Advanced Class Lesson 2

Introduction + the Pulse Generator

Introduction

- You know what a computer is.
- A PC is a **portable computer** (Not personal computer)
- By portable, it means **not the size of a room**
- Thus, when I say PC, I refer to **both** laptop and desktop PCs
- Note that the topic will not be taught with reference to any actual curriculum about what computers are. I'm just trying to teach you about how a computer works

The Home Computer

- Contrary to popular belief, computers are very simple things in idea
- The theoretical idea of a computer is a simple I/O device
- However, obviously, it has gone much past that state, so it’s pointless discussing the philosophy of what constitutes a computer

A minimal computer

- The minimal computer (That fits the common definition of ‘computer’) contains the following things:
  - A processor,
  - An input device, and
  - An output device
- However, let’s move up a step from ‘minimal’

A near-minimal computer

- Our near-minimal computer consists of:
  - A CPU,
  - A form of storage,
  - A form of volatile memory,
  - A pulse generator (or two),
  - An input device, and
  - An output device
- A computer seems so much simpler now, when I describe it like this, right?

Central Processor Unit

- A CPU basically just executes instructions
- It’s what you’d call the ‘brain’ of the computer, if only it could also remember stuff

Storage

- Storage is where you store information for long-term storage
- These are your HDDs, or SSDs, etc.
- Important for obvious reasons
- Getting information out of storage is v-e-r-y s-l-o-w.
- Even the fastest SSDs have around 40 to 100μs of latency
- Doesn't sound *that* slow, but you'll see.
- Storage is usually the biggest data storage component in a computer

Memory

- Memory is where you temporarily store information that you will need later
- It is also where information is placed predictively, in case you do need it earlier
- Why?
- Because memory is thousands of times faster than storage
- Storage access latency—40-200µs ($\approx\times 10^{-5}\text{s}$)
- Memory access latency—90-95ns ($\approx\times 10^{-8}\text{s}$)
- Wow such speed

Memory 2

- Note that this is *still* not the fastest form of memory.
- Also note that the SSD times are dependant on a lot of factors, i.e. how much you paid for them.
- I really did try my best to find the most expensive one with the fastest speed
- But, the time takes for RAM is basically defined by a standard

Memory 3

- Remember how I described memory as ‘volatile’ in my original list of components?
- I clearly didn’t, since I’m updating this a few hours after I wrote the subsequent slides.
- It’s called volatile because the moment you unplug your computer, the data in it is gone
- That’s why you cannot store data in RAM

Pulse generators

- Ever wonder what ‘clock speed’ means on your intel ‘CPU’ or motherboard?
- Me neither.
- Regardless, it’s an important part of a computer
- Their main purpose is to synchronise a computer

Pulse generators –

- Electricity and charge can only travel at the speed of light
- Very slow indeed
- Because of that, it takes time for a pulse to travel from one side of a motherboard to the other
- This means that if you let every single component run at its own pace, you can end up with ‘race conditions’
- A pulse generator produces a **clock signal** that makes everything update state at basically the exact same time, which minimises the race conditions

Race Condition

- The nightmare of both multithreaded programming and high-precision hardware
- When 2 or more things try to update a thing at once, causing uncertainty regarding which one updated last
- In this context, race conditions may be determined by a dust floating in the air that somehow alters the magnetic field of one of the signals and makes it slower, or whatever.
- When signals are the full length in $\approx\times 10^{-10}$s, even a few picoseconds of difference is significant!

