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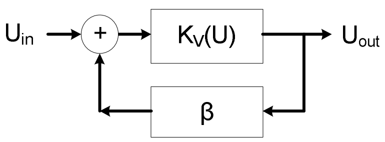
# Sin -wave oscillators



## Loop gain and phase

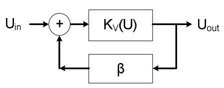



$$(U_{in} + \beta U_{out})K_V(U) = U_{out}$$

$$U_{out} = \frac{K_V(U)}{1 - K_V(U)\beta} U_{in}$$



## Oscillations - positive feedback (Barkhausen's criterion)




$$U_{out} = \frac{K_V(U)}{1 - K_V(U)\beta}$$

$$1 = K_V(U)\beta = |K_V(U)\beta| e^{j(\varphi_K + \varphi_\beta)}$$

$|K_V(U)\beta|=1$ AMPLITUDE condition

$\varphi_K + \varphi_\beta = n \cdot 360°$ PHASE condition (n=0,1,2..)

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## Phase and Amplitude conditions

$|K_V(U)\beta|=1$

usually $|K_V(U)\beta| > 1$
U increases → KV(U) decreases
so:
amplitude of oscillation is limited

$\varphi_K + \varphi_\beta(f)=n \cdot 360$

so:
frequency of oscillation is adjusted

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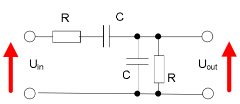
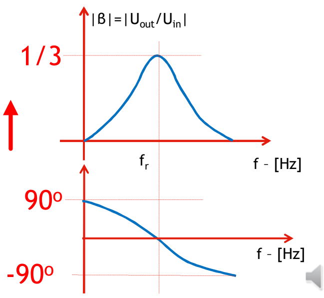
## Wien-bridge oscilator




$$f_r = \frac{1}{2\pi RC}$$

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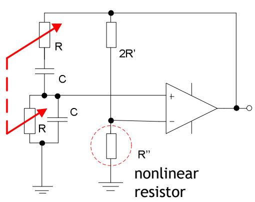
## Wien oscillator




$$f_r = \frac{1}{2\pi RC}$$

$$|K_V(U)|=\frac{2R'}{R''(U)}+1\approx 3$$

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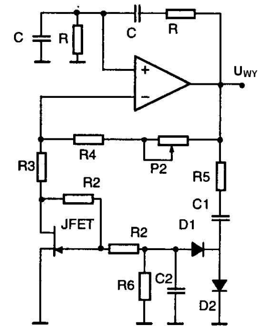
## Wien oascillator - automatic gain control

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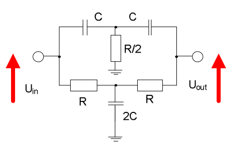
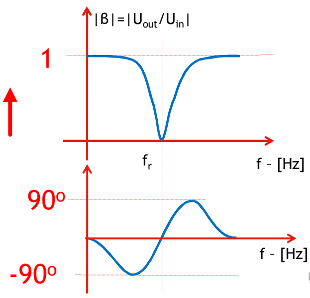
## Twin-T filter




$$f_r = \frac{1}{2\pi RC}$$

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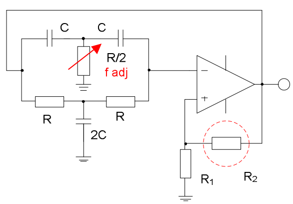
## Twin- T oscillator




$$\frac{R_2}{R_1} = 10 \cdots 1000$$

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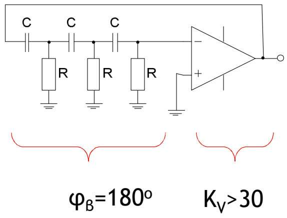
## Phase-Shift oscillators




$$f_r = \frac{1}{2\pi RC\sqrt{6}}$$

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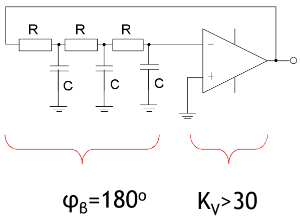
## Phase-Shift oscillators




