EE204: Analog Electronics

Models and Biasing

What is a model?

A model tells us the **important information** in an **easy-to-use** format

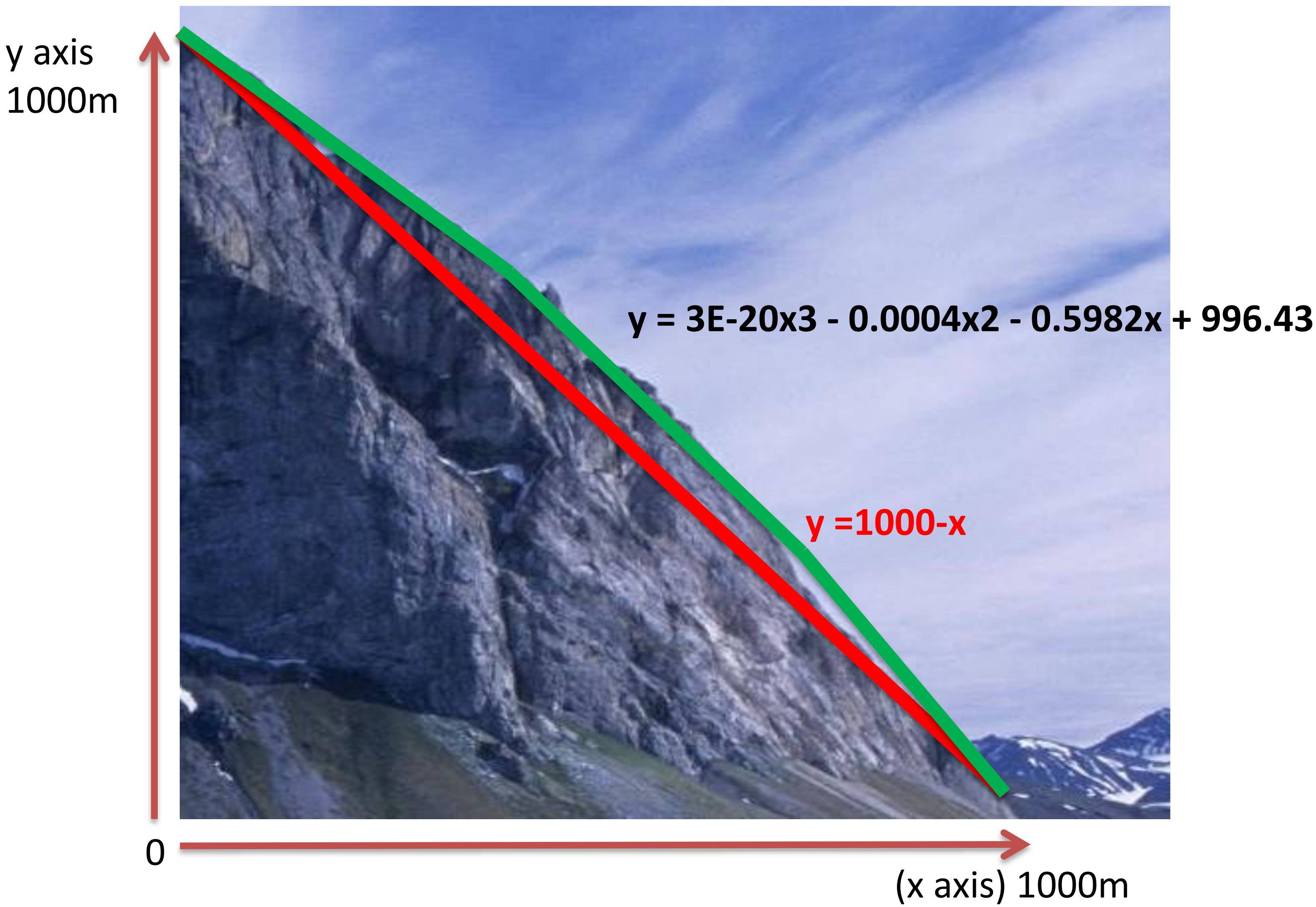
Models are **simplifications**. The complexity of the model depends on how **precisely** we want to represented the real behaviour

Models can be derived from the **underlying physics** (theoretical), but more commonly are found my **taking measurements** (empirical) and ideally combining the two approaches.

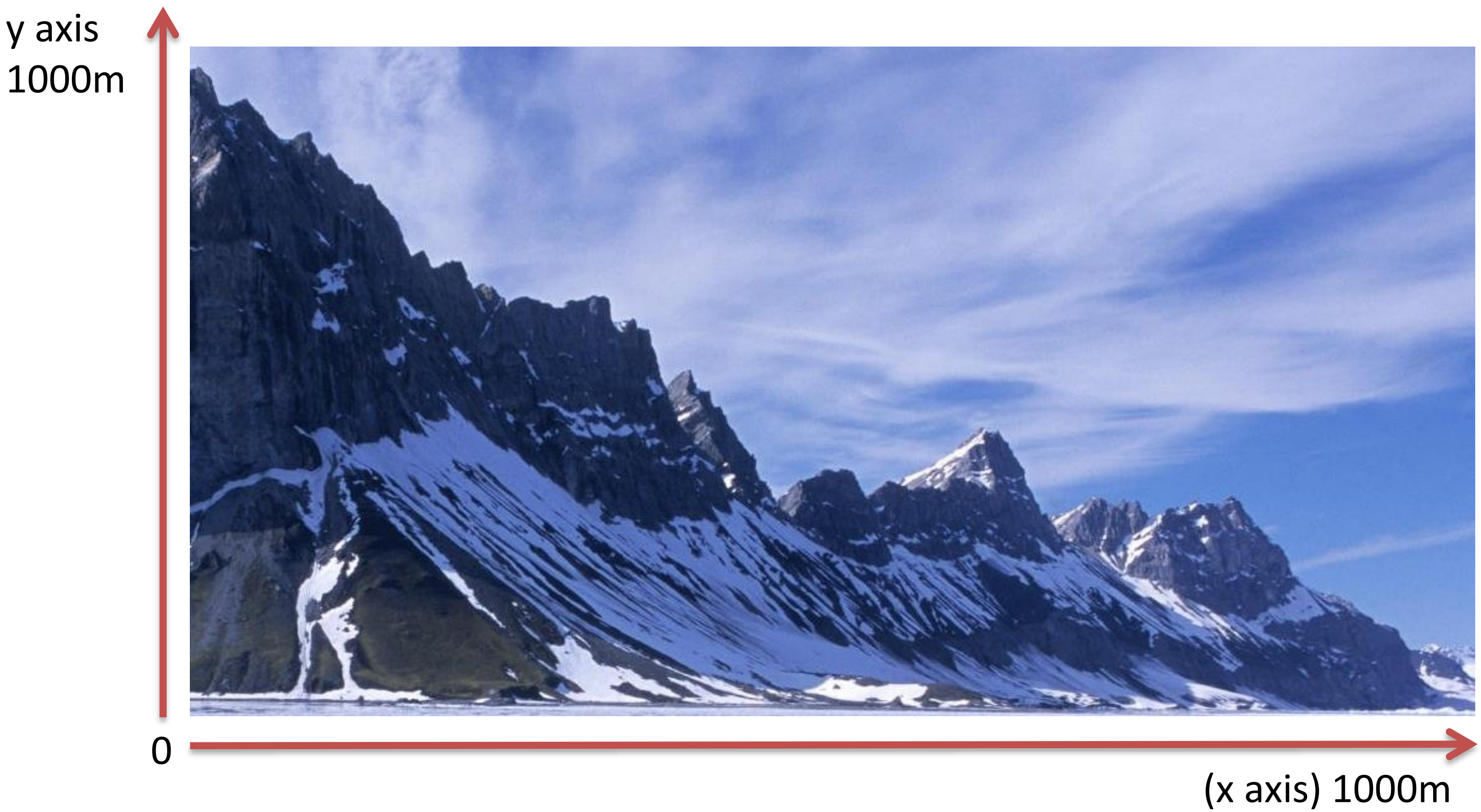
Models are **NOT** perfect, but they can be useful

What sort of curve (we call it a model) could we use for this mountain to describe it's slope?

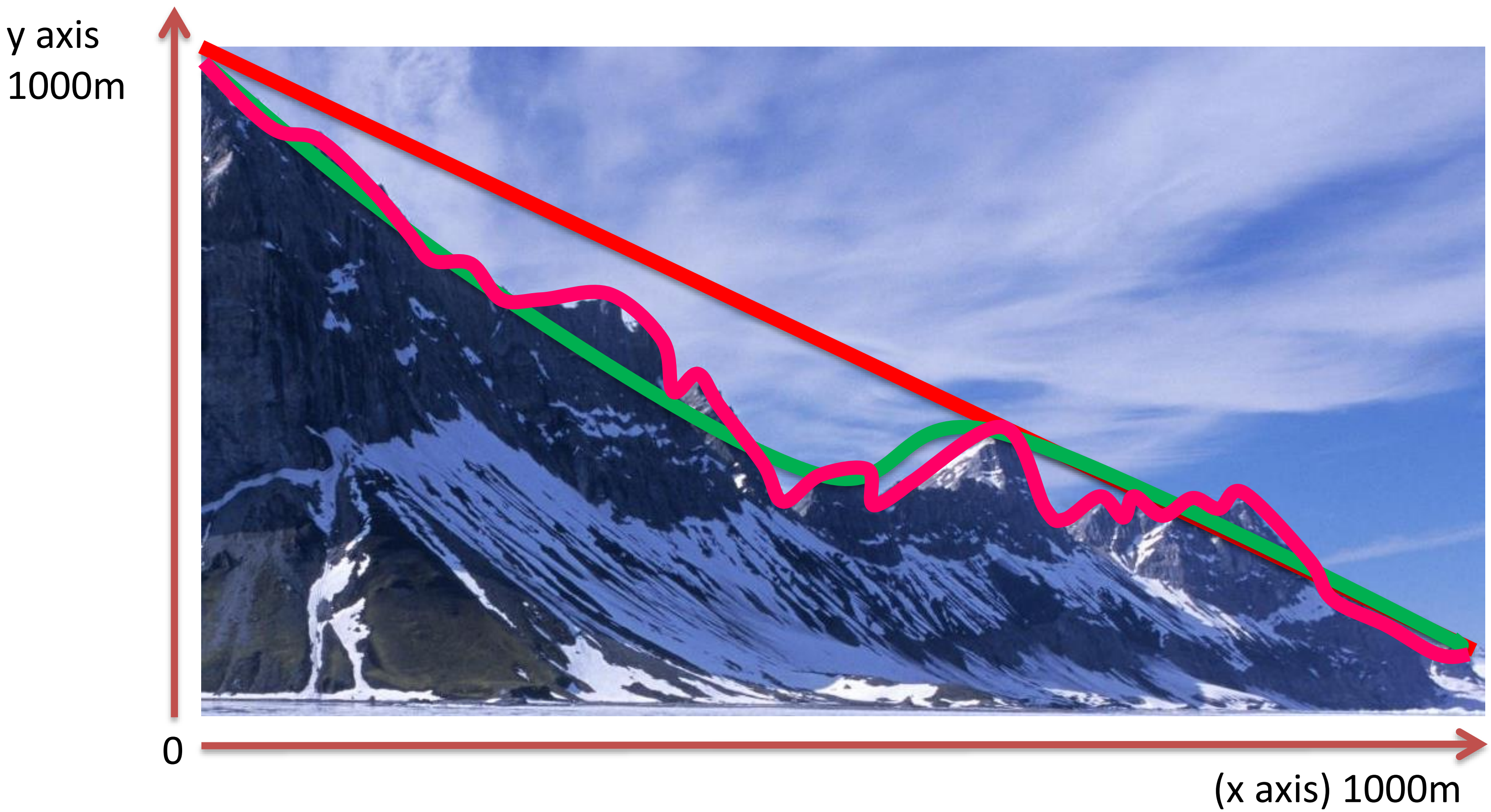
We like using **MATHS** as the language to explain things in a repeatable fashion, and it helps solve problems as well



What sort of Models could we use for this mountain?



