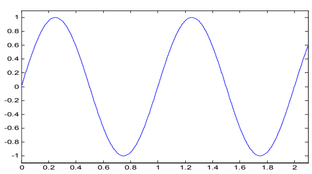
Oscillators

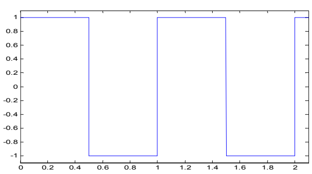
Waveforms

We have four basic waveforms for oscillators

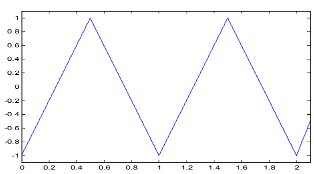
Sinodial



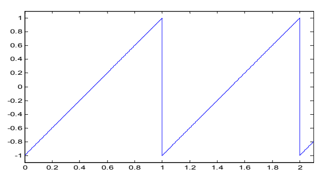
Squarewave



Triangle



Sawtooth



Flip-flops

Lets´s start with squarewave generators

We talk about flip-flops

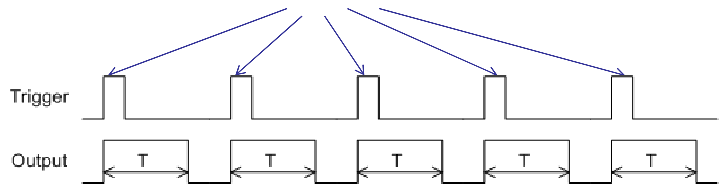
Flip-flops

There are three basic types of flip-flops

• Monostable flip-flop	Stable in one position
• Bistable flip-flop	Stable in both positions
• Astable flip-flop	Unstable

Monostable flip-flop

Each trigging pulse gives an output pulse of length T



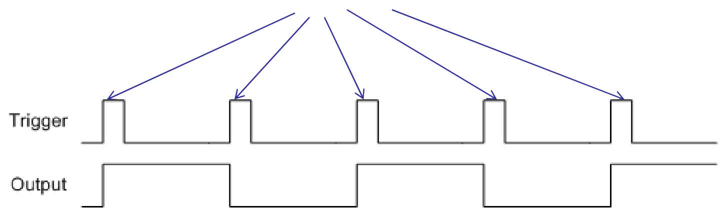
Depending on the construction of the flip-flop different things can happen if the trigging pulses comes to close and retriggering occures before the time T has passed.

