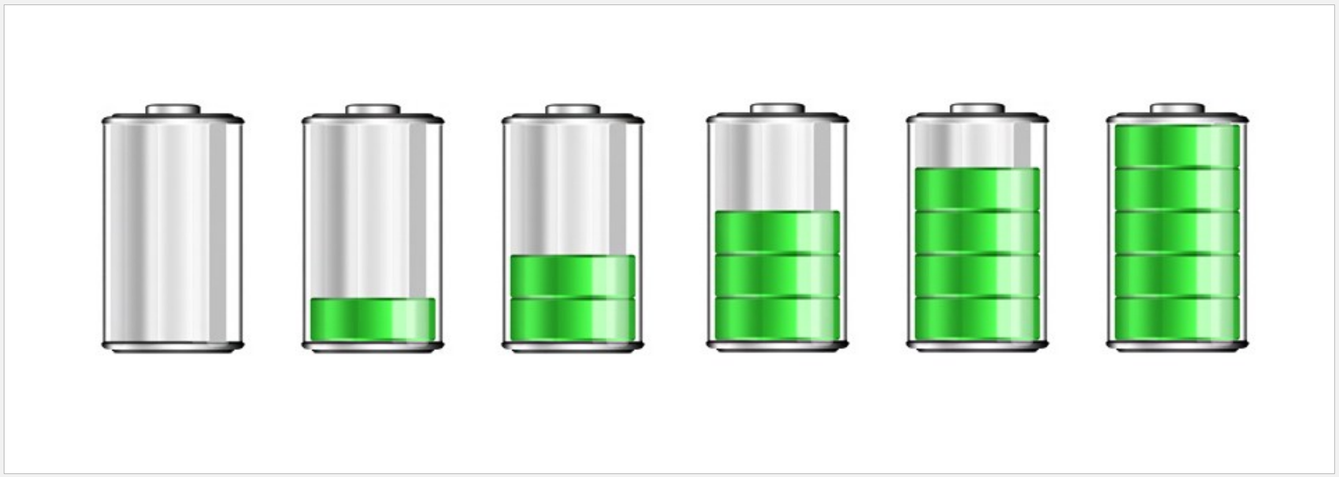
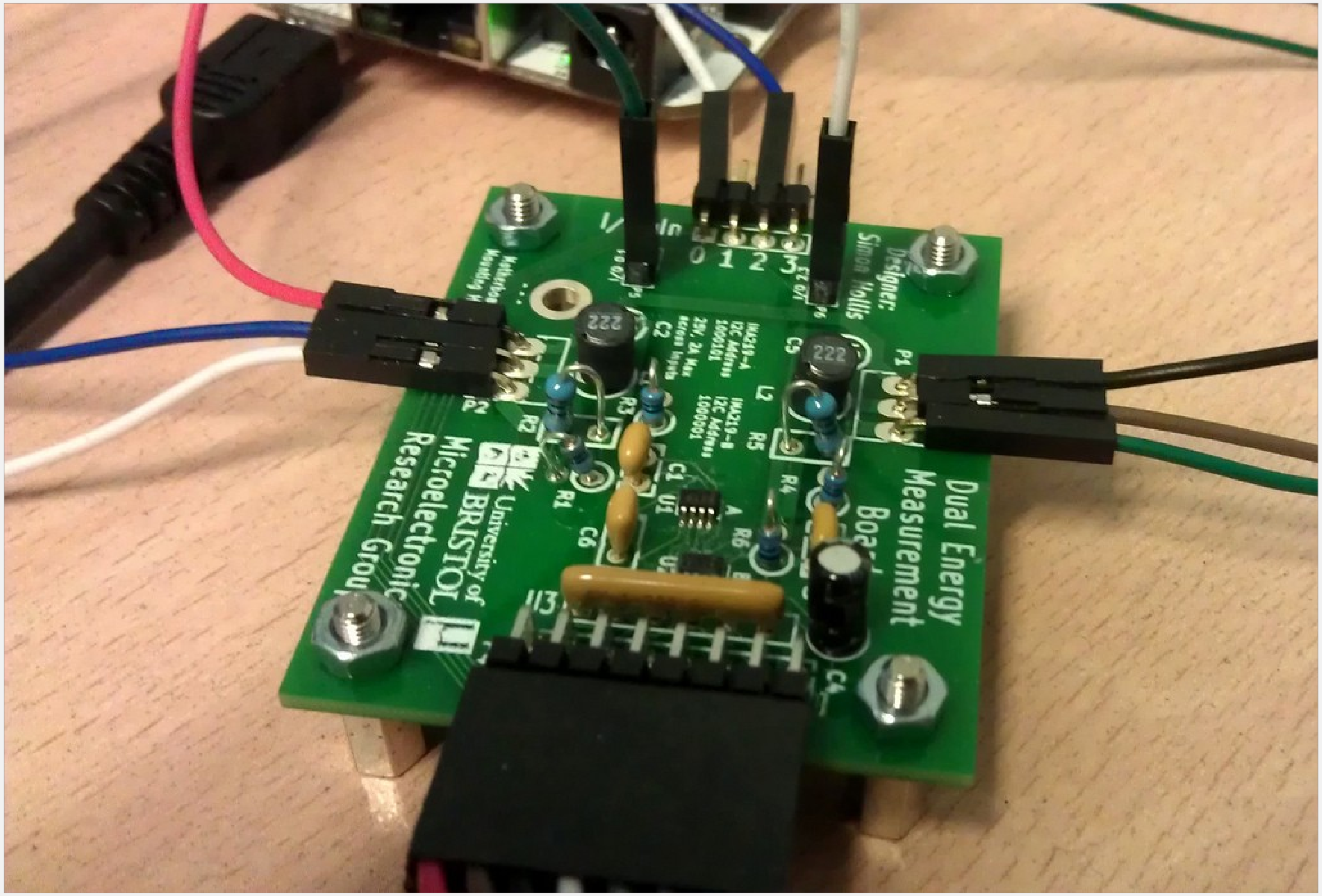
Energy (in Embedded Systems)



James Pallister

Research Engineer, Embecosm
PhD Student, University of Bristol


Dual Energy
Measurement
Board
Designer:
Simon Hollis
University of
BRISTOL
Microelectronic
Research
0 1 2 3
P1
P2
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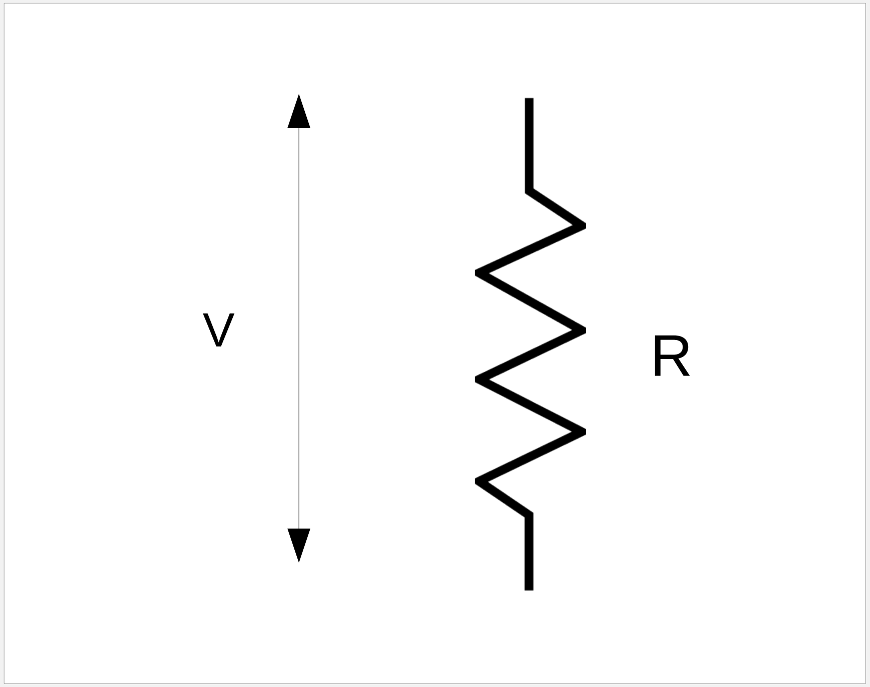
222

Quick electronics recap

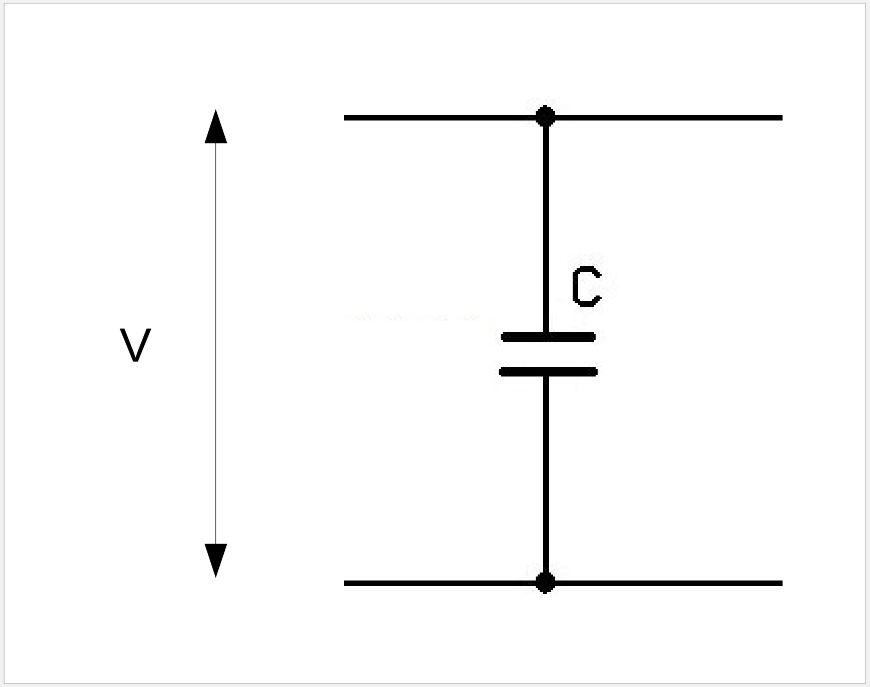
Resistors



$$V = I \times R$$

Quick electronics recap

Capacitors



$$Q = C \times V$$

What is energy?