A choice: **simplicity versus accuracy**
Reality is messy, our tools only work well with simple models



Question: for your application... Do you really need to know about all the bumps and dips???

What is a model?

It’s a tool to make our **lives easy**... Simple brains

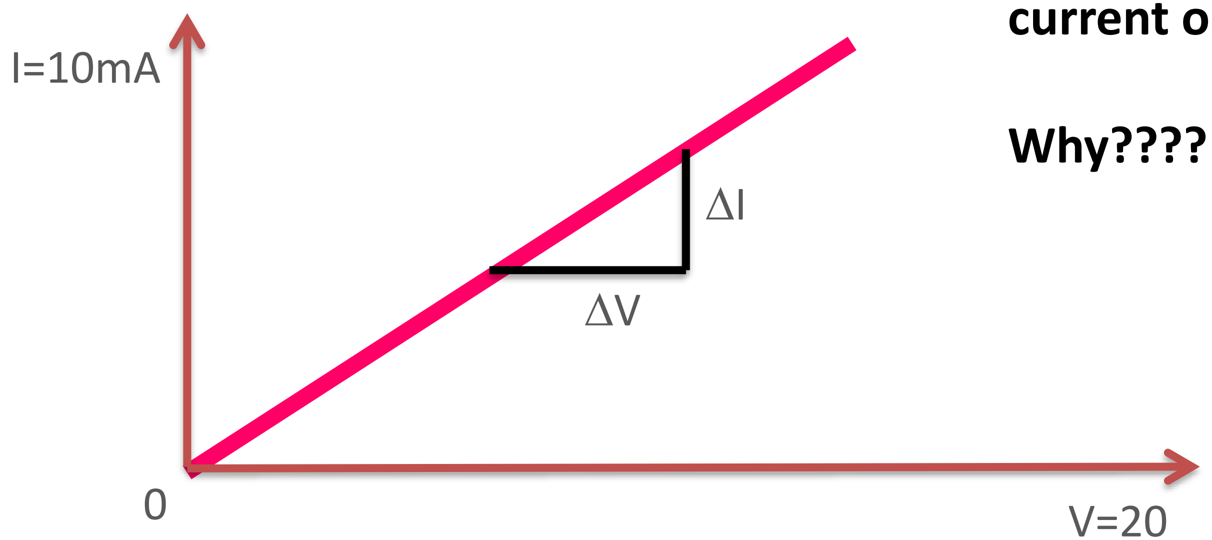
It’s a **mathematical representation** of reality that allows us to use maths to extract some useful information.

It’s imperfect, it has errors. It will never match reality perfectly... But it’s a good first guess..

A good model is “**close enough**” but “**simple enough**” to use

Looking at a Resistor

Ohms Law $V = I * R$

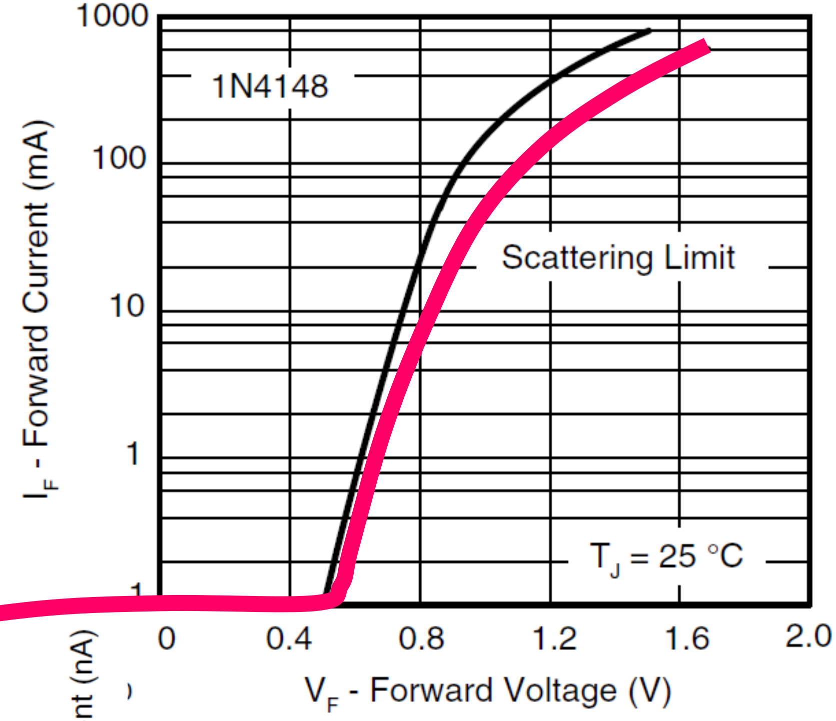


We normally plot voltage on X axis and current on Y.

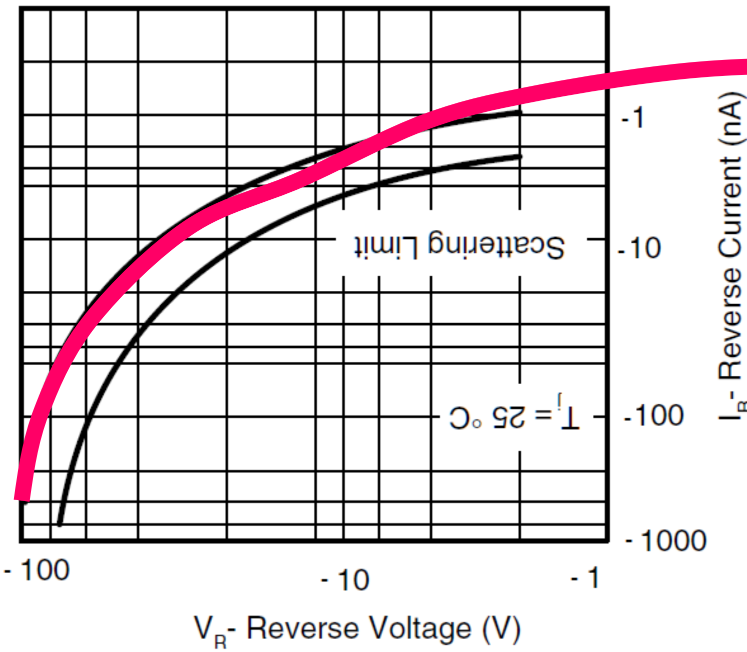
Why????

What does the slope of the line correspond to??

Looking at a Diode



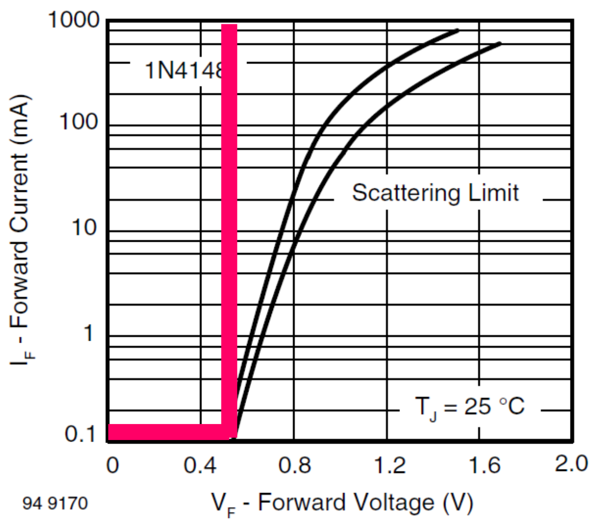
Reverse current is 1000 times smaller than forward current

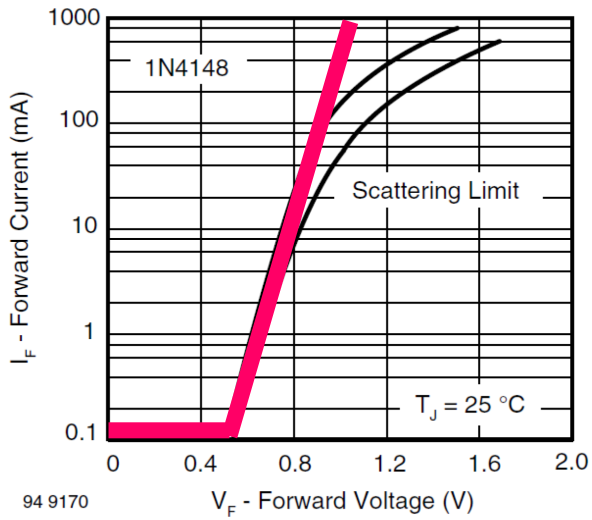


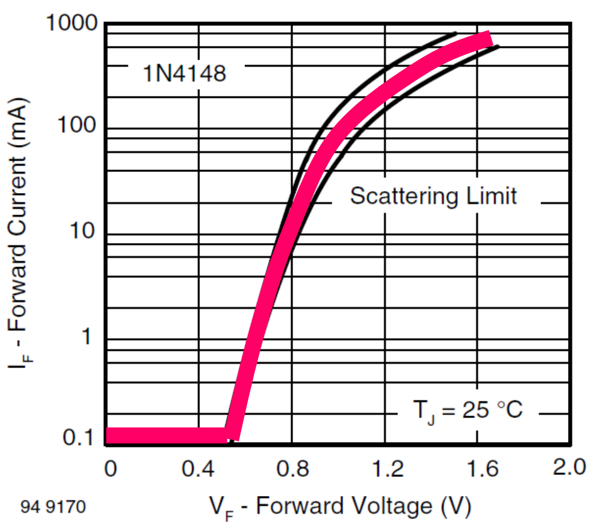
$$I_D = I_S\left(\exp\left(\frac{V_D}{nV_T}\right) - 1\right)$$

$$n = \text{ideality factor}$$

One device, multiple models







Which model is most accurate?

Which model is the best to use?

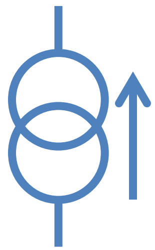
A circuit-based model

We have tools to solve circuits, and sometimes we can see ways to simplify circuits to help us solve them for a specific purpose.

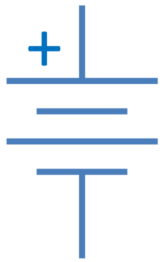
So can we take a mathematical expression and convert it to a circuit representation.

Lets add some new circuit elements to our collection

Independent Sources



$I_{out} = 0.3$ (or any constant)

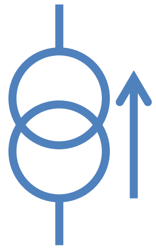


$V_{out} = 0.3$ (or any constant)

These are constant valued sources. Nothing effects what they do. An independent voltage source is a battery.

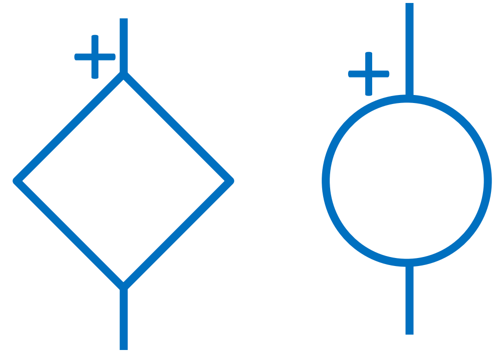
Independent current sources are rarer.