It can

- Do nothing
- Retrigger immediately
- Retrigger when time T has passed

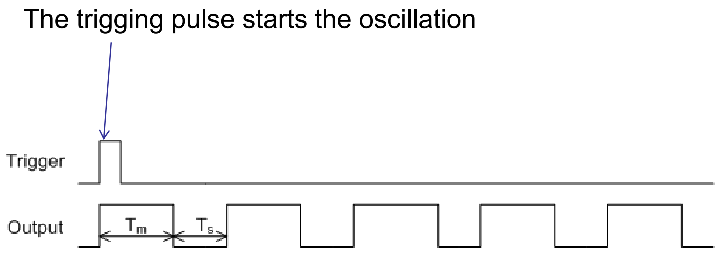
Bistable flip-flop

The flip-flop toggles on each trigging pulse



Retriggering can not occure

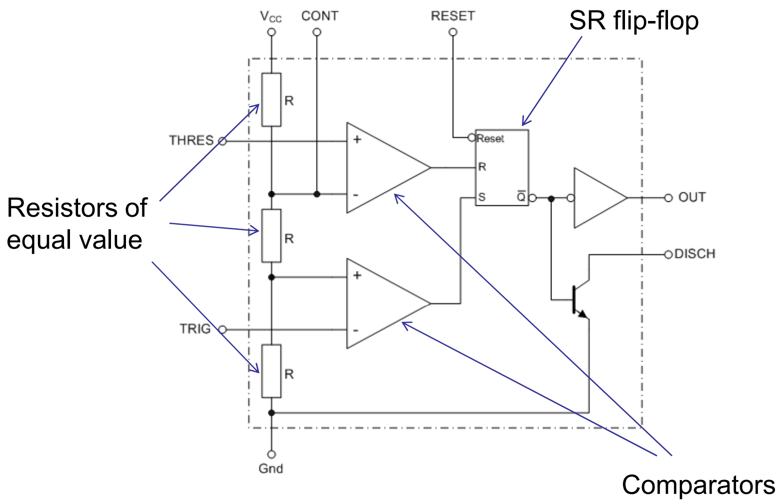
Astable flip-flop



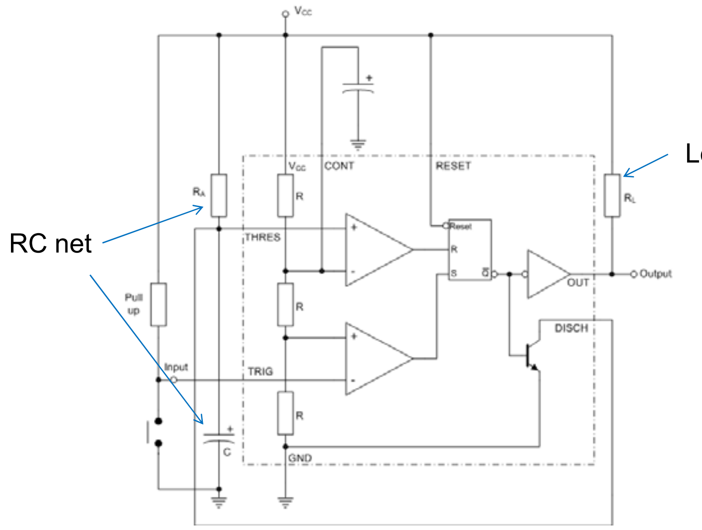
In many cases no trigging pulse is required, turning on the power is sufficient to start the oscillation.

The pulse and the pulse space could be of different length

Example NE555



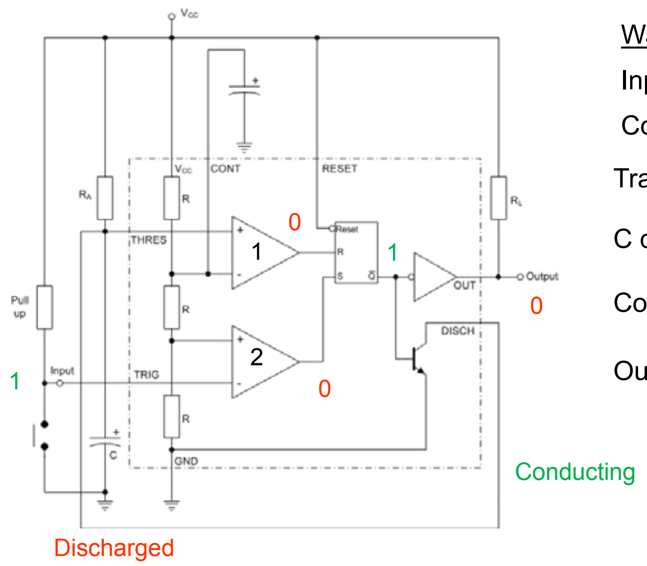
Monostable NE555 flip-flop



Pulse time

$T_P = 1.1 \cdot R_A \cdot C$

Monostable NE555 flip-flop cont.



Wait state

Input high

Comp 2 low

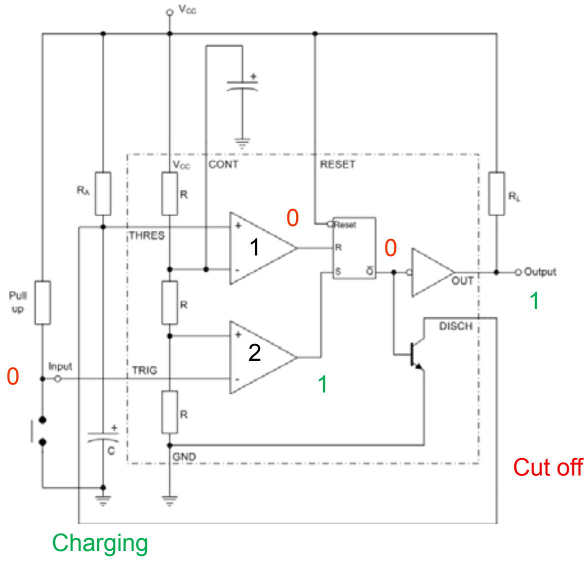
Transistor active

C discharged

Comp 1 low

Output low

Monostable NE555 flip-flop cont.