Pulse generators –_

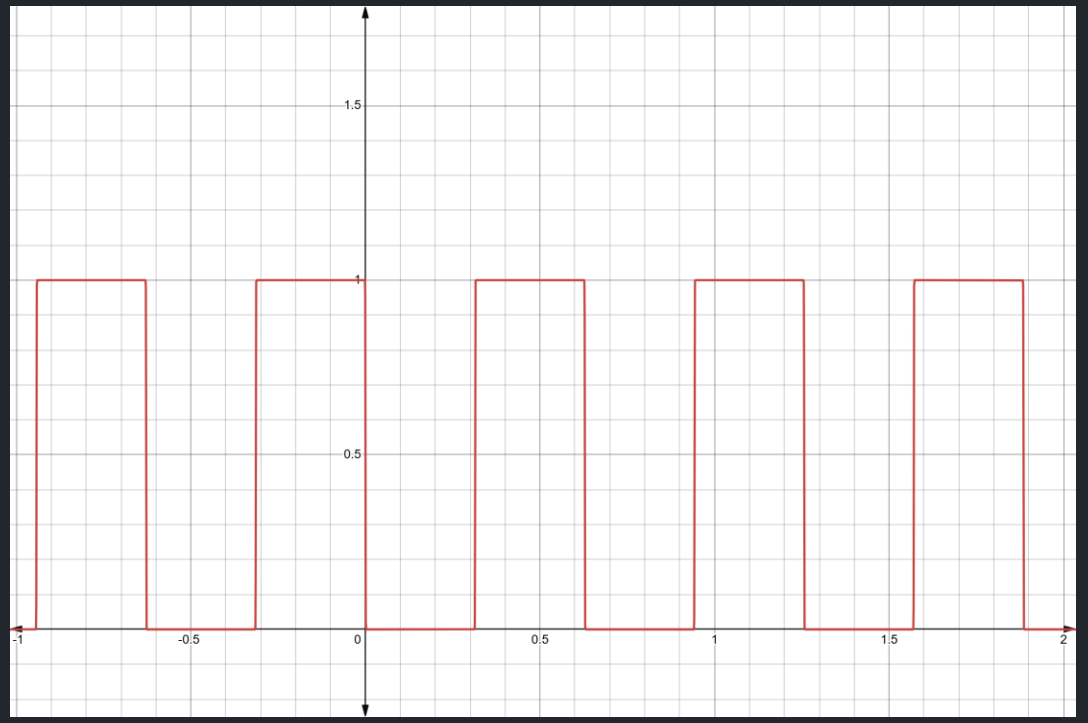
- Clocks minimise such situations by giving circuit designers a way of making sure that the actions go one after the other
- The period of the signal must last long enough that every signal reaches their destination before the next cycle
- Very fun.

Interlude

- You now know what the components in a PC do
- Now, let’s look at each component in more detail
- This section will be spread across multiple lessons

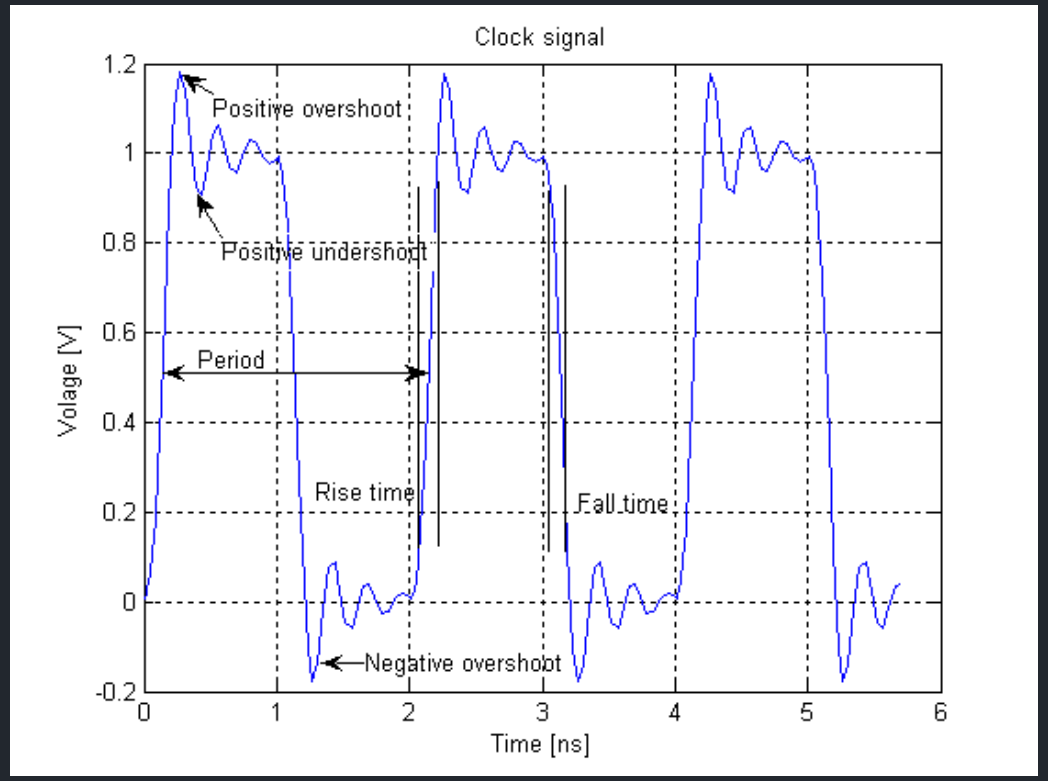
Pulse Generators

- Let’s start with pulse generators
- As stated above, a pulse generator is used with the sole purpose of synchronising parts in a motherboard
- A pulse generator generates electricity in a square wave (Right) that flips between 0V and 1V
- Ideally, that is.