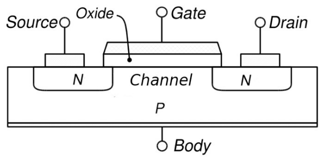
- In this context – amount of charge
  - Amount of charge taken to do something
  - Amount of charge available in my battery

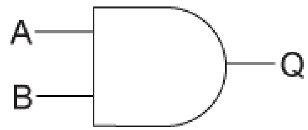
Units

- Energy or power?
- Energy
  - How much charge my battery contains
  - Joules (J)
- Power
  - How fast am I using that charge
  - Watts (W) = Joules per second (J/s)

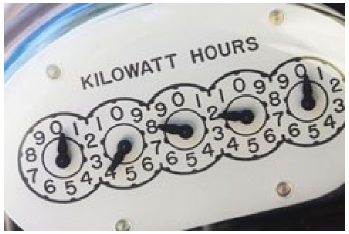
Topics

Where energy consumption comes from?

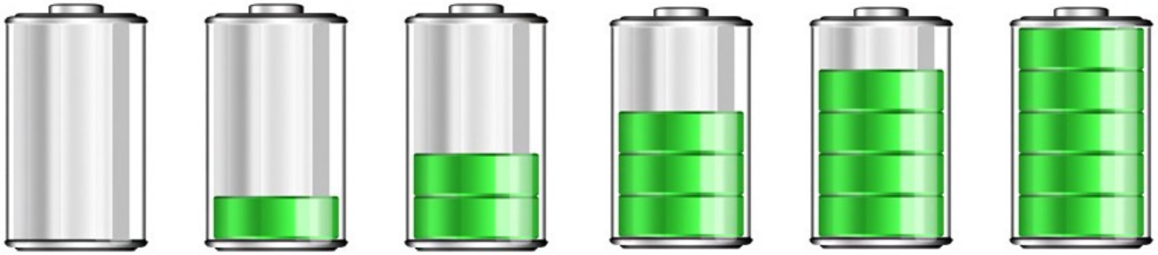




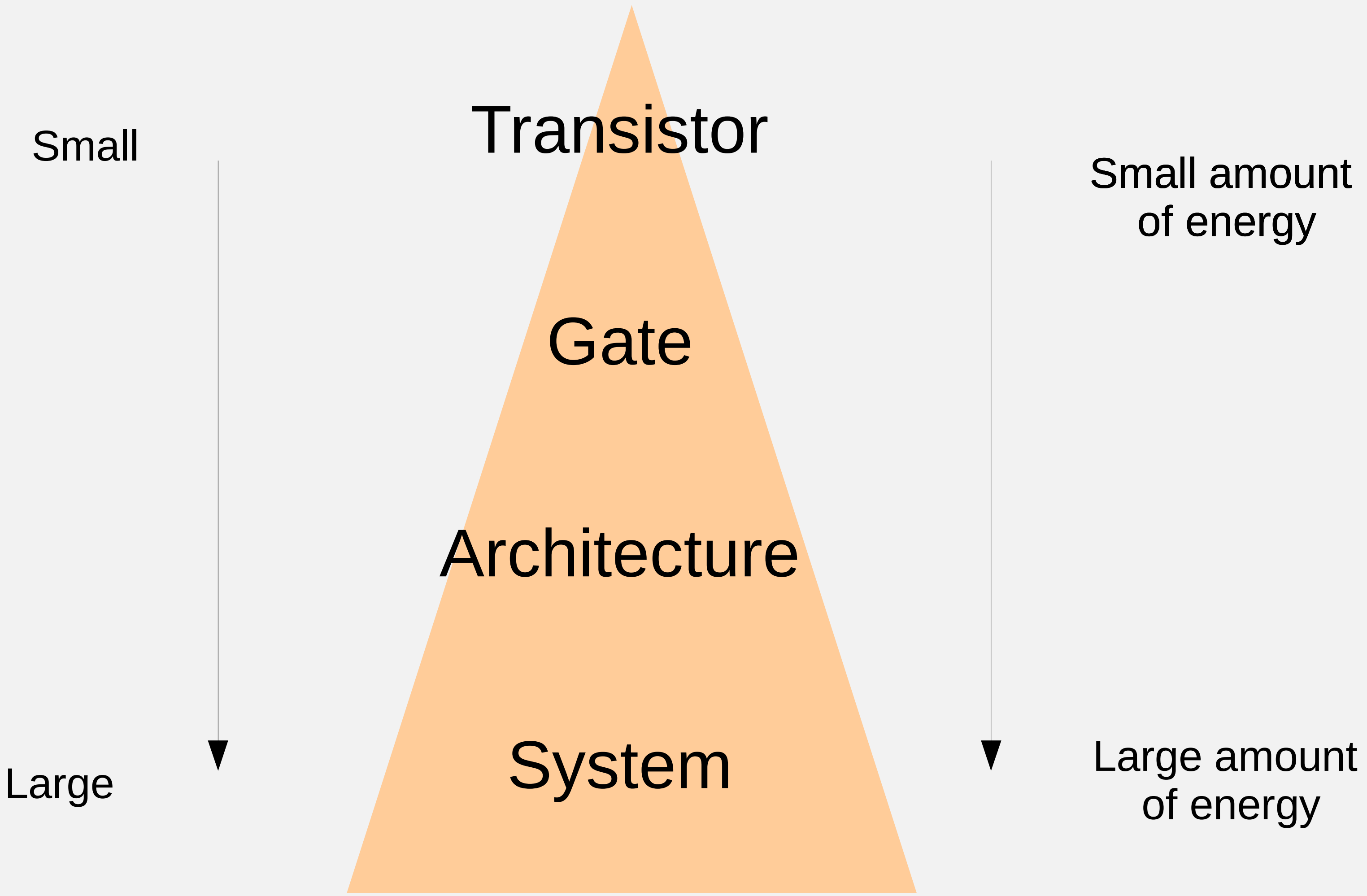
How do we measure energy consumption?



How do we minimise energy consumption?

