

MIDEM 2026

Transient Noise Simulation in VACASK



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What is VACASK

- Verilog-A Circuit AnalySis Kernel
- Analog circuit simulator
- Spectre-like input syntax
- Parsers for Spectre, HSPICE, ...
- Modern C++
- KLU & SuperLU linear solvers
- Fast, scalable
- IHP SG13G2, GF180
- RF analyses
(HB, HBAC, HBNOISE, PSS, PAC, PNOISE)

<https://codeberg.org/arpadbuermen/VACASK>

CMOS ring oscillator

```
load "psp103v4.osdi"  
include "cmos_models.inc"  
model isrc isource  
model vsrc vsource
```

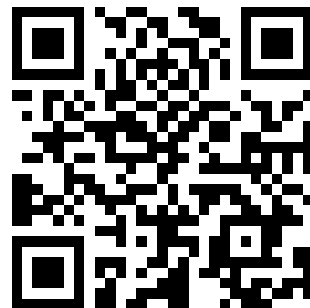
```
subckt inv(in out vdd vss)  
parameters w=10u l=0.2u fac=2  
  mp (out in vdd vdd) pmos w=w*fac l=l  
  mn (out in vss vss) nmos w=w l=l  
ends
```

```
subckt ring()  
  x1 (1 2 vdd 0) inv  
  x2 (2 3 vdd 0) inv  
  x3 (3 1 vdd 0) inv  
ends
```

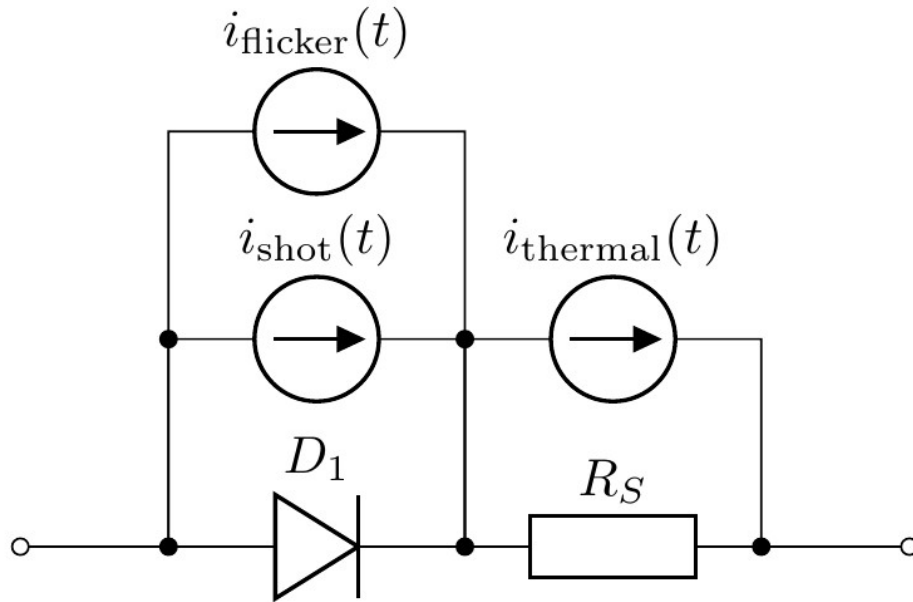
```
vdd (vdd 0) vsrc dc=1.2
```

```
subckt start()  
  ipulse (0 1) isrc type="pulse" v0=0 v1=1u delay=1n rise=1n fall=1n width=1n  
ends
```

```
control  
  elaborate circuit("ring", "start")  
  analysis tran1 tran step=0.05n stop=1u maxstep=0.05n  
endc
```



