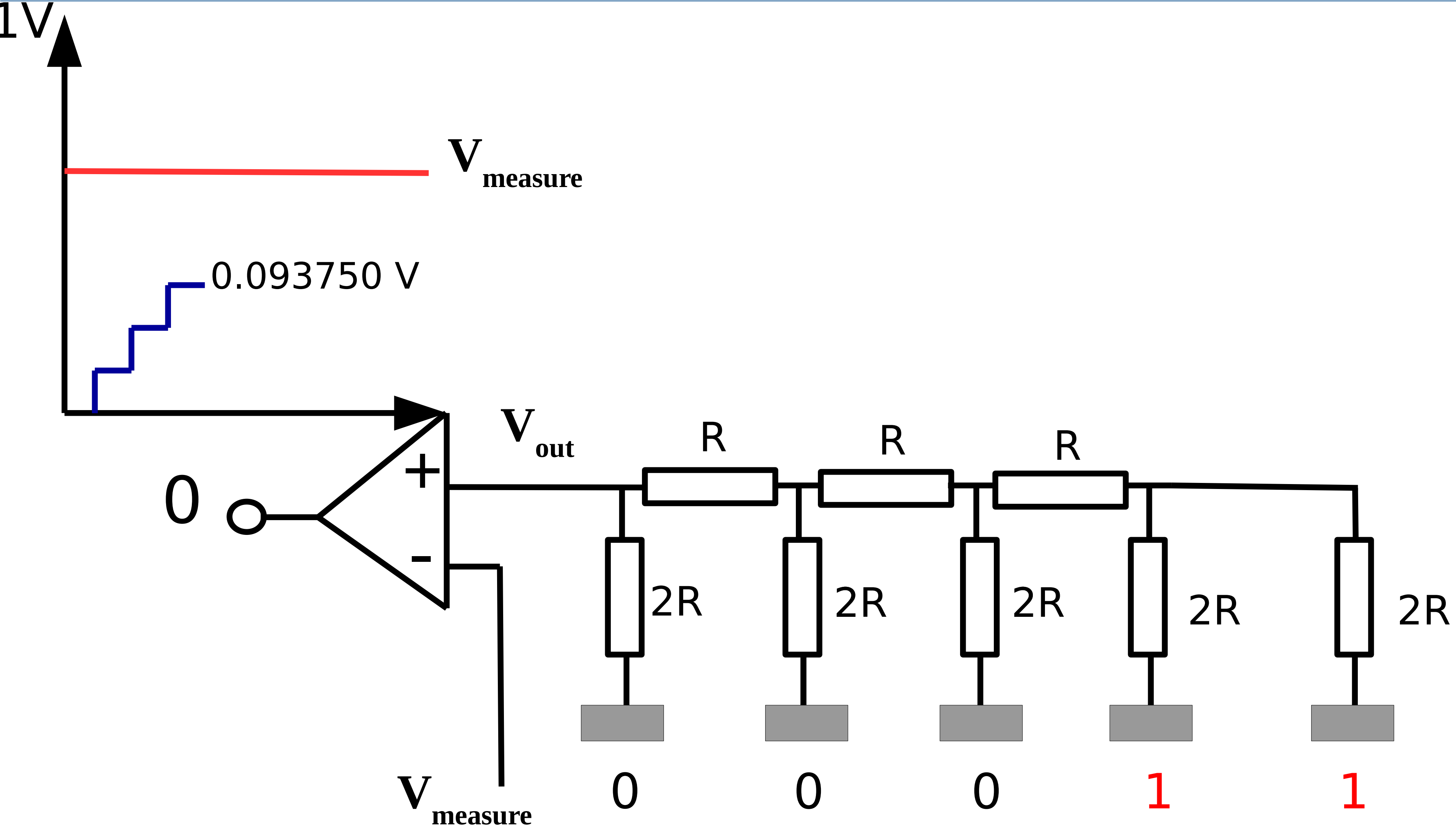


•We start increasing the voltage given by the R2R ladder.

