date: 2024-03-14

TFE4188 - Lecture 9

Oscillators

Goal

Why

Introduction to **Crystal Oscillators**

Introduction to **VCOs**

Introduction to **Relaxation-oscillators**

Why

I just want the most precise clock that can be made !!!

Atomic clocks

Cesium standard

The second is defined by taking the fixed numerical value of the cesium frequency Cs, the unperturbed ground-state hyper-fine transition frequency of the cesium 133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s–1

Microchip 5071B Cesium Primary Time and Frequency Standard

- < 5E-13 accuracy high-performance models
- Accuracy levels achieved within 30 minutes of startup
- < 8.5E-13 at 100s high-performance models
- < 1E-14 flicker floor high-performance models

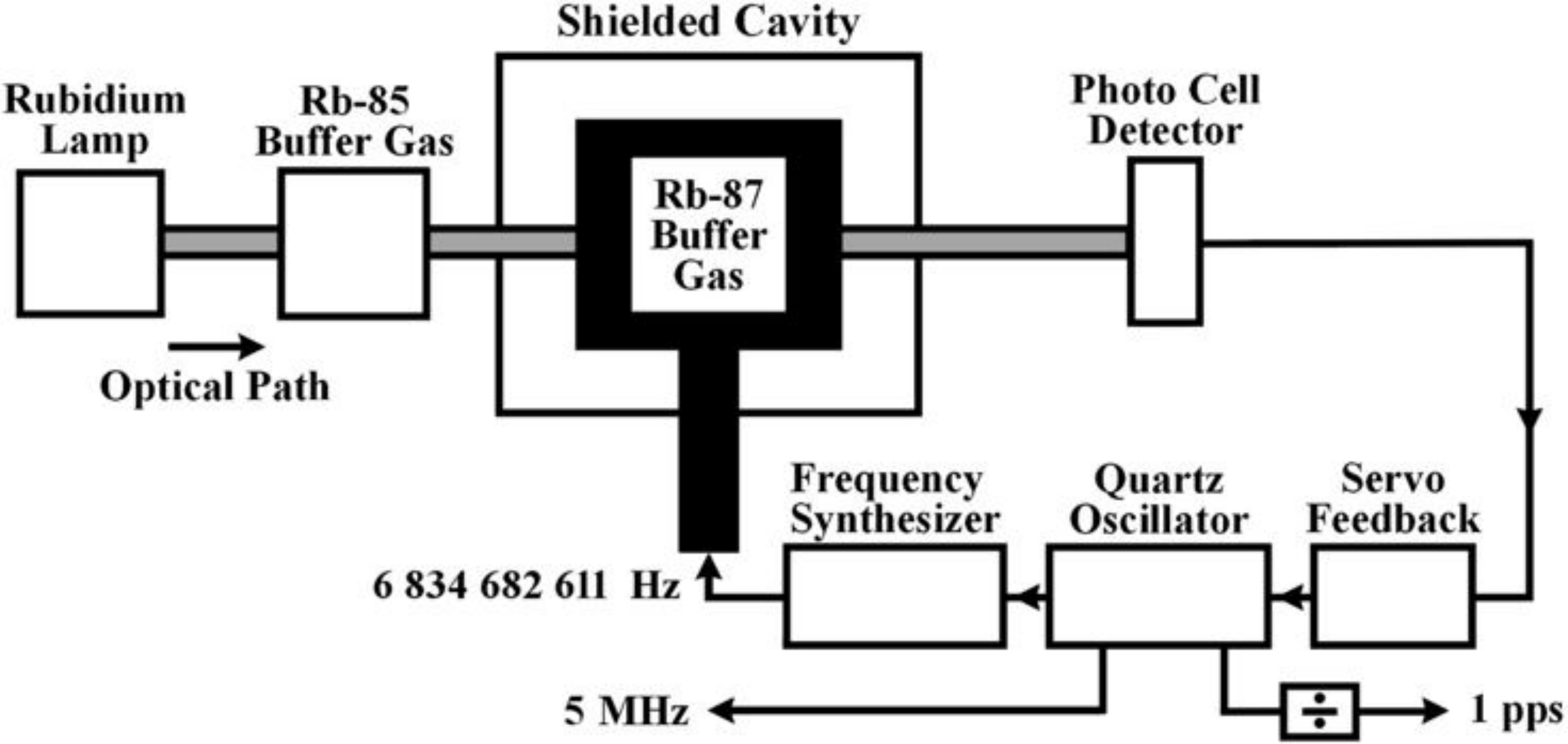
"Ask for a quote" => The price is really high, and we don't want to tell you yet

Rubidium standard

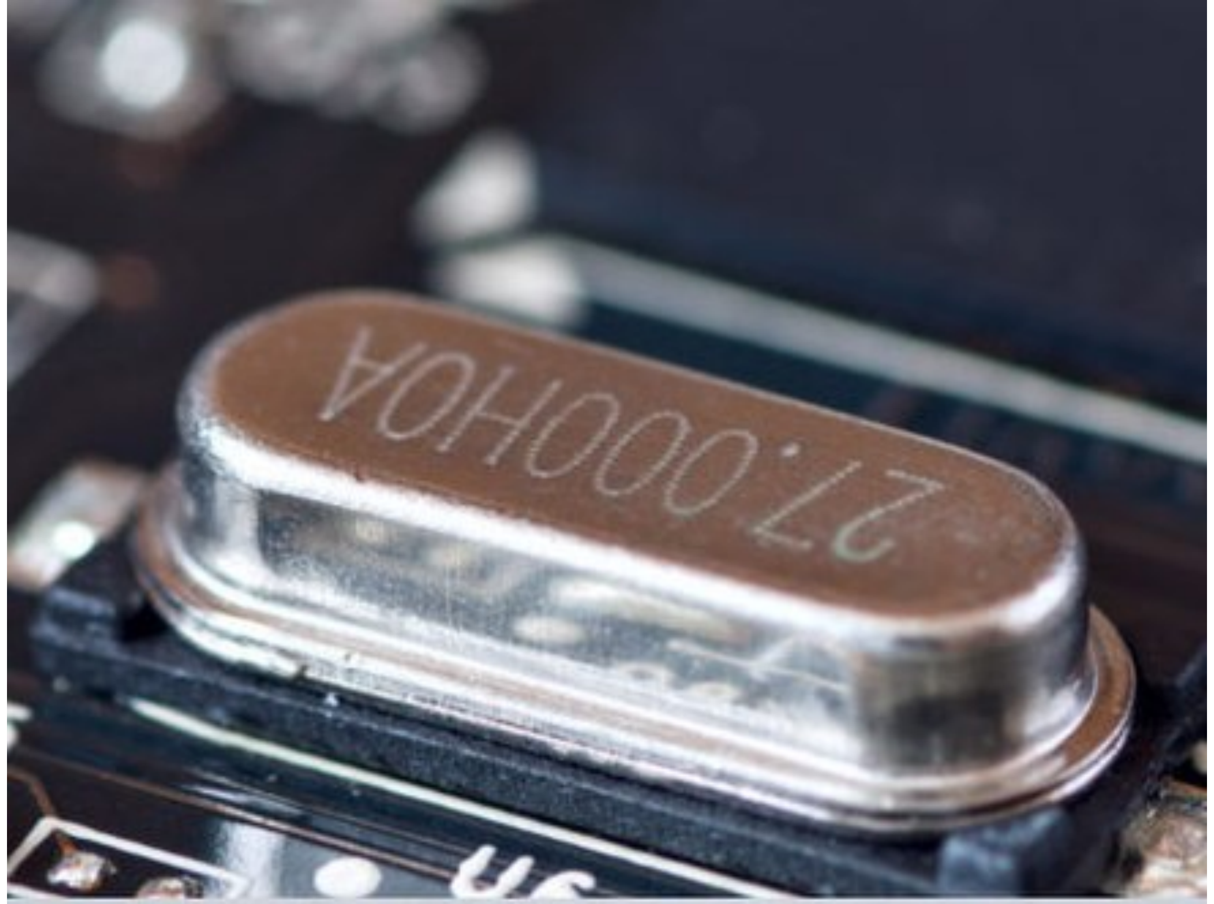
Rubidium standard, use the rubidium hyper-fine transition of 6.8 GHz (6834682610.904 Hz)