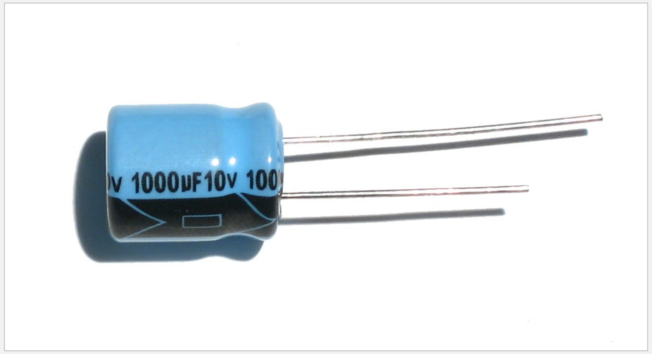


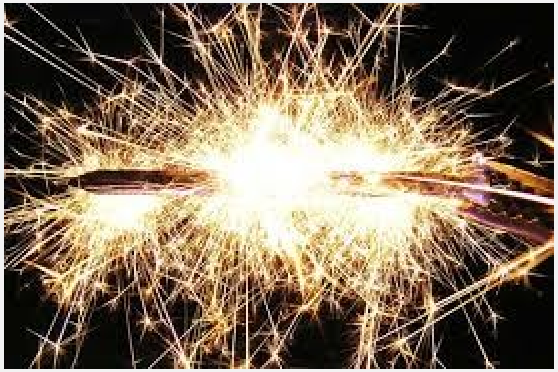
'Levels' of Energy Consumption



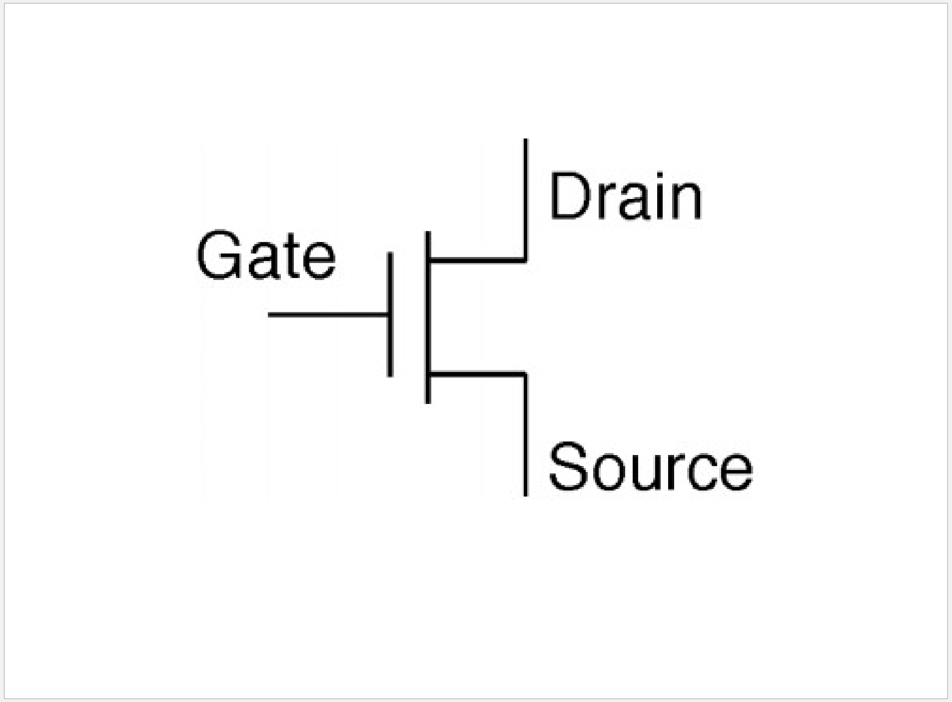
The Low Level

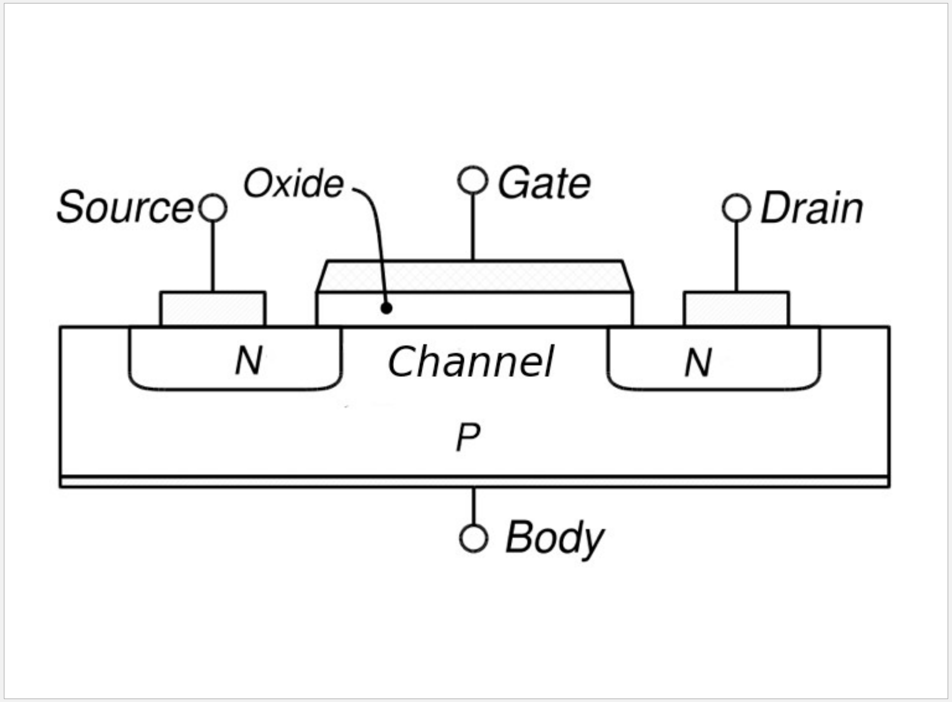
- Transistor's energy consumption
  - Resistive
  - Capacitative
  - Short circuit