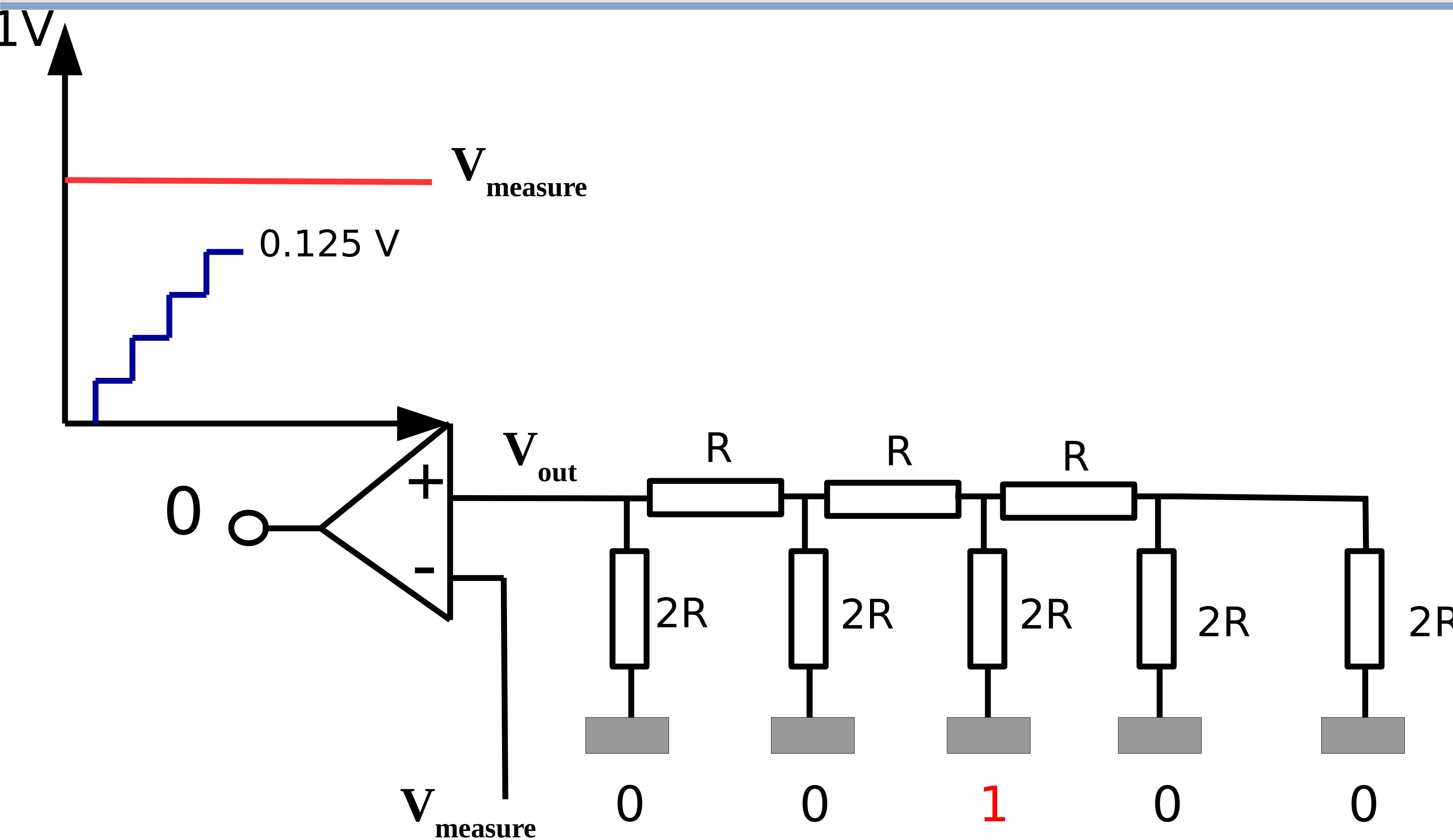
Binary 2



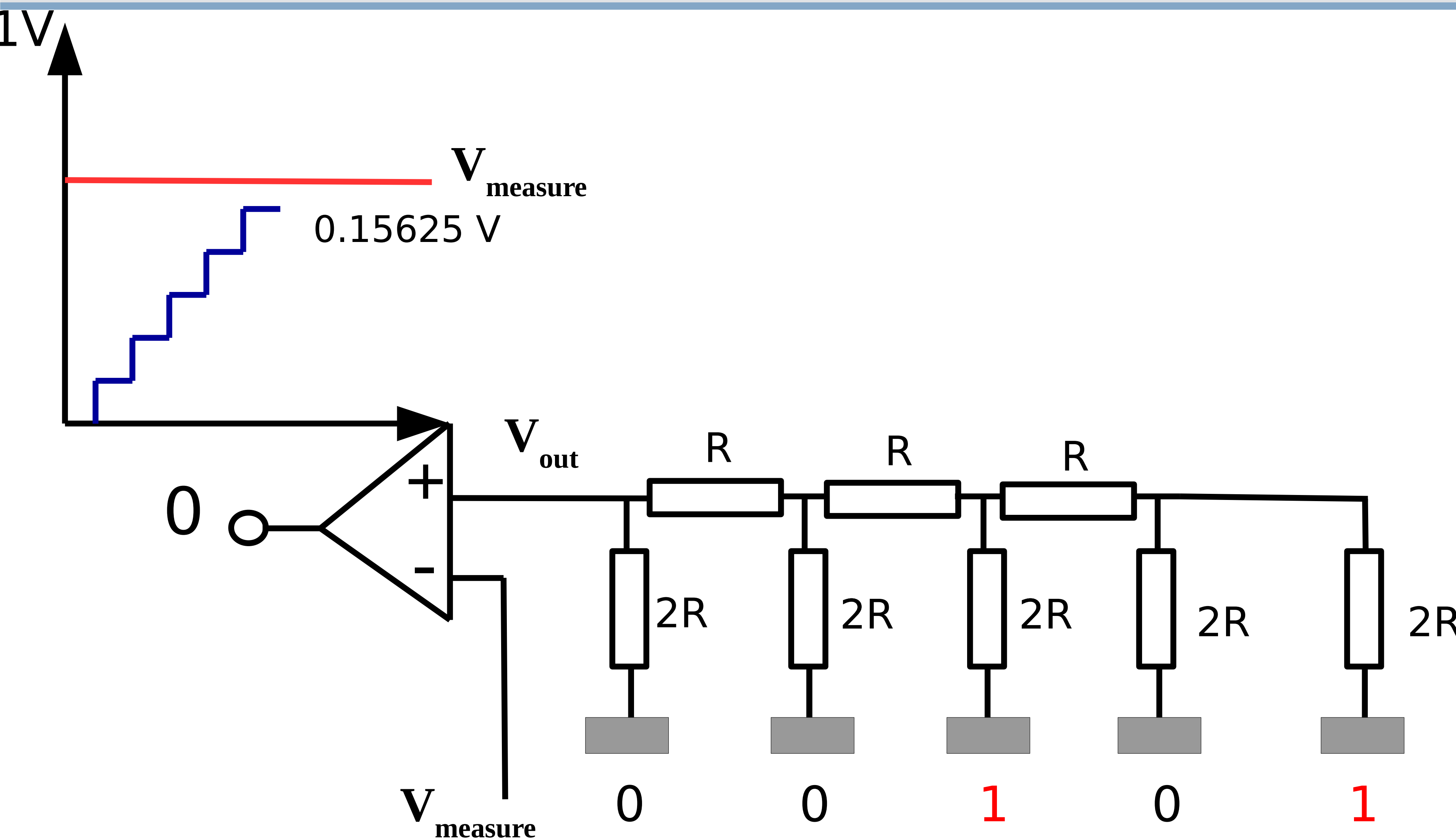
Binary 3



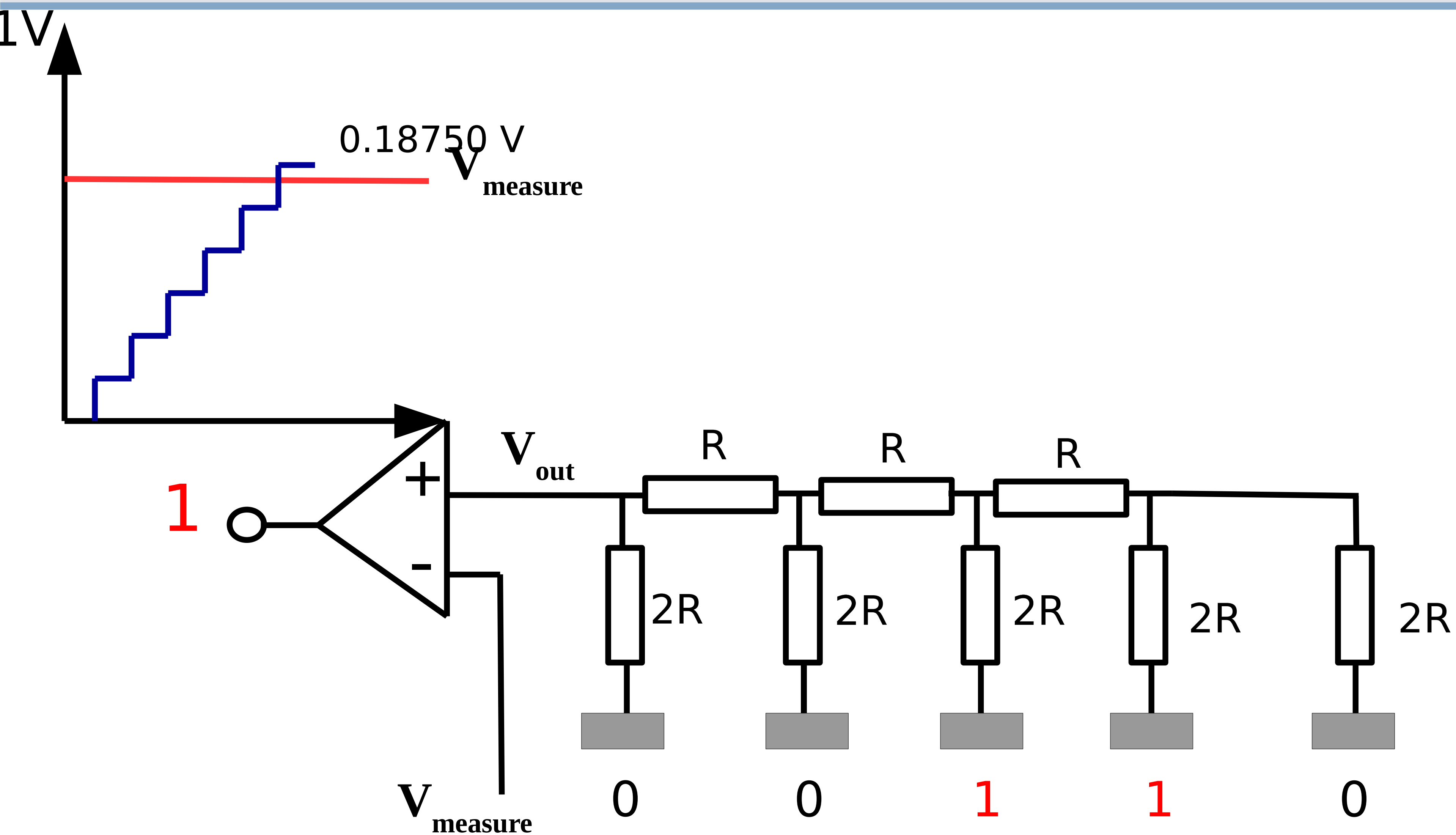
Binary 4



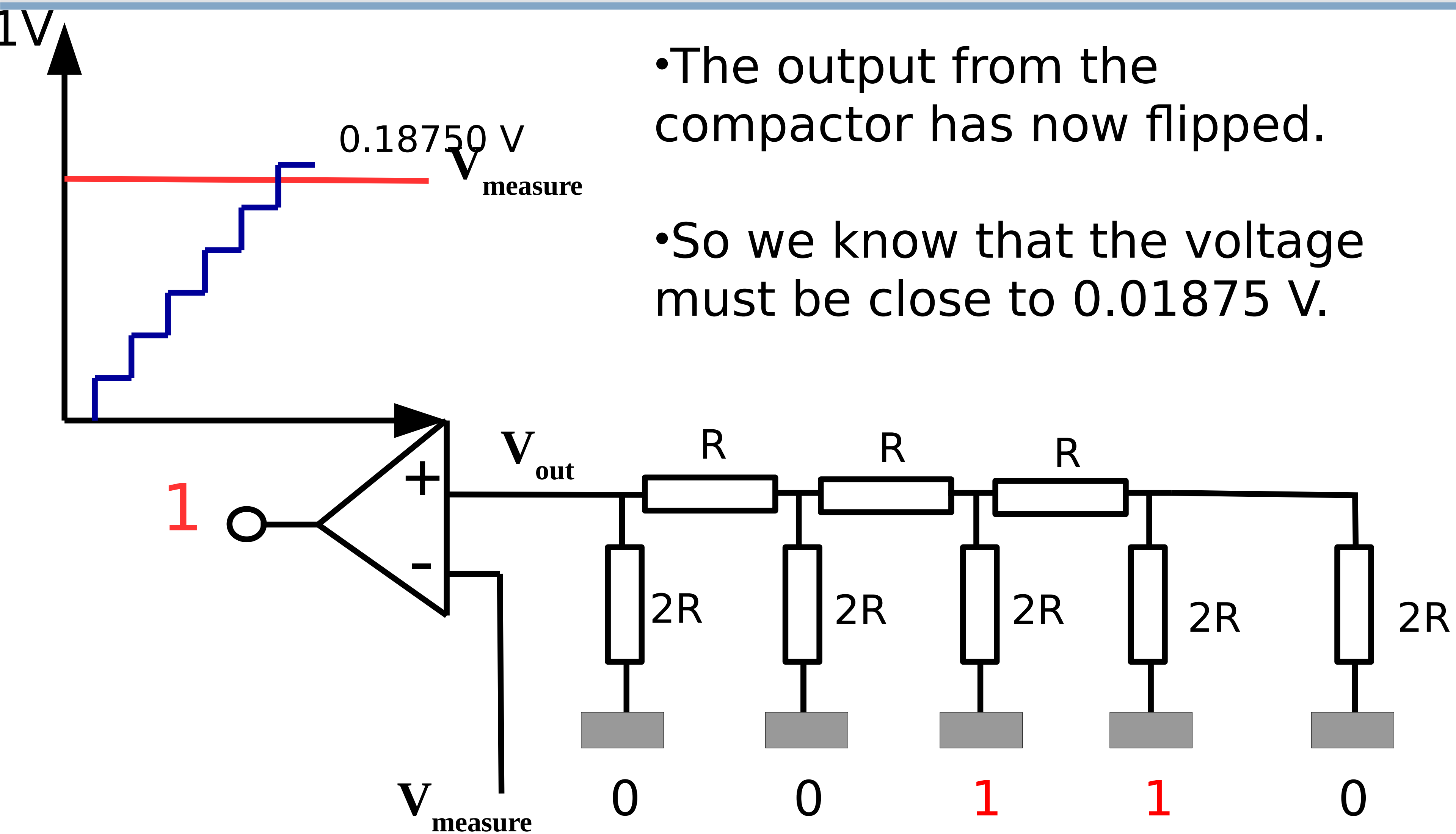
Binary 5



Binary 6 – and the output bit flips



Binary 6 – and the output bit flips



- The output from the compactor has now flipped.
- So we know that the voltage must be close to 0.01875 V.

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Disadvantages of R2R based converters

•The problem with the analog to digital converter based on the R2R ladder is that is takes a finite amount of time to count up.