Dependent Sources



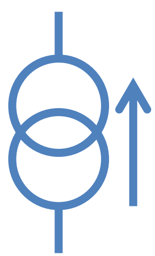
Voltage Controlled Current Source

$I_{out} = k\ V_{control}$



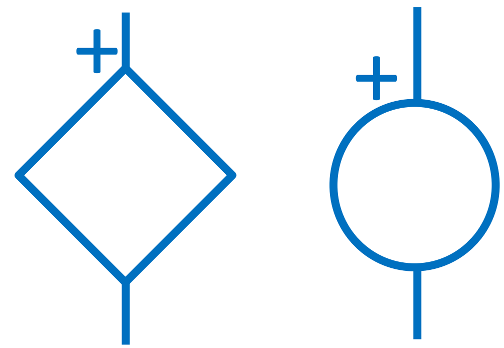
Voltage Controlled Voltage Source

$V_{out} = k\ V_{control}$



Current Controlled Current Source

$I_{out} = k\ I_{control}$



Current Controlled Voltage Source

$V_{out} = k\ I_{control}$

Don’t worry about how these are made, they are normally useful quirks of physics. With these, you need to write out what their controlling signal is as symbols don’t tell you enough

Making a circuit model (1)

I am told that for this “device”, the following happens

the current through the device is unknown, but the voltage across the device is a constant value **k**

$$\Delta V = k$$
$$I = \text{unknown}$$

This is the expression for a constant voltage source, or a battery.

We have no information about what the current through the device is.

Making a circuit model (2)

I am told that for this "device", the following happens

the voltage across a device is unknown, but the current through this device is **k** amps

$$\Delta V = \text{unknown}$$
$$I = k$$

This is the expression for a constant current source

We have no information about what the voltage dropped across the device is.

Making a circuit model (3)

I am told that for this "device", the following happens

the voltage across this device is proportional (k) to the current flowing through it.

$$\Delta V \quad = k*I$$

This is the expression for a resistor, where resistance R=K

Making a circuit model (4)

I am told that for this “device”, the following happens

the current through the device is proportional (**k**) to the voltage applied across it.

$$I \qquad = k^* \Delta V$$

This is again Ohm’s law but for a conductance. The conductance of a device is inversely proportional to it’s resistance (R=1/k)

Making a circuit model (5)

I am told that for this "device", the following happens

the voltage across a device is unknown, but the current through the device is **k** times the current I_{in} that is being measured somehow.

$$\Delta V = \text{unknown}$$
$$I = k*I_{in}$$

This is the expression for a current controlled current source.

NOTE: I_{in} is not the same as the current through the device. It's from somewhere else in the circuit.

Making a circuit model (6)

I am told that for this "device", the following happens

the voltage across a device is unknown, but the current through the device is **k** times the voltage V_{in} that is being measured somehow.

$$\Delta V \quad = \text{unknown}$$
$$I \quad = k*V_{in}$$

This is the expression for a voltage controlled current source.

NOTE: V_{in} is not the same as the voltage across the device. It's from somewhere else in the circuit.

Making a circuit model (7)

I am told that for this “device”, the following happens

the current through the device is unknown but the voltage is **k** times the value of Vin, which is measured somehow.

$$\Delta V = k*V_{in}$$
$$I = \text{unknown}$$

This is the expression for a voltage controlled voltage source

NOTE: V_{in} is not the same as the voltage across the device. It’s from somewhere else in the circuit.

Making a circuit model (8)

I am told that for this "device", the following happens

the current through the device is unknown but the voltage is **k** times the value of Vin, which is measured somehow.

$$\Delta V \quad = k{*}I_{in}$$
$$I \quad = \text{unknown}$$

This is the expression for a current controlled voltage source

NOTE: I_{in} is not the same as the current through the device. It's from somewhere else in the circuit.

Making a circuit model (the fun part)

The important thing to understand here is that we have two types of devices – those that produce current and those that produce voltages.

You cannot successfully mix current and voltage output devices. The question "3 amps + 4 volts =" is meaningless.

So imagine that you have two forms of equations that you can use

$$I_{XY} = 3 + V_X*(0.2) - 13*V_1 + 5*V_2 + 0.1*I_3$$

$$V_{XY} = 0.2 + 5\, I_{XY} + 13*V_1 - 2*V_2 - 1.1*I_3$$

Making a circuit model (the fun part)

$$I_{XY} = 3 + V_{XY}*(0.2) - 13*V_1 + 5*V_2 + 0.1*I_3$$

Something that adds a current that is proportional to the current I_3

Something that adds a current that is proportional to the voltage V1 and V2

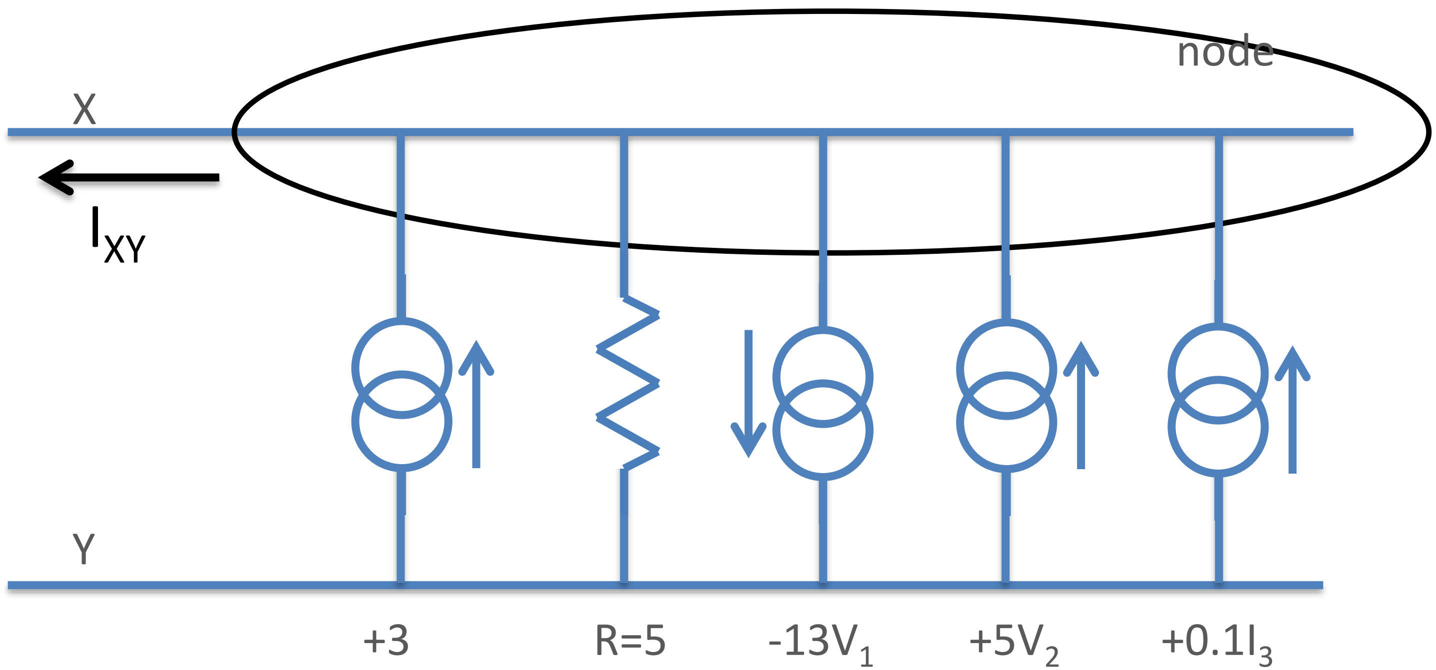
Something that adds a current that is proportional to the voltage across the points XY

Something that adds a constant current… easy

Making a circuit model (the fun part)

$$I_{XY} = 3 + V_{XY}*(0.2) - 13*V_1 + 5*V_2 + 0.1*I_3$$

Remember, KCL says that currents add at a node. Be careful with the arrows.



Making a circuit model (the fun part)

$$V_{XY} = 0.2 + 5\,I_{XY} + 13{*}V_1 - 2{*}V_2 - 1.1{*}I_3$$

Something that adds a voltage that is proportional to the current I_3

Something that adds a voltage that is proportional to the voltage V1 and V2

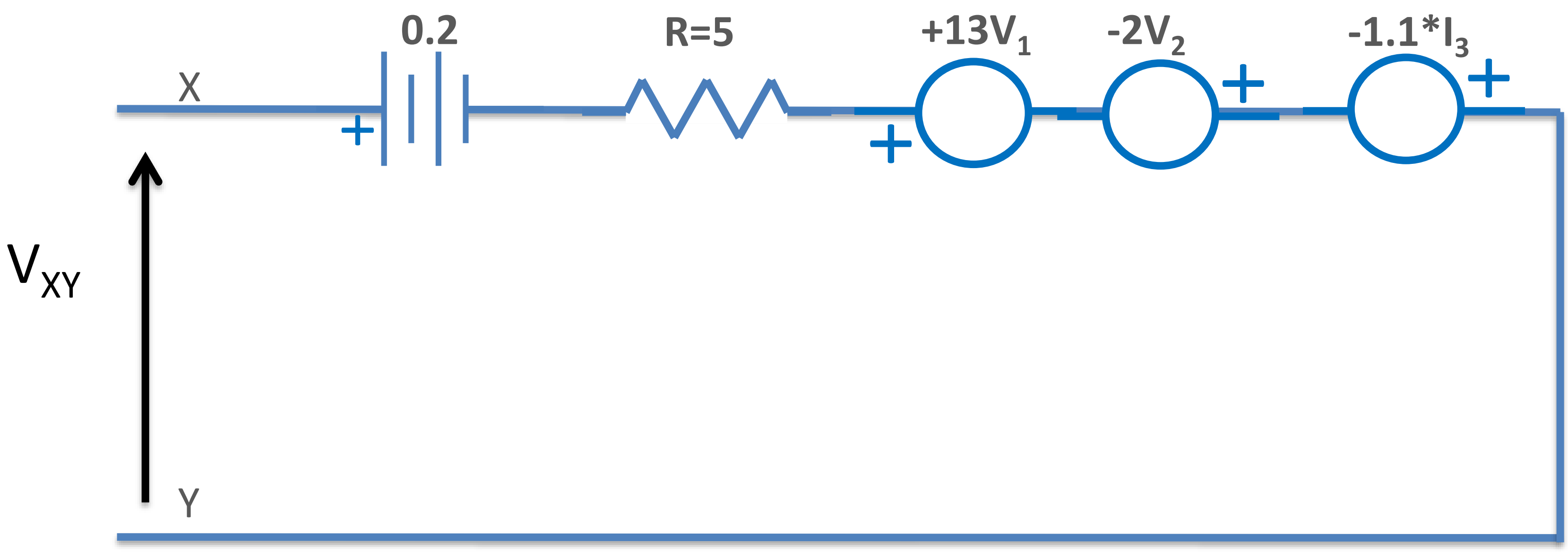
Something that adds a voltage that is proportional to the current flowing through it

Something that adds a constant voltage… easy

Making a circuit model (the fun part)

$$V_{XY} \quad = \quad 0.2 \ + 5\, I_{XY} + 13^*V_1 - 2^*V_2 - 1.1^*I_3$$

Remember, KVL says that voltages add in a loop.
Be careful of the signs.



Making a circuit model

Circuit models have a directly equivalent mathematical model. We use which ever one is easiest.

In circuit models, we will attempt to never use $()^2$ or anything complicated. Our aim is simplicity

Remember all models are simplifications. Computers are great at crunching equations.

They'll give you the answer to 6 decimal places but they can't tell you if it's the right answer to the problem you wanted to solve.

Biasing and Small Signal Behaviour

What is a small signal?

It’s a change in your signal that is small.

What is small?

Small enough that you don’t get any weird behaviours

Seriously... What is small??