Noise models of elements



$$S_{\text{thermal}} = \frac{4kT}{R_S}$$

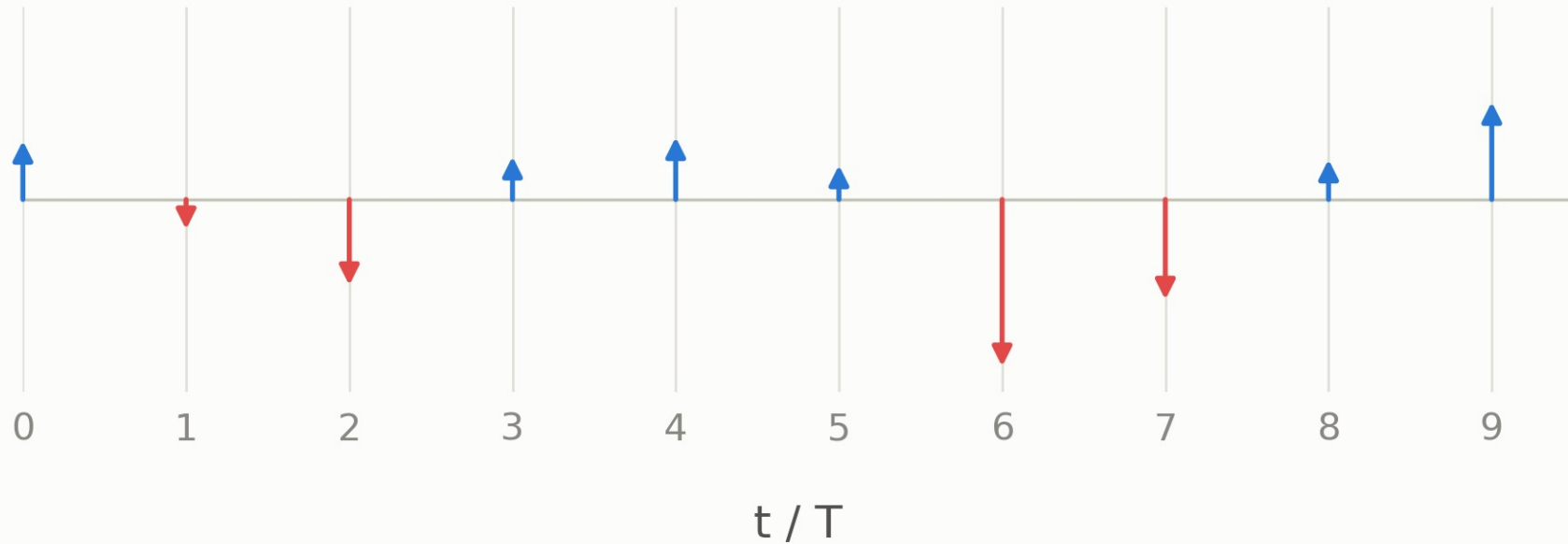
$$S_{\text{shot}} = 2qI$$

$$S_{\text{flicker}} = \frac{K_f I^{A_f}}{f^{e_f}} \quad (e_f = 0 \dots 2)$$

ZOH approach - white noise

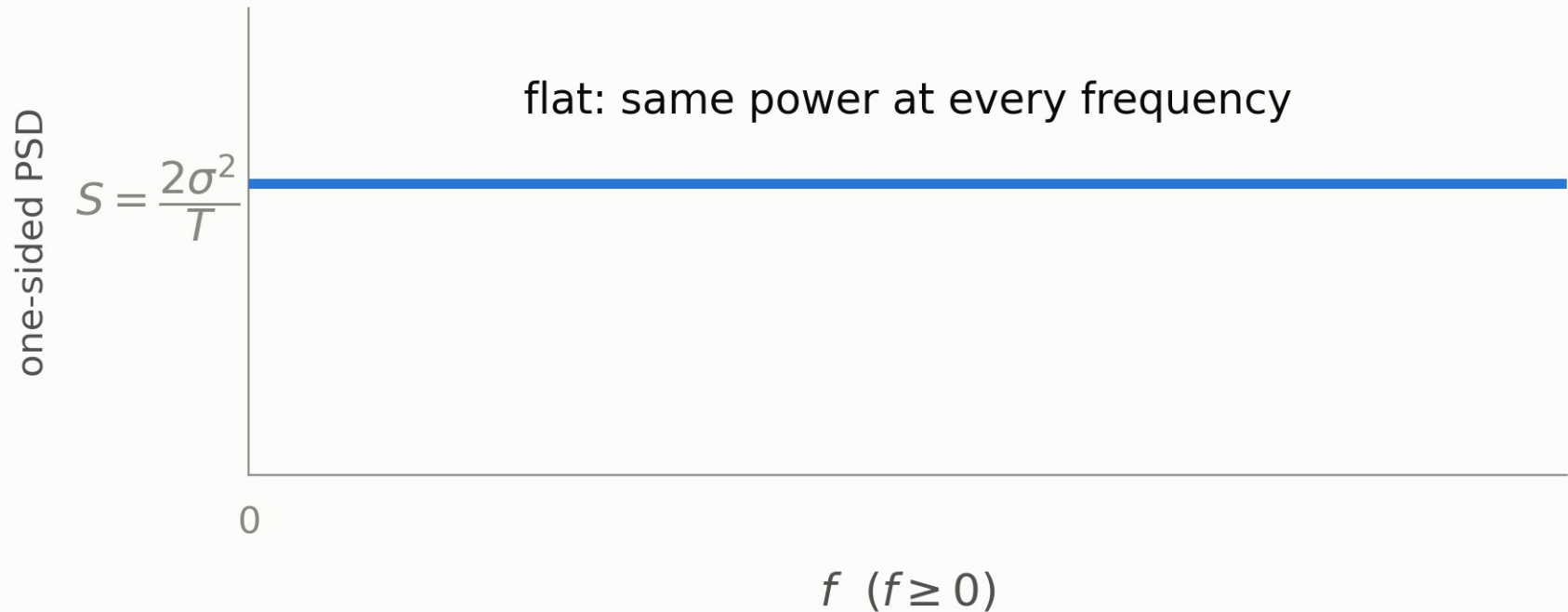
Impulse train with random magnitude

$a_n \sim \mathcal{N}(0, \sigma^2)$ at each sample, spacing $T = 1/f_s$



Spectrum of white noise (PSD)