$$f_r = \frac{1}{2\pi RC\sqrt{6}}$$

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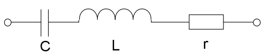
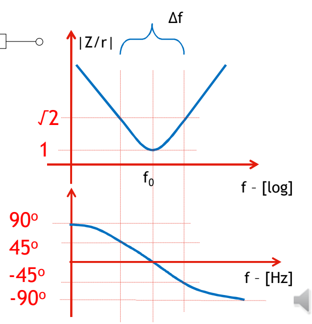
## LC oscillators resonant circuit (serial)

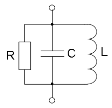



$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \frac{f_0}{\Delta f} = \frac{\omega_0 L}{r}$$

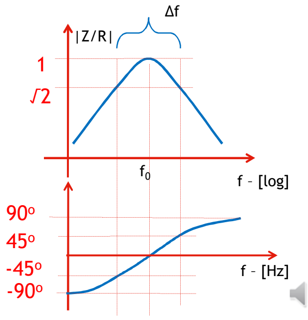


# LC oscillators resonant circuit (serial)




$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \frac{f_0}{\Delta f} = \frac{R}{1/\omega_0 C}$$

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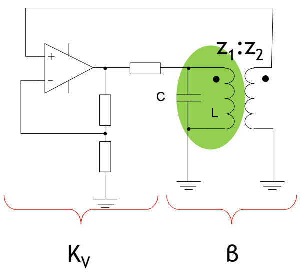
# Meissner (Armstrong) oscillator




$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$\beta(f_0) = \frac{z_1}{z_2}$$

$$K_{Vmin} = \frac{z_2}{z_1}$$

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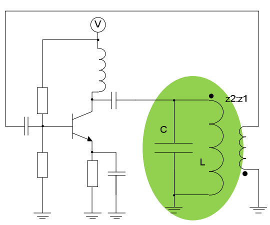
# MIESSNER




$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$\beta(f_0) = \frac{z_1}{z_2}$$

$$K_{Vmin} = \frac{z_2}{z_1}$$

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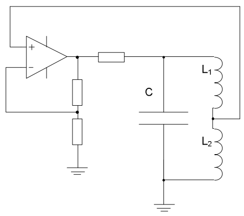
# Hartley oscillator




$$f_0 = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}$$

$$\beta(f_0) = \frac{L_2}{L_1 + L_2}$$

$$K_{Vmin} = \frac{L_1 + L_2}{L_2}$$

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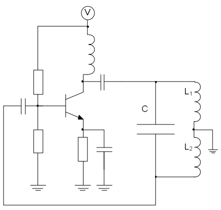
# Hartley oscillator




$$f_0 = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}$$

$$\beta(f_0) = \frac{L_2}{L_1 + L_2}$$

$$K_{Vmin} = \frac{L_1 + L_2}{L_2}$$

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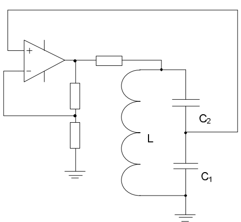
# Colpitts oscillator




$$f_0 = \frac{1}{2\pi\sqrt{L\frac{C_1C_2}{C_1+C_2}}}$$

$$\beta(f_0) = \frac{C_2}{C_2 + C_1}$$

$$K_{Vmin} = \frac{C_2 + C_1}{C_2}$$

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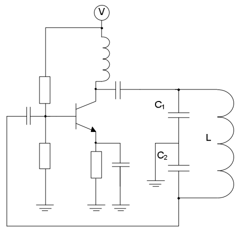
## Colpitts oscillator




$$f_0 = \frac{1}{2\pi\sqrt{L\frac{C_1 C_2}{C_1 + C_2}}}$$

$$\beta(f_0) = \frac{C_2}{C_2 + C_1}$$

$$K_{Vmin} = \frac{C_2 + C_1}{C_2}$$

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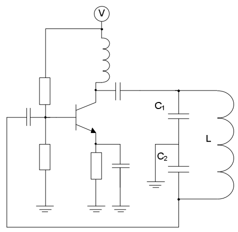
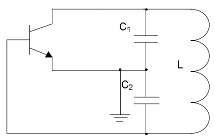
## Colpitts oscillator