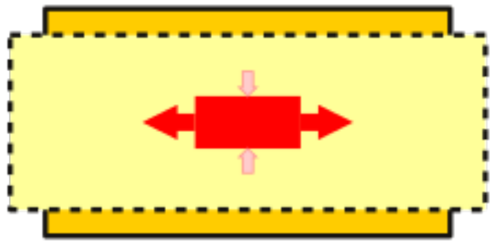
The MAC is a passive atomic clock, incorporating the interrogation technique of Coherent Population Trapping (CPT) and operating upon the D1 optical resonance of atomic Rubidium Isotope 87.

A rubidium clock is basically a crystal oscillator locked to an atomic reference.

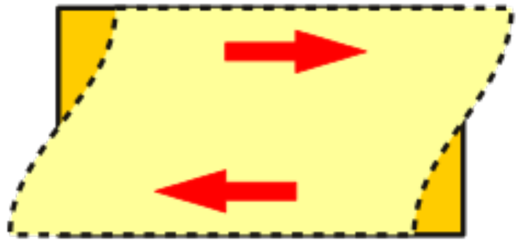

Shielded Cavity
Rubidium Lamp
Rb-85 Buffer Gas
Rb-87 Buffer Gas
Photo Cell Detector
Optical Path
Frequency Synthesizer
Quartz Oscillator
Servo Feedback
6 834 682 611 Hz
5 MHz
÷
1 pps