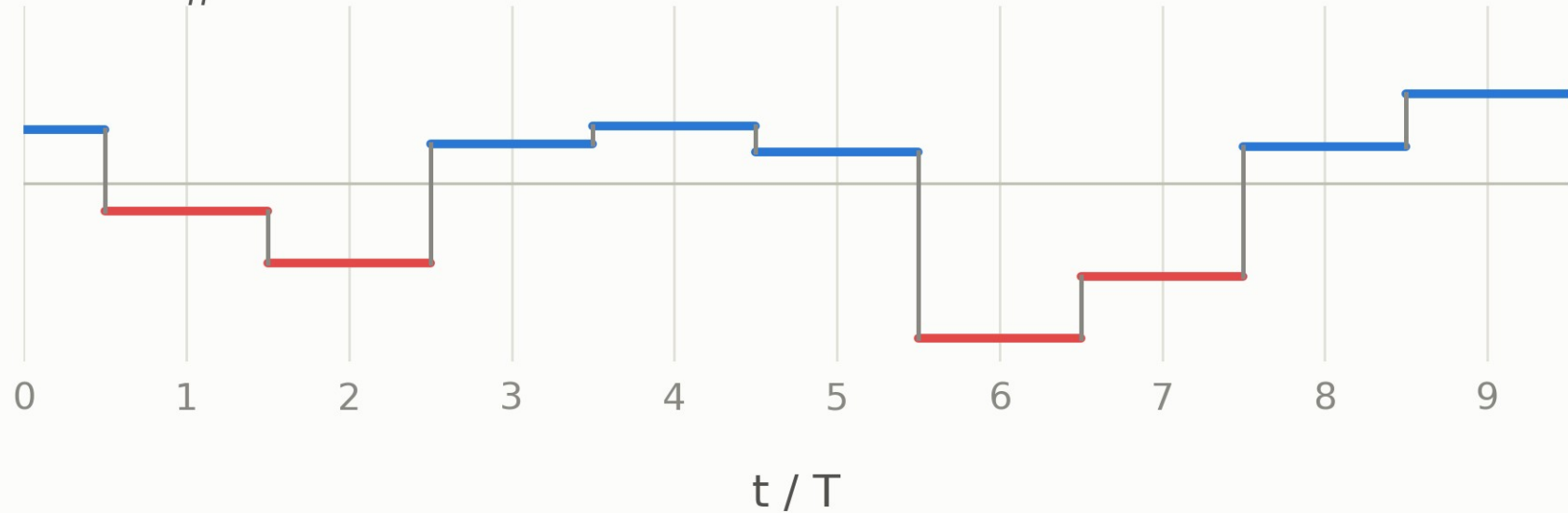
PSD of the impulse train is white



Apply zero-order hold (ZOH)... pulse train

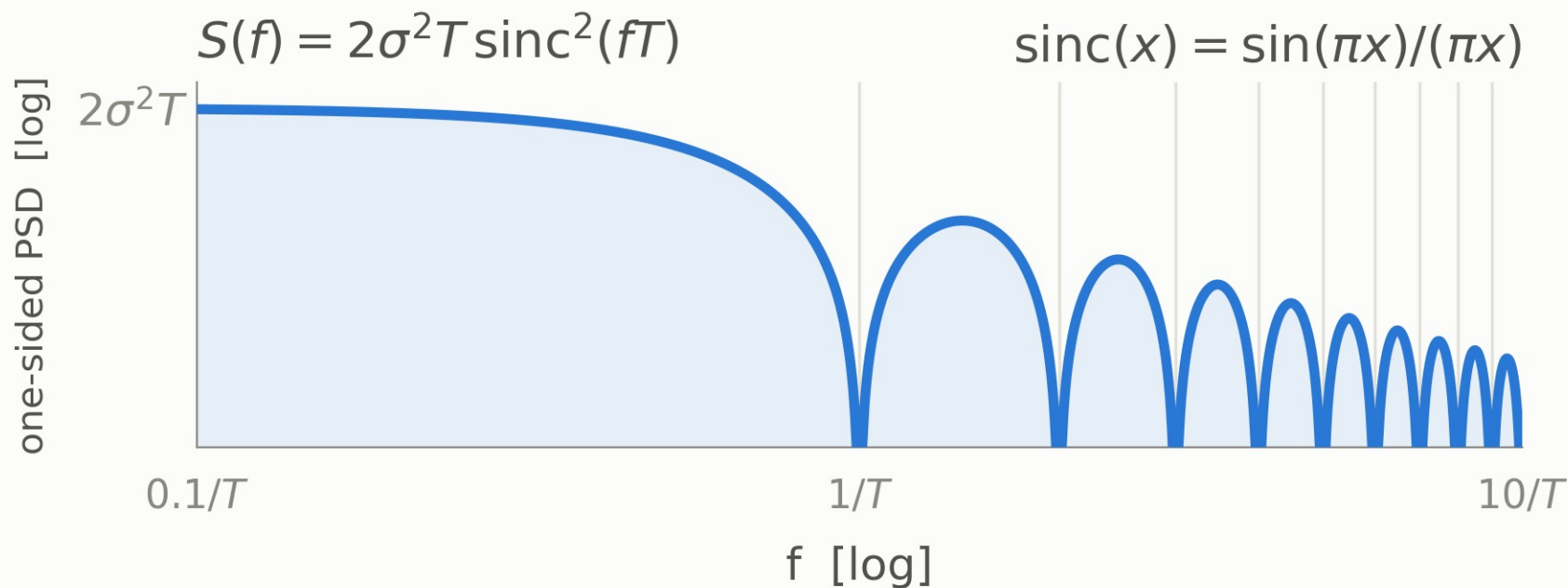
Pulse train (zero-order hold)