I am being serious... There is no good definition

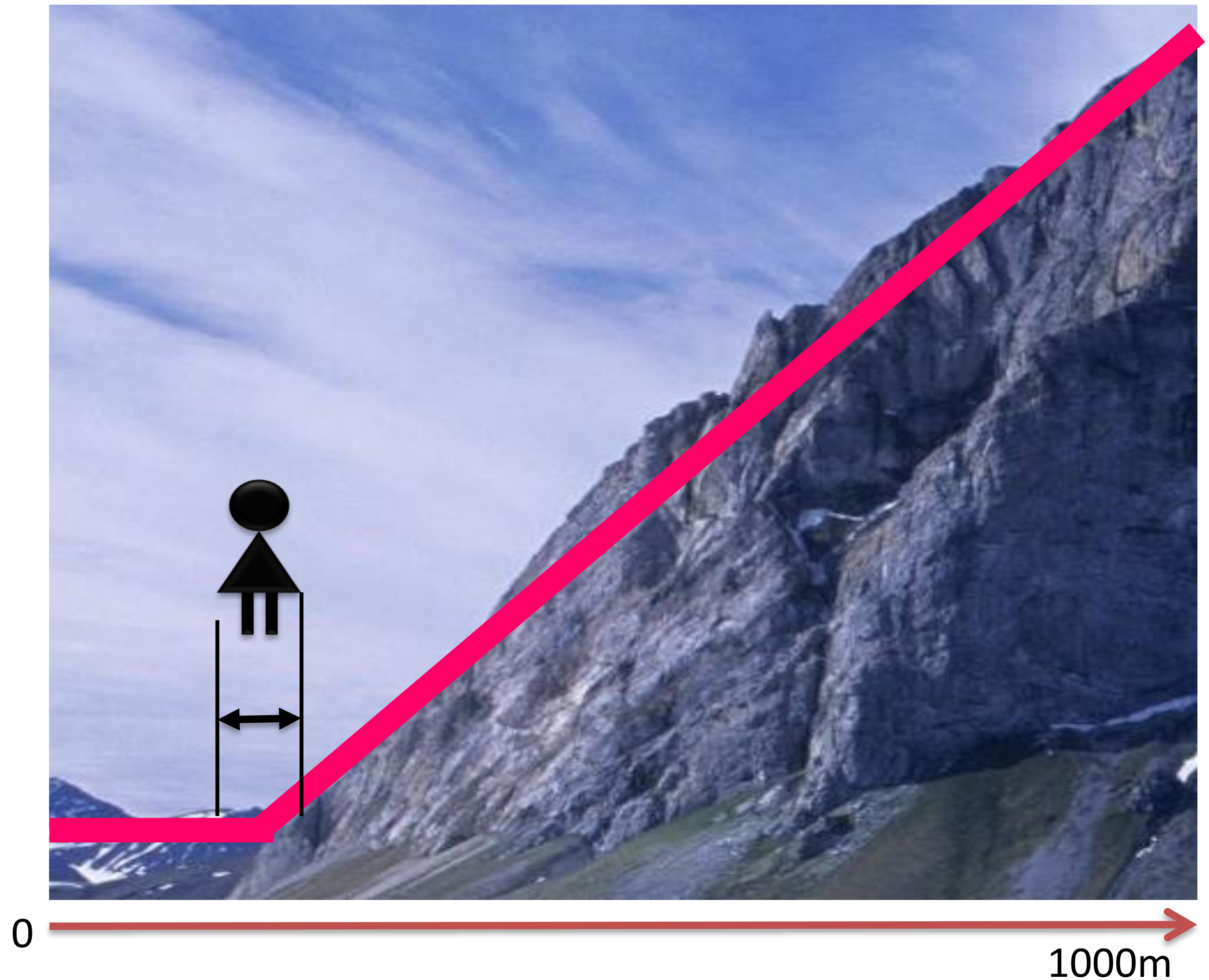
Got an example?

Usually these are AC signals, for example microphone audio output signal (mV)

What slope does the person experience?
How far can they go before they experience a different slope?

What slope does the person experience?
How far can they go before it changes significantly?

What slope does the person experience?
How far can they go before the slope changes significantly?

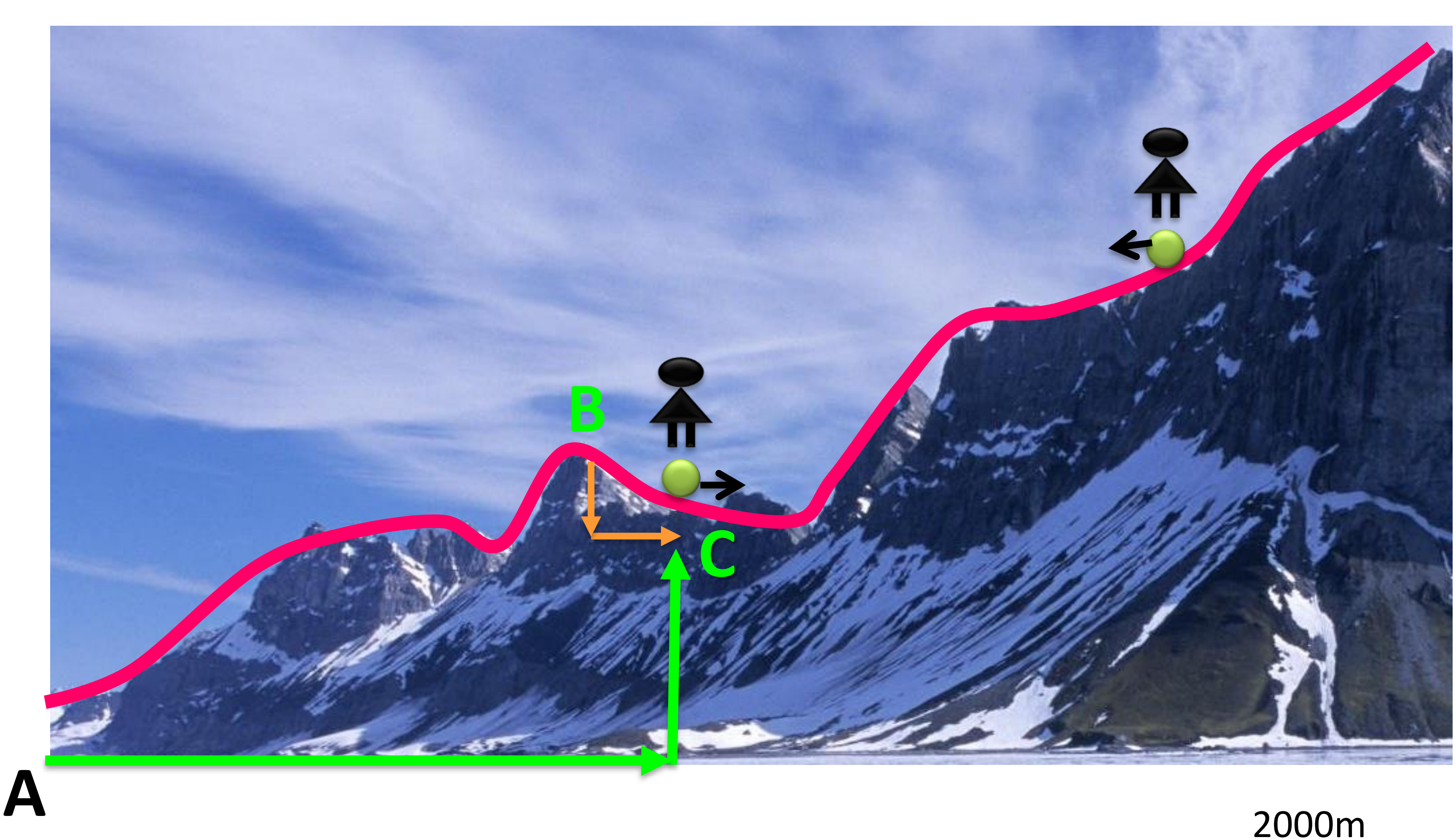


As I walk left to right… there will be points where I may end up walking downhill.

What does this mean??

Over a very small distance, everything looks like a straight line

The slope of the line at each point can of course change.

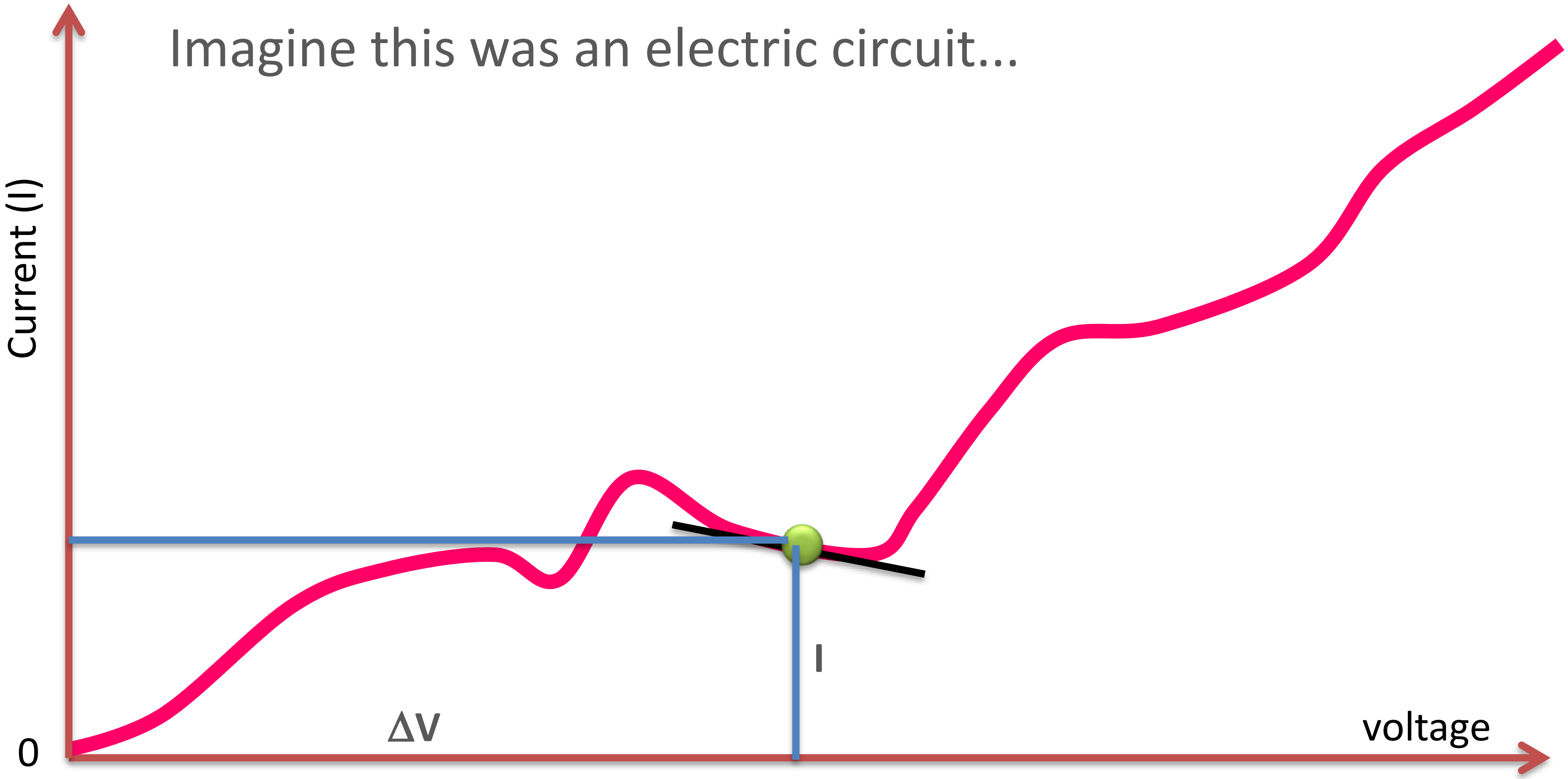


So am I walking uphill or not… it depends on your perspective..