Pulse Generators –

- However, in reality, it creates a sort of weird wave that approximates a square wave.
- This is because, repeat after me, eddy currents.
- Always blame eddy currents.
- Anyways, this is because voltage and change in voltage can’t change instantly since this isn’t physics land.



Credits: Wikimedia

Pulse Generators –_

- But why is it important?
- It isn’t (Usually).
- Just saying this because it’s important to keep in mind that **the world isn’t perfect**.
- Anyways, it’s just a short digression.

Pulse Generators –_–

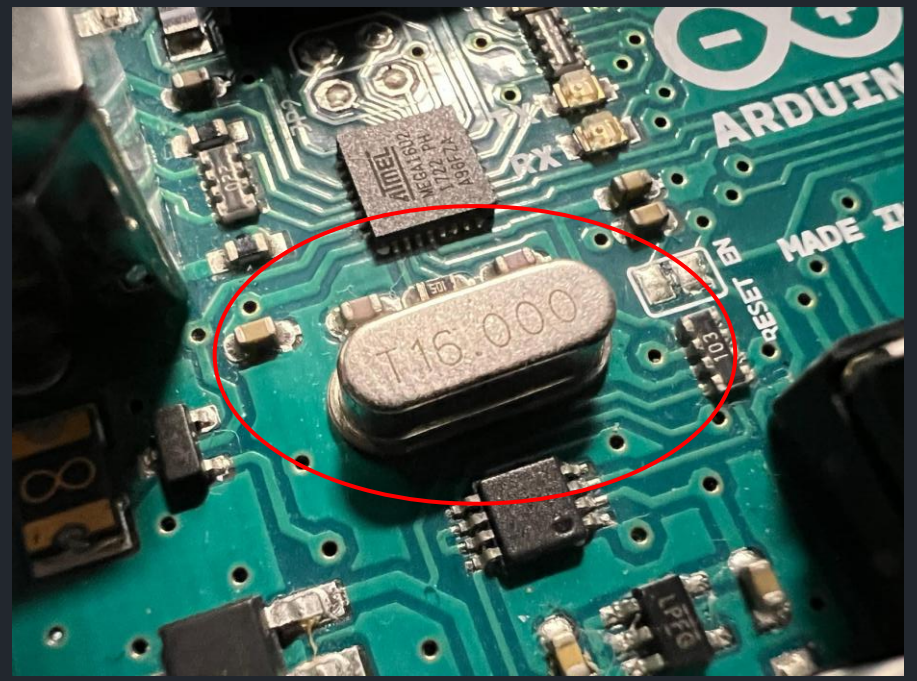
- Wait, so why are we starting with this component?
- It isn’t the most important component, isn’t it?
- Of course it isn’t.
- But, it’s also the simplest, and every single oscillator works in the exact same way
- So, it’s the easiest to teach
- I’m leaving the pain for later.

Pulse Generators –_–_

- So, how does a pulse generator work anyway?
- I’m glad you asked.
- If you didn’t ask, then forget bullet point 2.
- The most common form of pulse generator in PCs nowadays is the crystal oscillator

Pulse Generators –_–_–

- Specifically For This Course™, I went to an NUS Electronics Engineering Course™ and borrowed an Arduino Uno™ from them just to show you the parts In Context of an Arduino™.
- Such dedication.
- Anyways, the oscillator.
- It’s labelled T16.000, which means it’s a 16.000 MHz oscillator.
- Which matches up with an Arduino’s 16MHz clock speed.



Pulse Generator –_–_–_

- So, why is it called a crystal oscillator?
- It’s because it has a crystal in it
- Shock.
- Precisely, it’s a tiny quartz crystal

Pulse Generator –_–_–_–_

- Is this the crystal energy that cures cancer?
- Sort of, in that it solves race conditions, which is a cancer in its own right.
- But that has nothing to do with Magic Crystal Powers™.
- In particular, it has to do with Quartz's piezoelectricity

Pulse Generator –_–_–_–_–

- A simplified definition of piezoelectricity is that when you change the shape of something, it generates a voltage
- The explanation for this requires Ch*mistry, so I won’t explain further.
- A result of this is that if you keep hitting it with a hammer, it will produce an electrical wave that has the same frequency at which you’re hitting it with a hammer.

