408D – 5 Impedance Spectrometer in Sky130 PDK

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Impedance Spectroscopy

- Obtain **impedance** profile over **frequency** range
- Biomedical material characterization (materials like DNA and cells) [1,2]
- **Cancer detection** and virus detection [2]
- Design an **open-source** impedance spectrometer for cancer/virus detection
- **Standard interface** (SPI) for use with common microcontrollers for low-cost prototyping

Background

- To obtain impedance, **need to know I and V** across component

$$Z(\omega) = \frac{\hat{V}(\omega)}{\hat{I}(\omega)}$$

- **Mixing** can be used to **extract real and imaginary** parts of Z [1]

$$V_z(t) = C_0 + A_0 \frac{e^{j\omega t + j\phi} + e^{-j\omega t - j\phi}}{2}$$

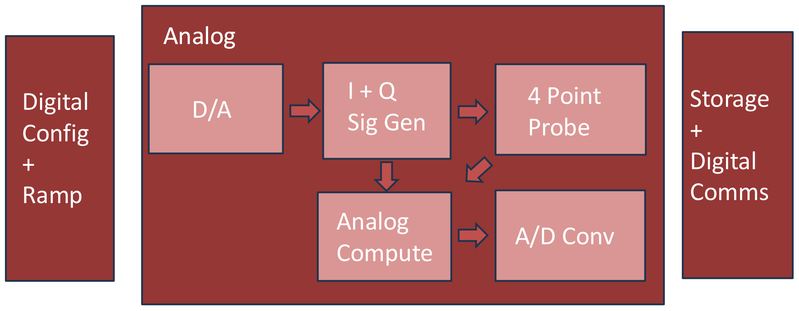
$$V_I(t) = B_0 \frac{e^{j\omega t} + e^{-j\omega t}}{2}, V_Q(t) = B_0 \frac{e^{-j\omega t} - e^{j\omega t}}{2j}$$

$$LPF(V_Z(t)V_I(t)) = \frac{A_0 B_0}{2}(\cos(\phi)) = \frac{B_0}{2} Re\{\hat{V}_Z\}$$

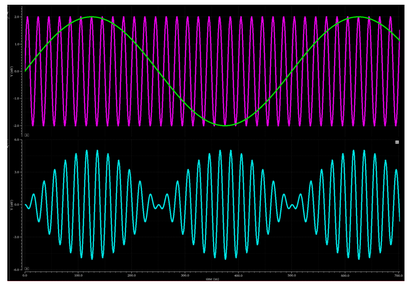
$$LPF(V_Z(t)V_Q(t)) = \frac{A_0 B_0}{2}(\sin(\phi)) = \frac{B_0}{2} Im\{\hat{V}_Z\}$$

