Ch 10 | Part 1

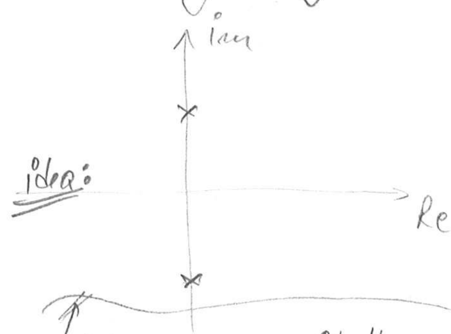
Signal Generators

- Has the function to generate a waveform of prescribed characteristic such as frequency, amplitude, shape and duty cycle.
- Generally can be seen as a freq. converter DC $\rightarrow f$. (similar to $f_1 \rightarrow f_2$, with $f_1 = 0$)

Sinusoidal oscillators:

Type 1

- pair of conjugate poles on the imaginary axis of the complex plane



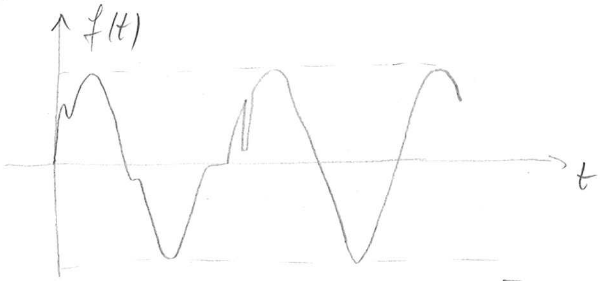
Ask in class if they master s-plane and complex plane!

"Sinusoidal purity" is expressed via THD = total harmonic distortion.

$$THD(\%) = 100 \cdot \sqrt{D_2^2 + D_3^2 + D_4^2 + \ldots}$$

$$D_k = \frac{\text{amplitude of the k-th harmonic}}{\text{amplitude of the fundamental}}, \quad k = 2, 3, 4, \ldots$$

A sine wave has $THD = 0\%$, a triangular one $THD \cong 12\%$.



The Fourier series of $f(t)$ is:

$$\boxed{f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left[a_n \cdot \cos(nt) + b_n \sin(nt) \right]}$$

where: $a_0 = \frac{1}{\pi} \int_{-\pi}^{\pi} f(t) dt$

where a_n, b_n are the Fourier coefficients.

$$a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(t) \cdot \cos(nt)\, dt$$

$$b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(t) \cdot \sin(nt)\, dt.$$

$f(t)$ is periodic of period $2\pi = T$

[Exponential Fourier series

$$f(t) = \sum_{n=-\infty}^{\infty} F[n] \cdot e^{jnt}, \qquad F[n] = \frac{1}{2\pi} \int_{-\pi}^{\pi} f(t) \cdot e^{-jnt}\, dt.$$]

if $f(t)$ is periodic with period T:

$$\boxed{f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left[a_n \cos(n\omega t) + b_n \sin(n\omega t) \right]} \qquad \boxed{\omega = \frac{2\pi}{T}}$$

$$a_n = \frac{2}{T} \int_{-T/2}^{T/2} f(t) \cos(n\omega t)\, dt$$

The nth term of the Fourier series:

$a_n \cdot \cos(n\omega t) + b_n \sin(n\omega t)$ is called the "nth harmonic" of it.

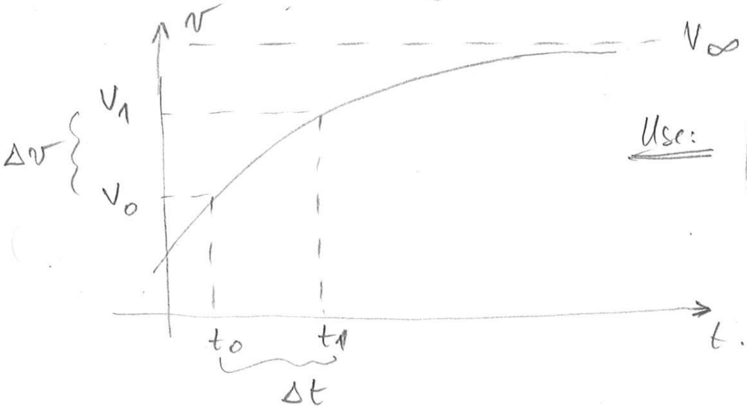
Its amplitude is:

$$A_n = \sqrt{a_n^2 + b_n^2} \quad , \quad A_n^2 = a_n^2 + b_n^2$$ is called energy of the nth harmonic.]