Pulse Generator –_–_–_–_–_

- But, why can’t it go backwards?
- It can, so if you provide a voltage to the crystal, it will also change shape
- This is called **Inverse Piezoelectricity**
- Very surprising, I’m howling in shock right now.
- Another result of this is that if you provide an electrical wave to it, the crystal will vibrate (i.e. change shape) at the same frequency as the wave

Pulse Generator –_–_–_–_–_–

- So, is there a hammer in my PC hitting a quartz crystal over and over?
- Yes, there is.
- If you put your ear up against it, you can even hear your brain knocking against your skull.
- No there isn’t
- The thing is, when you provide a voltage to the crystal, if you decrease the voltage, the crystal will produce a voltage
- This basically creates a feedback loop

Pulse Generator –_–_–_–_–_–_

- Is this infinite energy?
- Obviously not.
- It’ll run out of energy eventually
- However, in an oscillator, there’s also an amplifier that raises the voltage (With the help of an external power source)
- This is what actually sustains the feedback loop of the crystal
- There are a few other components, but they aren’t taught in A level physics, so I won’t go through them.

Pulse Generator –_–_–_–_–_–_–

- Wait, so how the hell does this thing start?
- After all, you need to feed it a waveform of the same frequency to get it started, right?
- Yes, that is correct
- However, you don’t have to start with the waveform all at once.

Digression

- Let’s imagine a bunch of suicidal kids jumping on a trampoline at the same time
- At first, they jump at a random frequency
- I think most of you know what happens then?
- It takes a lot of energy to jump any significant height
- How fun.

Pulse Generator –_–_–_–_–_–_–_–

- Back to the topic
- When you start the pulse generator initially, it’s not much of anything
- At most, it can be an amplifier, but it’s quite shit at being an amplifier
- However, as time passes, there are small variations in the voltage throughout the circuit
- Why is that?
- Because we’re not in physics land

Pulse Generator –_–_–_–_–_–_–_–

- As time passes, though, those minute changes in voltage add up, causing the waveform to become closer and closer to the waveform that you expect
- And over time, it starts itself
- How interesting.
- To clarify, this time that it takes is usually in the microseconds
- It also happens long before your PC can actually take any of your inputs
- So, your low FPS isn’t because of the clock

The Digression was Not A Digression™

- This is just like the children on the trampoline
- As they continue jumping, they slowly begin jumping at the same frequency
- And once they hit that frequency, it becomes goddamn hard to jump at any other frequency
- It’s also hard to stop, too
- At least, until one of them gets launched too high and breaks their back.

Pulse Generator –_–_–_–_–_–_–_–_

- So, a crystal oscillator is actually a self-regulating system
- Wait, isn’t the waveform supposed to be a square wave looking thingy?
- Yep.
- Thing is, the amplifier has a cutoff voltage at which it decides to dump all the voltage at once
- Below that, it doesn’t output any voltage
- That’s why the resulting wave is the waveform I showed you earlier.

Pulse Generator –_–_–_–_–_–_–_–_–_–_–

- Why did we pick quartz for this?
- One reason is piezoelectricity
- Quartz is sort of the middle ground between the common natural piezoelectric minerals

Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_

- Rochelle Salt ($KNaC_4H_4O_6 \cdot 4H_2O$) is the most piezoelectric mineral that I could find
- This means that it produces the maximum vibration per unit voltage
- Wow, very shaky.

Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–

- Tourmalline is the least piezoelectric mineral that I could find
- It’s just what I put in the last slide, but opposite.
- Wow, very pretty

Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_

- Quartz
- Very quartz.
- It’s just sand but pure.
- Fun.
- Sort of the midpoint between Rochelle Salt and Tourmaline
- Not literally the midpoint, but it’s between them

Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_–

- Then why are we even using quartz?
- There’s Rochelle Salt, right?
- But the problem with piezoelectricity is that piezoelectricity tends to be proportional to brittleness
- So, Rochelle Salt is far too brittle to be used in computers reasonably

Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_

- So why not tourmaline?
- It’s not piezoelectric enough, so it takes a while to start generating the clock signal

Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_–_–

- Regardless, why quartz?
- Isn’t there a better version that material scientists have come up with?
- Indeed, there are a lot of them.
- But quartz is the cheapest
- I’m sure than 70% of the reasons for everything in engineering is just “It’s the cheapest”.
- Honestly, you don’t even have to consider the piezoelectric quality of the other minerals, because quartz is still the cheapest.