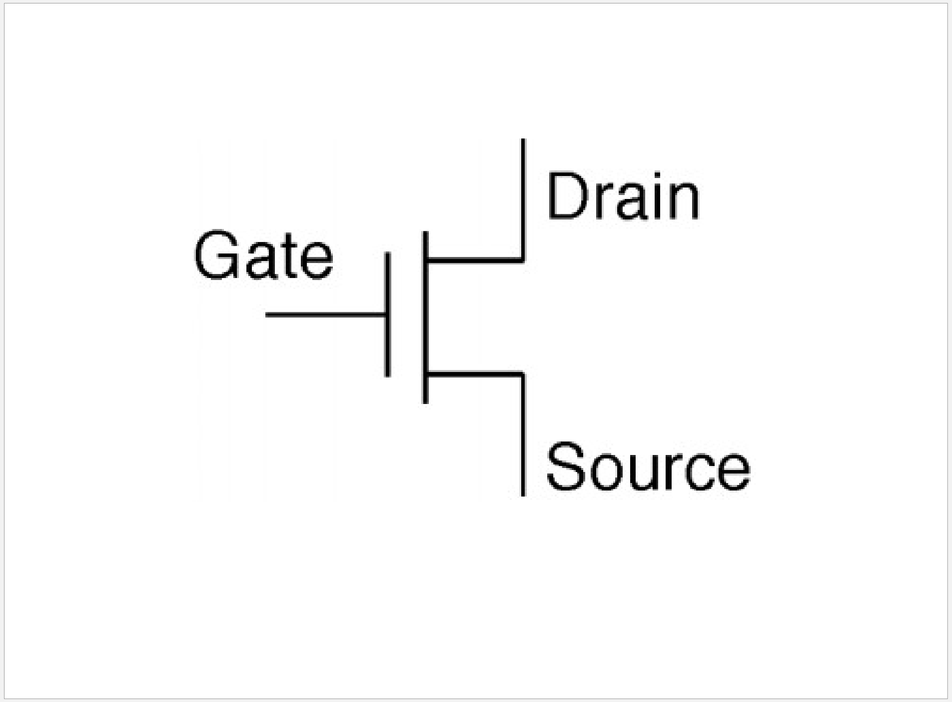


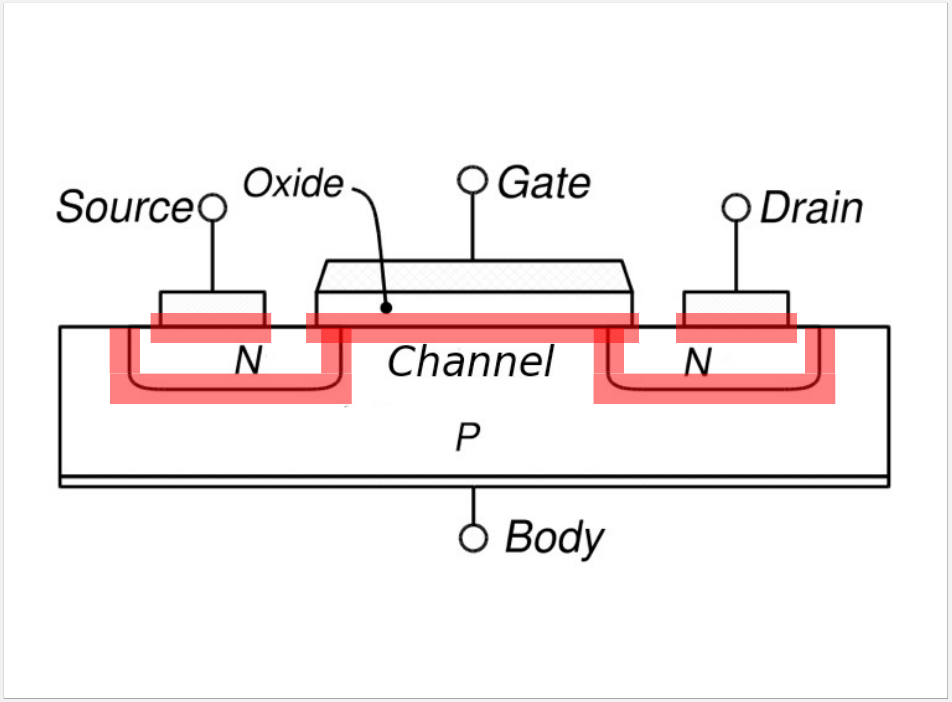
Transistors





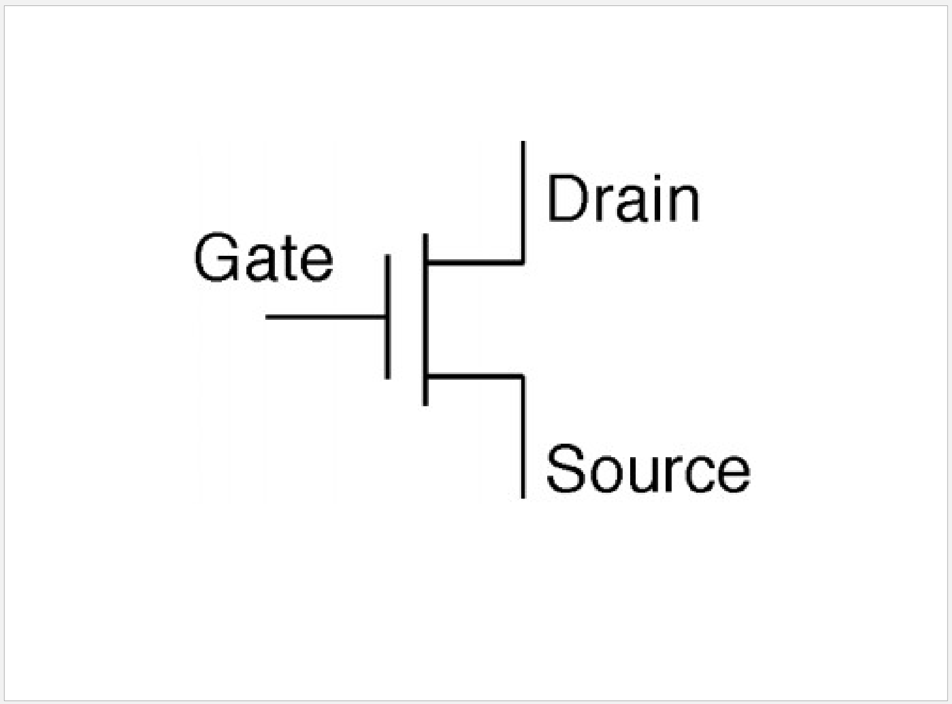
Transistors - Capacitance

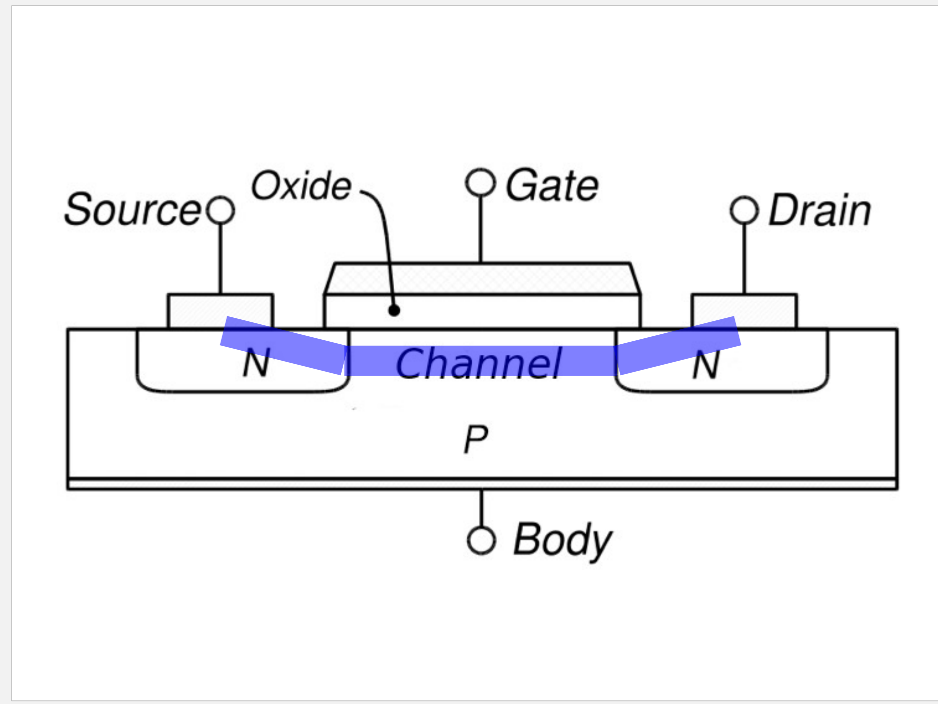




A certain amount of charge (I.e energy) is needed to charge up the capacitors

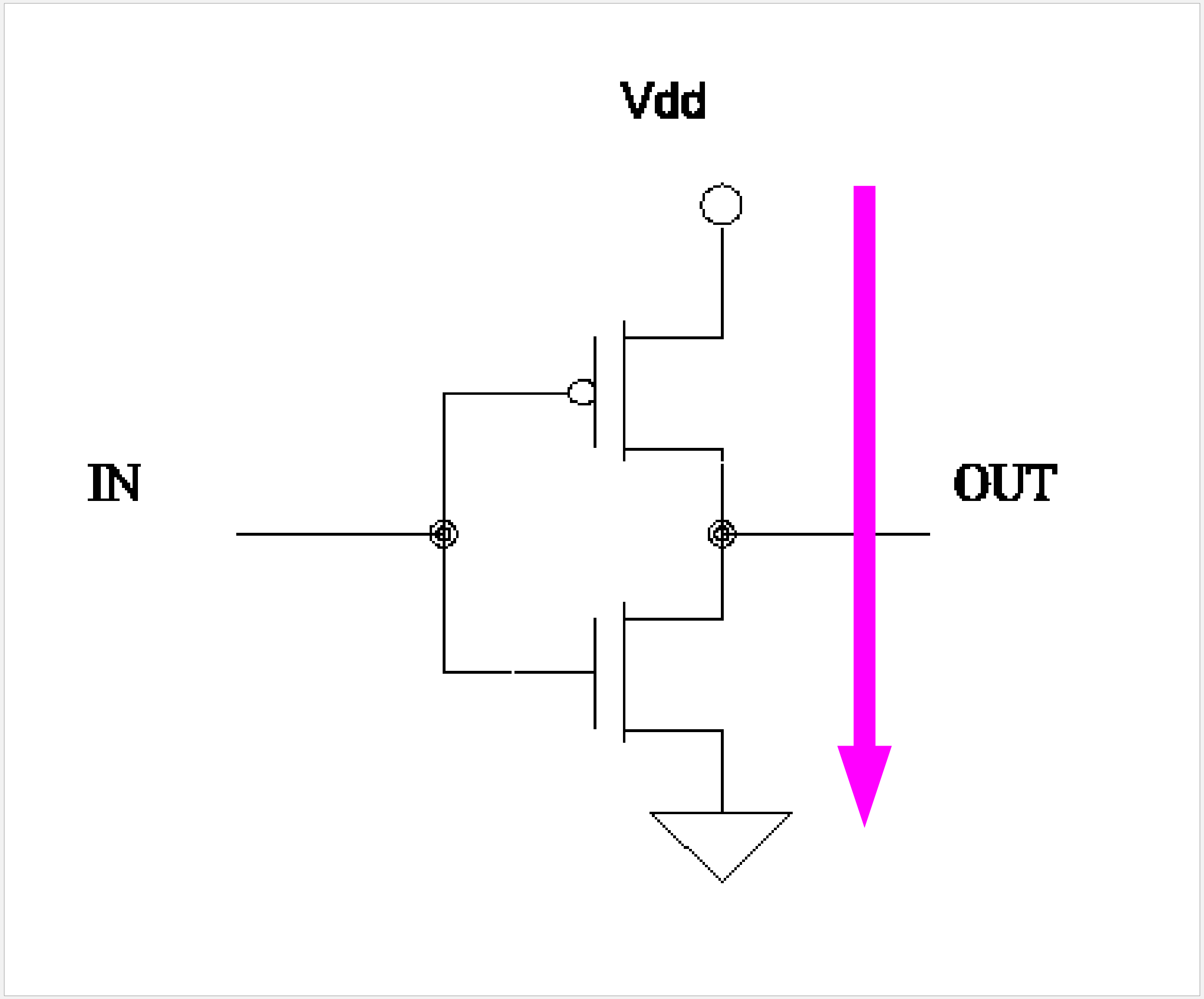
Transistors - Resistance





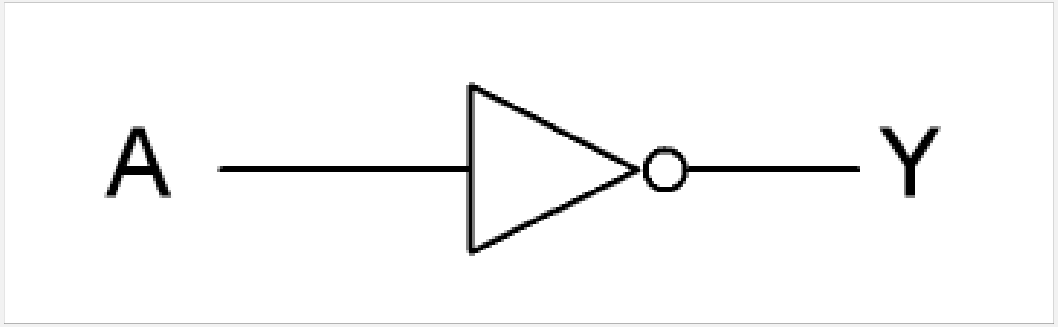
Resistors affect the flow of charge (i.e. power)