CE

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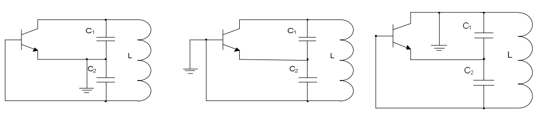
## CE, CC, CB amps in oscillators

CE
Grounded E

CB
Grounded B

CC
Grounded C



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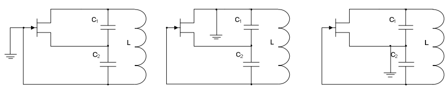
## FET amps as oscilltors
## CG, CD, CS

CG CD CS

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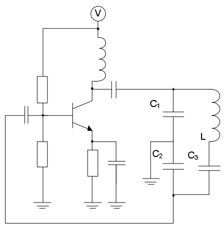
## Clapp oscillator




$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\beta(f_0) = \frac{C_2}{C_2 + C_1}$$

$$K_{Vmin} = \frac{C_2 + C_1}{C_2}$$

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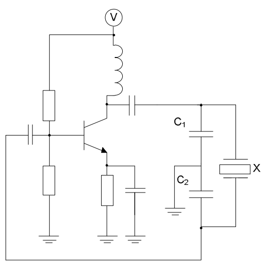
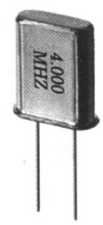
## Quartz (crystal) oscillator
## Clapp



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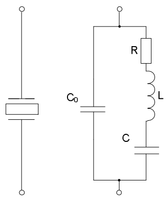
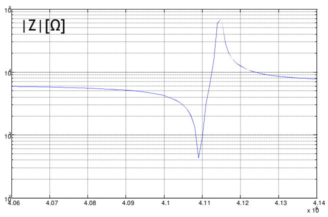
## Crystal equivalent circuit




| f [Hz] | 100 k | 500 k | 1 M | 4 M | 10 M | 20 M | 60 M | 120 M |
|---|---|---|---|---|---|---|---|---|
| R [Ω] | 400 | 500 | 250 | 100 | 20 | 10 | 30 | 50 |
| L [H] | 93,8 | 20,3 | 3,62 | 0,100 | 0,0169 | 0,0042 | 0,0035 | 0,00293 |
| C [pF] | 0,027 | 0,005 | 0,007 | 0,015 | 0,015 | 0,015 | 0,002 | 0,0006 |
| $C_0$ [pF] | 6 | 6 | 5 | 5 | 3,5 | 3 | 5 | 4 |

Q=25e3

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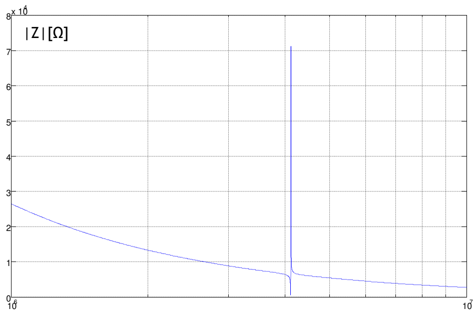
## |Z(f)|

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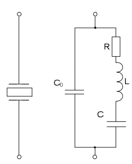
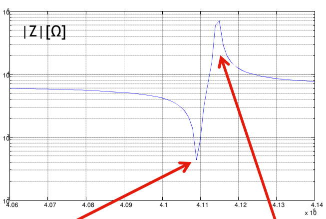
## Series and Parallel resonance of a crystal resonator of 4MHz




