EECS240 – Spring 2010

Lecture 22: Offset Cancellation

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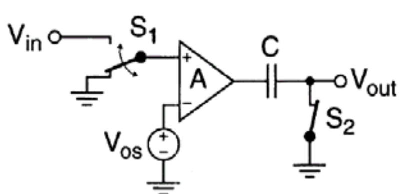
Offset Cancellation Overview

- Two main ideas/approaches
- Modulate and/or filter offset so that it is outside of signal band
  - CDS (auto-zeroing)
  - Chopping (synch. detection, DEM)
- Inject a DC signal that opposes the offset
  - Trimming
  - Often digitally controlled (especially for comparators)

Filtering/Modulating Offset

- **General idea:**
  - **Put elements around the amplifier that treat offset differently than signal**
- **CDS:**
  - **Configure amplifier so that offset is (approx.) differentiated**
- **Chopping:**
  - **Modulate offset to frequencies beyond signal band, then filter it out**

CDS #1: Output Offset Cancellation



Phase 1:

$$V_C = -AV_{os}$$

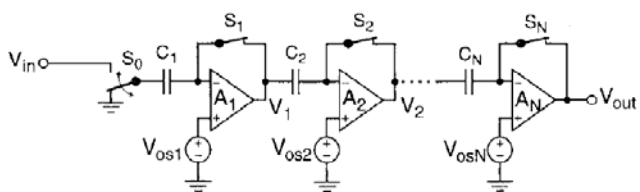
Phase 2:

$$V_{out} = A(V_{in} - V_{os}) - V_C$$
$$= AV_{in}$$

- **Relatively insensitive to switch errors**
  - **Storing amplified offset**
- **But, what happens if gain is large?**

CDS #2: Input Offset Cancellation

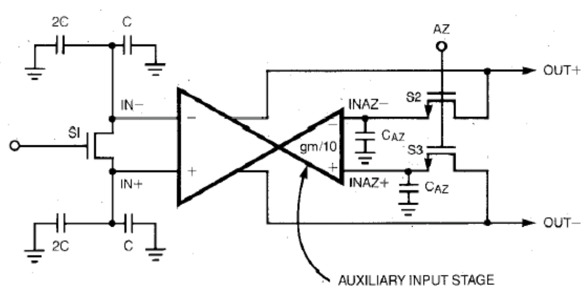
Multistage Cancellation



- **Open switches left to right**
  - **Errors from S_1 … S_{N-1} cancelled by final stage**
- **Application: continuous time comparators**

Auxiliary Amplifier Offset Cancellation

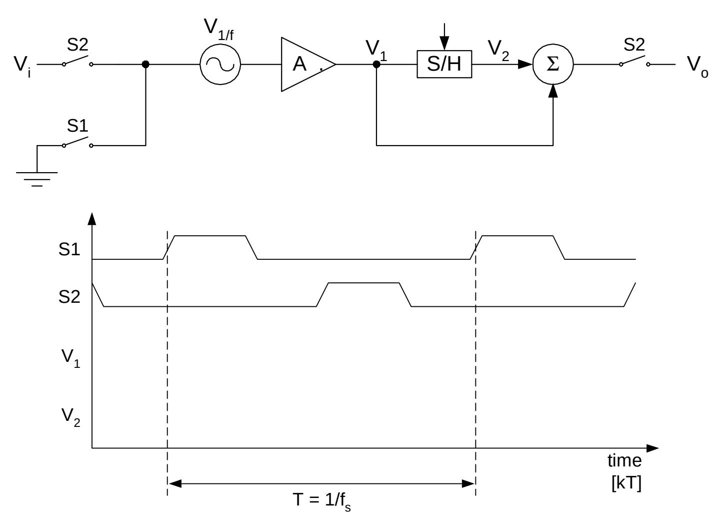
Aux. Amplifier Example



H. Ohara, H. X. Ngo, M. J. Armstrong, C. F. Rahim, and P. R. Gray, "A CMOS programmable self-calibrating 13-bit eight-channel data acquisition peripheral," *IEEE Journal of Solid-State Circuits,* vol. 22, pp. 930 - 938, December 1987.