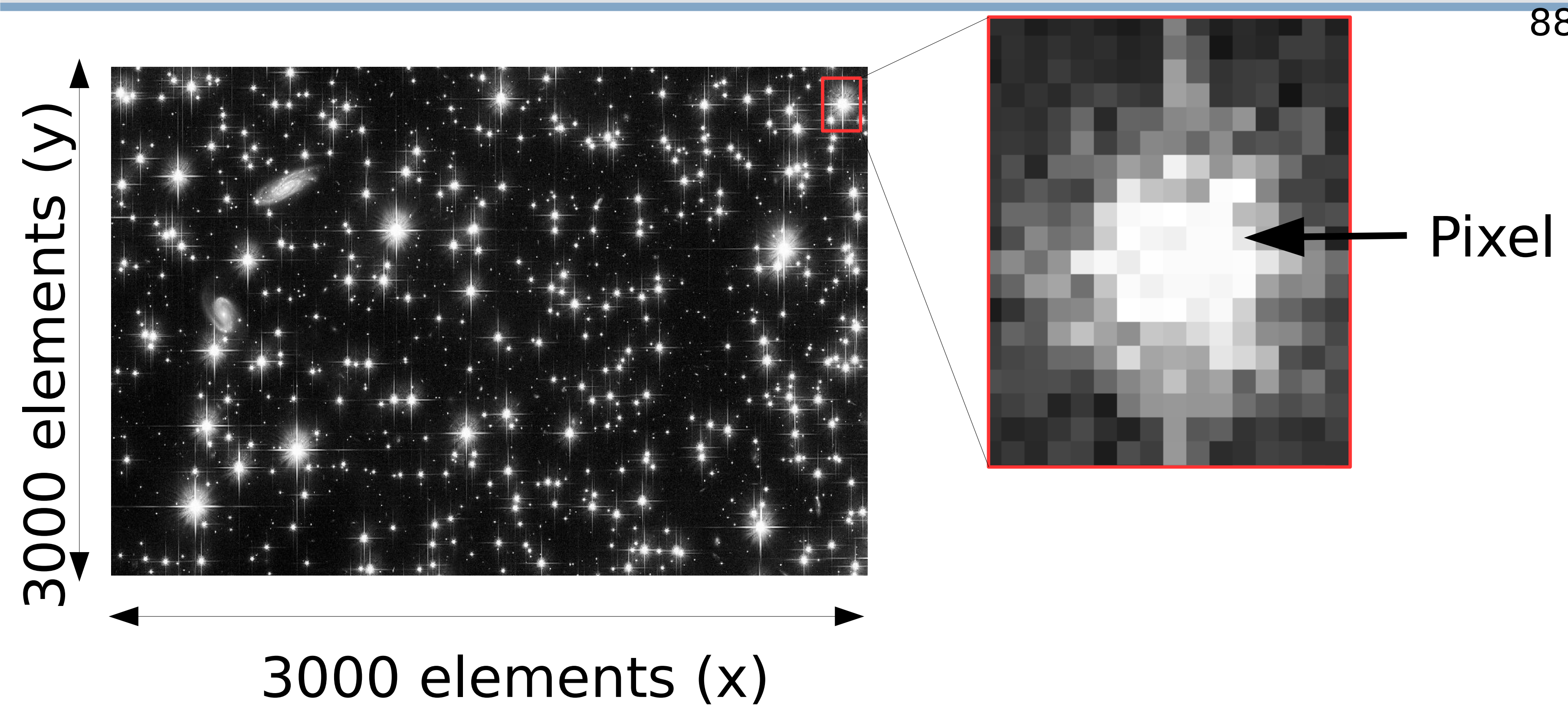
•This means conversion is ***slow***.

André Karwath

•However they are low cost and you do find them in lots of places – such as in volt meters.

•The ***flash converter*** for video and other speed applications.

Video data

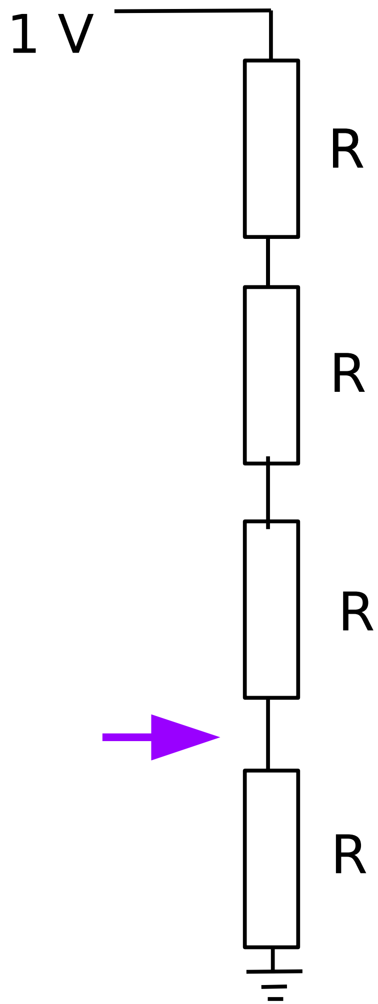


- To capture video we will need to convert all these pixels (voltages) to binary numbers instantly.

- There is no time for counting and using R2R ladders.

The Flash converter

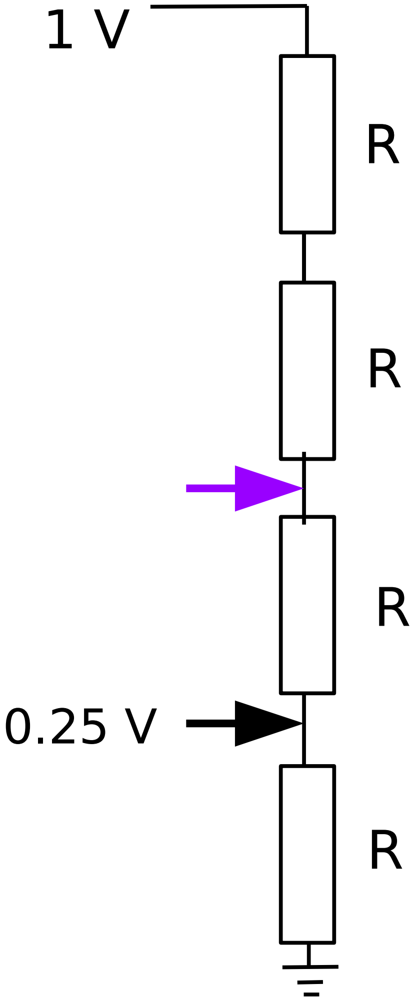
- Think about these resistors



- What will the voltage here?