Transistors – Short Circuit



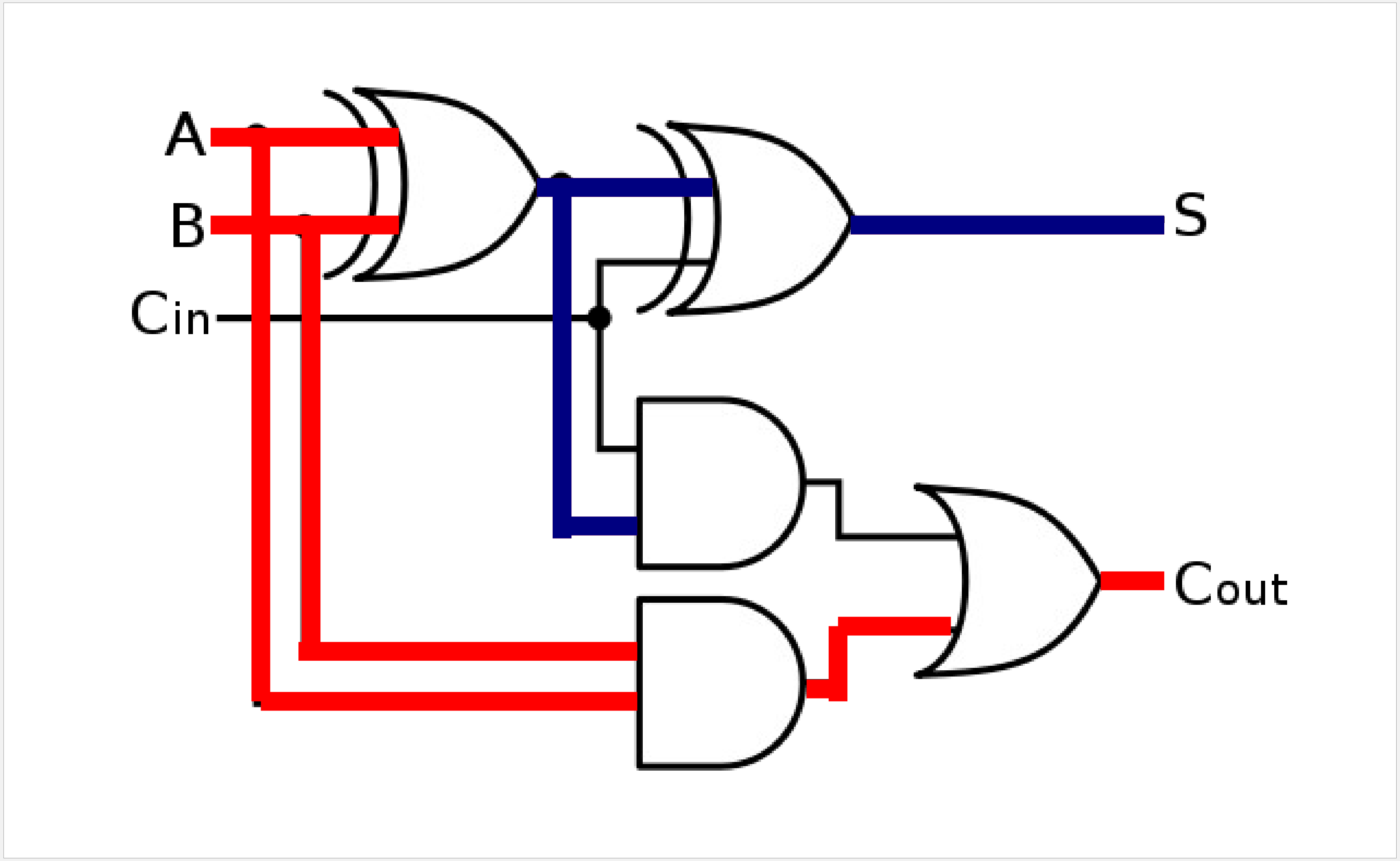
The Next Level - Gates

Bit flipping



A	Y
0	1
1	0

A Circuit



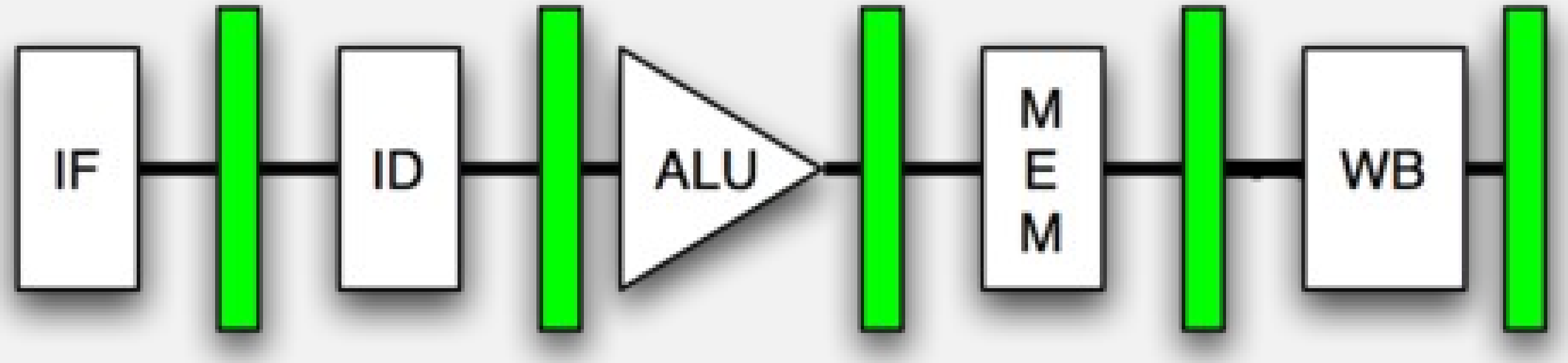
Consequences

Faster clock = Faster flipping

Faster flipping = More flips per second

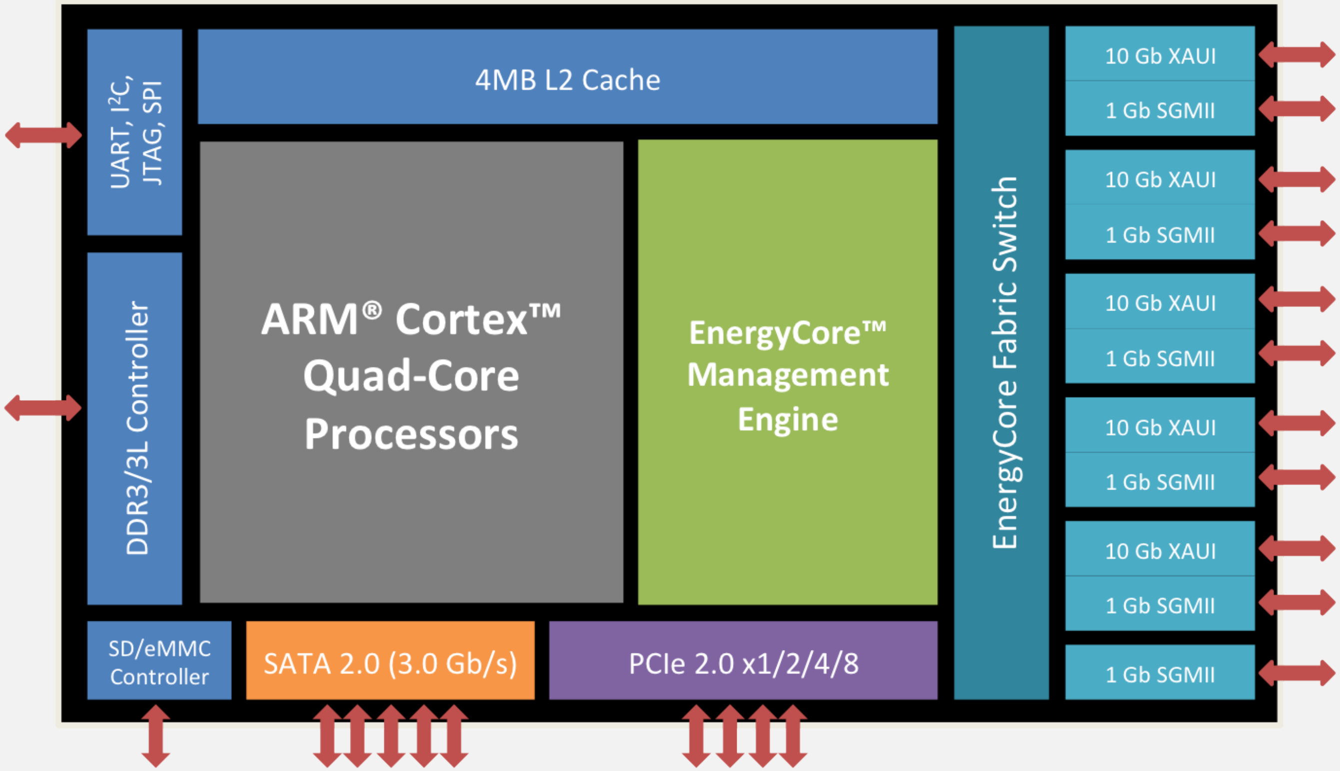
More flips per second = Higher power

Processors



Each instruction takes a different amount of energy

Systems



Average power for each block, while active

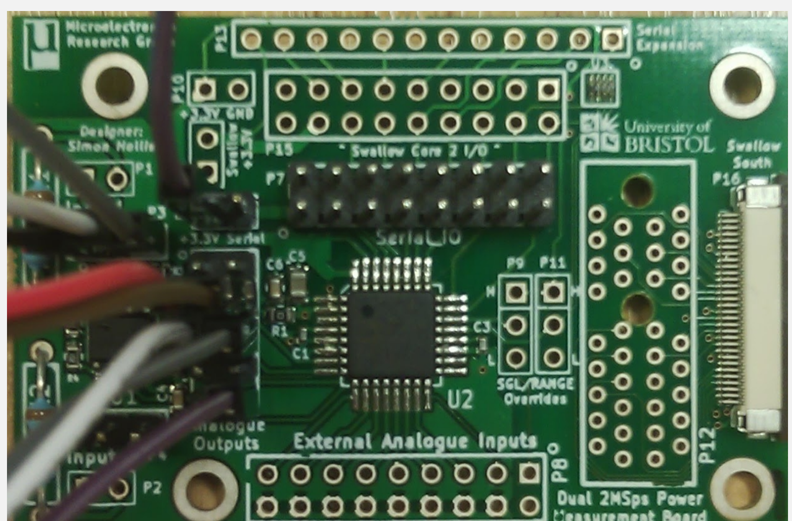
or

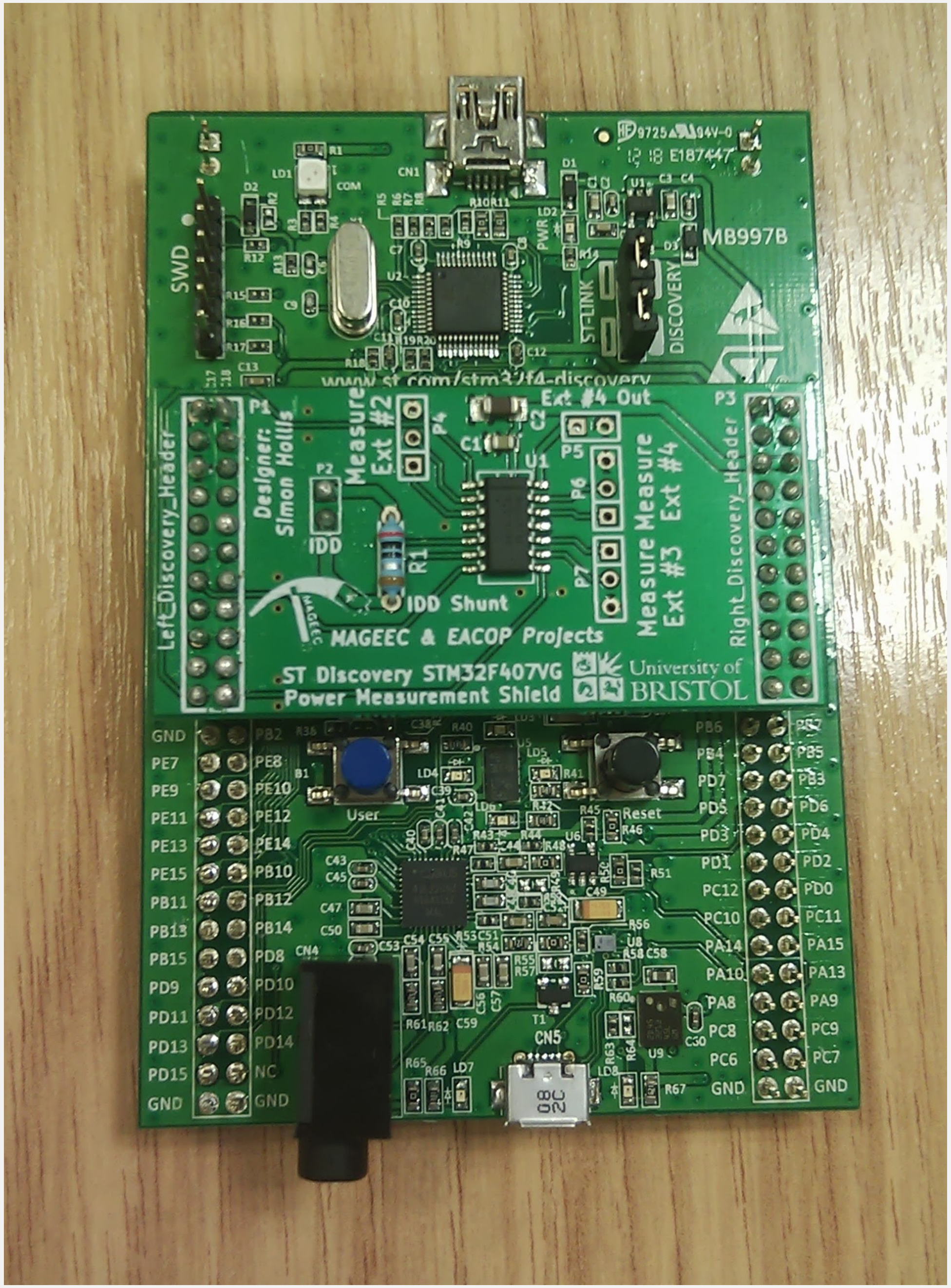
Assign an energy to each high level operation