<u>At trigger</u>

Input low

Comp 2 high

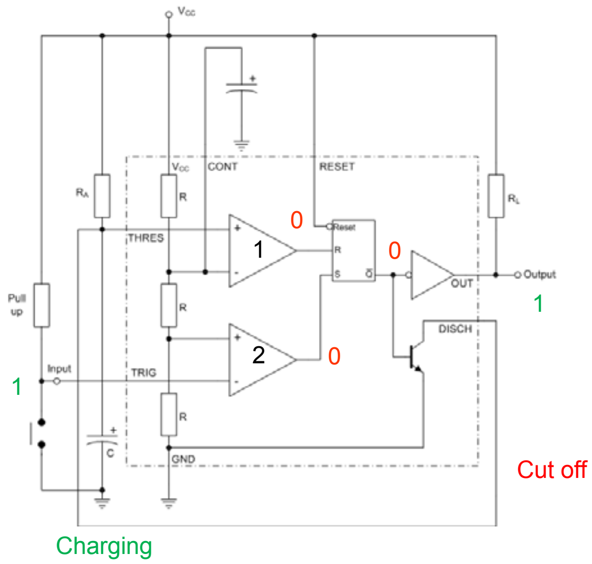
Transistor cut off

C charging

Comp 1 low

Output high

Monostable NE555 flip-flop cont.



<u>When charging</u>

Input high

Comp 2 low

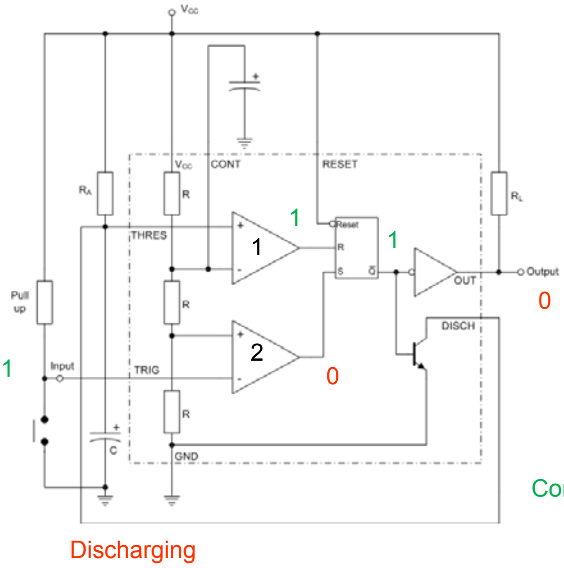
Transistor cut off

C charging

Comp 1 low

Output high

Monostable NE555 flip-flop cont.



Conducting

When C charged to 2/3Vcc

Input high

Comp 2 low

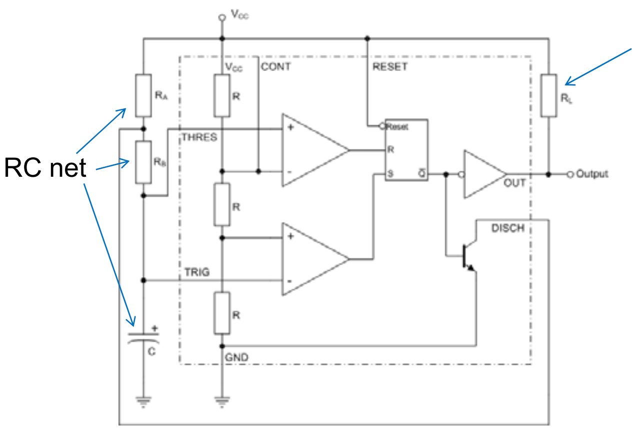
Comp 1 high

Transistor active

C discharging

Output low

Astable NE555 flip-flop



Load

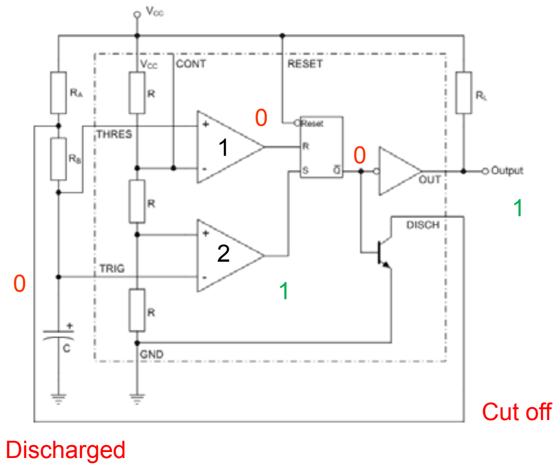
High pulse time

$$T_{mark} = 0.7 \cdot (R_A + R_B) \cdot C$$

Low pulse time

$$T_{space} = 0.7 \cdot R_B \cdot C$$

Astable NE555 flip-flop cont.