$$y(t) = \sum_n a_n p(t - nT)$$



PSD of pulse train

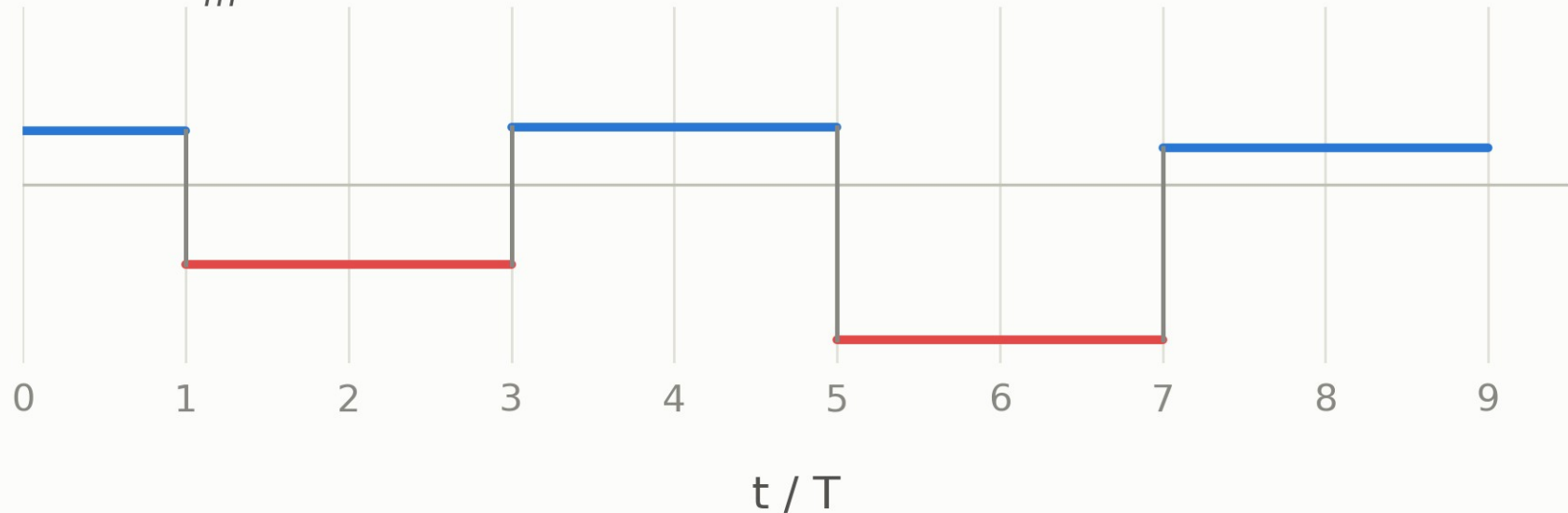
PSD after zero-order hold



Flicker noise ($S=a/f$) ... decimated pulse train

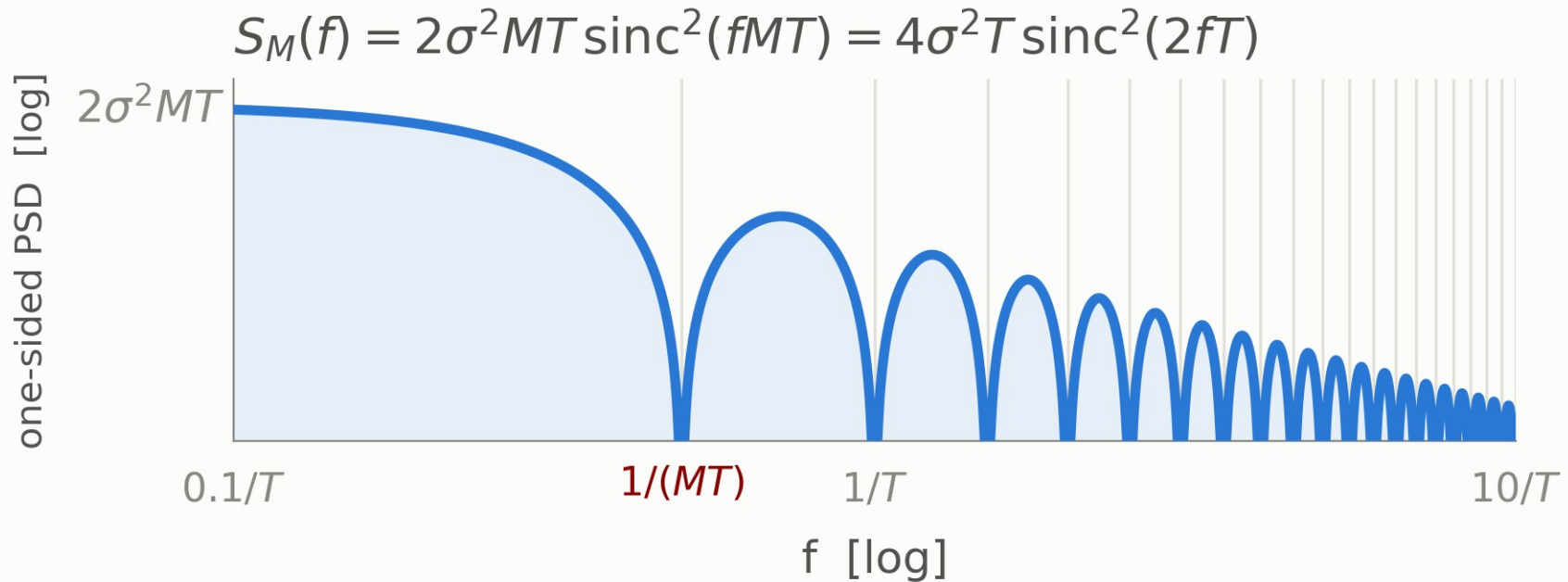
Pulse train for $M = 2$

$$y_2(t) = \sum_m a_{2m} p_{2T}(t - 2mT)$$