Crystal oscillators

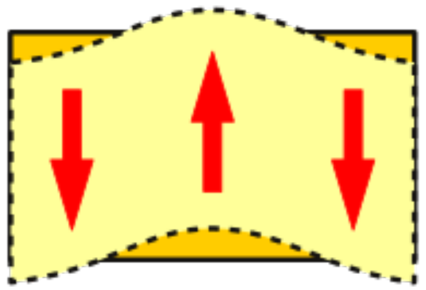

27.000H0A



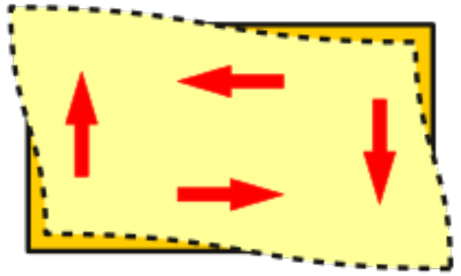
Longitudinal mode



Thickness shear mode

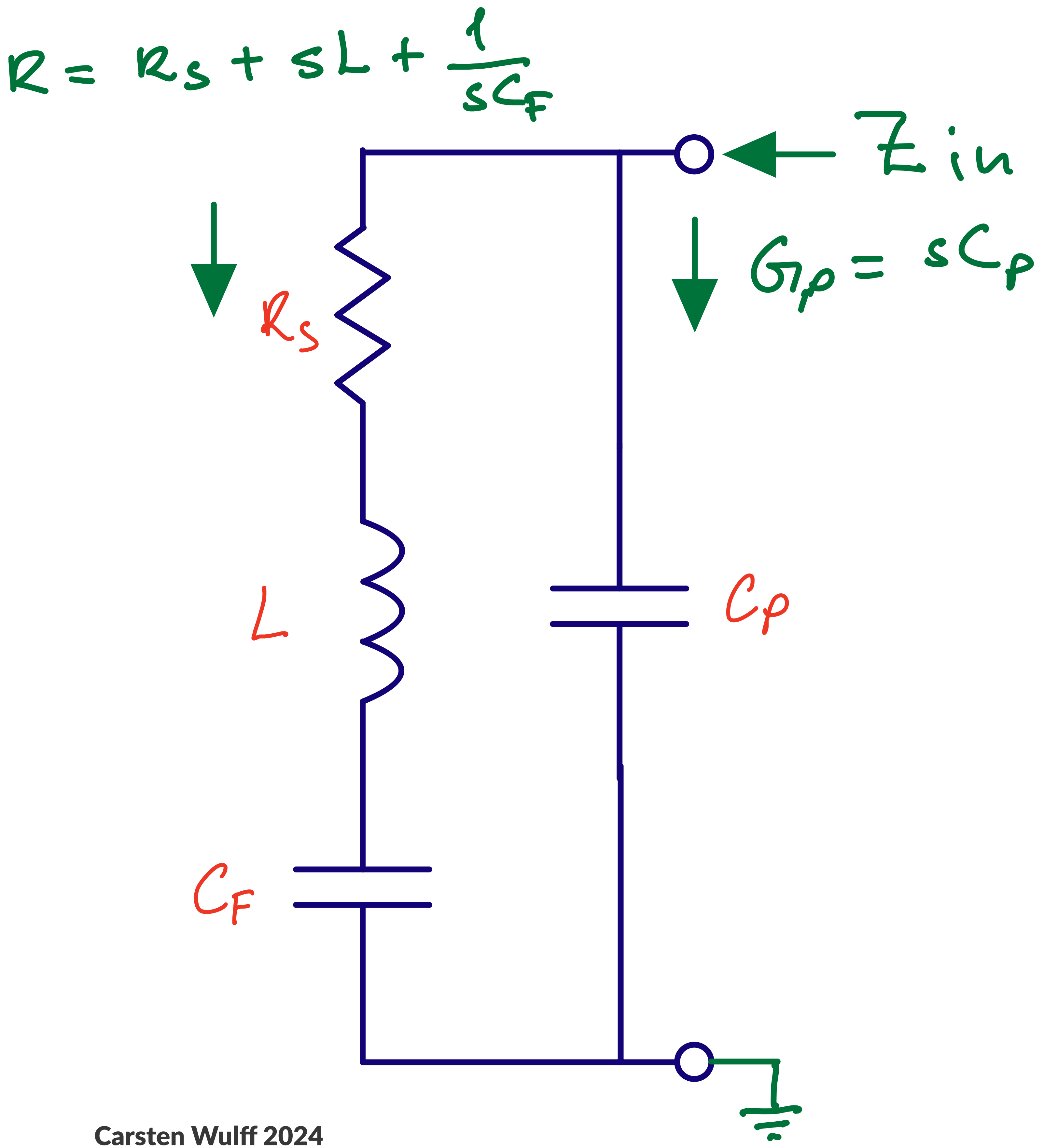


Flexural mode



Face shear mode

Tuning fork



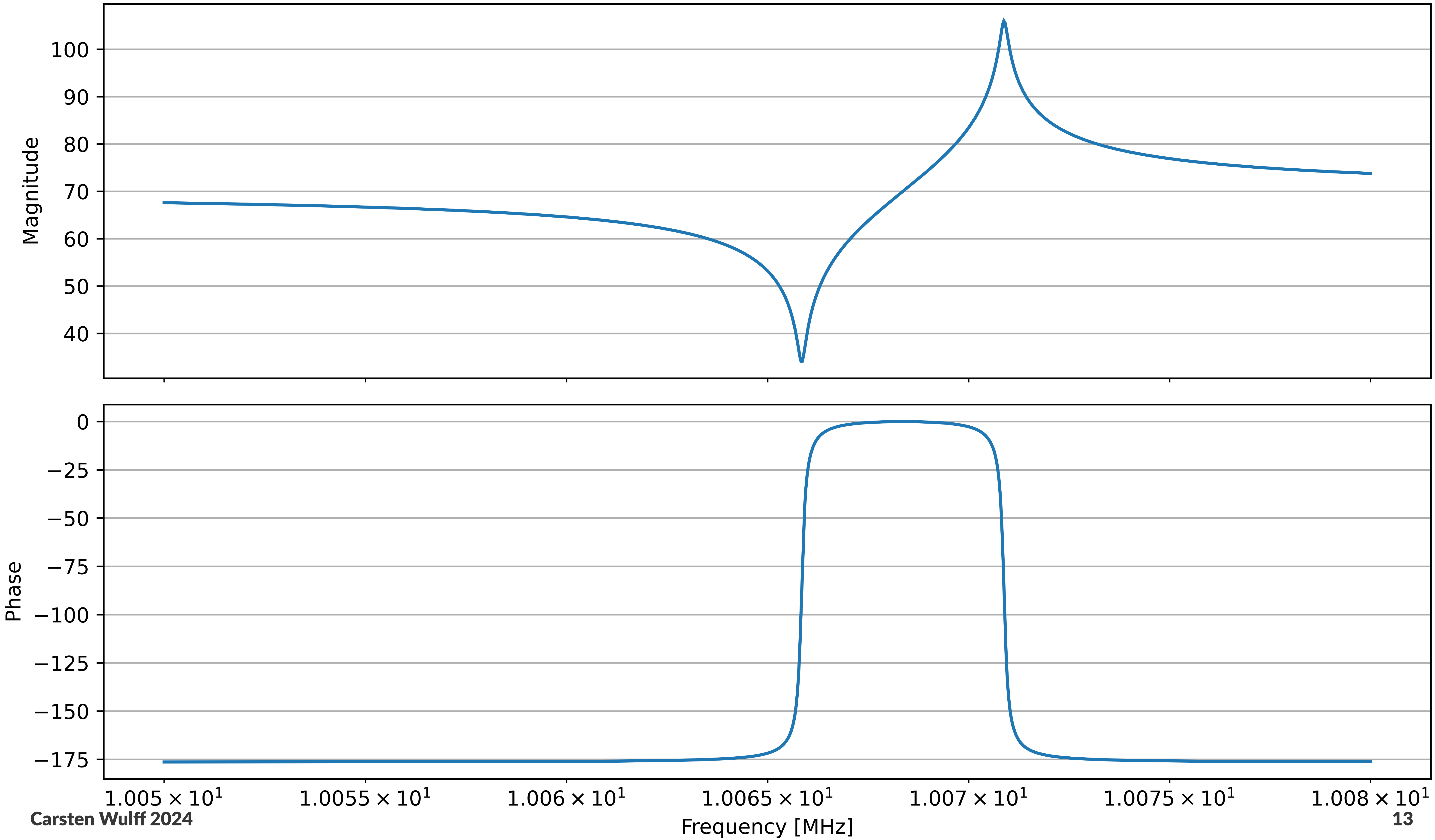
Assuming zero series resistance

$$Z_{in} = \frac{s^2 C_F L + 1}{s^3 C_P L C_F + s C_P + s C_F}$$

Since the 1/(sCp) does not change much at resonance, then

$$Z_{in} \approx \frac{L C_F s^2 + 1}{L C_F C_p s^2 + C_F + C_P}$$

See Crystal oscillator impedance for a detailed explanation.