Start

C discharged

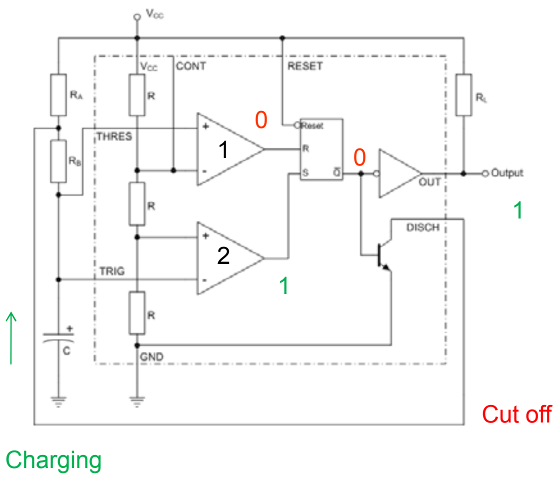
Comp1 low

Comp2 high

Transistor cut off

Output high

Astable NE555 flip-flop cont.



After start

C charging

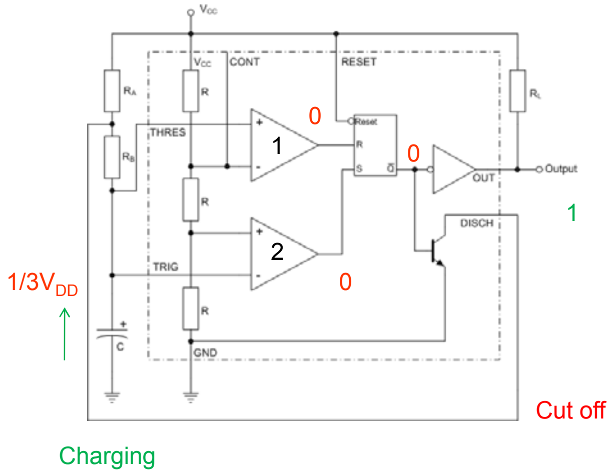
Comp1 low

Comp2 high

Transistor cut off

Output high

Astable NE555 flip-flop cont.



At $1/3V_{DD}$

Comp1 low

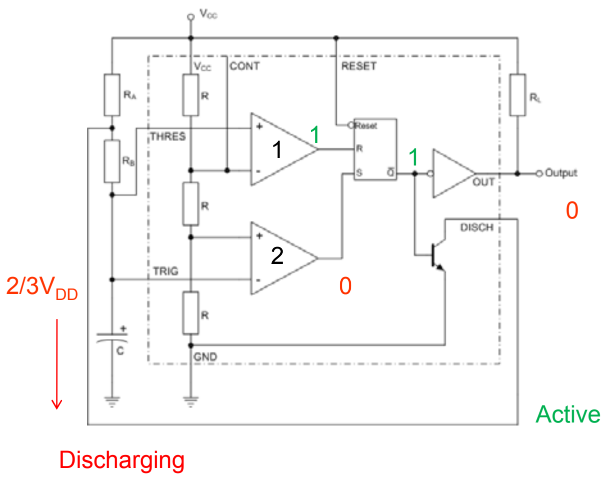
Comp2 low

Transistor cut off

Output high

C charging

Astable NE555 flip-flop cont.