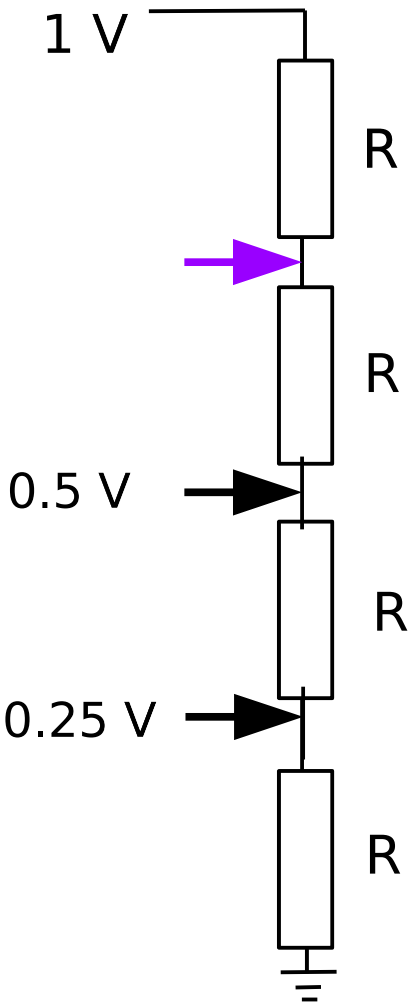
The Flash converter

- Think about these resistors



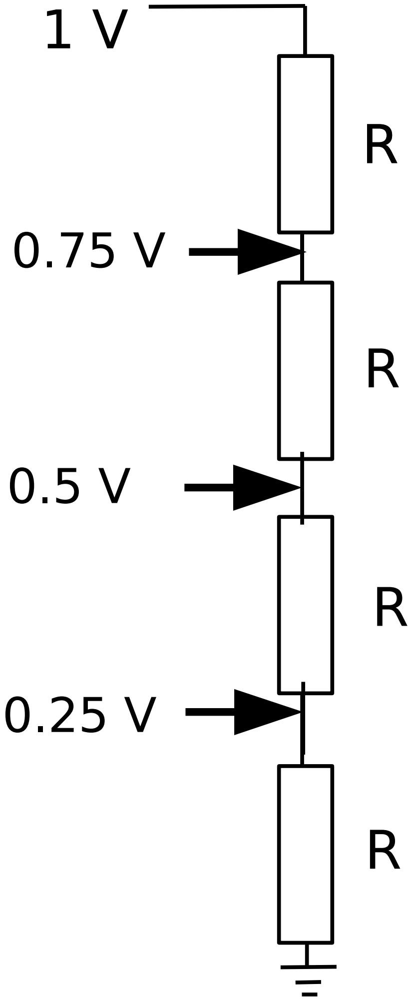
The Flash converter

- Think about these resistors

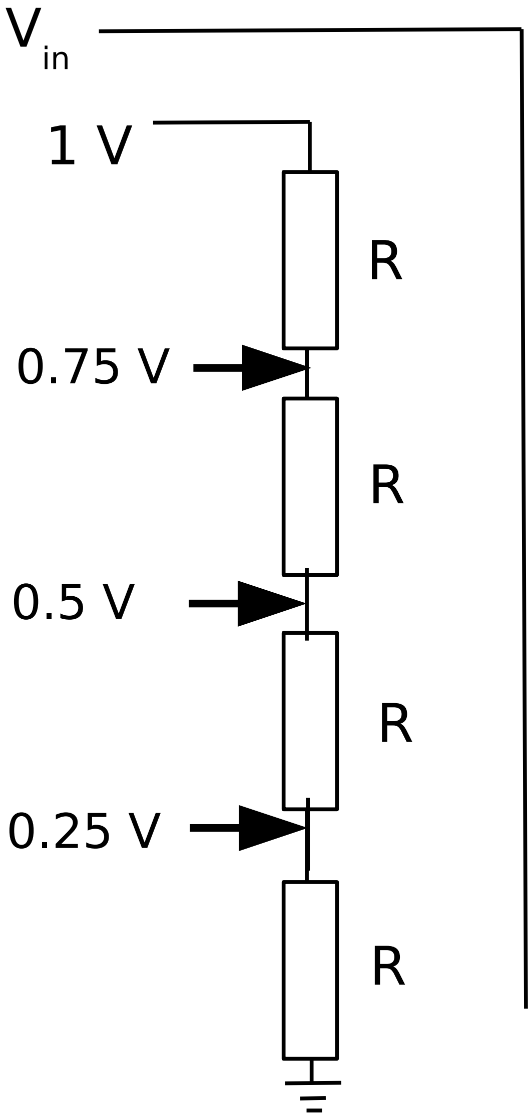