If I am starting at A….
If I am starting at B…

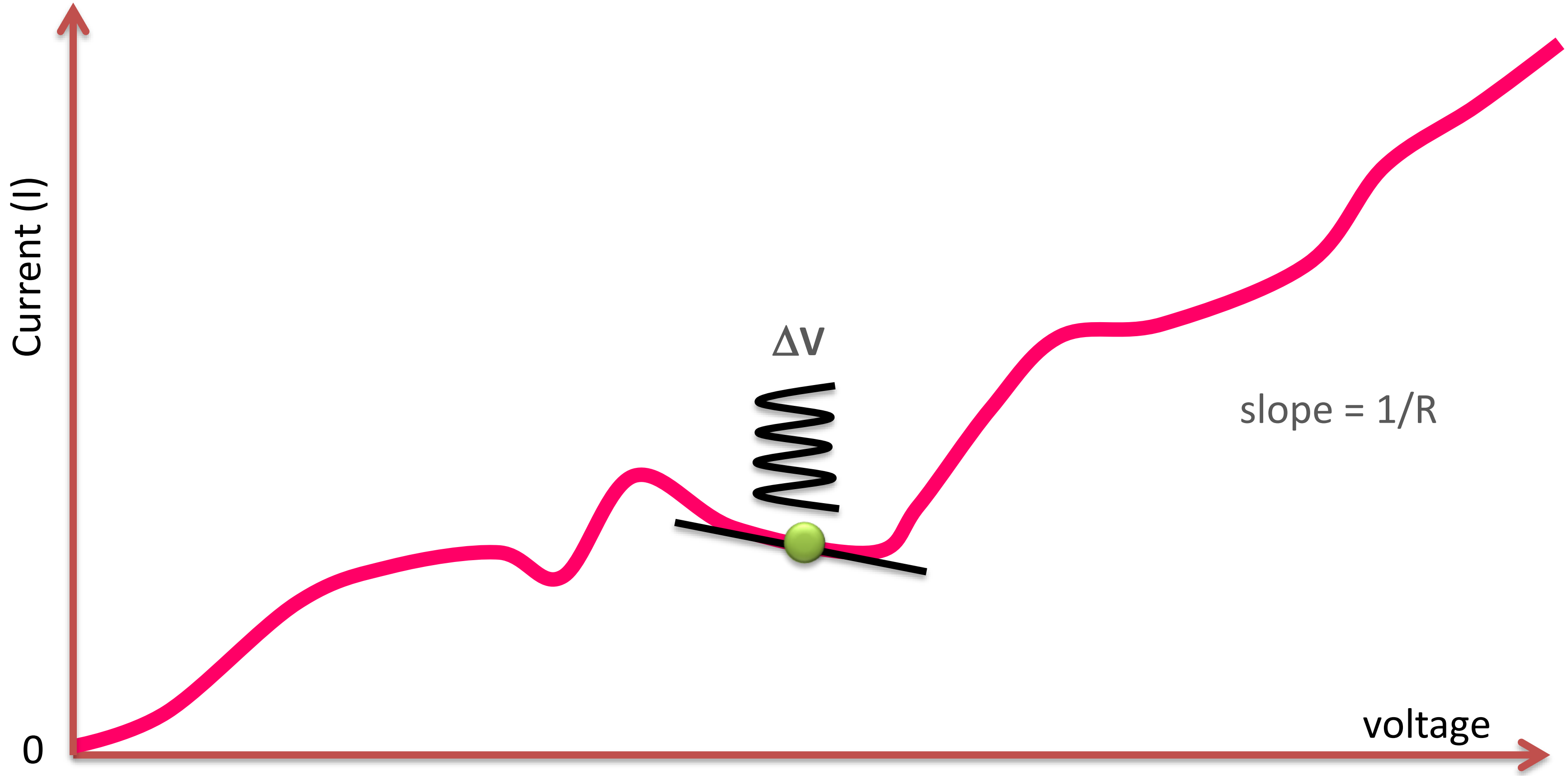
The same applies to Voltages and Currents

Imagine this was an electric circuit...



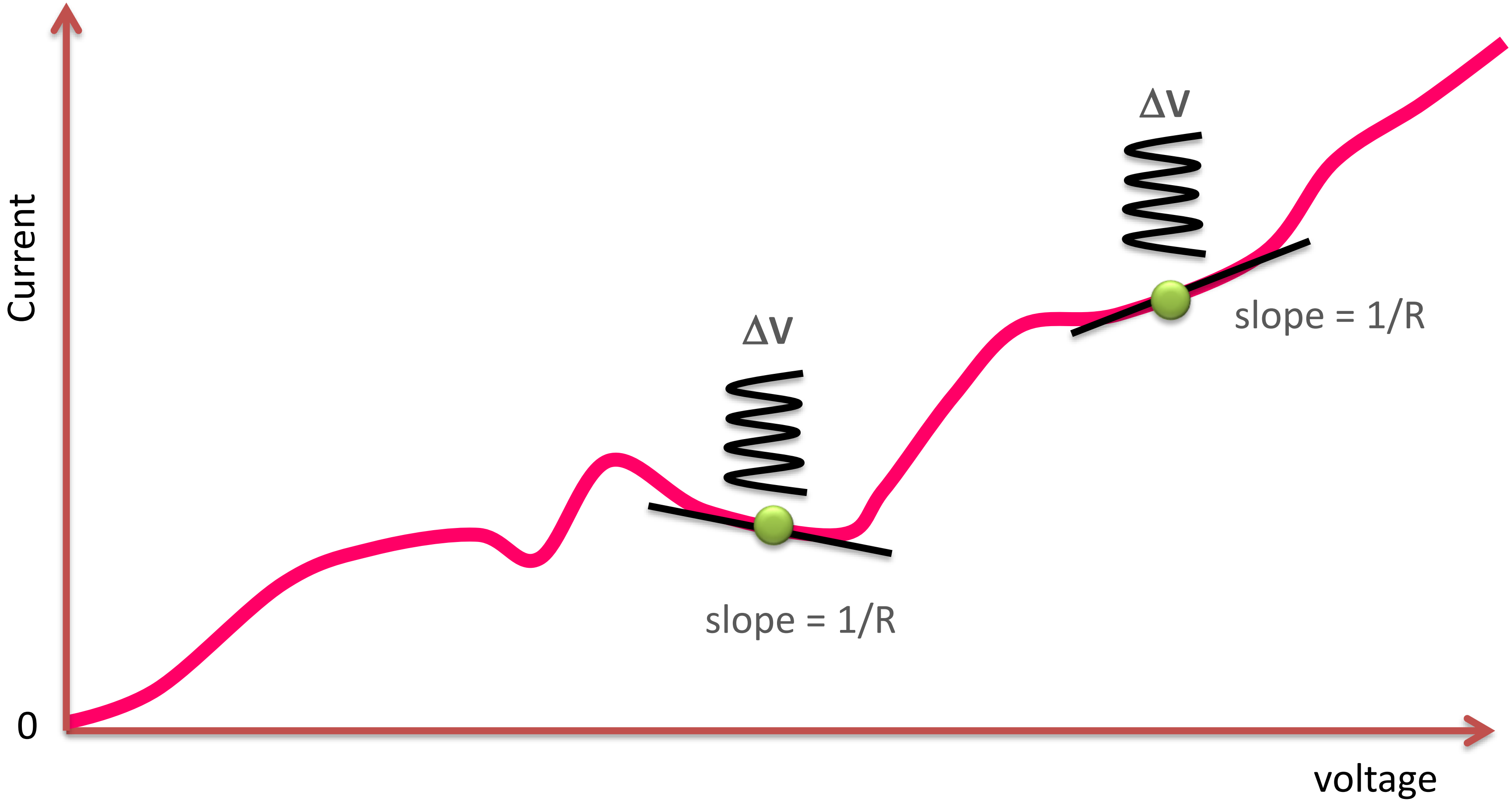
If I take the total voltage dropped, and the total current...

I get a value of resistance given by $\Delta V = I*R$



Now imagine the numbers where R=100, V=10, I= 0.1

Looking at this curve, what would happen to the current if I increased the voltage a little… would it go up or down?



A small change in voltage causes a small change in current

$$\Delta V = R_{small} (\Delta I)$$

This Resistance to small changes is not always positive and it's clearly not always the same for different parts of the curve and it's not the same as the resistance for large signals

Small Signals and Large Signals

Small Signals are small changes that are so small that they stay is a region on the curve where everything looks like a **straight line** (we call straight-line regions **LINEAR**) **(this is the correct exam-paper answer)**

Small Signals are always considered to be time-varying signals with zero average values – often picked up from the sensors and need to be amplified.

Small Signal Resistance is given by

$$\Delta V = R_{small} (\Delta I)$$

Small signals use lower case letters (v, i)
Large signals use upper case letters (V,I)

Large signals are any and all signals that are not small
Large signal Resistance is given by

$$\Delta V = R (I)$$

What is Biasing

The **Bias Point** is where you **get the behaviour** you want for your small signals.   You choose it and then you design your biasing. A good bias point is far away from sharp changes in your curve.

Biasing is the process of **getting to the point** in the curve that you want. The curve represents the behaviour of the device

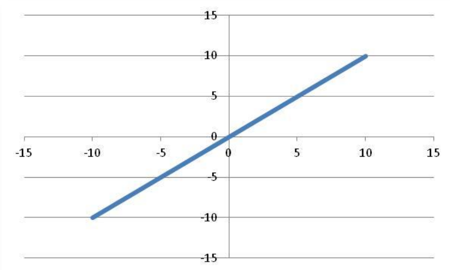
Biasing is done through the use **of DC signals**.

Small Signals are small changes that are so small that they stay in a linear region on the curve, anything between 10 and 100 times smaller than the big signals is a good definition of small.

Your real signal is your **small signal + biasing**. Or else it's just a very small signal and won't let you do much.

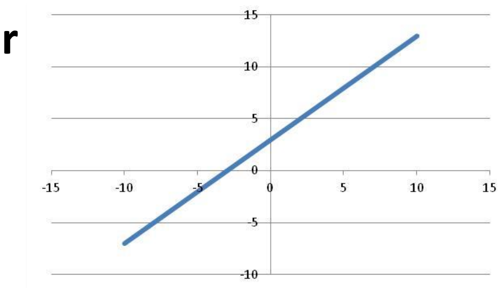
Some more curves or models….