$Q = 25000$

$$f_s = \frac{1}{2\pi\sqrt{LC}}$$

$$f_p = \frac{1}{2\pi\sqrt{L\frac{CC_0}{C+C_0}}}$$

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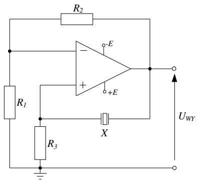
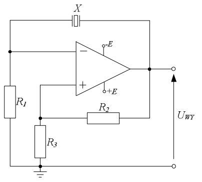



fs - |z|=min




fp - |z|=max

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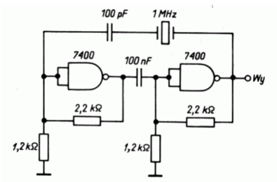
## series resonans

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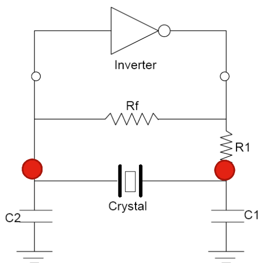
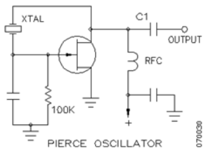
## Pirce oscillator – an example



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## Frequency stability

$$f_0(t) = f_0 \pm \Delta f_0$$

$$S = \frac{\Delta f_0 / f_0}{24h}$$

| Type of oscillator | Stability |
|---|---|
| RC | 10e-2 - 10e-3 |
| LC | 10e-3 - 10e-4 |
| Crystal | 10e-6 - 10e-7 |
| Crystal (temp. stab.) | (10e-8 - 10e-10) |
| Atomic references | 10e-12 - 10e-14 |

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## Features of oscillators

- frequency stability
- harmonics (THD)
- frequency range
- amplitude and phase noise (jitter)

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## Summary

- amplitude and phase conditions of oscillation
  - Wien bridge generator
  - Twin - T filter and oscillator
  - RC phase shifter oscillators
- Meissner, Hartley, Colpits oscillators - topologies
- crystal (quartz) - parallel and series resonances, model, |Z(f)| -graph
- frequency stability and other parameters of generators

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# Flip-Flops and multivibrators

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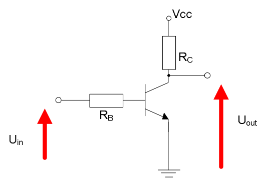
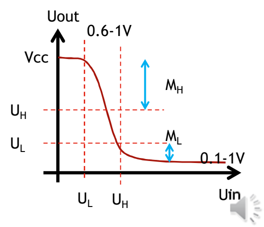
## BJ-Transistor as a switch

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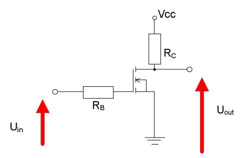
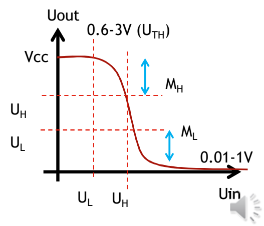
## MOSFE-Transistor as a switch



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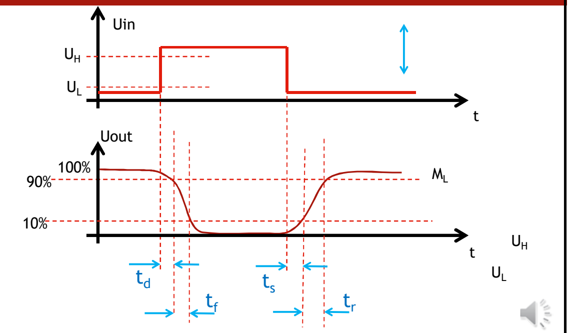
# Dynamic feathures

## delay-, fall-, storage-, rise-time

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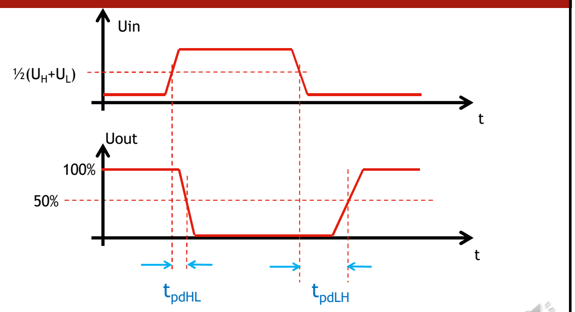
# Dynamic feathures