The Flash converter

- Think about these resistors

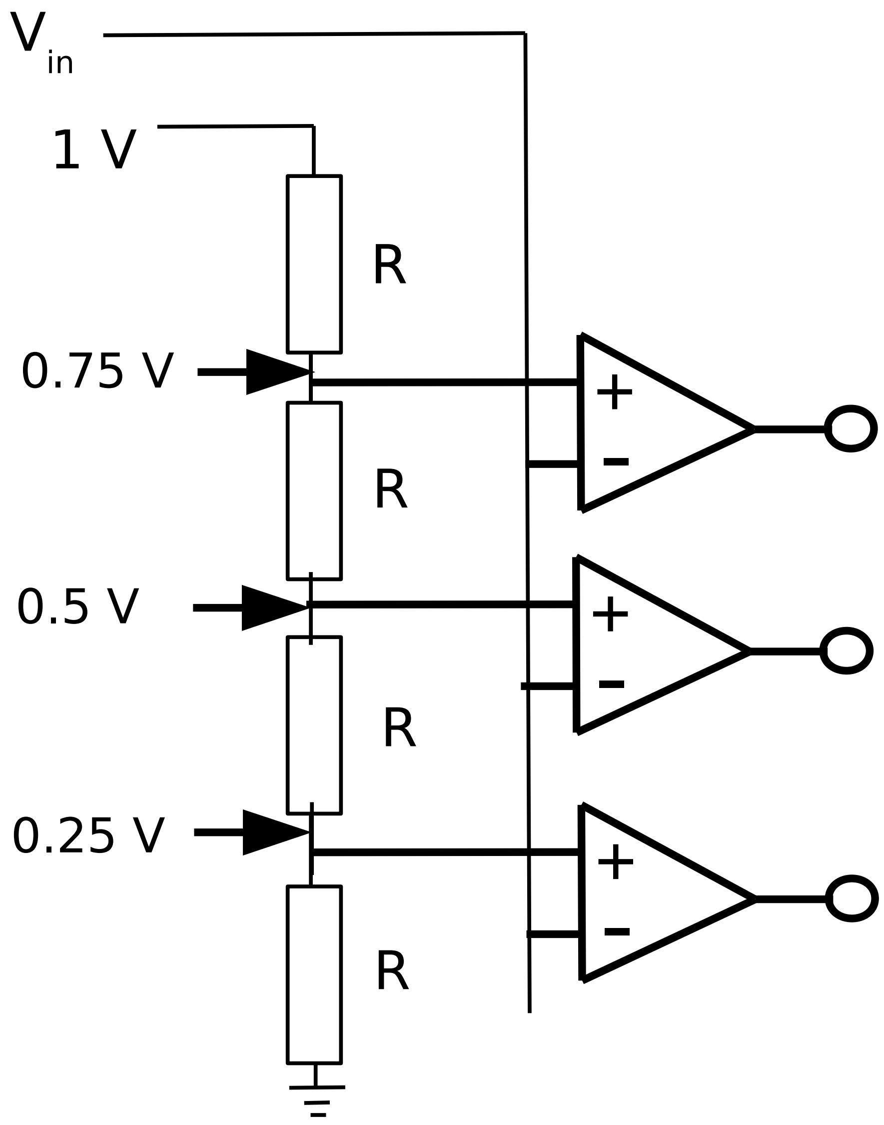


The Flash converter

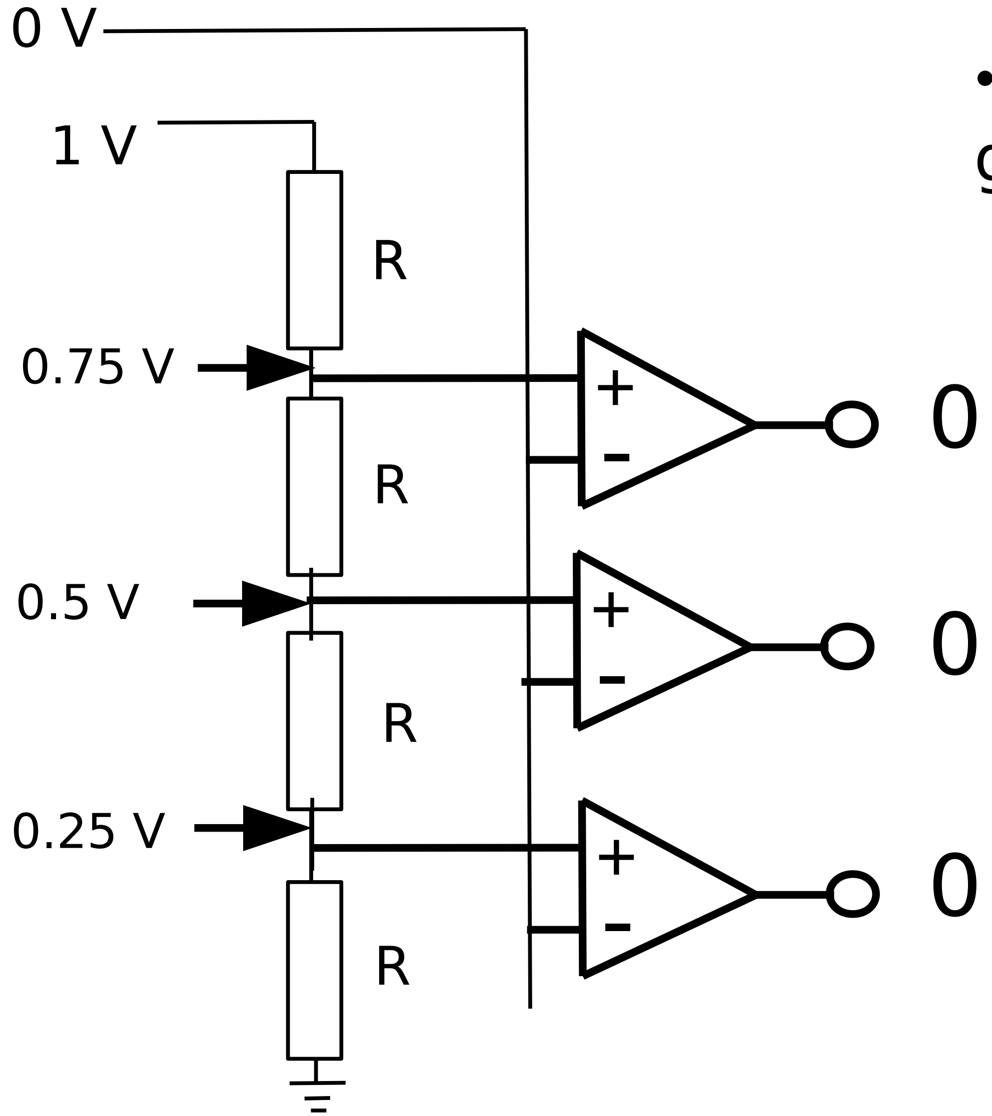


•Connect some comparitors

The Flash converter

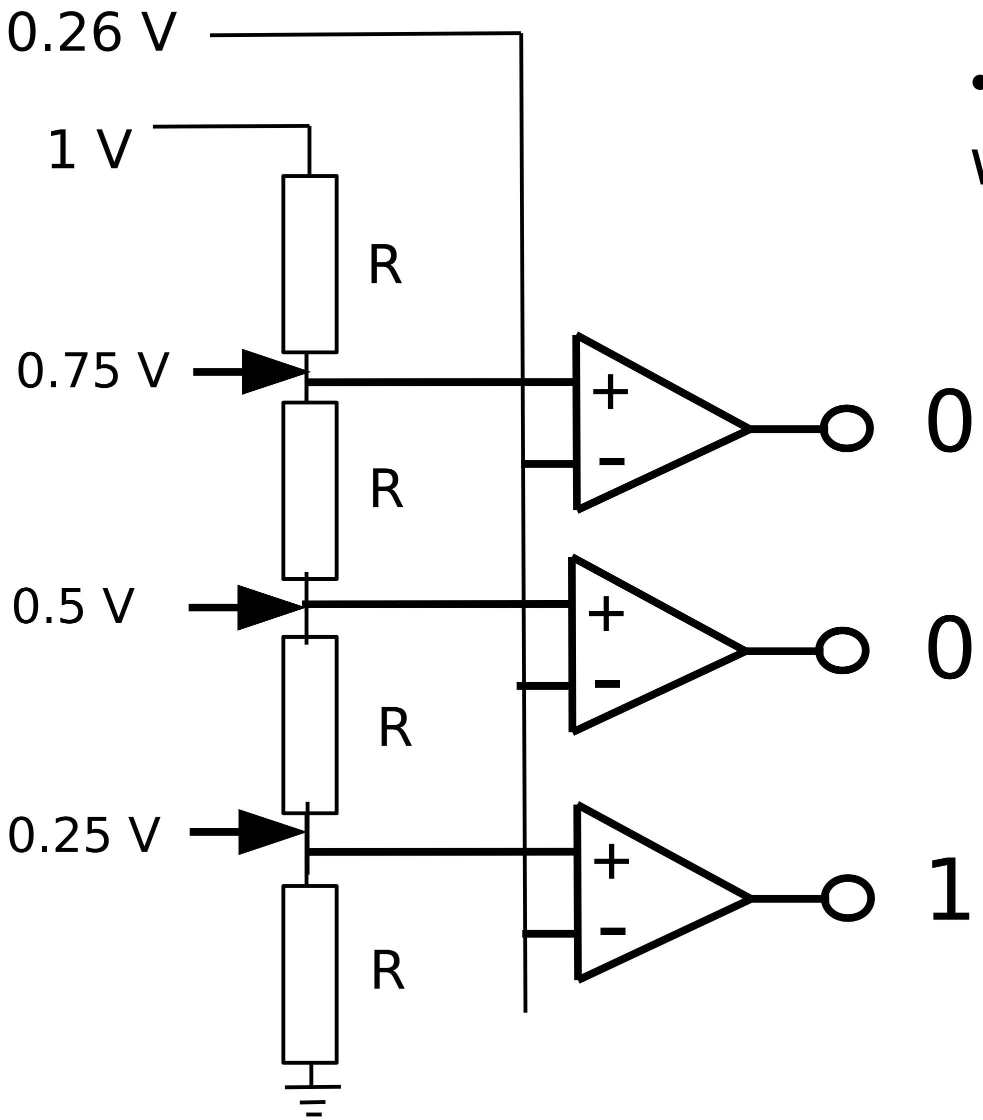