Relaxation Oscillators – employ bistable devices; repeatedly charge/discharge a capacitor (usually).

Type (2)

- typical waveforms – triangular, sawtooth, square, exponential
- Charging/discharging of a capacitor can be { – linear — $\Delta t = \frac{C}{I} \Delta v$ (1)
  { – exponential



Use: $$v(t) = V_\infty + [V_0 - V_\infty] \cdot e^{-\frac{t - t_0}{\tau}}$$ Exersize! (its derivation)

$\tau = RC$.

to obtain:

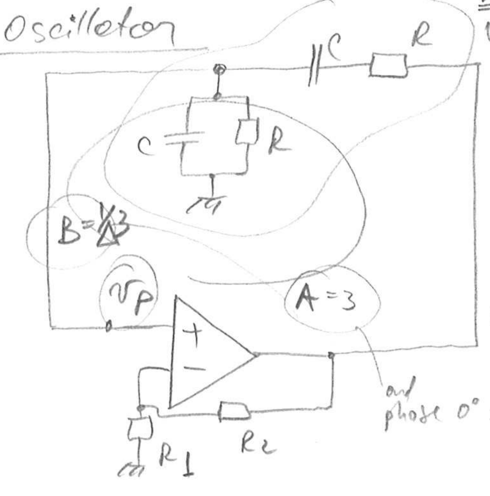
$$\Delta t = \tau \cdot \ln \frac{V_\infty - V_0}{V_\infty - V_1}$$ (2) very useful to compute T

10.1 Sine-wave generators

1) { Wien-bridge oscillator
   { quadrature oscillator

2) { triangular → sine conversion

Wien-bridge Oscillator



≙ Wien bridge as positive feedback!

fascinating circuit!

and phase 0° ⇒ initiated and maintained to signal!

Can be seen as a noninv. amplifier:

$$A = \frac{v_O}{v_P} = 1 + \frac{R_2}{R_1}$$

The positive feedback:

$$v_p = \underbrace{\frac{Z_p}{Z_p + Z_s}}_{= B(jf)} v_0 \quad , \quad \begin{cases} Z_p = R \parallel \dfrac{1}{j2\pi f C} \\ Z_s = R + \dfrac{1}{j2\pi f C} \end{cases}$$

$$\Rightarrow B(jf) = \frac{v_p}{v_0} = \frac{1}{3 + j\left(\frac{f}{f_0} - \frac{f_0}{f}\right)} \quad , \quad f_0 = \frac{1}{2\pi R C}$$

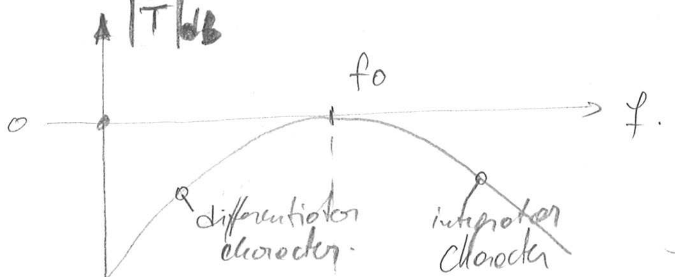
Therefore the loop gain (around the positive feedback loop):

$$\boxed{T(jf) = A \cdot B = \frac{1 + R_2/R_1}{3 + j\left(\frac{f}{f_0} - \frac{f_0}{f}\right)}} \quad A = \left(1 + \frac{R_2}{R_1}\right)$$