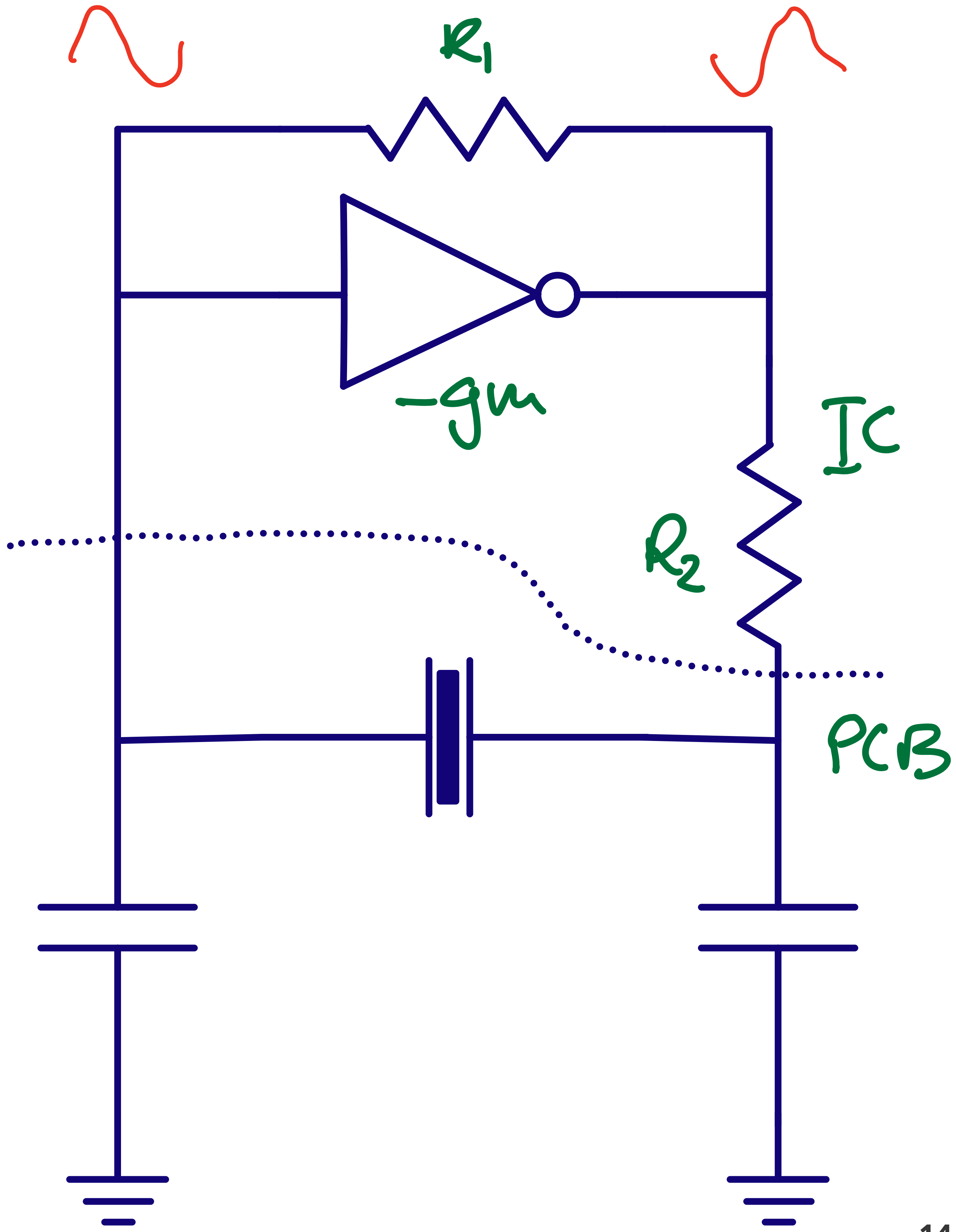


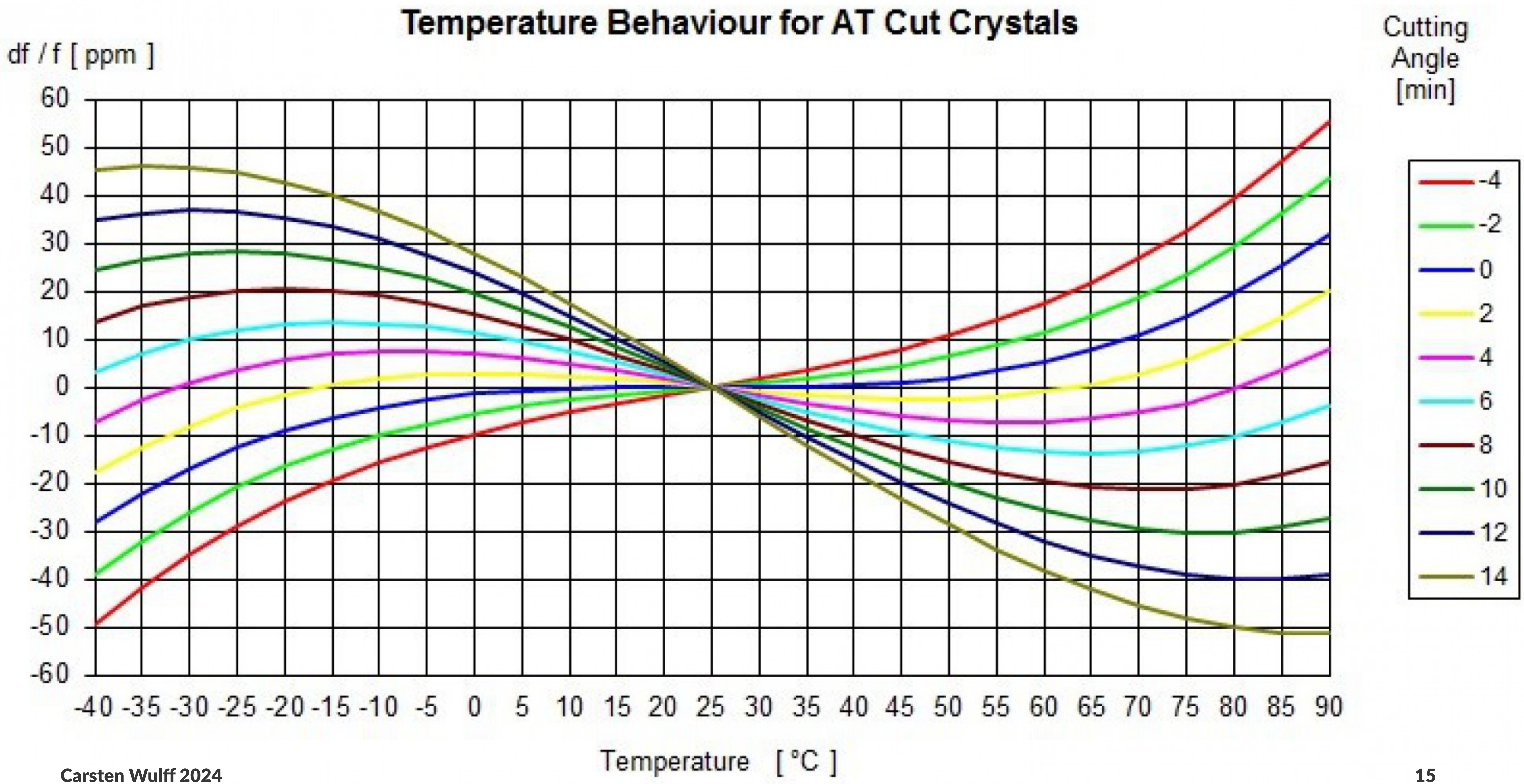
Magnitude
100
90
80
70
60
50
40
Phase
0
−25
−50
−75
−100
−125
−150
−175
1.005 × 10^1
1.0055 × 10^1
1.006 × 10^1
1.0065 × 10^1
1.007 × 10^1
1.0075 × 10^1
1.008 × 10^1
Frequency [MHz]

Negative transconductance compensate crystal series resistance

Long startup time caused by high Q

Can fine tune frequency with parasitic capacitance

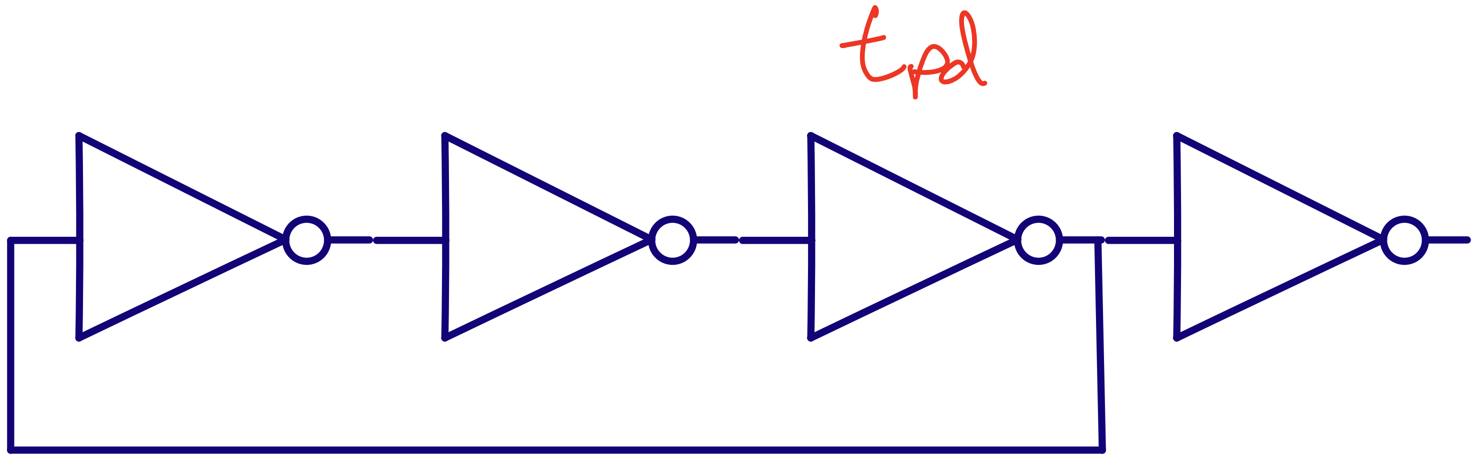




Temperature Behaviour for AT Cut Crystals
df / f [ppm]
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
Temperature [°C]
Cutting Angle [min]
-4
-2
0
2
4
6
8
10
12
14

Controlled Oscillators

Ring oscillator



$$t_{pd} \approx RC$$

$$R \approx \frac{1}{gm} \approx \frac{1}{\mu_n C_{ox} \frac{W}{L} (VDD - V_{th})}$$