At $2/3V_{DD}$

Comp1 high

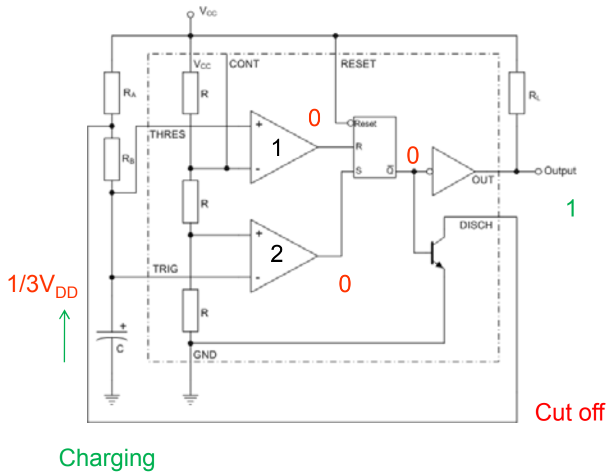
Comp2 low

Transistor active

C discharging

Output low

Astable NE555 flip-flop cont.



We are back at $1/3V_{DD}$

Comp1 low

Comp2 low

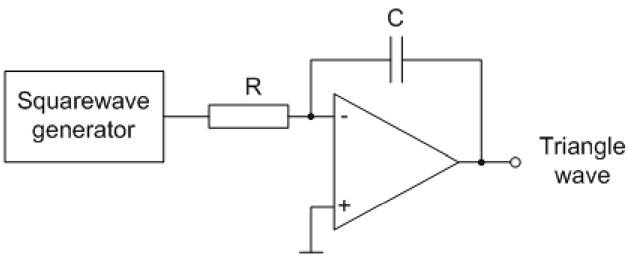
Transistor cut off

Output high

C charging

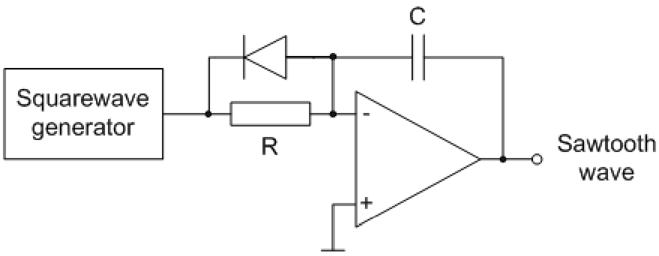
Trianglewave generator

The square wave can be converted to trianglewave by adding an integrator

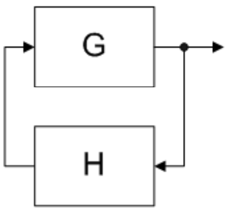


Sawtooth generator

We can also turn it into a sawtooth generator



General sinodial oscillator



Condition for oscillation

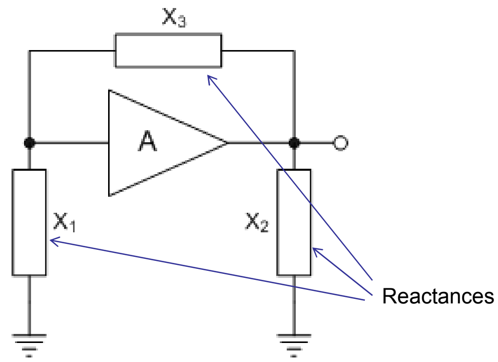
$$G(j \cdot \omega) \cdot H(j \cdot \omega) = 1$$

Amplitude = 1

Phase = 0 or 360°

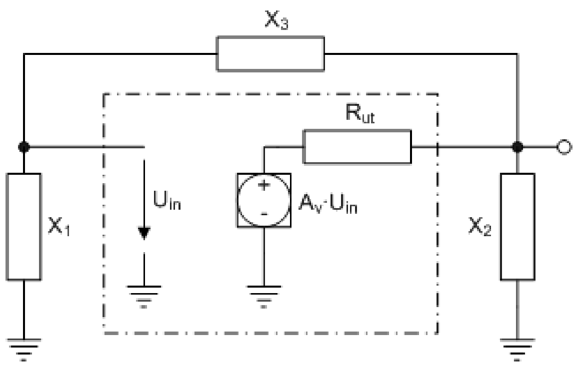
This can only be true for one frequency if the oscillator is to function properly

General oscillator cont.

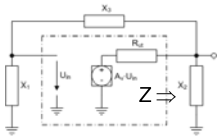


Let´s redraw using a small signal model of the amplifier

General oscillator cont.