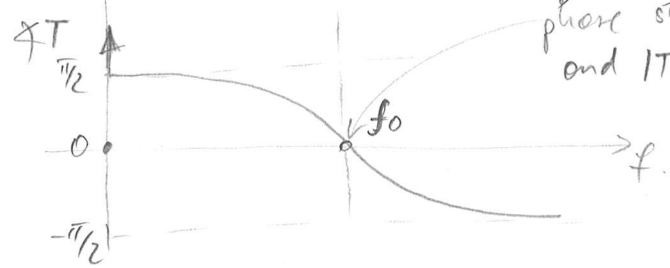
Band-pass function!

The peak value occurs at $f = f_0$.

when $T(jf_0) = \frac{1}{3}\left(1 + \frac{R_2}{R_1}\right)$.



sort of let's go thru only the f_0 component and STOP the rest! imagine the f_0 started and then maintained thru the positive loop!



phase shift is zero and $|T(jf_0)|$ is real!

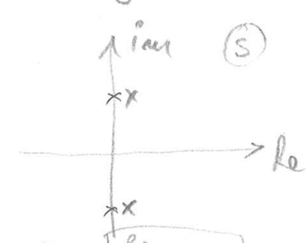
Cases:

(1) $T(jf_0) < 1 \Leftrightarrow A < 3 \Rightarrow$ loop gain less than unity, $\forall$ oscillations are degenerative.

- Negative feedback prevails over the positive one!

(2) $T(jf_0) > 1 \Leftrightarrow A > 3 \Rightarrow \forall$ disturbance will be amplified regeneratively.

- Oscillations build up.
- System is unstable
- Poles are in the right plane
- Positive feedback prevails



(3) $T(jf_0) = 1 \Leftrightarrow A = 3 \Rightarrow$ oscillations $\Leftrightarrow \boxed{\frac{R_2}{R_1} = 2}$

$\boxed{\measuredangle T(jf_0) = 0^\circ, \ |T(jf_0)| = 1}$ $\triangleq$ Barkhausen Criterion.

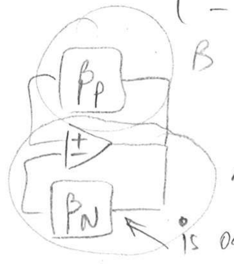
Issue: $A = 3 \Leftrightarrow \frac{R_2}{R_1} = 2$ exactly is difficult to maintain due to component tolerances

Solution: $\boxed{\text{automatic amplitude control}}$: all practical oscillators must have it. (controls the amplitude too)

$\frac{R_2}{R_1}$ is made dependent on amplitude such that:

- low signal levels $\Rightarrow \frac{R_2}{R_1} > 2$ ≡ poles in right half to ensure start-up!
- high signal levels $\Rightarrow \frac{R_2}{R_1} < 2$

$\triangleq$ amplitude Stabilization! (typically using nonlinear elements such as diodes)

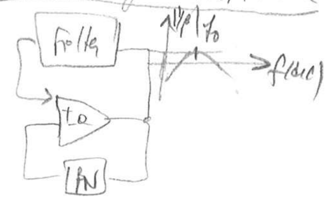


is amplitude dependent / feedbacked negative feedback :)

Observations -

- R_2/R_1 control the amplitude stabilization in all practical oscillators!
- RC (the Wien bridge) controls the frequency of oscillations f_0
- components have to be of good quality.
- How is V_m (amplitude) determined? By what?