Aux. Amplifier Implementation

CDS and Flicker Noise



Flicker Noise Analysis

$$V_o(kT) = A\left\{\underbrace{V_i(kT)}_{\text{signal}} + \underbrace{V_{1/f}(kT) - V_{1/f}\left(kT - \frac{T}{2}\right)}_{\text{input referred error } V_{nieq}}\right\}$$

Laplace Transform

$$\text{Delay by } t_d \quad \rightarrow \quad e^{-st_d}$$

$$V_{nieq}(s) = V_{1/f}(s)\underbrace{\left\{1 - e^{-s\frac{T}{2}}\right\}}_{H_n(s)}$$

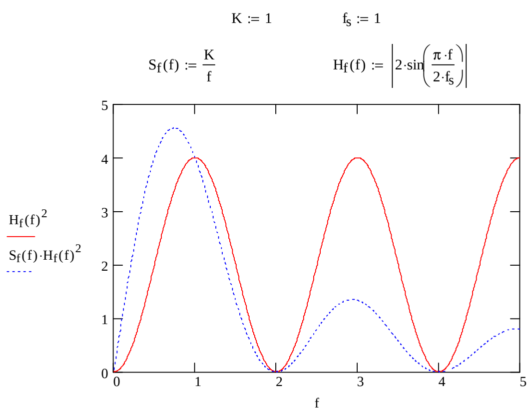
Flicker Noise Frequency Response

$$\begin{aligned} H_n(s) &= 1 - e^{-s\frac{T}{2}} \\ &= 1 - e^{-j\omega\frac{T}{2}} \\ &= 1 - \cos\frac{\omega T}{2} + j\sin\frac{\omega T}{2} \end{aligned}$$

$$\begin{aligned} \left|H_n(s)\right|^2_{s\to j\omega} &= \left(1 - \cos\frac{\omega T}{2}\right)^2 + \left(\sin\frac{\omega T}{2}\right)^2 \\ &= 1 - 2\cos\frac{\omega T}{2} + \underbrace{\cos^2\frac{\omega T}{2} + \sin^2\frac{\omega T}{2}}_{1} \\ &= 2\left(1 - \cos\frac{\omega T}{2}\right) \\ &= 4\sin^2\frac{\omega T}{4} \end{aligned}$$

$$\boxed{\left|H_n(s)\right|_{s\to j\omega} = \left|2\sin\frac{\omega T}{4}\right| = \left|2\sin\frac{\pi f}{2 f_s}\right|}$$

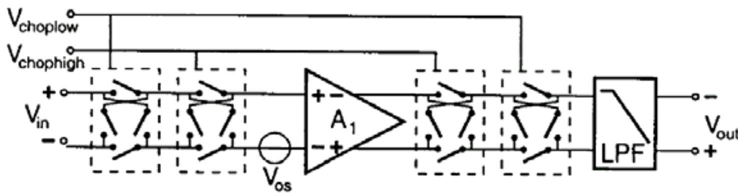
Flicker Noise Spectrum



- Flicker noise is differentiated
  - As is thermal noise
- Noise removed at low freq.
  - But amplified at "high" freq.
- Noise above $f_s/2$ folds to baseband

Chopping

Nested Chopper Amplifier



- Inner chopper at high freq. to remove 1/f noise
- Outer chopper at low frequency to minimize "spiking" and remove residual offset from inner chopper.

Offset Trimming

Digital Trimming

Comparator Trimming

Trim Implementation Issues

- Infinite number of ways to introduce digitally controlled offset
  - People have tried just about all of them

- Key issues:
  - Power overhead
  - Circuit Imbalance
  - Effective resolution
  - Area overhead

Comparator Trim Schemes

Pre-Amp Trim

Pre-Amp Trim