## propagation delay time

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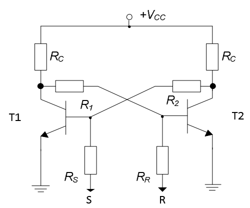
# RS flip-flop



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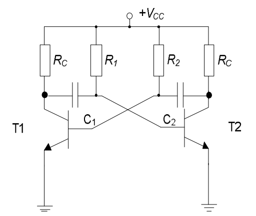
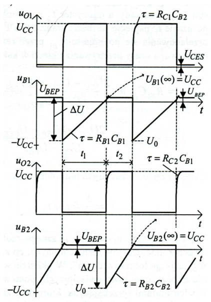
## Astable Flip-Flop




$t_1 \approx 0.7 R_1 C_1$ $\quad t_2 \approx 0.7 R_2 C_2$

$$R_C \ll R_1, R_2 \ll \beta R_C$$

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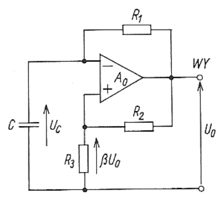
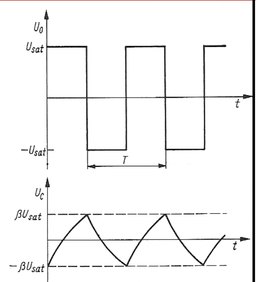
## OpAmp(Comparator) Flip-Flop




$$T = 2R_1 C \ln\frac{1+\beta}{1-\beta}$$

$$\beta = \frac{R_3}{R_2 + R_3}$$

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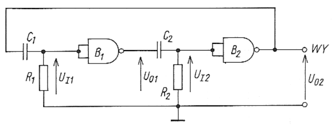
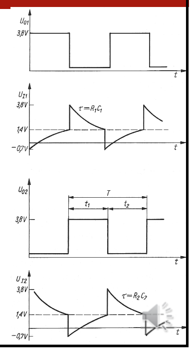
## Astable Flip-Flop with NAND Gate




$$f = \frac{1}{t_1 + t_2} = \frac{1}{R_1 C_1 + R_2 C_2}$$



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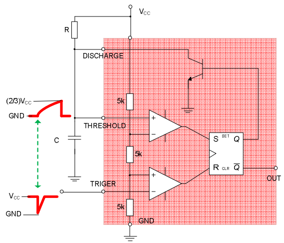
## Timer „555" – monostable mode




$$T = \ln 3 \cdot RC$$

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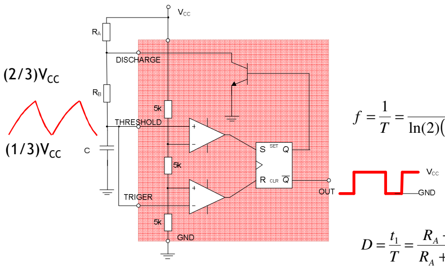
## Timer „555" – astable mode




$$f = \frac{1}{T} = \frac{1}{\ln(2)(R_A + 2R_B)C}$$

$$D = \frac{t_1}{T} = \frac{R_A + R_B}{R_A + 2R_B}$$

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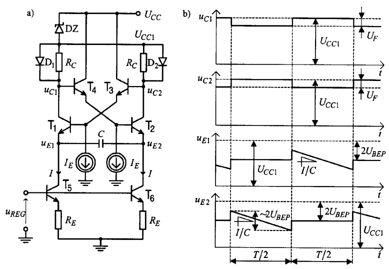
## VCO F-F
## - Emmiter coupling




$$f = \frac{I}{4U_{BE}C}$$

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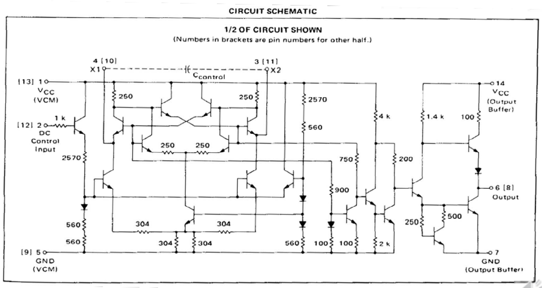
## Emitter coupled Voltage-controlled multivibrator MC4024