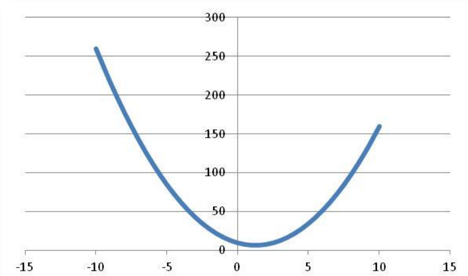
Linear, Quadratic, Cubic, etc…



Linear, special term **AFFINE** as it goes through the origin. It does not need to be 1:1, just a straight line

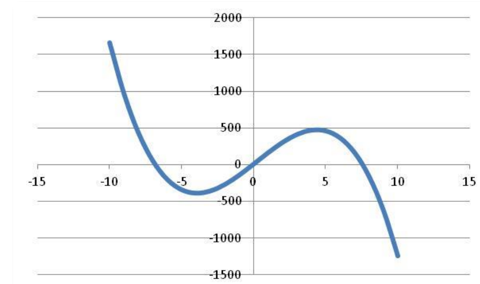
Linear

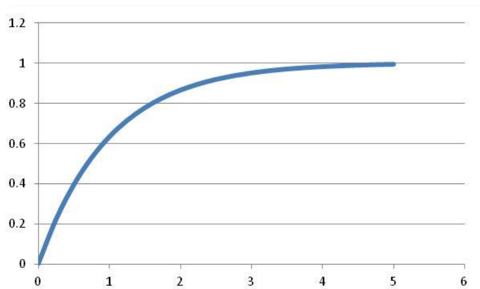




Quadratic

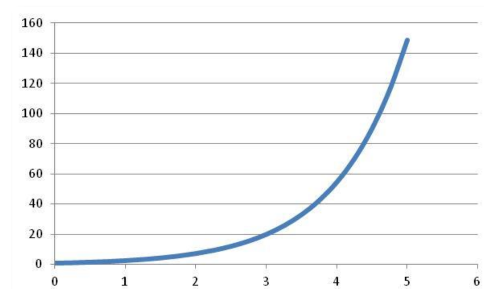
Cubic



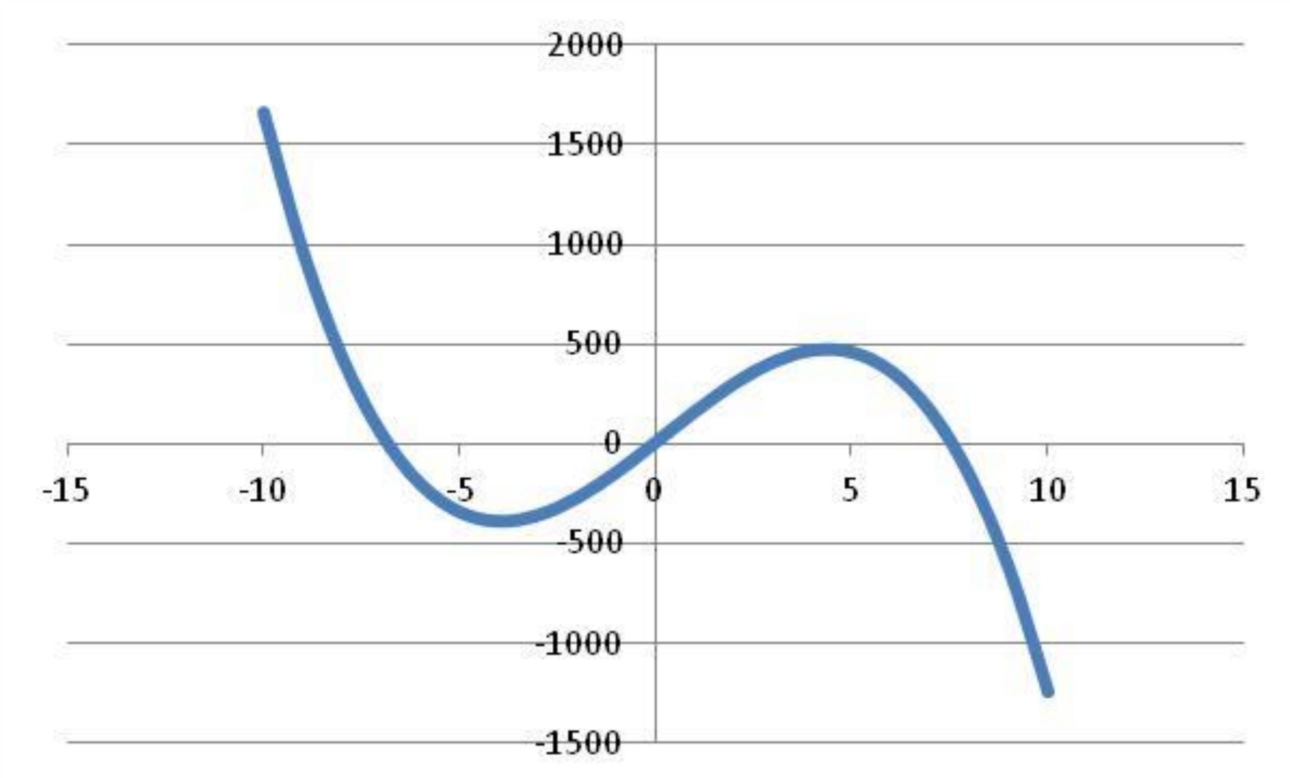


Asymptotic exponential but there are other forms that do this too

Exponential



Piecewise Linear

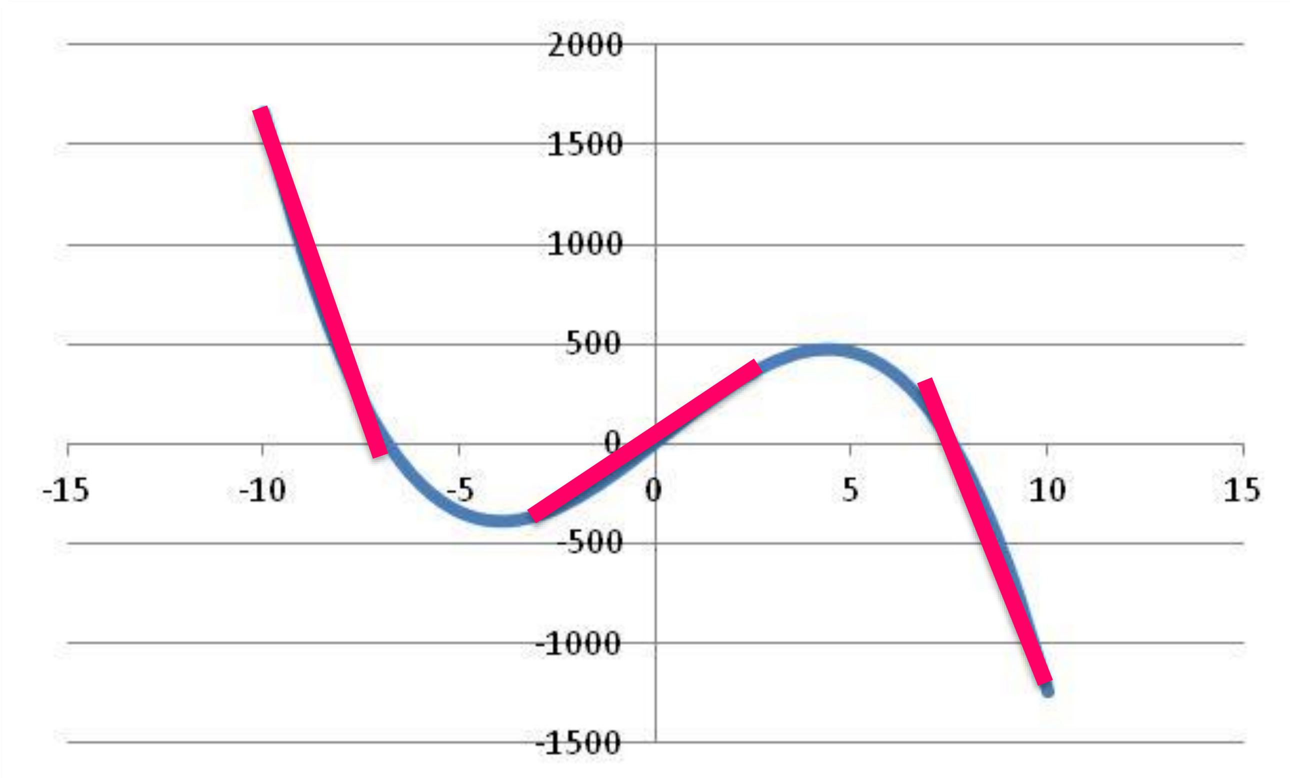


We say something is piecewise linear if we can remake the curve using a bunch of linear sections. It cannot ever be a perfect fit unless the pieces are infinitely small. The smaller the pieces, the better the bit.

Piecewise Linear – small pieces

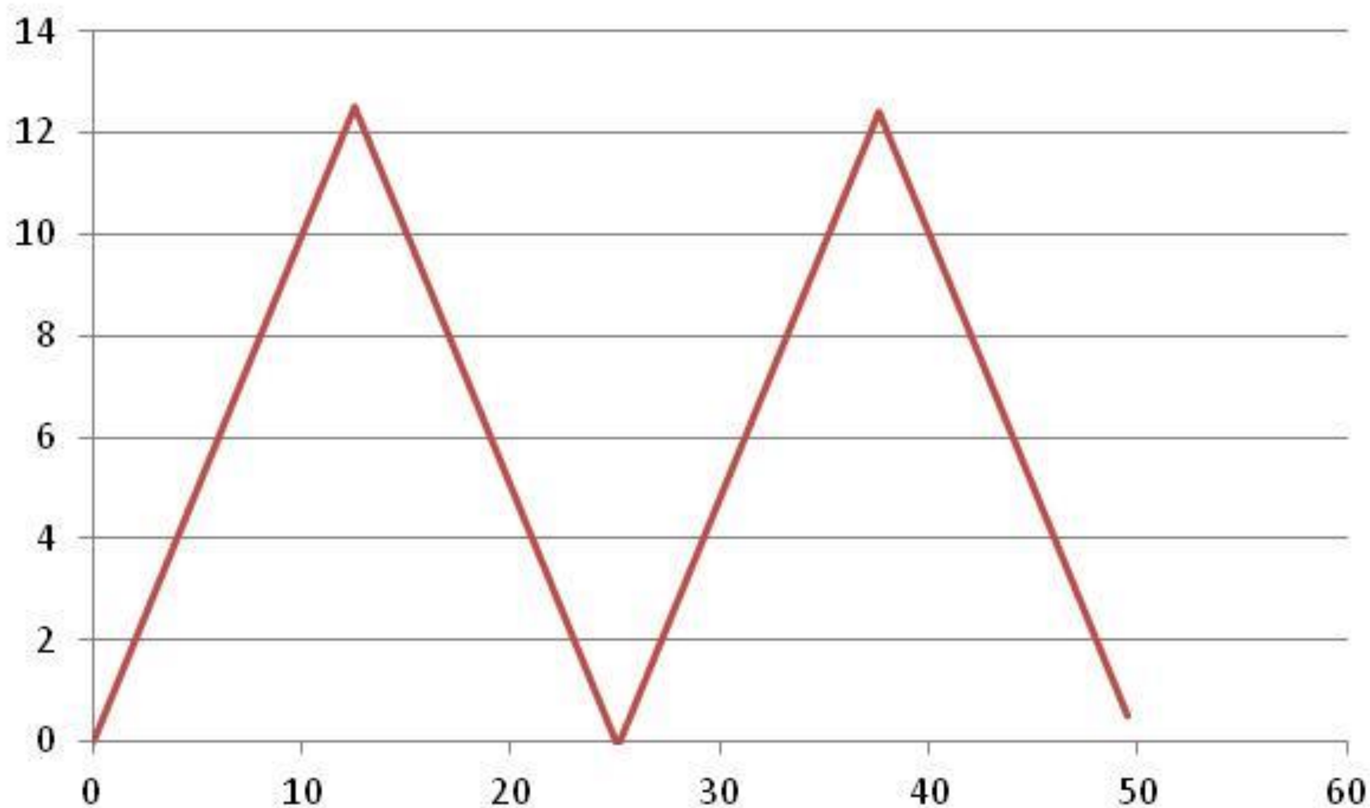
This should remind you of numerical techniques for doing integration (simpson's rule)

Piecewise Linear – small pieces



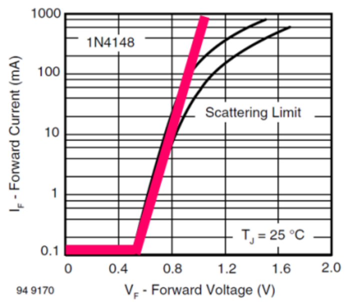
Usually when we are doing piecewise linear approximations... We ignore the messy bits and only look at whether there are large regions that can be well approximated by a straight line... Otherwise it's not that useful to us.