General oscillator cont.



$$U_{in} = \frac{j\cdot X_1}{j\cdot X_1 + j\cdot X_3}\cdot\frac{Z}{R_{ut}+Z}\cdot A_v\cdot U_{in}$$

$$Z = \frac{j\cdot X_2\cdot(j\cdot X_1 + j\cdot X_3)}{j\cdot X_1 + j\cdot X_2 + j\cdot X_3} = \frac{j\cdot X_2\cdot(X_1+X_3)}{X_1+X_2+X_3}$$

$$1 = \frac{X_1}{X_1+X_3}\cdot\frac{\frac{j\cdot X_2\cdot(X_1+X_3)}{X_1+X_2+X_3}}{R_{ut}+\frac{j\cdot X_2\cdot(X_1+X_3)}{X_1+X_2+X_3}}\cdot A_v$$

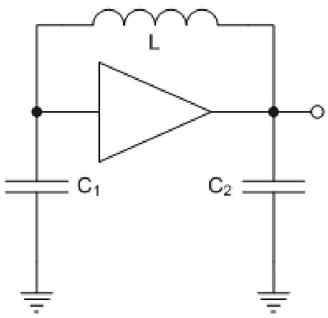
$$1 = \frac{j\cdot X_1\cdot X_2}{R_{ut}\cdot(X_1+X_2+X_3) + j\cdot X_2\cdot(X_1+X_3)}\cdot A_v$$

Condition for oscillation

$X_1 + X_2 + X_3 = 0$ Must be both inductive and capacitive elements

$$1 = \frac{j\cdot X_1\cdot X_2}{j\cdot X_2\cdot(X_1+X_3)}\cdot A_v \Rightarrow 1 = \frac{X_1}{X_1+X_3}\cdot A_v \Rightarrow X_3 = (1 - A_v)\cdot X_1 \Rightarrow A_v = 1 - \frac{X_3}{X_1}$$

Colpitt oscillator



$$X_1 = -\frac{1}{\omega\cdot C_1}$$

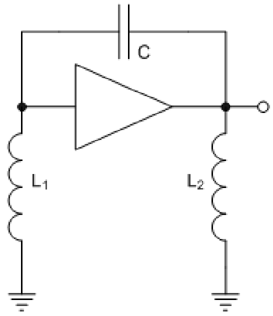
$$X_2 = -\frac{1}{\omega\cdot C_2}$$

$$X_3 = \omega\cdot L$$

$$X_1 + X_2 + X_3 = -\frac{1}{\omega\cdot C_1} - \frac{1}{\omega\cdot C_2} + \omega\cdot L = 0 \Rightarrow f = \frac{1}{2\cdot\pi\cdot\sqrt{L\cdot\frac{C_1\cdot C_2}{C_1+C_2}}}$$

$$A_v = 1 - \frac{w\cdot L}{-\frac{1}{w\cdot C_1}} = 1 + w^2\cdot L\cdot C_1$$

Hartley oscillator



$$X_1 = \omega \cdot L_1$$

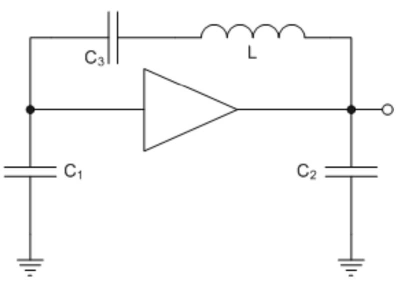
$$X_1 = \omega \cdot L_2$$

$$X_3 = -\frac{1}{\omega \cdot C}$$

$$X_1 + X_2 + X_3 = \omega \cdot L_1 + \omega \cdot L_2 - \frac{1}{\omega \cdot C} = 0 \quad \Rightarrow \quad f = \frac{1}{2 \cdot \pi \cdot \sqrt{C \cdot (L_1 + L_2)}}$$

$$A_v = 1 - \frac{-\frac{1}{\omega \cdot C}}{\omega \cdot L_1} = 1 + \frac{1}{\omega^2 \cdot C \cdot L_1}$$

Clapp oscillator



$$X_1 = -\frac{1}{\omega \cdot C_1}$$

$$X_2 = -\frac{1}{\omega \cdot C_2}$$

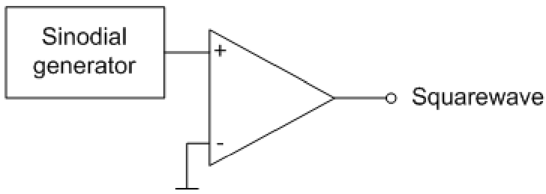
$$X_3 = \omega \cdot L - \frac{1}{\omega \cdot C_3}$$

$$X_1 + X_2 + X_3 = -\frac{1}{\omega \cdot C_1} - \frac{1}{\omega \cdot C_2} + \omega \cdot L - \frac{1}{\omega \cdot C_3} = 0 \quad \Rightarrow \quad f = \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{1}{L} \cdot \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right)}$$