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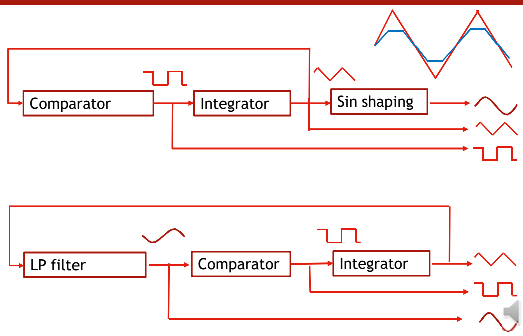
## Sine, Triangle, Square generator

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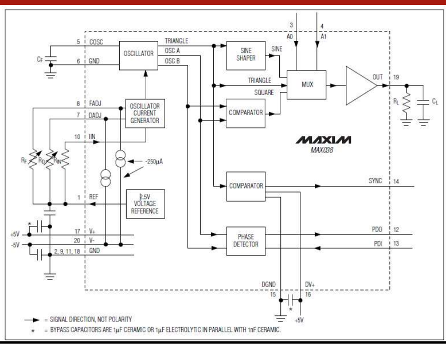
## Sine, Triangle, Square generator -IC



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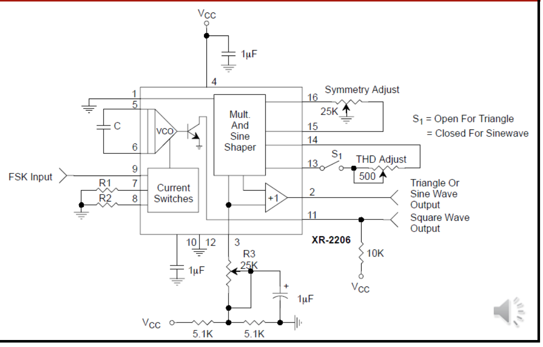
## Sine, Triangle, Square generator -IC

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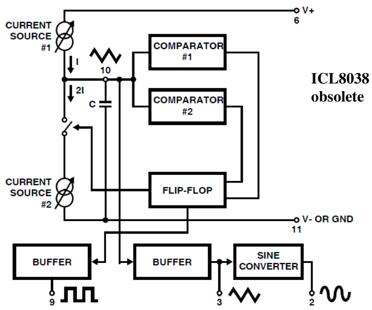
## Sine, Triangle, Square generator -IC




ICL8038
obsolete

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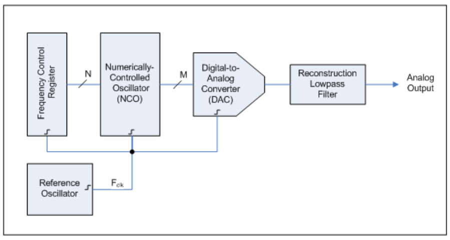
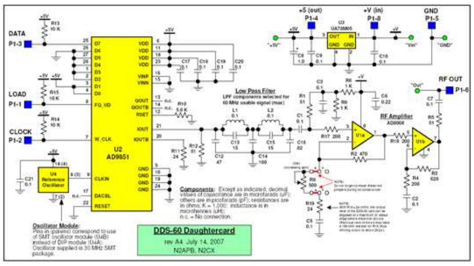
## DDS - *Direct Digital Synthesis*








## Summary

- Flip-Flop as a-stable and mono-stable
- Timer 555
- Function generator
- DDS, arbitrary generator