The Flash converter



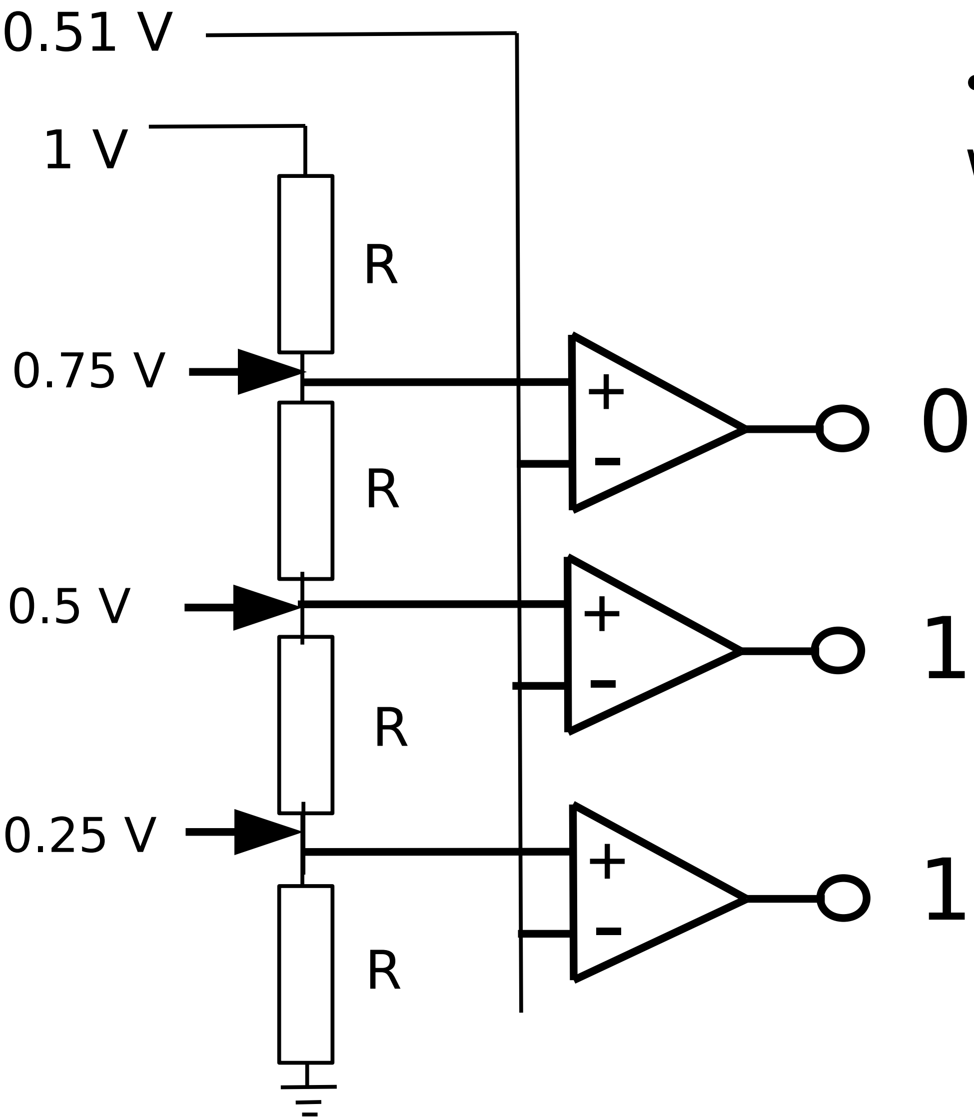
- If we have 0 V input we will get all 0's out.

The Flash converter



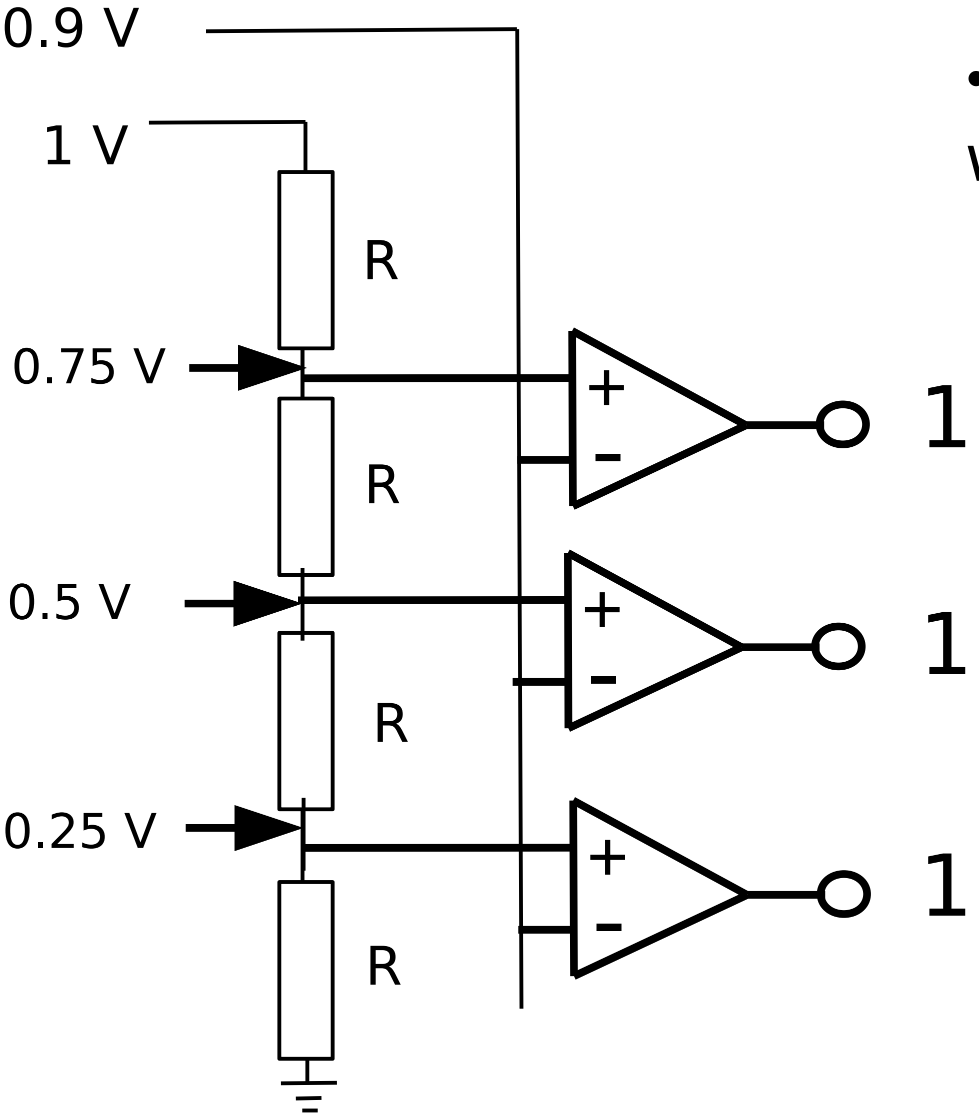
- If we have 0.26 V input we will get 001 out.