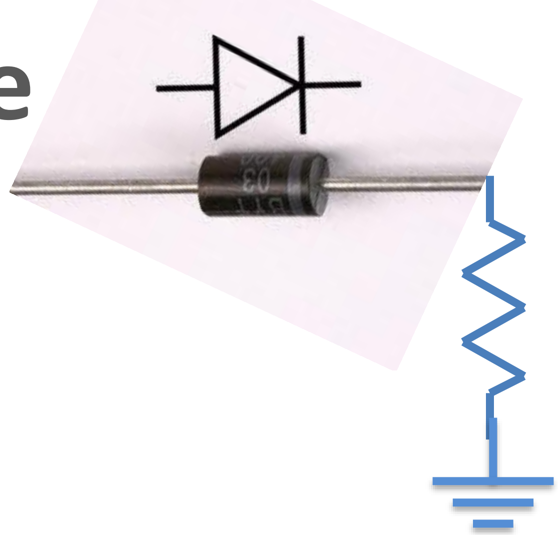
Piecewise Linear – small pieces



Some shapes are very easy to represent as piece-wise linear, provided you avoid wondering what happens at the junctions ☺

An example



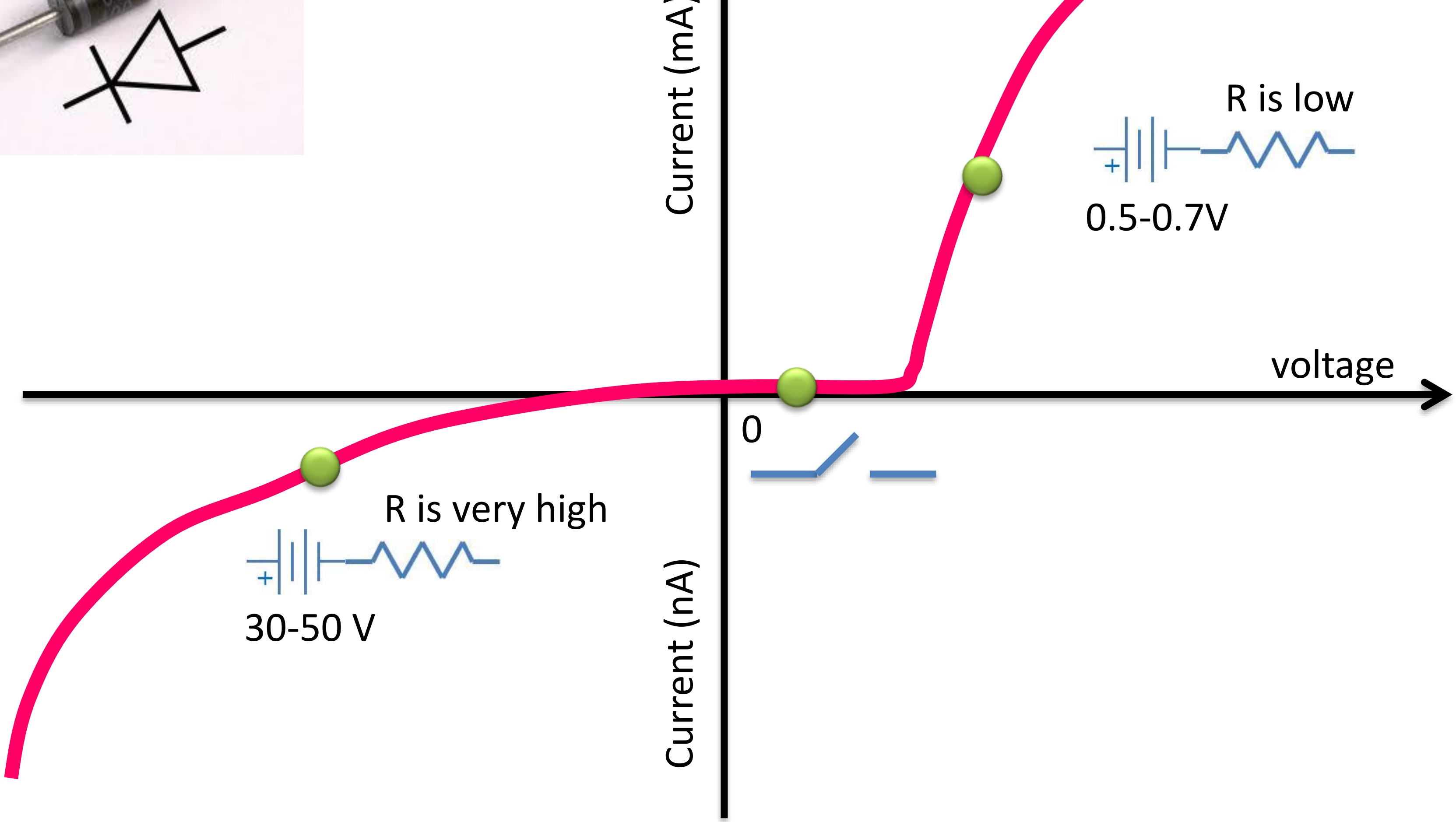


Threshold voltage = 0.7 Volts
On resistance of 1 ohm
Load Resistance of 100 ohms

I input a sinusoidal signal of amplitude +/- 100mV,
what voltage do I see on the resistor? Sketch!

I input a sinusoidal signal of amplitude +/- 100mV with a +1Volt constant offset
what voltage do I see on the resistor? Sketch!

Looking at a Diode



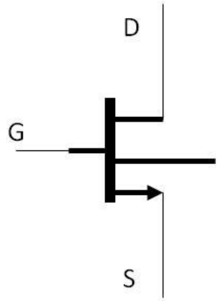
Equations with more than 1 input

For diodes, capacitors, resistors, inductors, the current is dependent only one factor, the voltage applied across it.

There are some devices where the current that flows through it is dependent on **MORE THAN ONE VALUE**. The most important one of these is a transistor

More on this later, but one type of transistor has the following equation for current flow

$$I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{tn})V_{DS} - \frac{V_{DS}^2}{2}\right]$$



Scary Solid-state equations

$$I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{tn})V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$I_D = I_S\left(\exp\left(\frac{V_D}{nV_T}\right) - 1\right)$$

You will not be asked to derive them or memorise them

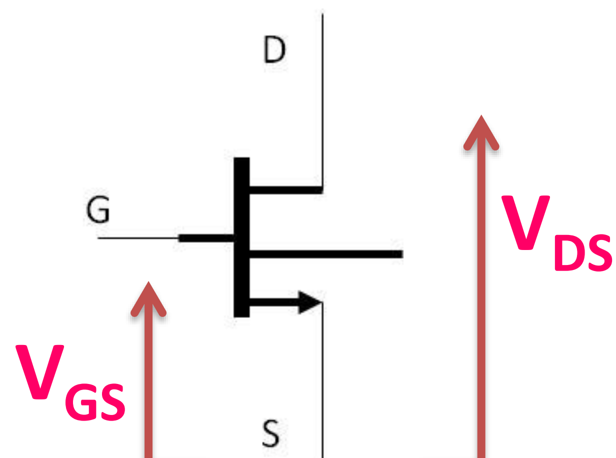
You do need to be able to interpret them, which bits are constant and which bits cause a change

They explain behaviours but they're not perfect either

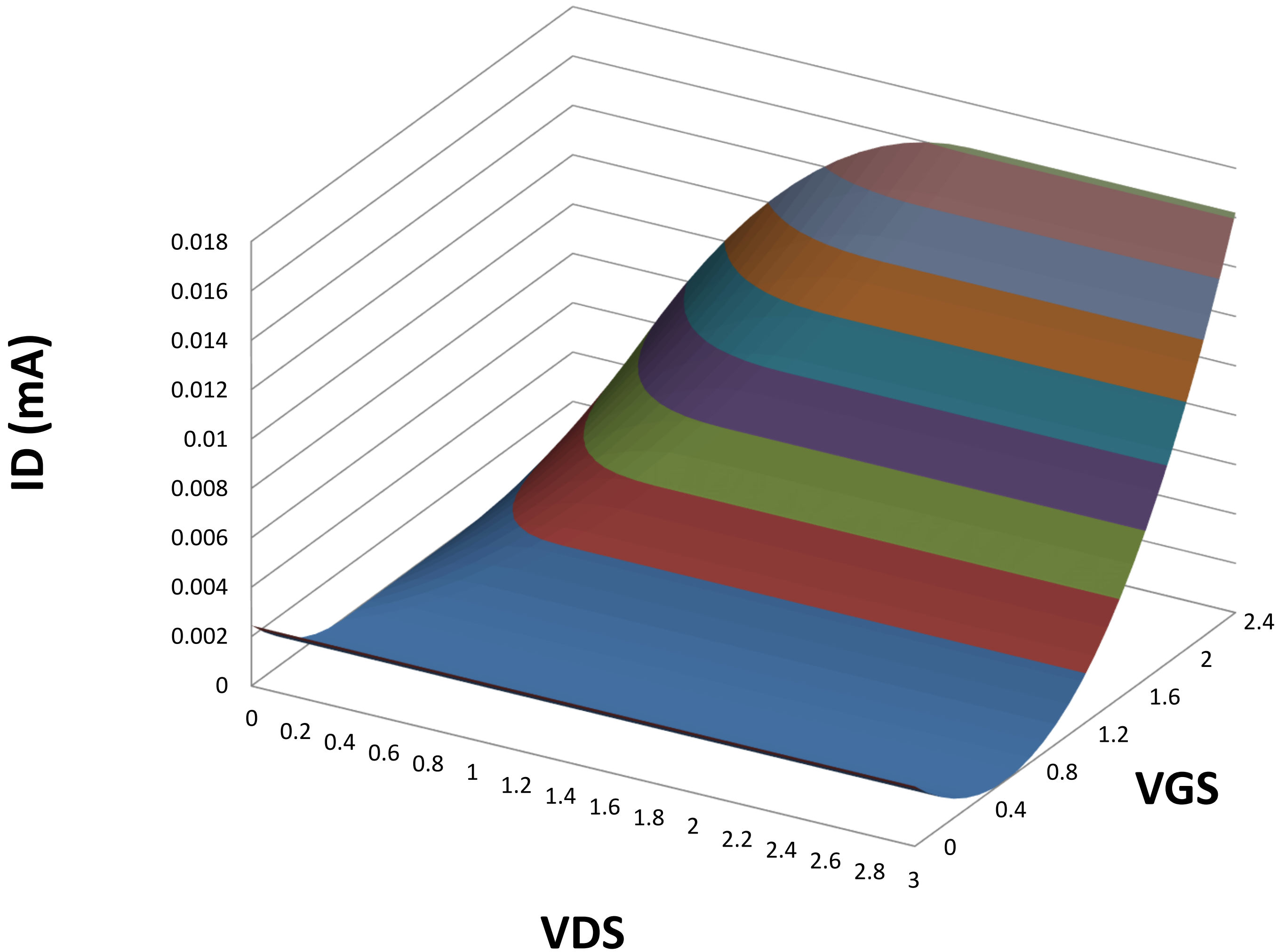
Explaining this equation – just a little

These are constants that depend on the construction and physical make up of the transistor. They do not change

$$I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{tn})V_{DS} - \frac{V_{DS}^2}{2}\right]$$