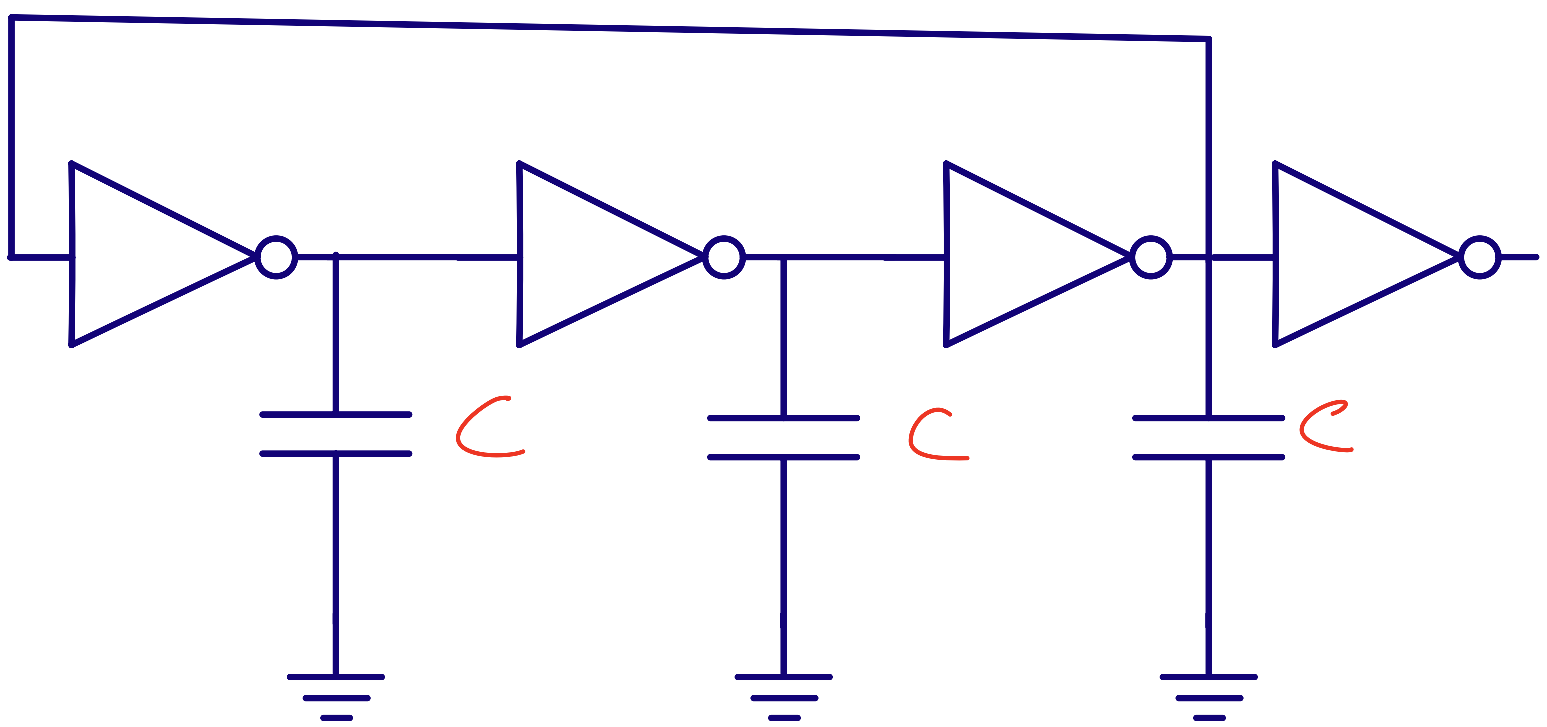
$$C \approx \frac{2}{3} C_{ox} W L$$

$$t_{pd} \approx \frac{2/3 C_{ox} W L}{\frac{W}{L}\mu_n C_{ox}(VDD - V_{th})}$$

$$f = \frac{1}{2N t_{pd}} = \frac{\mu_n (VDD - V_{th})}{\frac{4}{3} N L^2}$$

$$K_{vco} = 2\pi \frac{\partial f}{\partial VDD} = \frac{2\pi \mu_n}{\frac{4}{3} N L^2}$$

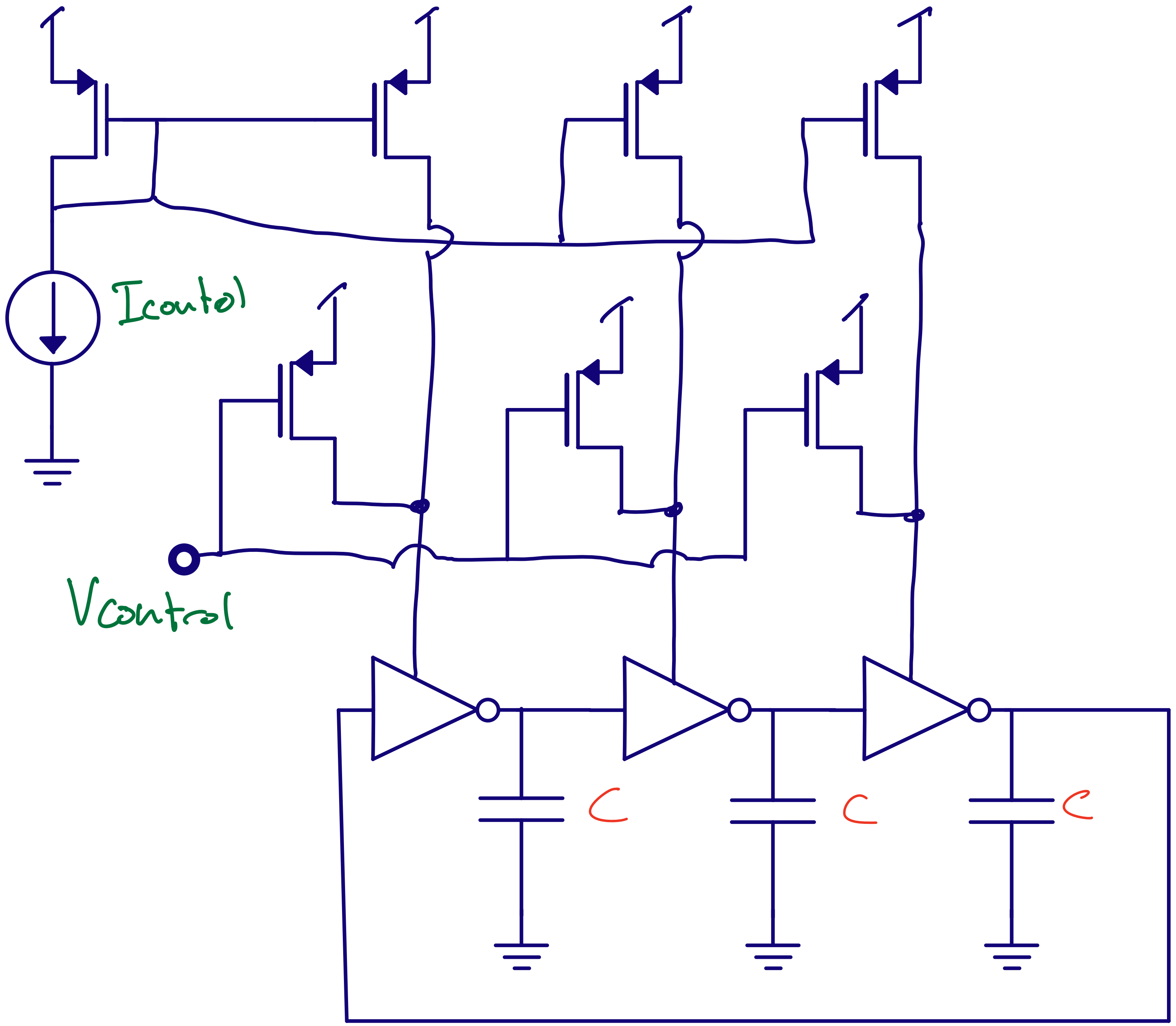
Capacitive load



$$f = \frac{\mu_n C_{ox} \frac{W}{L}(VDD - V_{th})}{2N\left(\frac{2}{3}C_{ox}WL + C\right)}$$

$$K_{vco} = \frac{2\pi \mu_n C_{ox}\frac{W}{L}}{2N\left(\frac{2}{3}C_{ox}WL + C\right)}$$