Measuring Energy

We don't know enough about the electronics we use to model it with theory

So we measure it

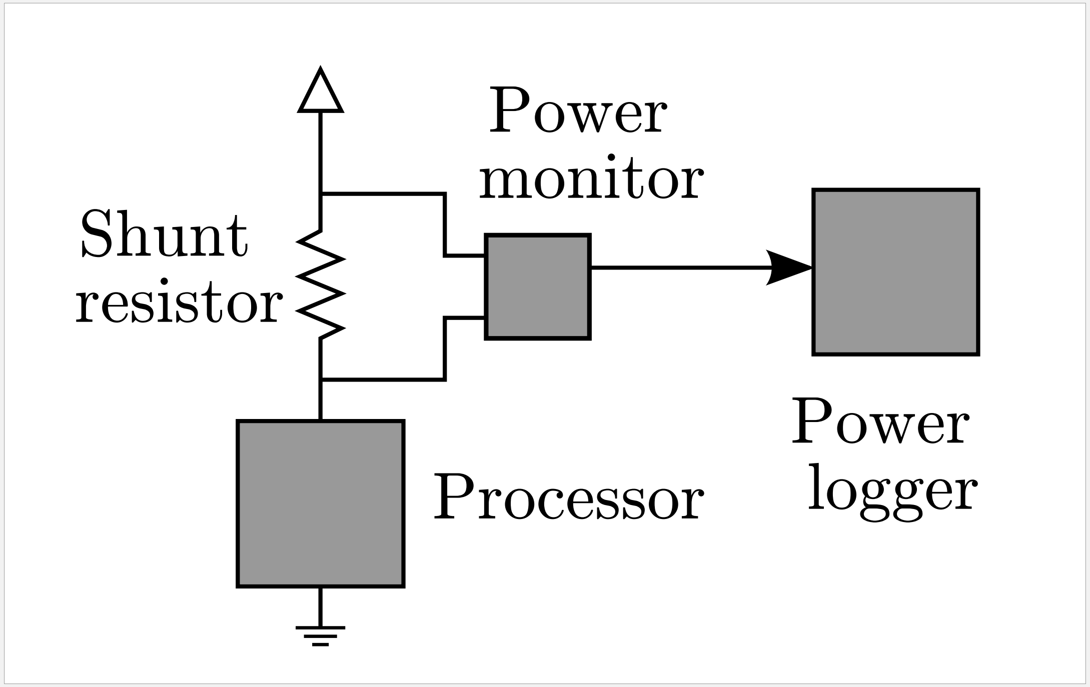



Designer: Simon Hollis
Measure Ext #2
Ext #4 Out
Measure Ext #4
Measure Ext #3
IDD
IDD Shunt
Left_Discovery_Header
Right_Discovery_Header
MAGEEC & EACOP Projects
ST Discovery STM32F407VG
Power Measurement Shield
University of BRISTOL
SWD
MB997B
ST-LINK
DISCOVERY
User
Reset

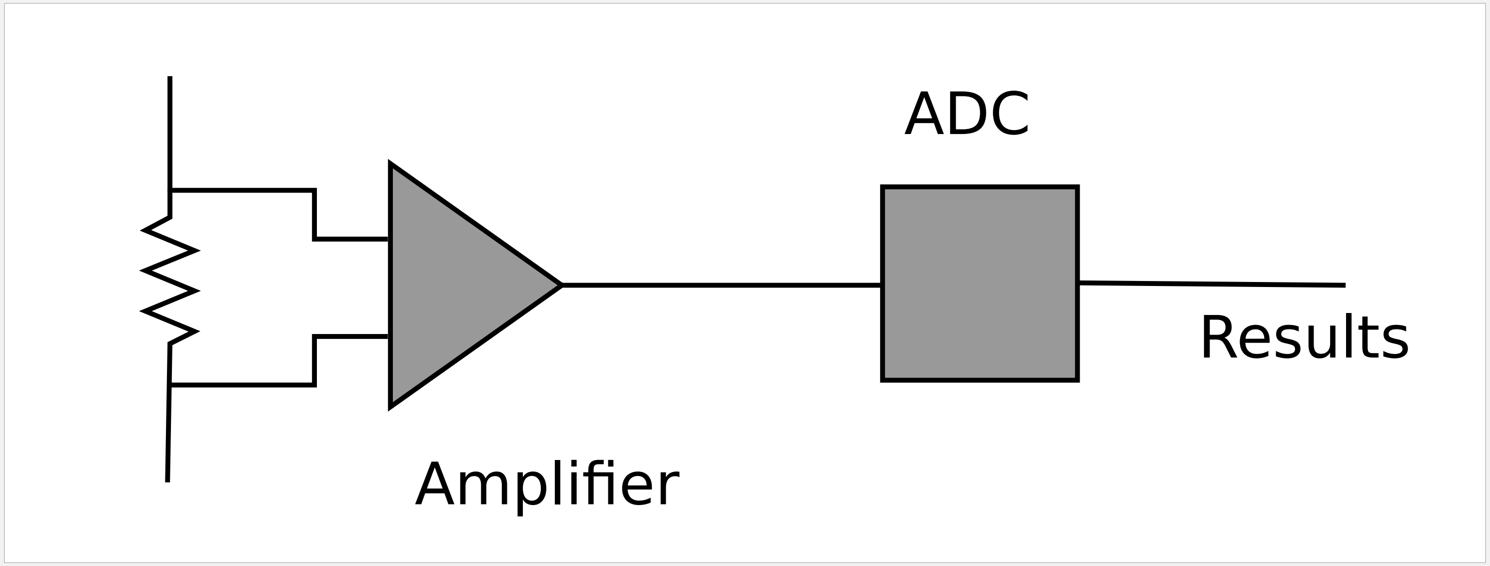
Measuring Power

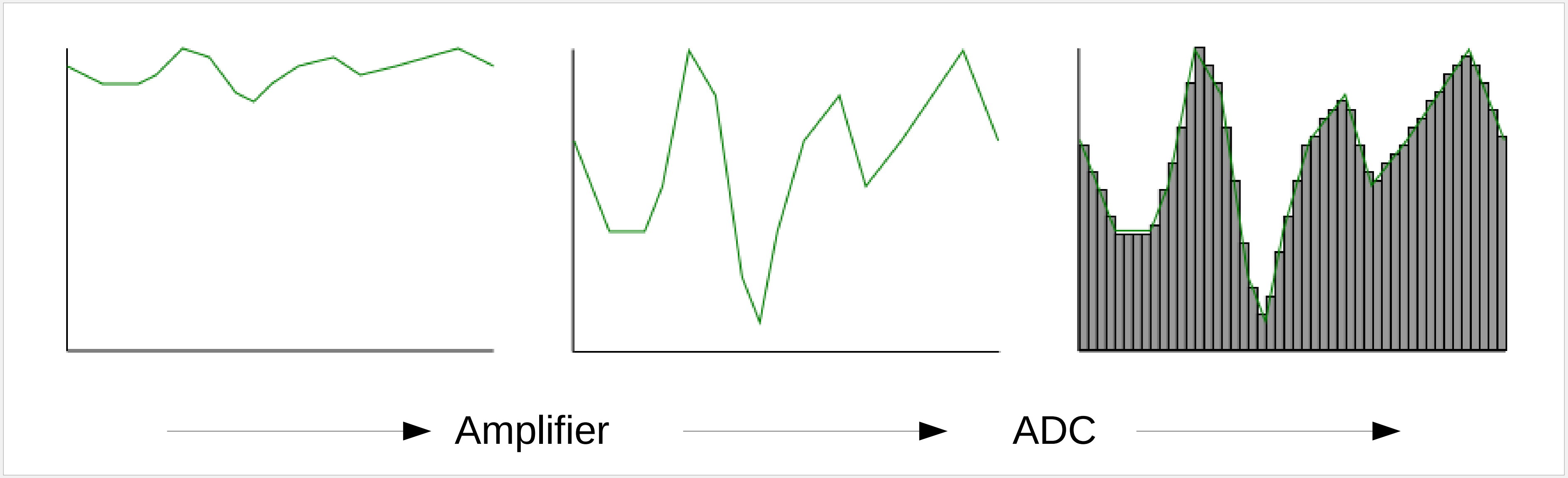
Repeat frequently, timestamp each sample