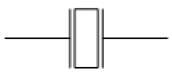
$$A_v = 1 - \frac{w \cdot L - \frac{1}{w \cdot C_3}}{-\frac{1}{w \cdot C_1}} = 1 - \frac{C_1}{C_3} + w^2 \cdot L \cdot C_1$$

Sinodial to squarewave

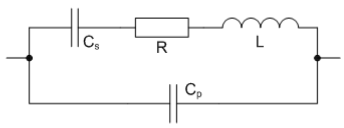
The sinodial wave can be turned into a squarewave by adding a comparator



Crystals



Symbol



Equivalent schematic

Impedance

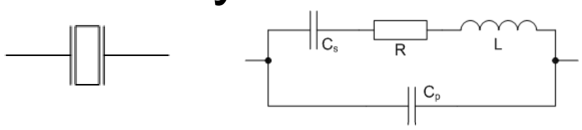
$$Z = \frac{1}{j \cdot \omega \cdot (C_p + C_s)} \cdot \frac{1 - \omega^2 \cdot L \cdot C_s + j \cdot \omega \cdot R \cdot C_s}{1 - \omega^2 \cdot L \cdot \frac{C_p \cdot C_s}{C_p + C_s} + j \cdot \omega \cdot R \cdot \frac{C_p \cdot C_s}{C_p + C_s}}$$

The device has one serial resonance frequency

and one parallel resonance frequency

Finding these is a bit complicated

Crystals cont.



If we ignore the resistance R we will get

$$Z = \frac{1}{j\cdot\omega\cdot\left(C_p + C_s\right)}\cdot\frac{1-\omega^2\cdot L\cdot C_s}{1-\omega^2\cdot L\cdot\frac{C_p\cdot C_s}{C_p + C_s}}$$

The expression will have a serial resonance where the impedance is zero at $f_s = \frac{1}{2\cdot\pi\cdot\sqrt{L\cdot C_s}}$

and a parallell resonance where the impedance goes towards infinity at

$$f_p = \frac{1}{2\cdot\pi\cdot\sqrt{L\cdot\frac{C_p\cdot C_s}{C_p + C_s}}} = \sqrt{\frac{C_p + C_s}{C_p}}\cdot f_s$$

Crystals cont.

Some sample data for a crystal could be

$R = 400\,\Omega$ $L = 3.3\text{H}$

$C_s = 0.042\,\text{pF}$ $C_p = 5.8\,\text{pF}$

Calculations will give the resonance frequencies

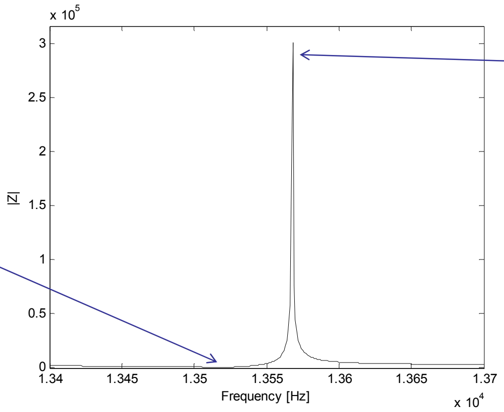
$f_s = 13.519\,\text{kHz}$

$f_p = 13.567\,\text{kHz}$

that is the two resonance frequencies are quit close.

Let´s draw the impedance curve as an absolute value

Crystals cont.

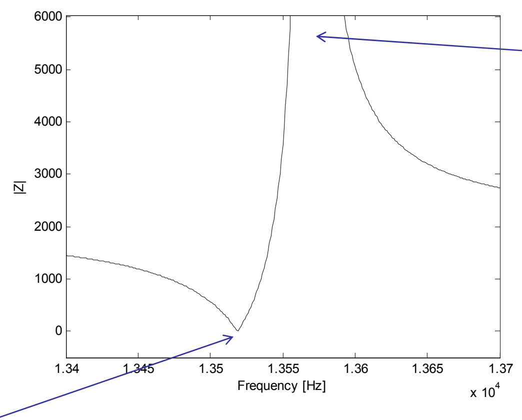


Parallel resonance

Serial resonance

Let´s zoom in

Crystals cont.