Guess What?

- It means that your computer clock has the same clock that clocks a quartz clock
- It also means that it has the same clock that clocks a digital clock because digital clocks have computer clocks that have a quartz clock in the clock signal generator
- Fun

Pulse Generator –_–_–_–_–_–_–_–_–_–

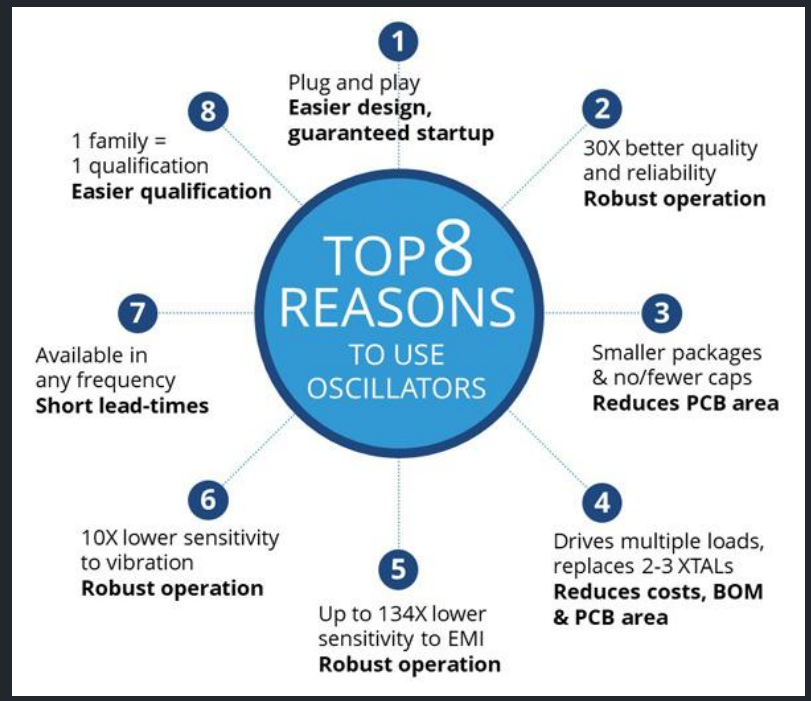
- Other than crystal oscillators, there is another form of crystal thing that’s used for such clocks
- They’re called crystal resonators
- I guess this is sort of cheating?
- Because resonators are just oscillators with some components missing
- So basically, it’s the DIY version of it.

Pulse Generator –_–_–_–_–_–_–_–_–_–_

- Why do crystal resonators even exist?
- Because they’re cheaper
- It’s cheaper to buy the amplifier, capacitors, and the resonator yourself than to buy the full oscillator

Pulse Generator _–_–_–_–_–_–_–_–_–_–_–_–_

- So why do crystal oscillators exist then?
- Is it a scheme for companies to milk us for our wallets?
- No.
- There’s 8 reasons on the right, but it’s from a crystal oscillator company, so I wouldn’t trust it that much.
- In general, though, it makes sense since it basically just says ‘less hassle’
- Fun.