- Measure voltage drop across the resistor — $I = V_{shunt} / R_{shunt}$ to find the current
- Measure voltage at one side of the resistor — $P = I \times V$ to calculate the power



The Power Monitor



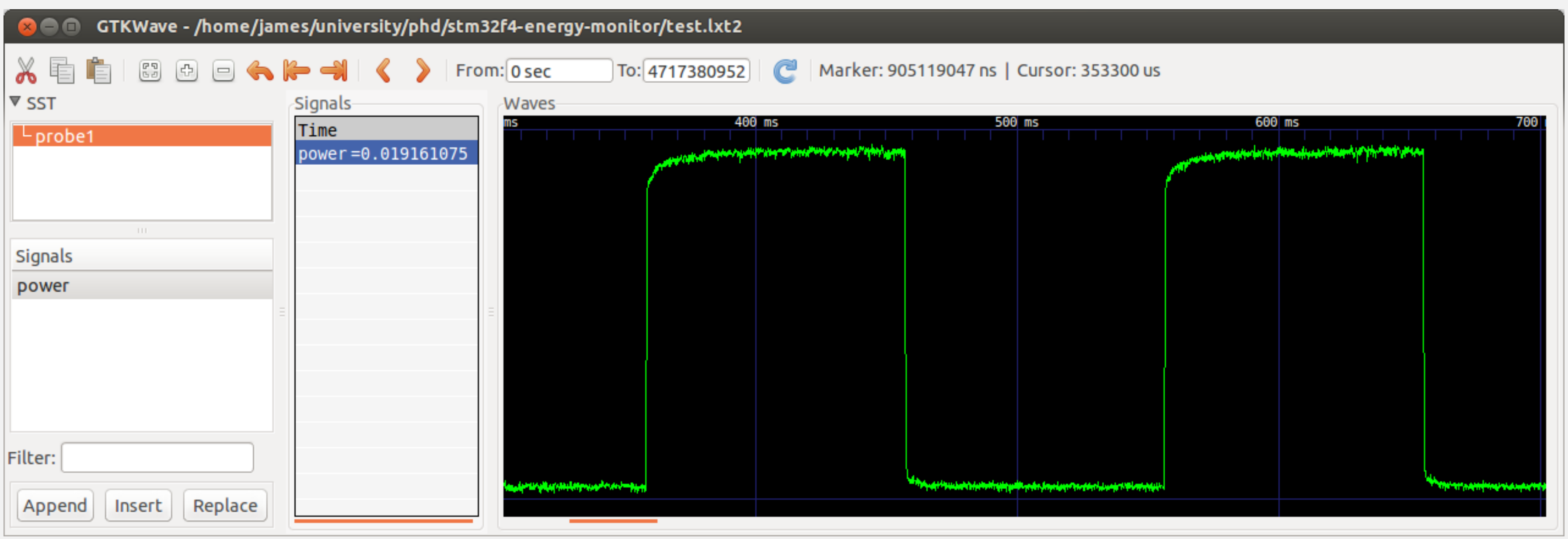


How much data?

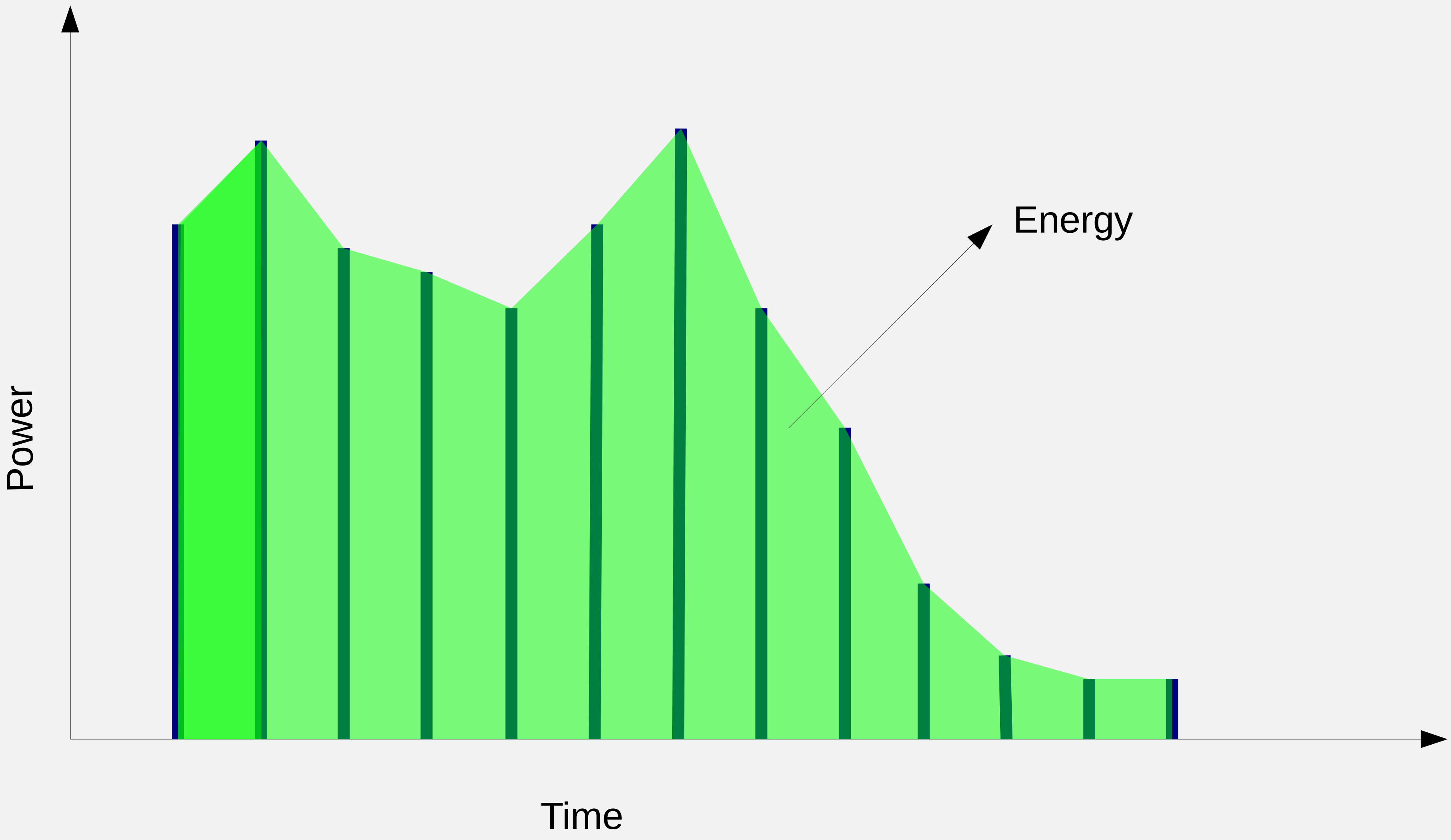
Currently 500,000 Samples/second

6,000,000 S/s possible

But 'High' speed USB is too slow



Measuring Energy



Shunt Resistor

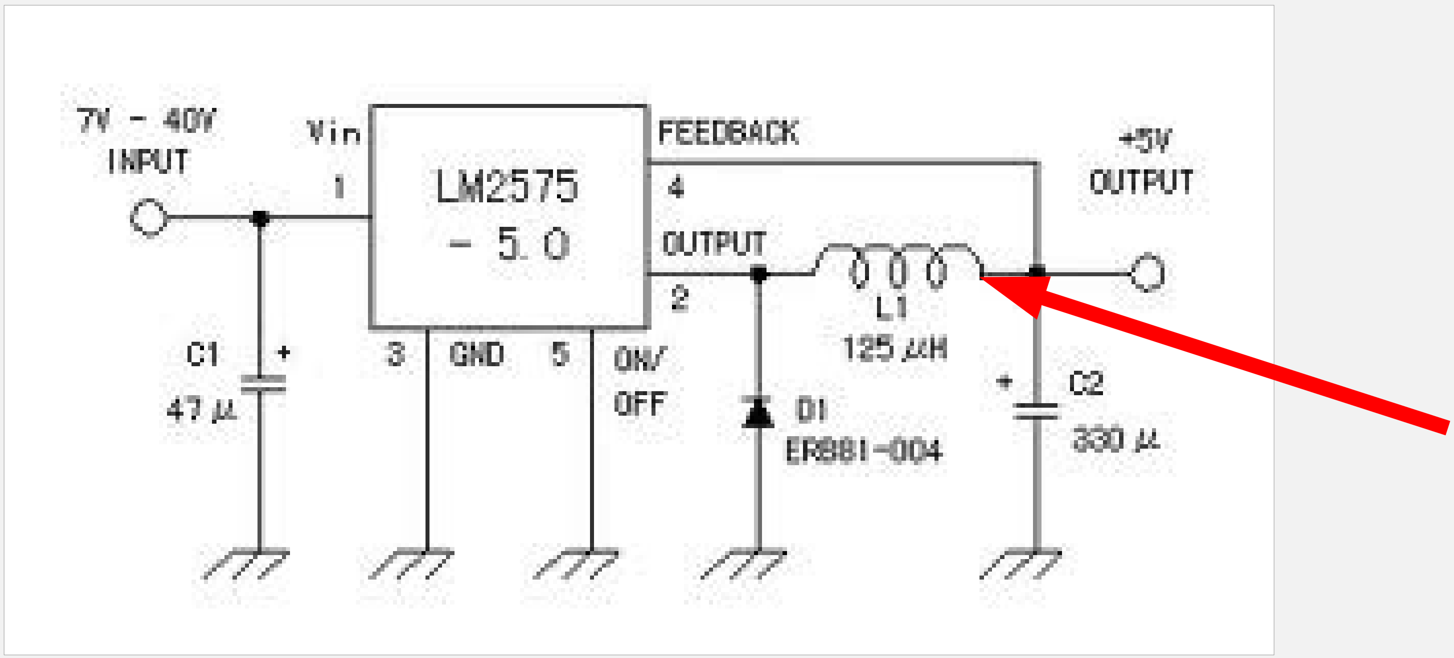
Picking the right value is important!