Oscillator generalization

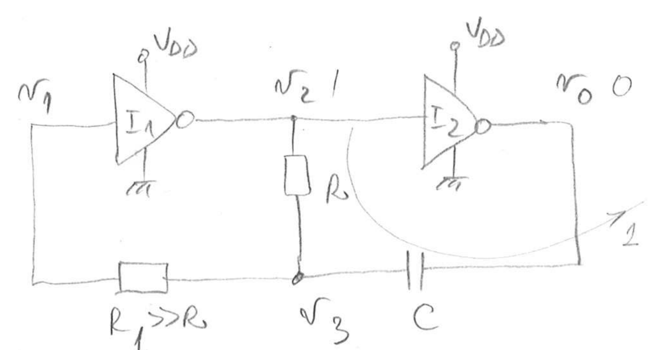


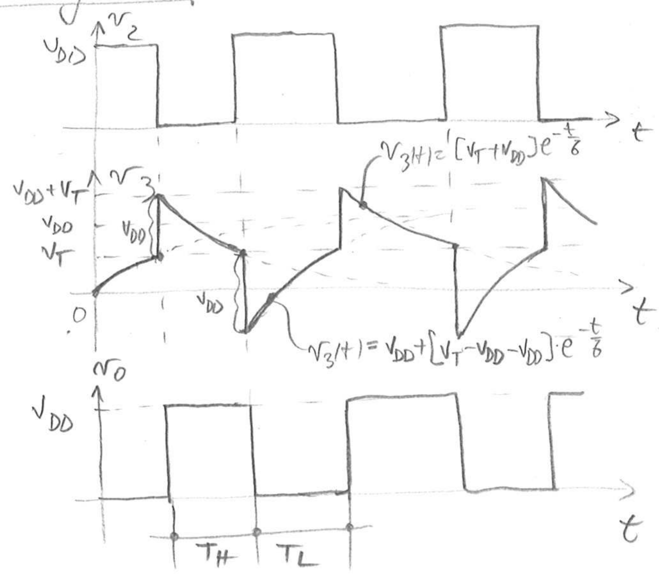
10.2. Multi-vibrators

Exercise!

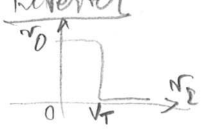
- Schmitt based (basic free-running)
- square wave generator with selectable decades.
- Single supply free-running.
- CMOS Crystal Oscillator.
- Monostable vibrator.

$\boxed{\text{Free-running multivibrator using CMOS gates}}$





inverter



5

$$f_0 = \frac{1}{T_H + T_L} = ?$$

$$v_C(t) = V_\infty - [V_\infty - V_0]\, e^{-\frac{t}{\tau}} = V_\infty + [V_0 - V_\infty]\, e^{-\frac{t}{\tau}}$$

Exercise: derive it!

case 1:

$$\Delta t = T_H, \quad \begin{cases} V_\infty = 0 \\ V_0 = V_T + V_{DD}, \quad V_1 = V_T \end{cases} \overset{(10.3)}{\Longrightarrow} T_H = \tau \cdot \ln \frac{0 - (V_T + V_{DD})}{0 - V_T}$$

$$\Rightarrow \boxed{T_H = \tau \cdot \ln \frac{V_T + V_{DD}}{V_T}}$$

case 2:

$$\Delta t = T_L \quad \begin{cases} V_\infty = V_{DD} \\ V_0 = V_T - V_{DD}, \quad V_1 = V_T \end{cases} \overset{(10.3)}{\Longrightarrow} T_L = \tau \cdot \ln \frac{V_{DD} - (V_T - V_{DD})}{V_{DD} - V_T}$$

$$\Rightarrow \boxed{T_L = \tau \cdot \ln \frac{2V_{DD} - V_T}{V_{DD} - V_T}}$$

$$\Rightarrow T_H + T_L = T = \tau \cdot \ln \frac{V_T + V_{DD}}{V_T} \cdot \frac{2V_{DD} - V_T}{V_{DD} - V_T}, \quad \tau = RC$$

$$\Rightarrow \boxed{f_0 = \frac{1}{T} = \frac{1}{RC \cdot \ln \frac{(V_T + V_{DD}) \cdot (2V_{DD} - V_T)}{(V_T - V_{DD}) \cdot (V_T)}}}$$

If $V_{DD}/2 = V_T \Rightarrow f_0 = \dfrac{1}{RC \cdot \ln 9} = \dfrac{1}{2.2 \cdot RC}$ and $D(\%) = 50\%$