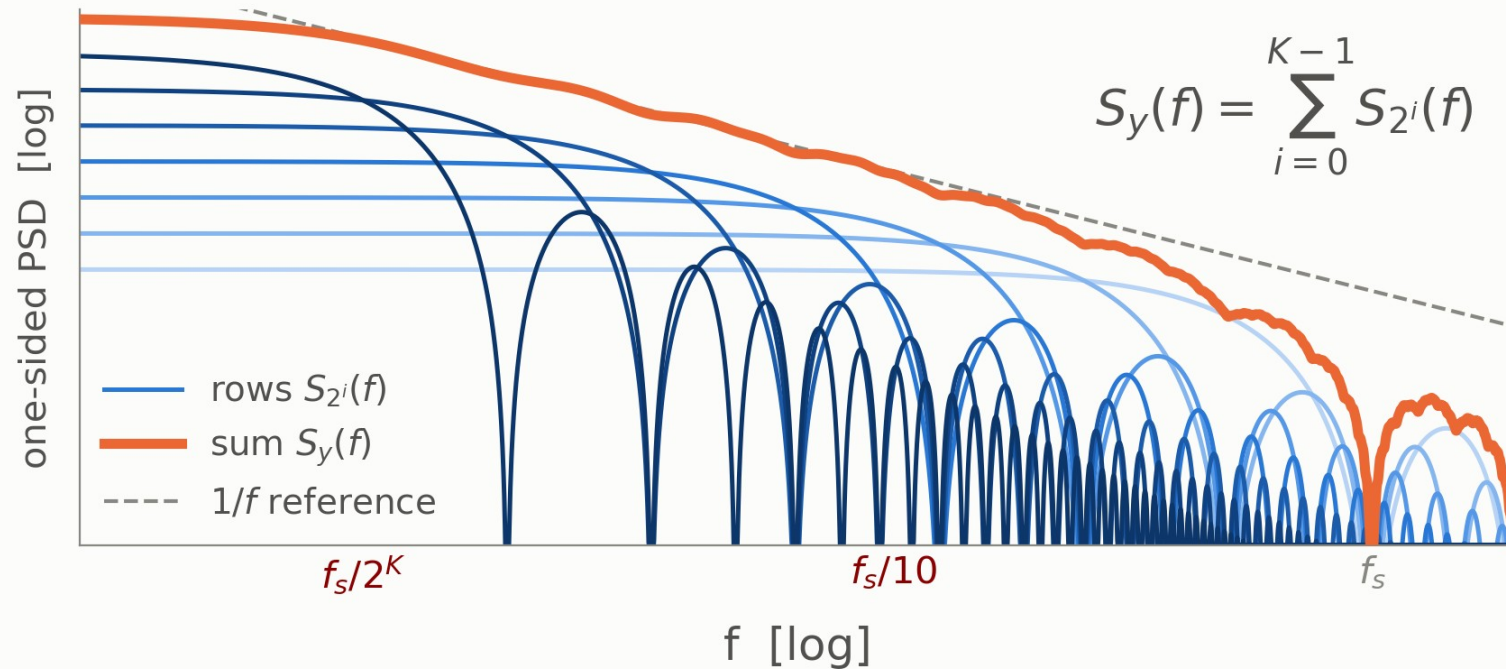
PSD of decimated pulse train

Decimated pulse train, keep every M-th sample



Sum of rows (decimated pulse trains)

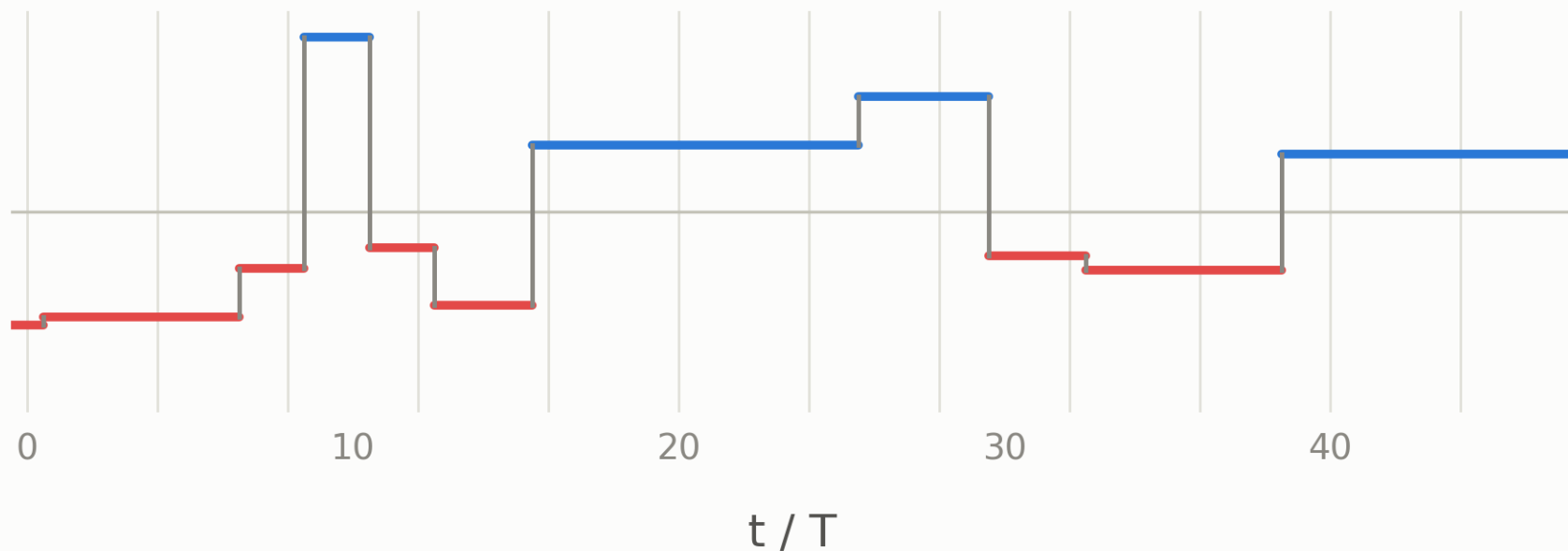
Voss-McCartney: rows and their sum ($K = 7$)



Randomize (change value with $p=1/2^i$)...