Difference between the processor under test working or failing

- Too small a shunt resistor = Low measurement range
- Too large a shunt resistor = High voltage drop, processor doesn't get the required voltage

Tricking the regulator

Switch-mode regulators have feedback

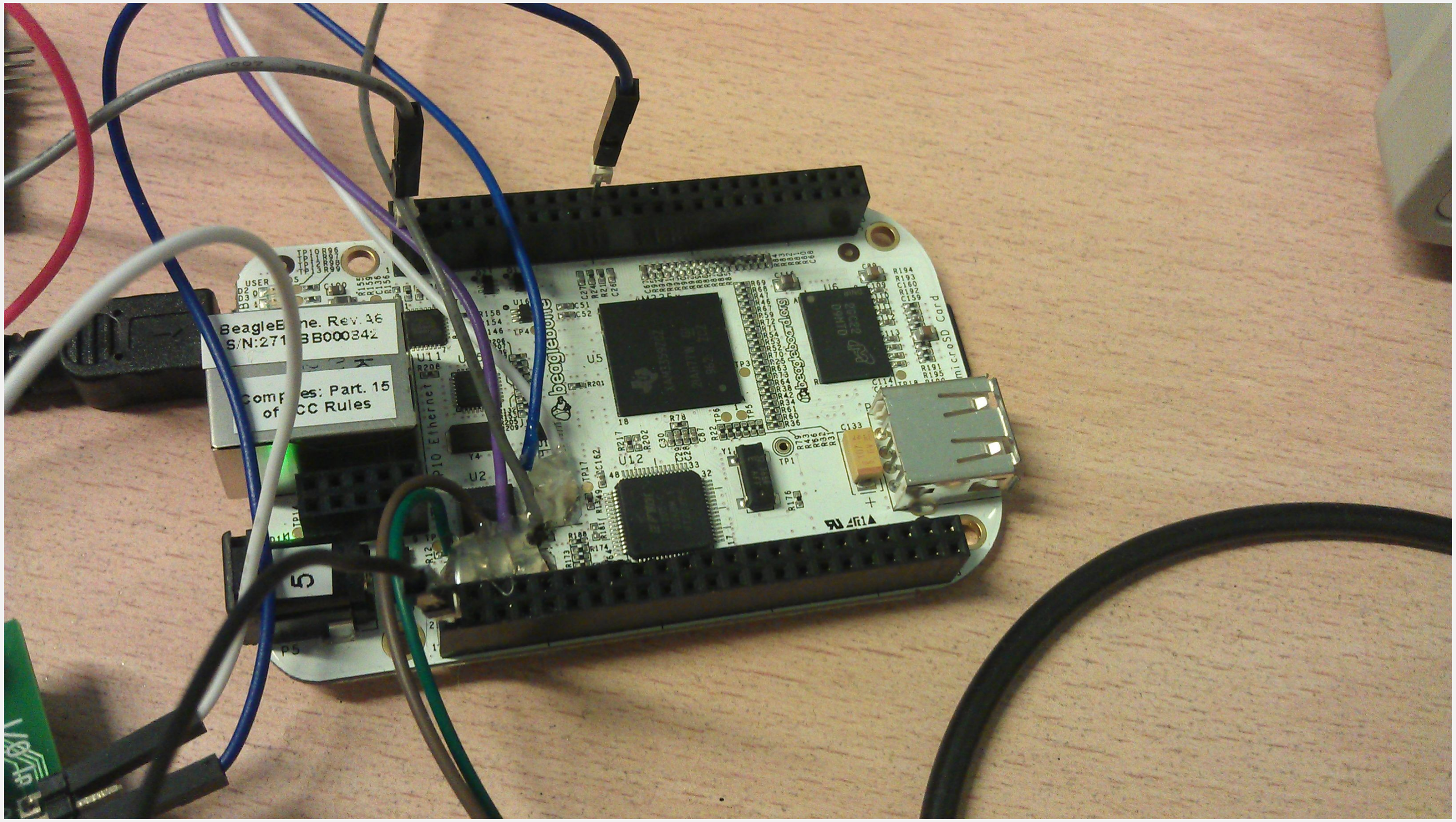


Insert shunt
resistor here

Regulator sees the voltage drop over the resistor, and compensates

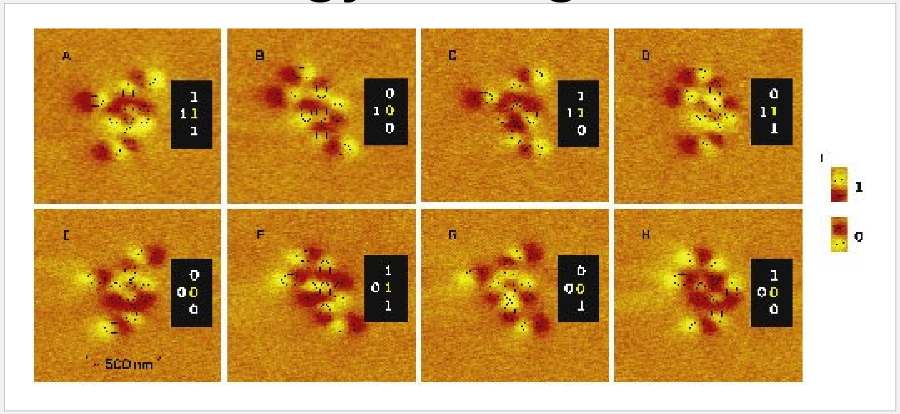
– The processor always gets the voltage it requires

Tricked the regulator



Other ways of measuring energy

- Current sensors
  - Non-invasive
  - Requires alternating current
- Heat cameras
  - Sometimes used on processors to find the hottest area of silicon
  - Hotter = more energy being used



Reducing Energy

Clock frequencies and voltages

Hot and fast or cool and slow?

Use less memory

Use dedicated hardware blocks

No bit-banging

Use the built in UART / SPI / I2C

Go to sleep (and use interrupts)

Higher clock frequencies

Faster bit flipping (capacitance)

- More energy in the same amount of time

Shorter execution time (resistance)

- Less time powered up = less energy

However... the processor gets hot

Hot Hot Hot

More leakage current.

More power dissipated.

More heat.

More leakage current.

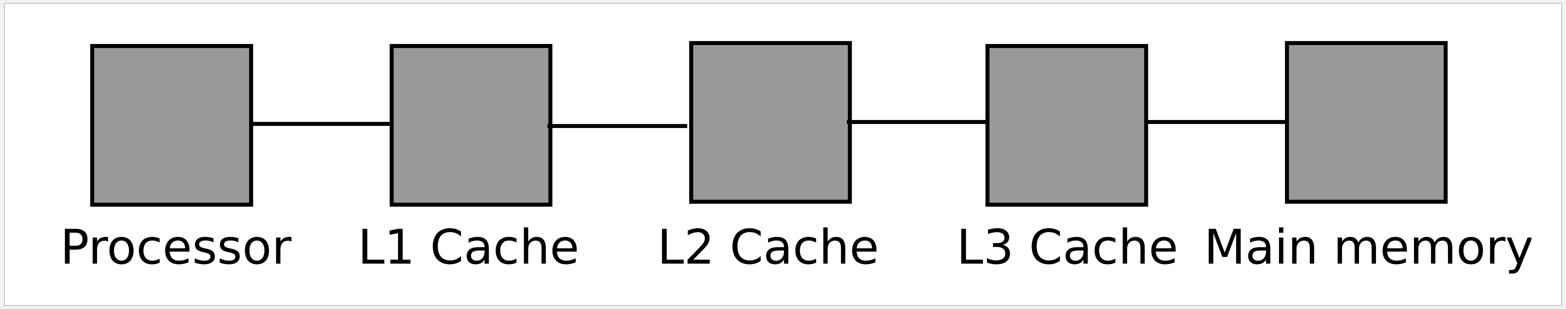
More power dissipated.

More heat.

Memory

Memory is expensive

Modern processor



But even on small processors.

Cortex-M0 Load: 12mW Add: 8mW

Conclusion

It starts with the transistors.

But that's too low level to think about.

Measure the energy.

Run fast and try not to access memory

Workshop tomorrow – come and try some of these!

Thanks!

Any questions?