Realistic

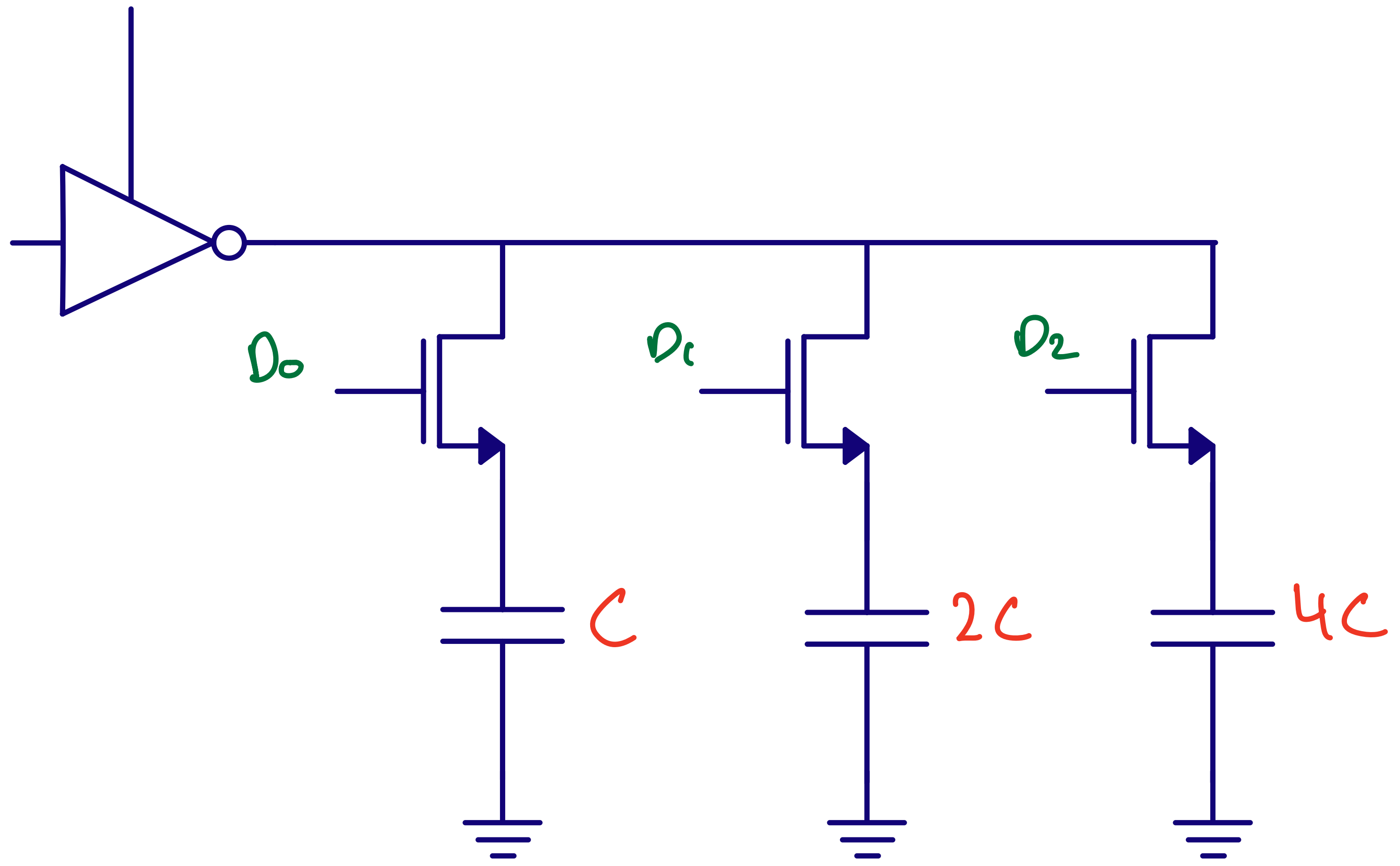


$$I = C\frac{dV}{dt}$$

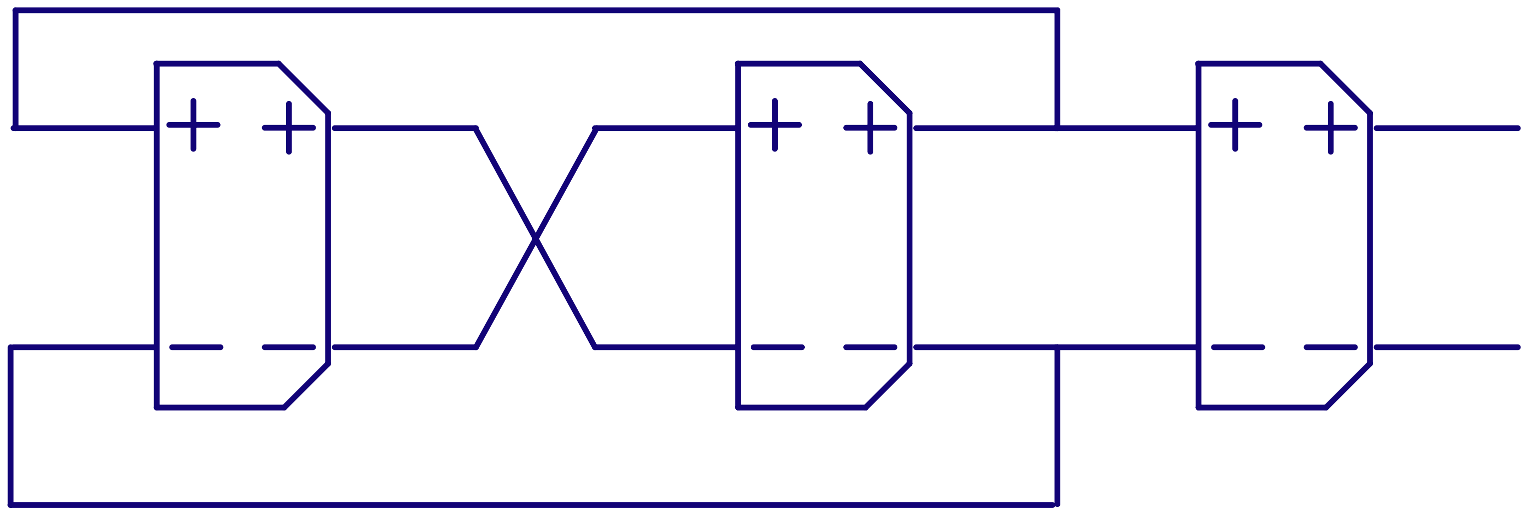
$$f \approx \frac{I_{control} + \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(VDD - V_{control} - V_{th})^2}{C\frac{VDD}{2}N}$$