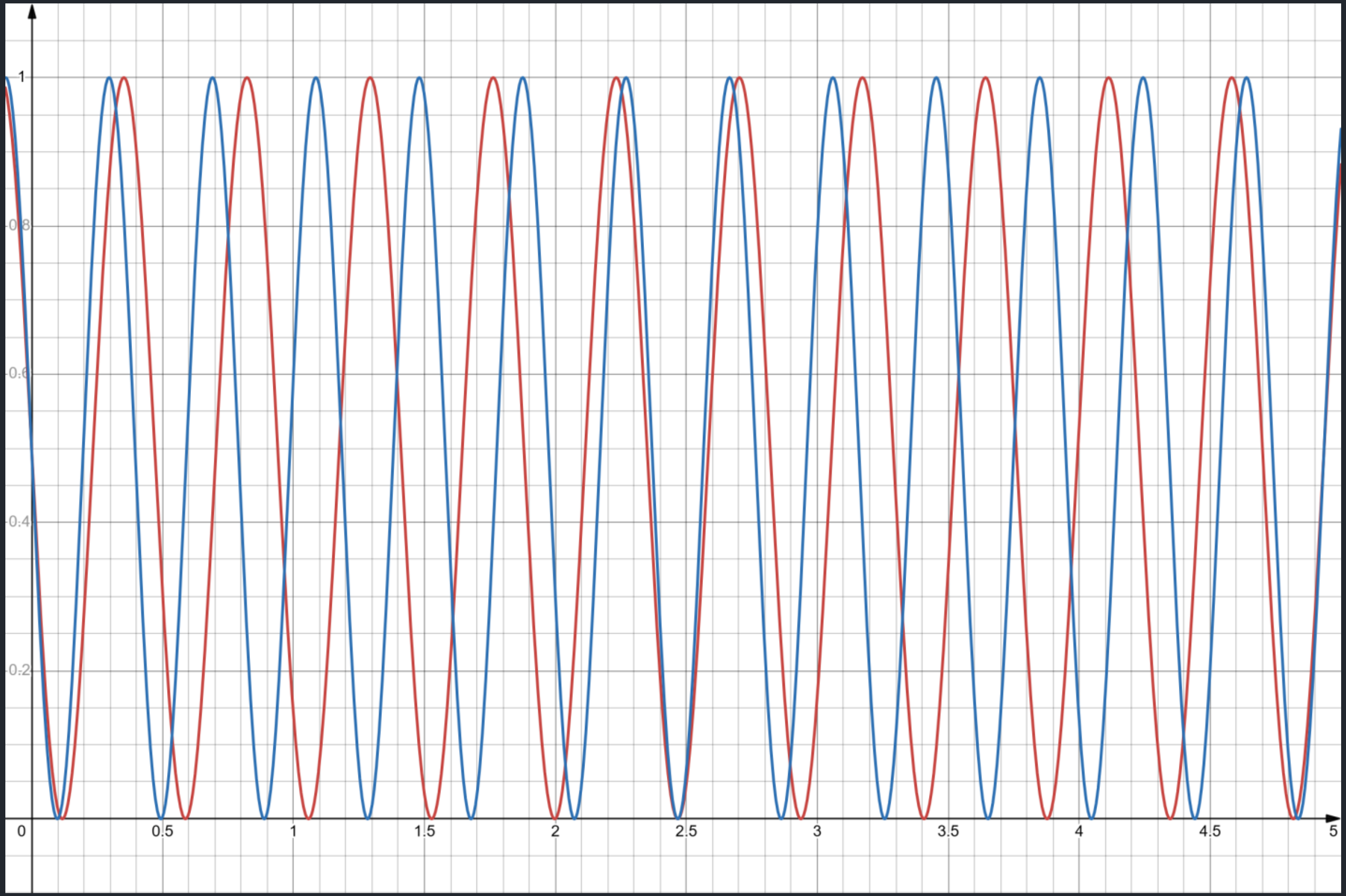


Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_–_–

- So how does this actually help a PC work?
- Like I said before, it synchronises a computer
- That way, it makes it easier for the designer to make sure things go one after the other