- Current phasor fixed, taking reference phase from I

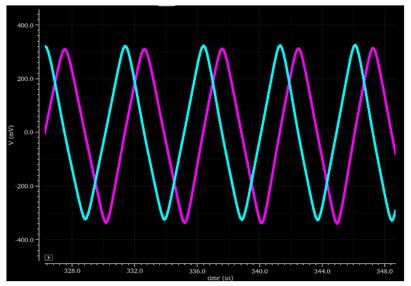
High Level View



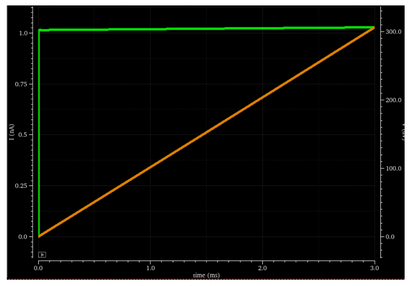
Initial Simulation Results



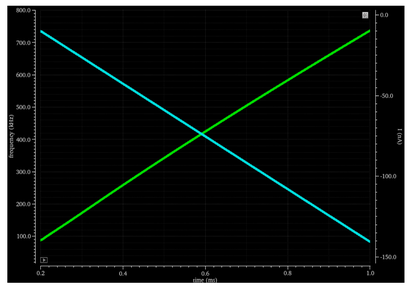
Gilbert cell mixer results



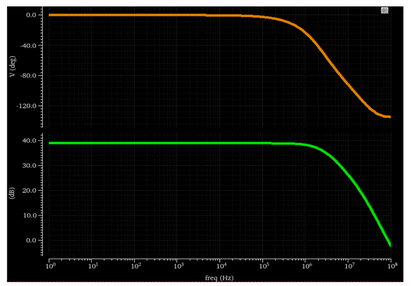
VCO waveforms



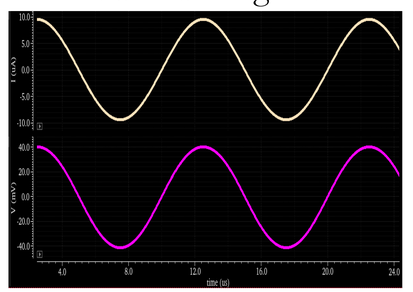
Howland integrator



VCO frequency sweep



Op-amp gain and phase frequency response



4-Point Probe Voltage Measurement

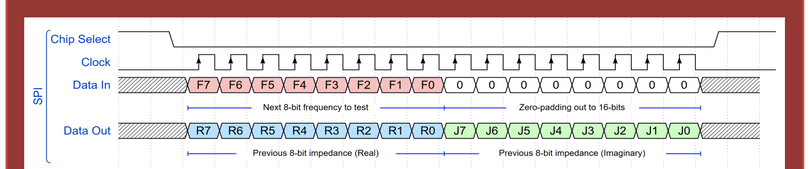
Relevant Circuits

- Obtained a phase margin of **45 degrees** and open-loop gain of **38dB**, CMR of **[–0.7V, 0.7V]**
- **Gm-C** oscillator used as **quadrature VCO**
- **Howland Current Pump** as AC current source
- Double balanced **Gilbert Cell** used as mixer

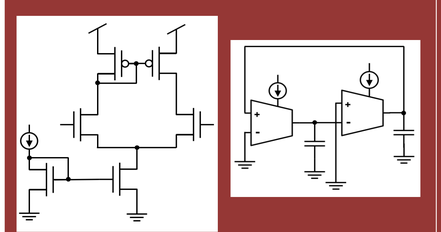
References

1. P. Abshire, "ENEE408D Projects"
2. Stupin, DD. Et al, Bio-Impedance Spectroscopy: Basics and Applications, URL: https://doi.org/10.48550/arXiv.2005.03275
3. P. Abshire, "ENEE411 Wide Swing Diff Amps"
4. Texas Instruments, AN-1515: A Comprehensive Study of the Howland Current Pump, Application Report, Nov. 2007. https://www.ti.com/lit/an/snoa474a/snoa474a.pdf
5. M. Aboy, "Single-slope integrating ADC", YouTube

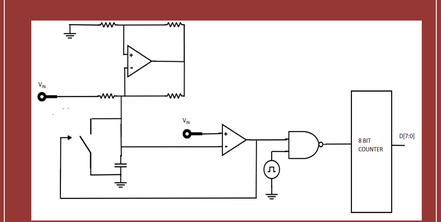
- Easy Device Control over **Serial Peripheral Interface (SPI)**
  - Uses standard SPI interface for simple product integration
  - Supported by common microcontrollers like STM32 and Arduino
  - Full-duplex: send in next frequency input and read out measurements simultaneously



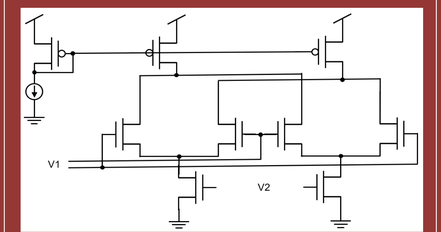
OTA



Single-slope ADC



Gilbert Cell



Instrumentation Amp