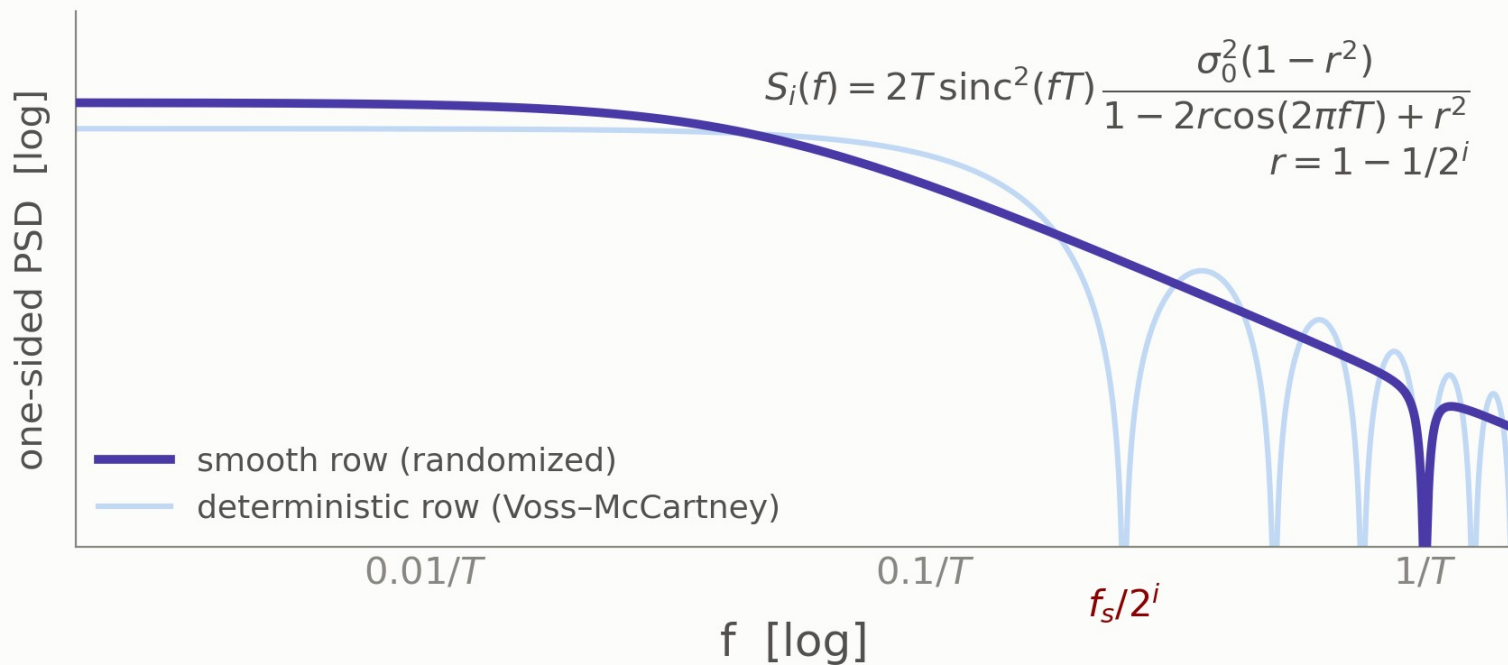
Randomized decimation, $i = 2$: pulse (ZOH) version