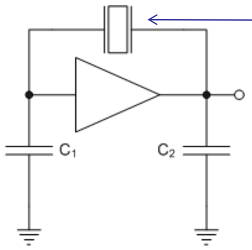


Parallel resonance

Serial resonance

Crystal oscillator

By placing the crystal in the feedback loop we can use the serial resonance to get a very stable oscillator



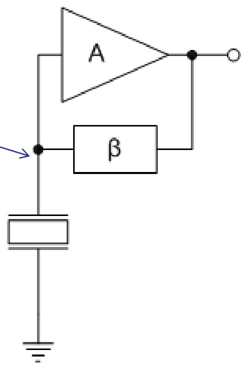
Low impedance only at the serial resonance frequency

The capacitors will make the oscillator start oscillating

Crystal oscillator cont.

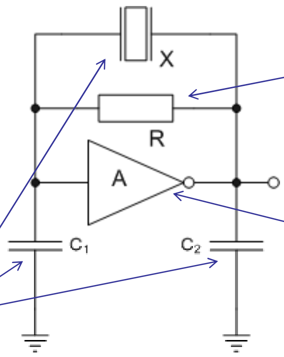
We can also use the parallel resonance to make a crystal oscillator although this is less common

High impedance only at the parallel resonance frequency



Pierce oscillator

The most common type of crystal oscillator is the Pierce oscillator, a serial resonance oscillator



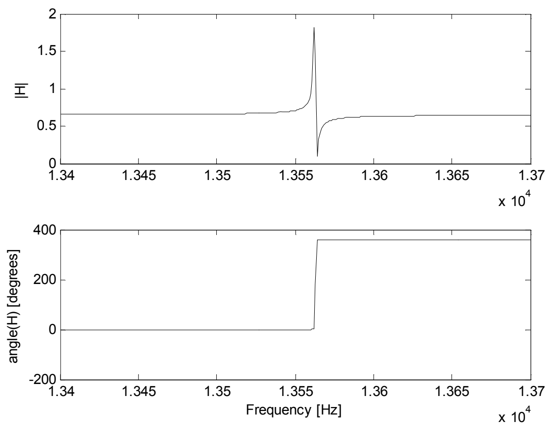
The resistor R biases the amplifier (inverter) in the active region

The amplification will have to be negative to compensate for the phase shift in the PI-network

The PI-network C_1-X-C_2 has a phase shift of 180° at approximately the resonance frequency of the crystal

Pierce oscillator cont.

Transfer function of the pi-network

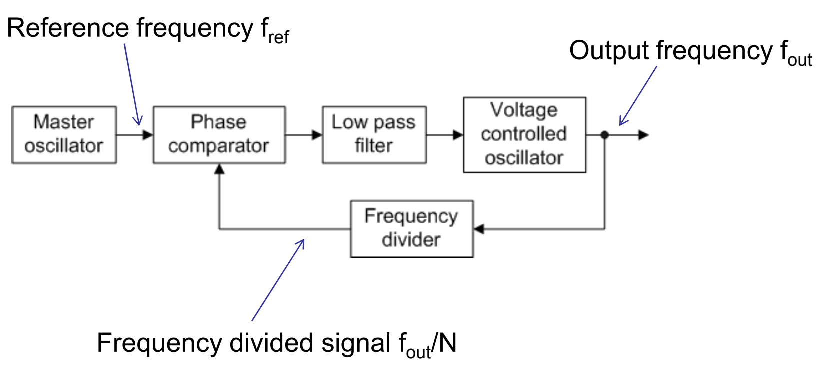


Phase locked loop (PLL)

A phase locked loop is a device that compares the frequences of two signals and produces an error signal proportional to the difference between the two frequencies. The error signal is low pass filtered and used to control a voltage controlled oscillator (VCO) that produces the output signal.

If one of the signals we compare is the output signal but with it´s frequency divided down to a lower frequency we can produce an output signal with a higher frequency than the frequency of the input signal which is the other signal in the comparation

Phase locked loop (PLL)



The output frequency can be higher than the input frequency