The Flash converter



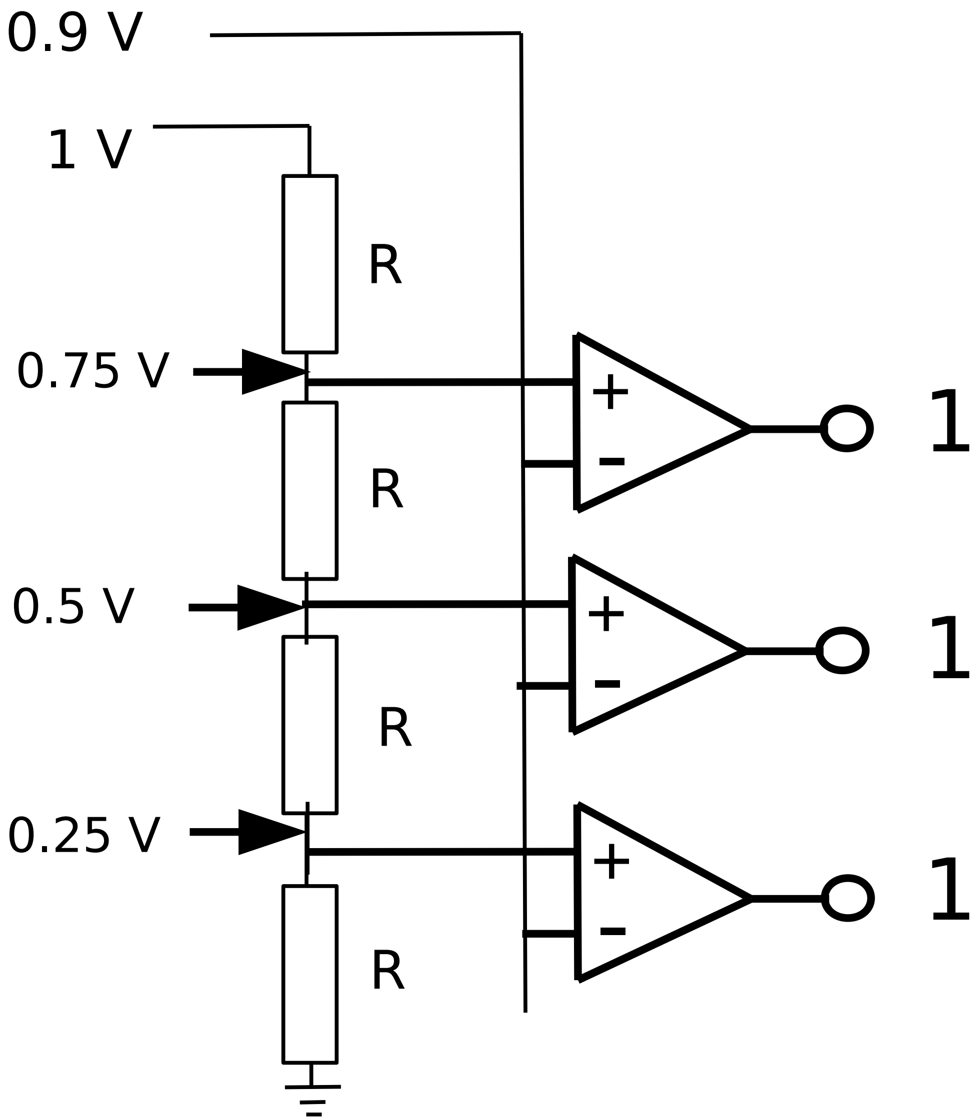
- If we have 0.51 V input we will get 011 out.

The Flash converter



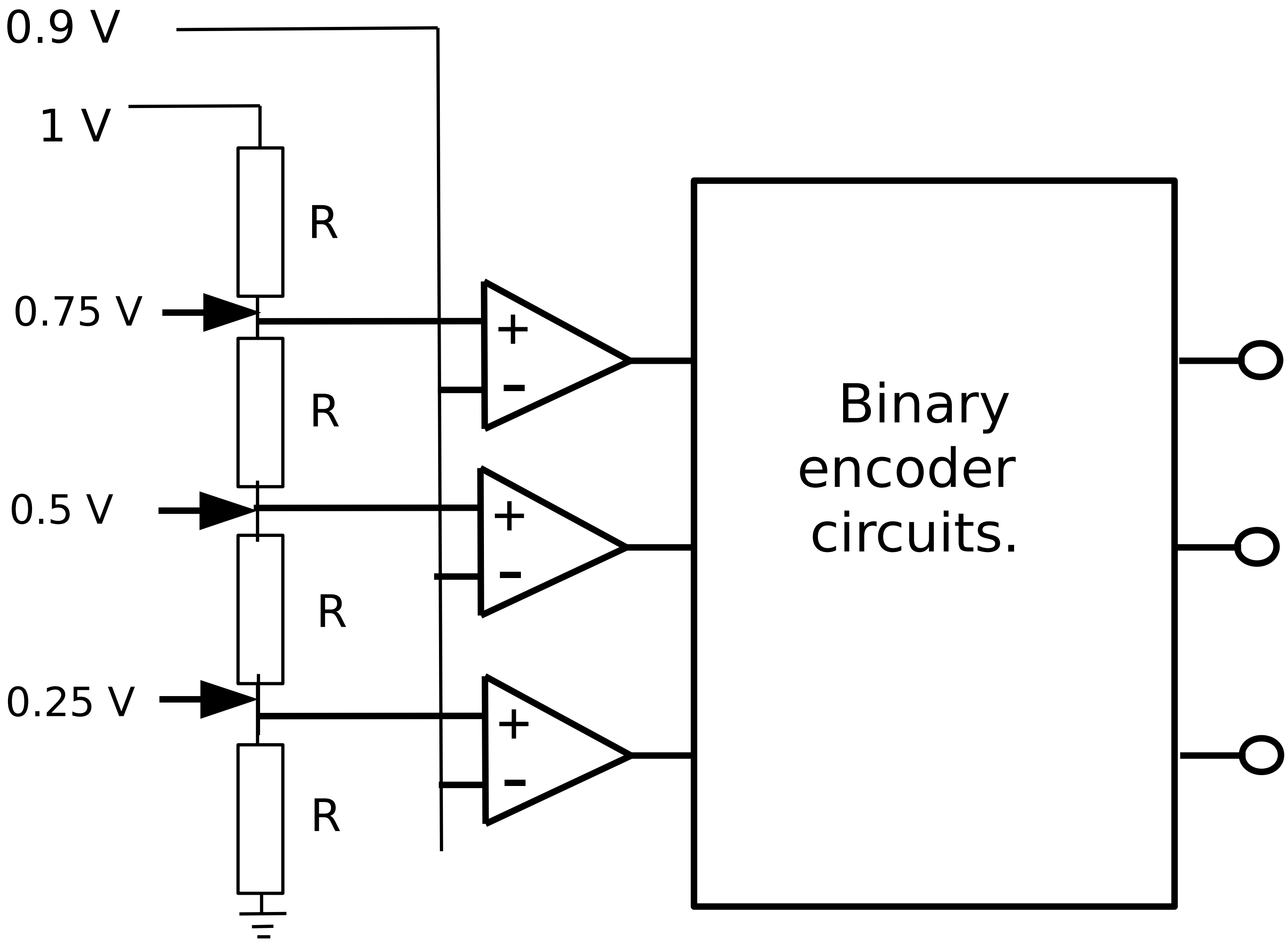
- If we have 0.9 V input we will get 111 out.

The Flash converter



- Notice the output is not binary code.
- We will therefore need a digital circuit to convert it to binary.

The Flash converter



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