after convolving with the width- T pulse, we get random-width blocks



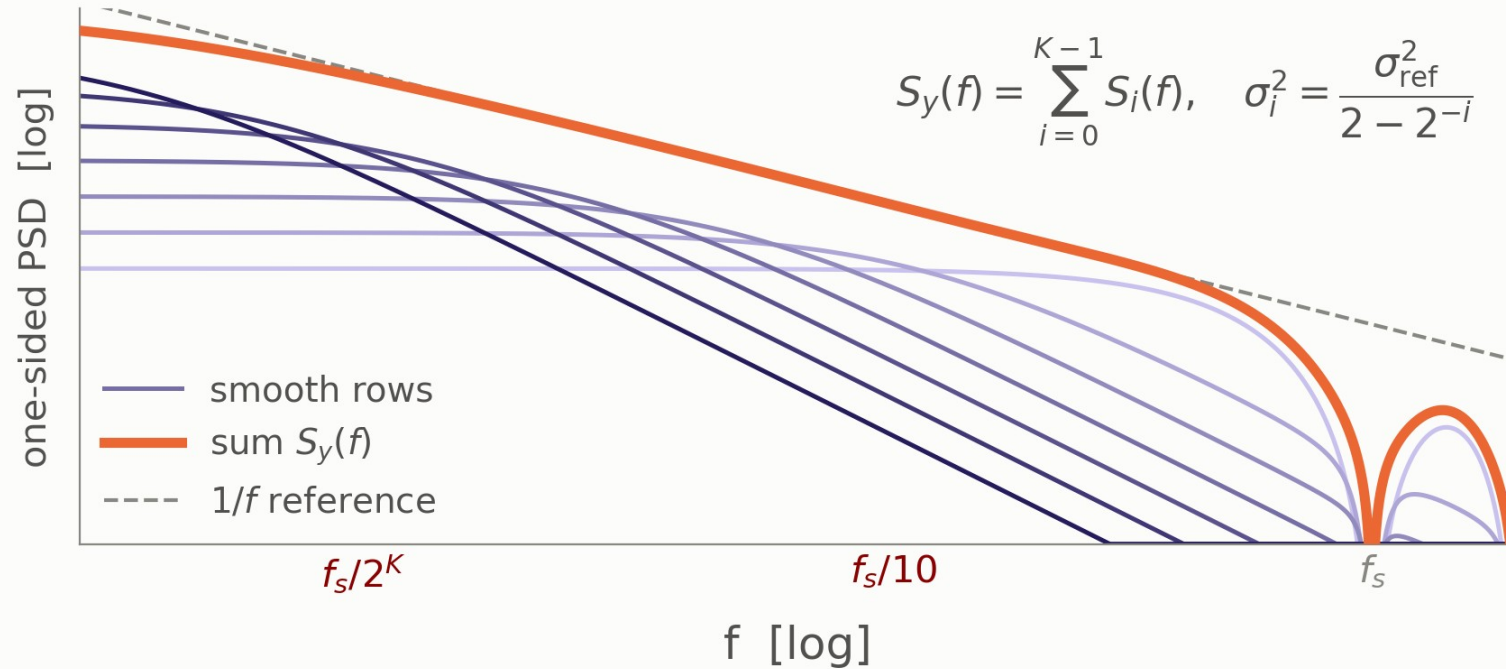
... and we get a smooth PSD

Smooth row: randomized decimation ($i = 2$)



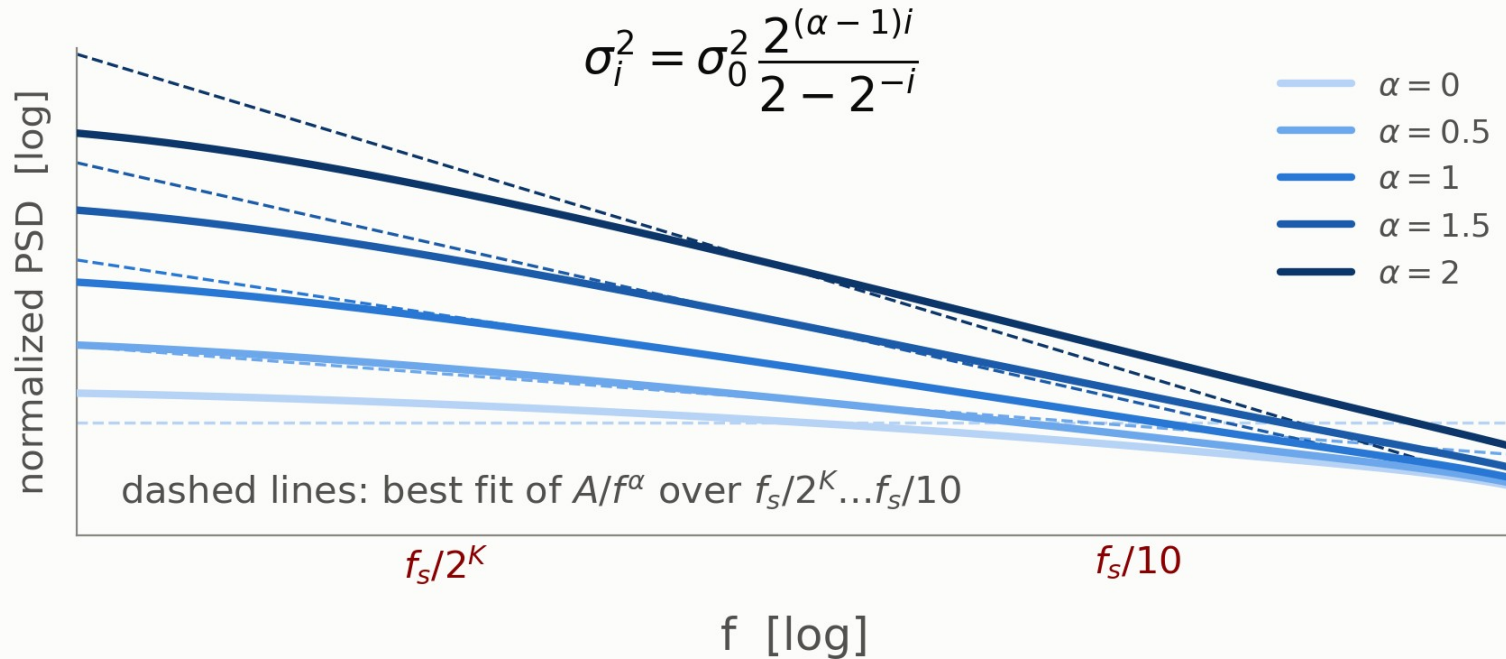
Sum of randomized rows

Assembling $1/f$ from smooth rows ($K = 7$)