$$K_{vco} = 2\pi\frac{\partial f}{\partial V_{control}}$$

$$K_{vco} = 2\pi\frac{\mu_p C_{ox} W/L}{C\frac{VDD}{2}N}$$

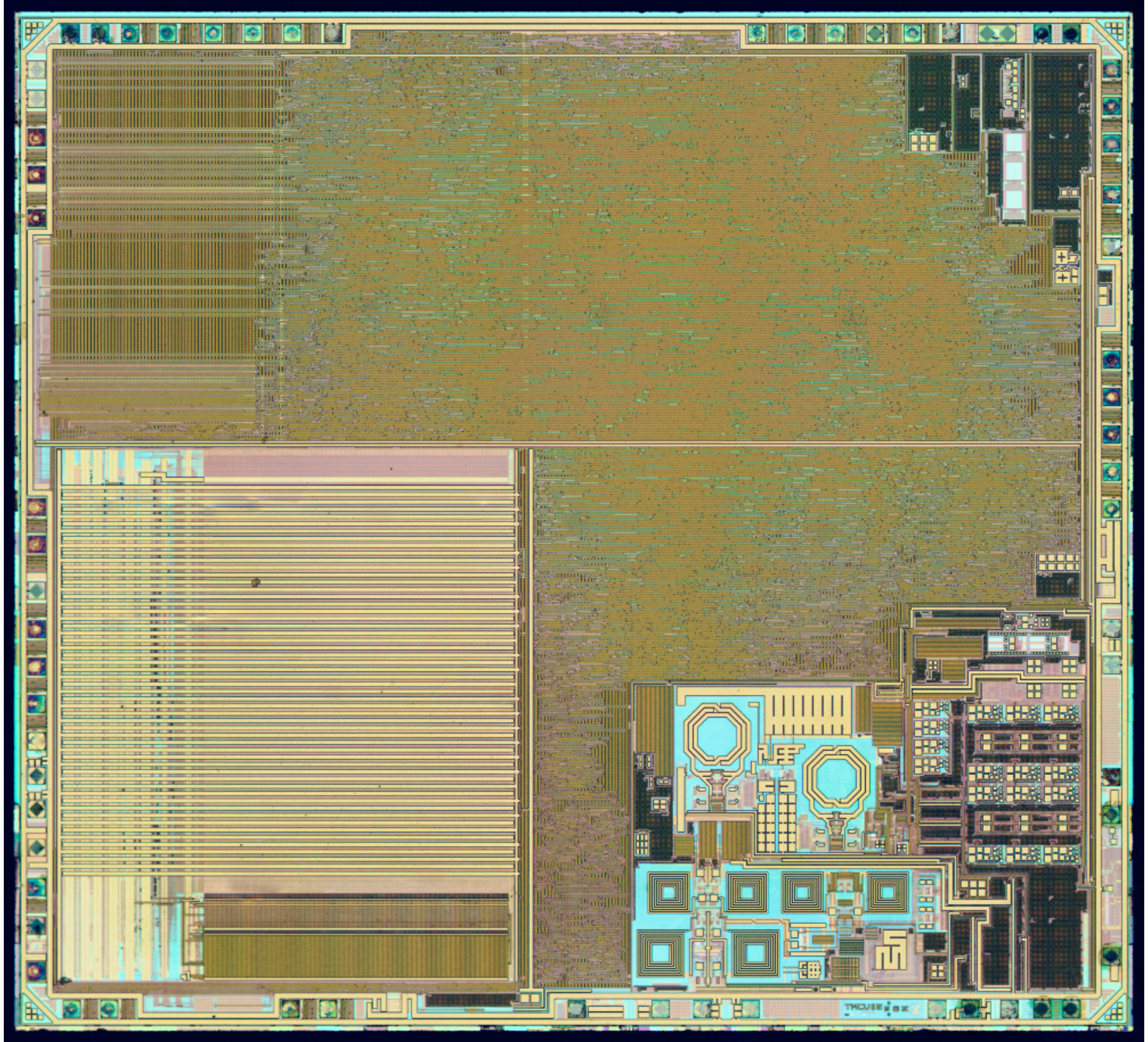


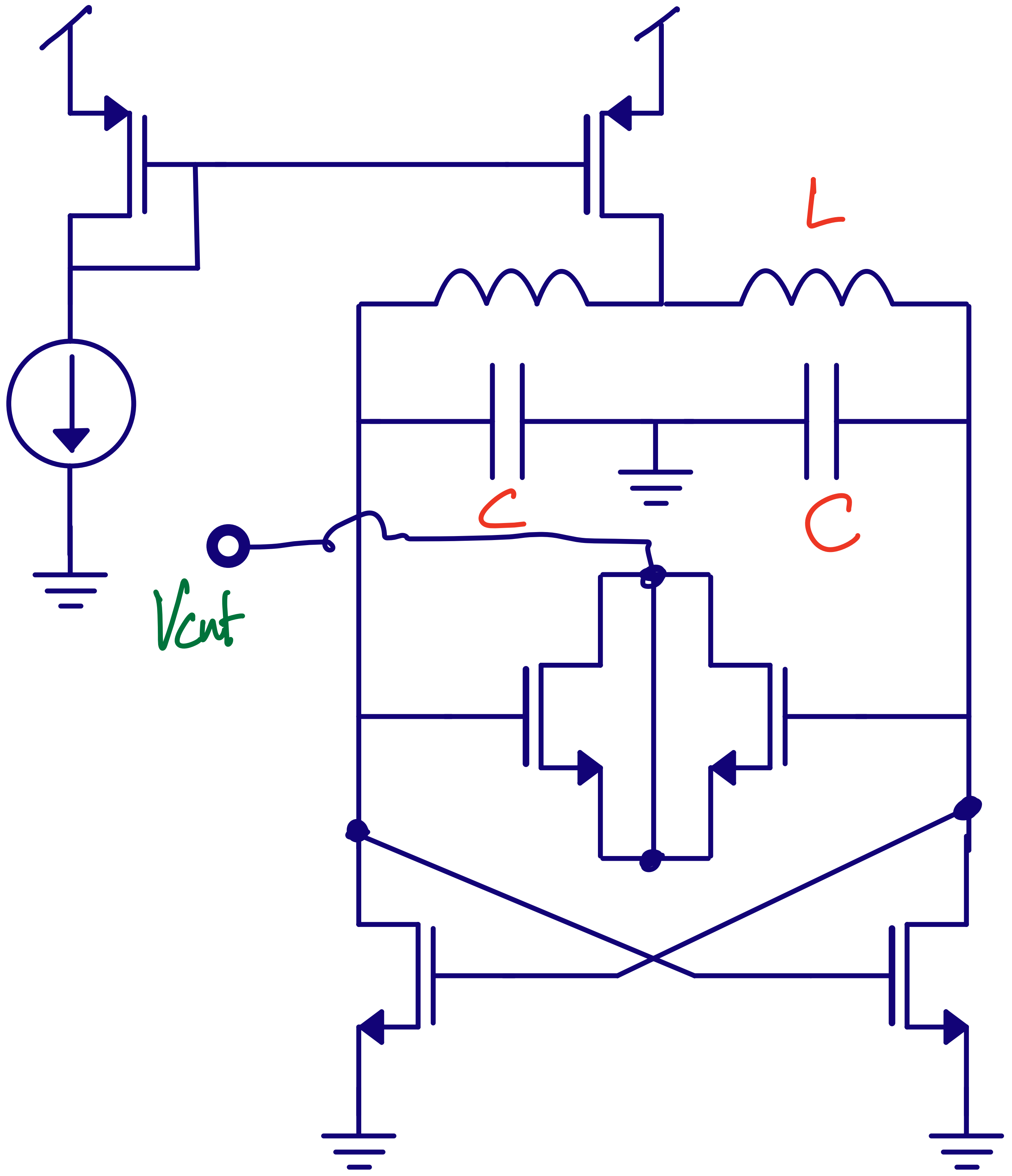
Digitally controlled oscillator



Differential

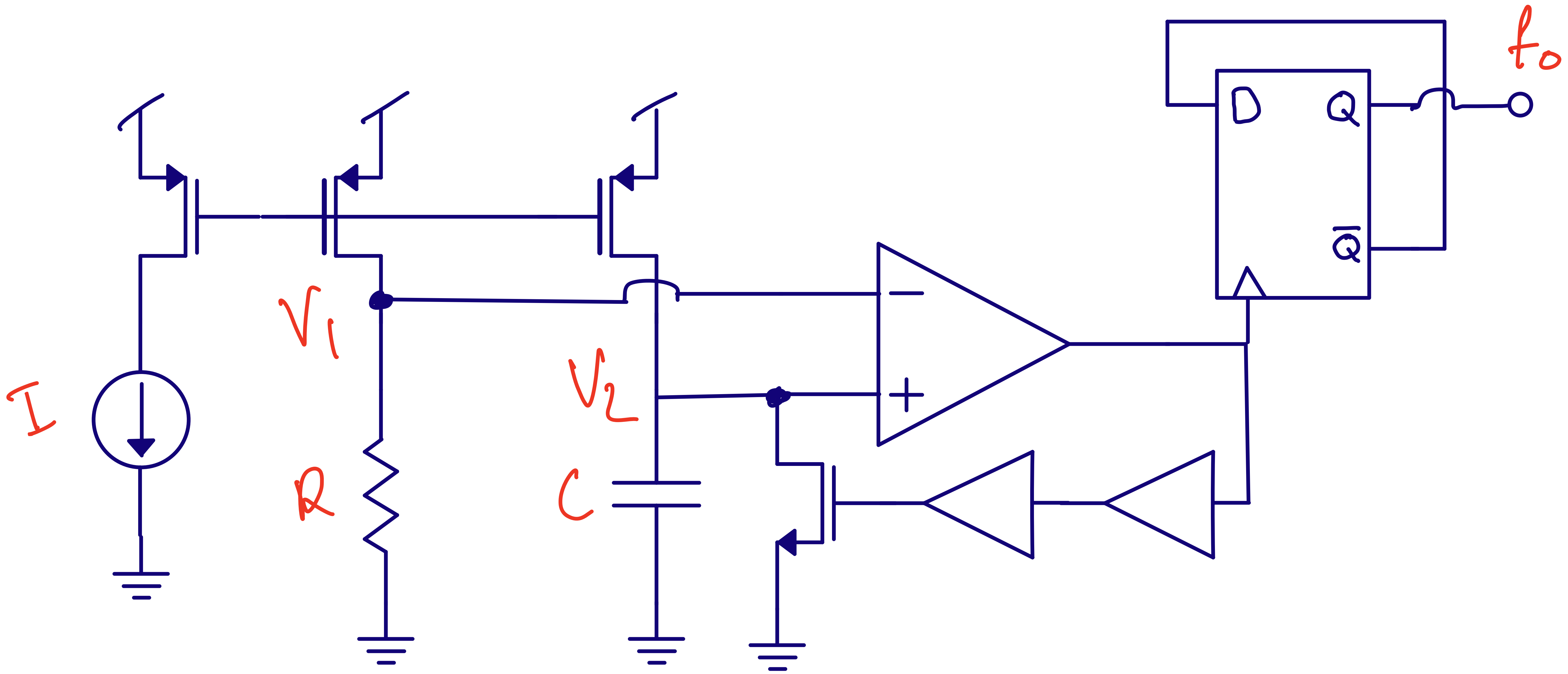
LC oscillator



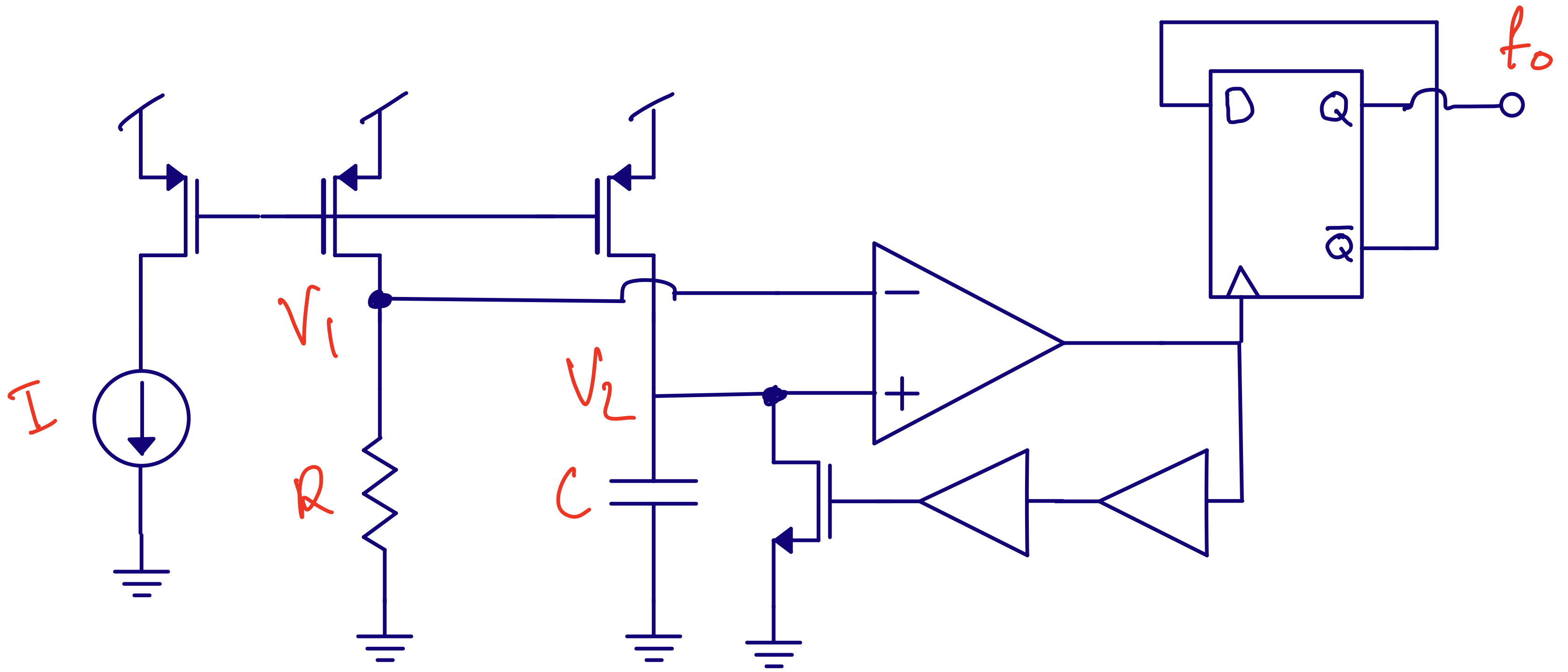


$$f \propto \frac{1}{\sqrt{LC}}$$

Relaxation oscillators



I
V_1
R
V_2
C
D
Q
$\bar{Q}$
f_o



$$V_1 = IR$$

$$I = C\frac{dV}{dt}$$

$$dt = \frac{CV_2}{I} = \frac{CIR}{I}$$

$$f = \frac{1}{dt} = \frac{1}{RC}$$

$$f_o = \frac{1}{2}f = \frac{1}{2RC}$$

Crystal oscillators

The Crystal Oscillator - A Circuit for All Seasons

High-performance crystal oscillator circuits: theory and application

Ultra-low Power 32kHz Crystal Oscillators: Fundamentals and Design Techniques

A Sub-nW Single-Supply 32-kHz Sub-Harmonic Pulse Injection Crystal Oscillator

CMOS oscillators

The Ring Oscillator - A Circuit for All Seasons

A Study of Phase Noise in CMOS Oscillators

An Ultra-Low-Noise Swing-Boosted Differential Relaxation Oscillator in 0.18-um CMOS

Ultra Low Power Frequency Synthesizer

Thanks!