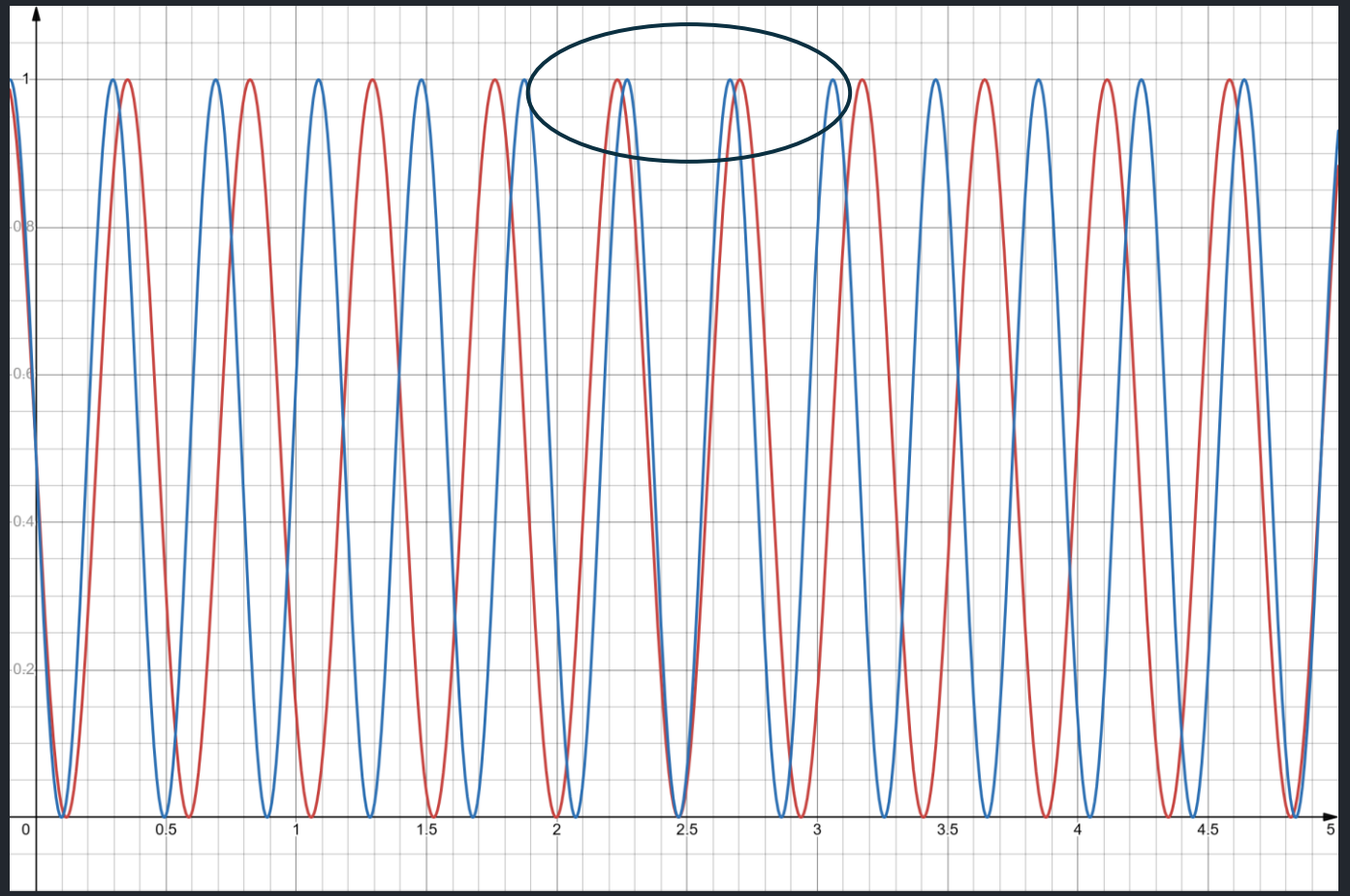
Pulse Generator

- Let's say you have 2 components that operate at 50Hz (blue) and 42Hz (red) respectively
- And let's assume that they both change state the moment the sine wave hits 1V



Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_–_–_–

- Over here, the blue graph has already crossed from hitting 1V after the red graph, to hitting 1V before the blue graph
- This means that your 50Hz component is going to update before the 42Hz component



Pulse Generator _‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_

- You can always account for this manually
- But why go through the trouble?
- This is why a clock signal generator is helpful
- It **does not directly eliminate race conditions**
- However, it is a very helpful tool to help with that process

Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_–_–_–_–

- You know how engineers are.
- Optimisation yay.
- One thing you’ll notice is that there are usually 2 or maybe 3 distinct clock signals within a PC
- Well, why is that?

Pulse Generator _‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_‾_

- Obviously it’s for more performance.
- A CPU/GPU tends to ‘do things’ more than it ‘takes input’ (Citation needed)
- A CPU/GPU is also usually smaller than a motherboard (Citation needed)
- So, you can make a CPU take a higher frequency clock signal than the motherboard it’s surrounding

Pulse Generator –_–_–_–_–_–_–_–_–_–_–_–_–_–_–

- To achieve that, PC manufacturers usually include a frequency multiplier somewhere to increase the frequency of the clock signal
- This is the idea behind ‘CPU’/GPU overclocking

Pulse Generator _–_–_–_–_–_–_–_–_–_–_–_–_–_–_

- Trade-offs of overclocking
  - Increased heat output, causing potential damage to the CPU
  - Higher power consumption, which can strain the power supply, decrease battery health, and increase energy costs
  - Stability issues causing system crashes

References

undefined. Stevenvh, “Crystals, Oscillators, and Resonators. What the difference?”, ,
(The post doesn’t have enough info to fill in the IEEE citation format)

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