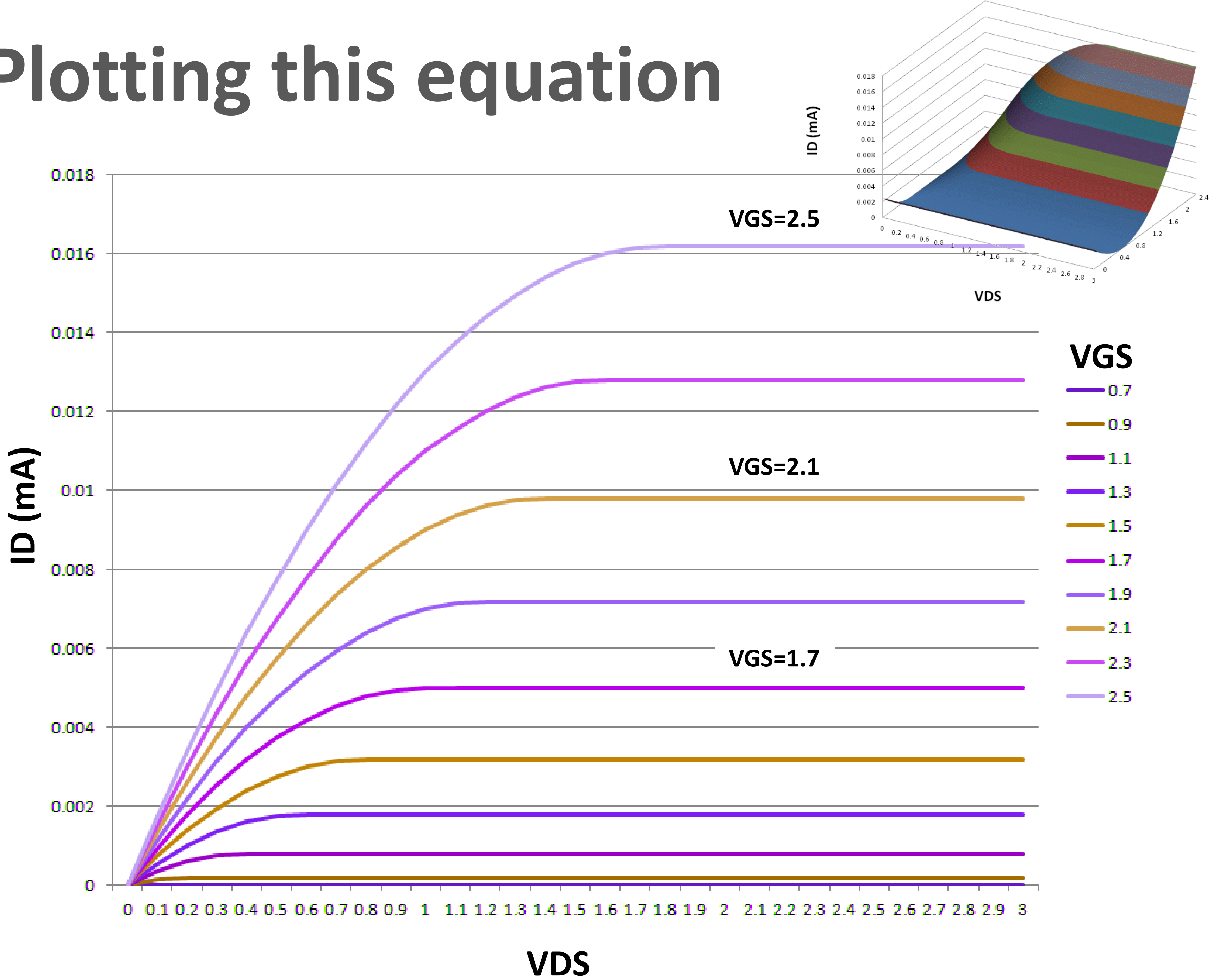


Plotting this equation



This was drawn from the equations.. Can anyone spot the problem???

Plotting this equation



3D Models

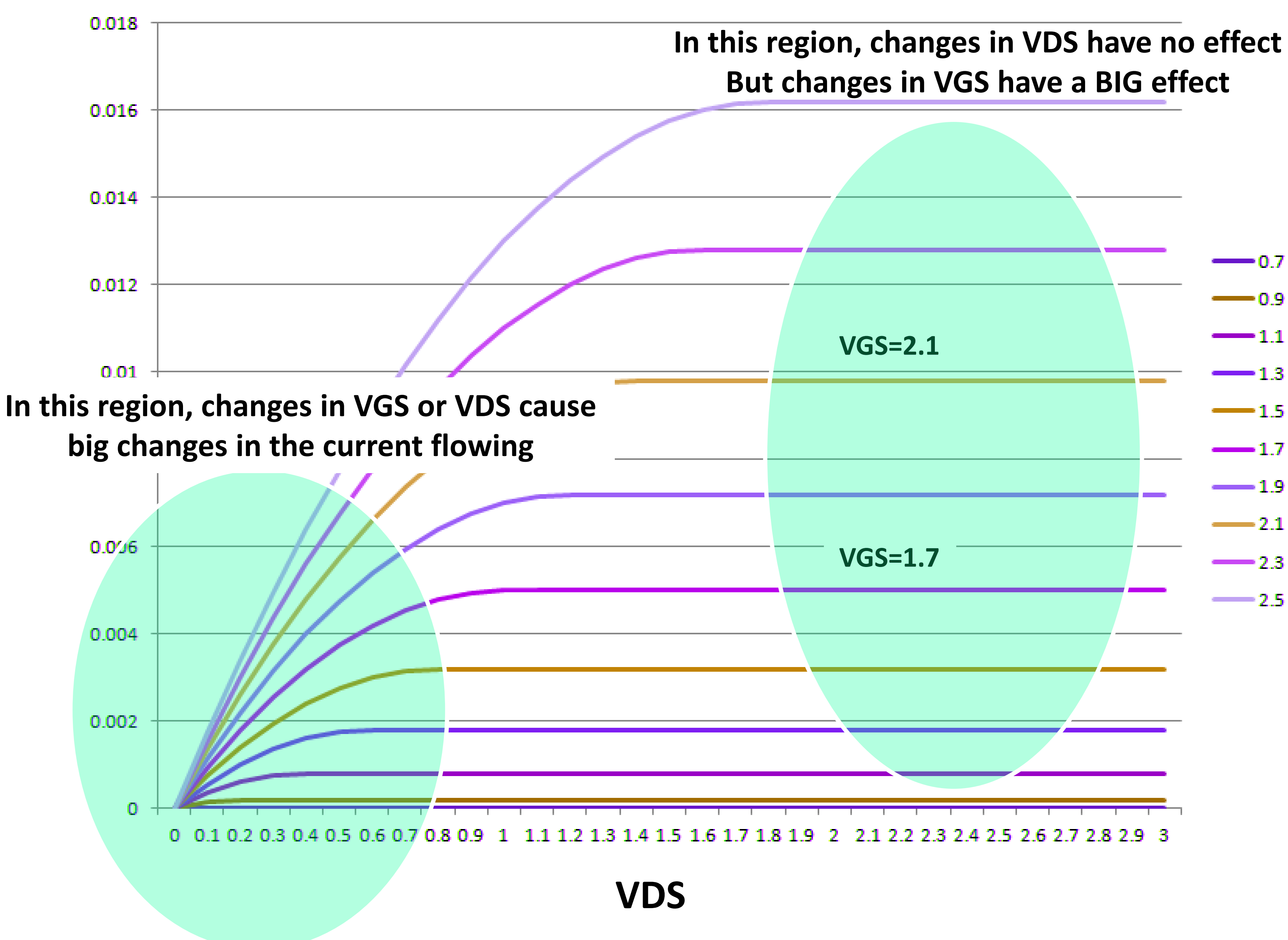
Much harder to visually interpret

These lines are smooth but reality definitely does not provide us with smooth lines

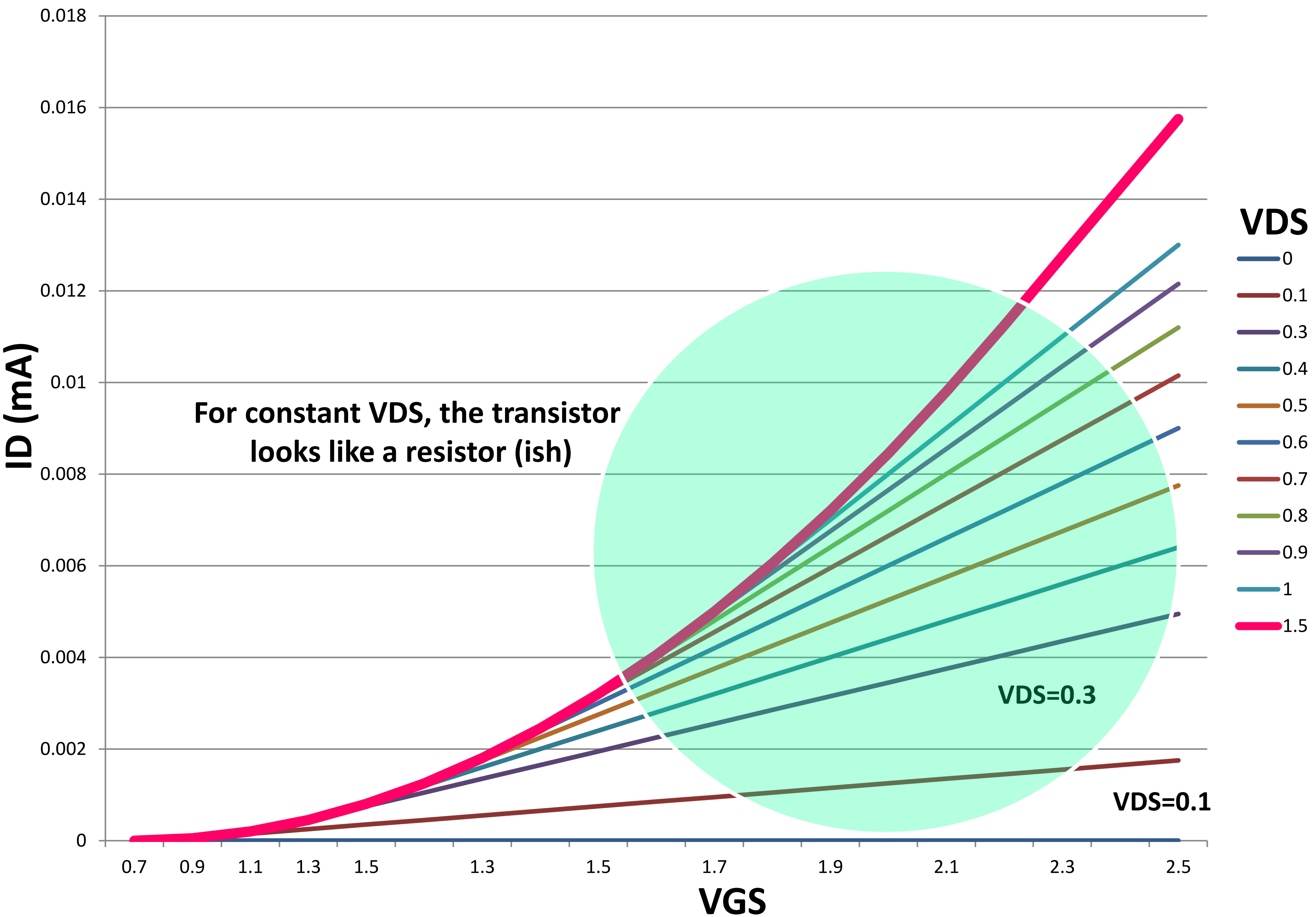
What we are looking for is something that we can use in these models... Can we get them to do something interesting or useful?

So lets look at the plots and see if anything jumps out (straight lines are always useful).

Plotting this equation



Plotting this equation (different X Axis)



Now we are going to use the different behaviours for small and large signals to make amplifiers