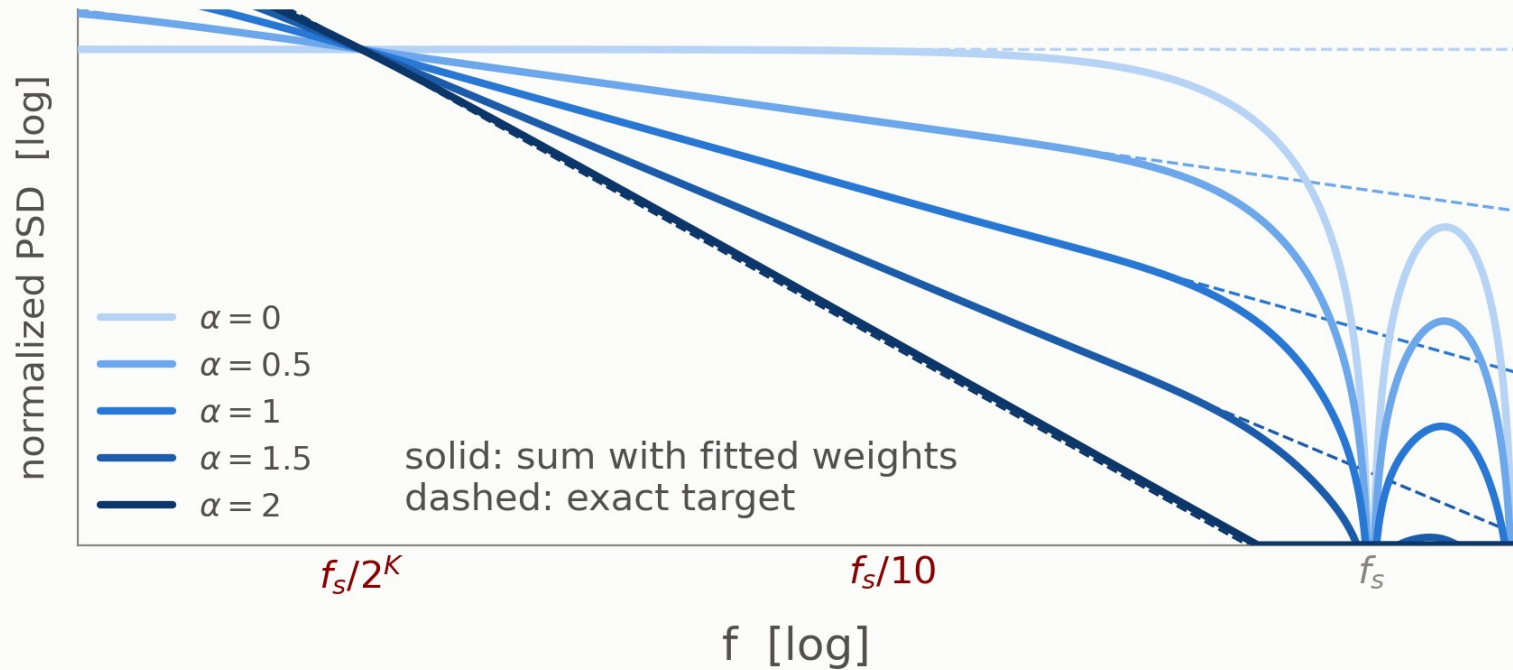
Change row weights ... $1/f^\alpha$

Smooth-row $1/f^\alpha$ family ($K = 7$)



Tune weights with gradient optimizer

Fitted $1/f^\alpha$ vs. exact target ($K = 7$)



Alternative to ZOH: stochastic differential equations

- White noise – increment is a Wiener process increment

$$dQ(t) = \sqrt{S/2} dW(t), \quad i(t) dt \stackrel{\text{formally}}{=} dQ(t)$$

- White noise sample $I[n]$ at t_k+h (timestep is h)

$$\text{Var}[I] = \frac{S}{2} \cdot \frac{h}{h^2} = \frac{S}{2h} \implies \boxed{I[n] = \sqrt{\frac{S}{2h}} \mathcal{N}(0, 1)}$$

- For flicker noise replace i -th row with an Ornstein-Uhlenbeck process

$$dx_i = -\omega_i x_i dt + \sigma_i dW_i(t), \quad i = 0, \dots, K-1$$

$$\omega_i = 2\pi f_i, \quad f_i = \frac{f_{\max}}{2^i}$$

Solving Ornstein-Uhlenbeck

- Closed-form solution for $S(f=0) = S_{i,LF}$

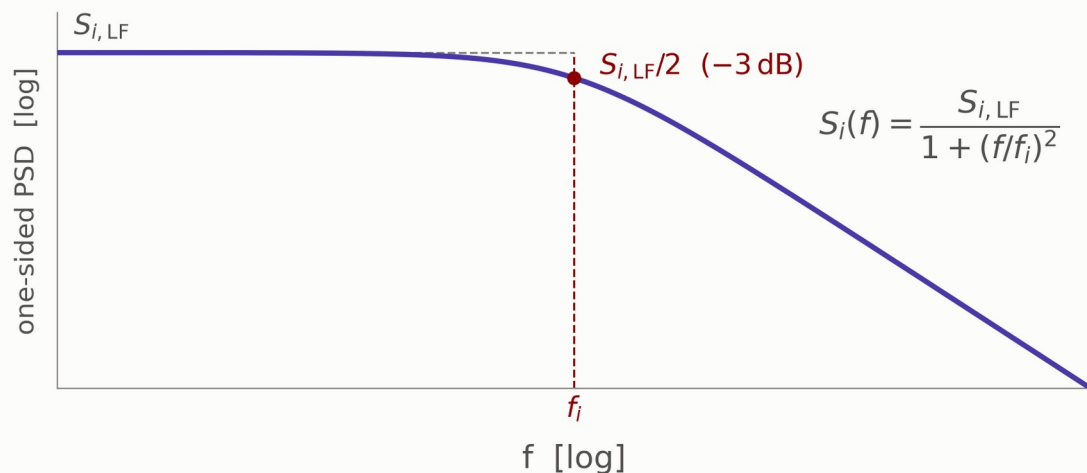
$$x_i(t+h) = a_i x_i(t) + b_i \mathcal{N}(0,1)$$

$$a_i = e^{-\omega_i h}, \quad b_i = \sqrt{S_{i,LF}} \frac{\sqrt{\omega_i(1-a_i^2)}}{2}$$

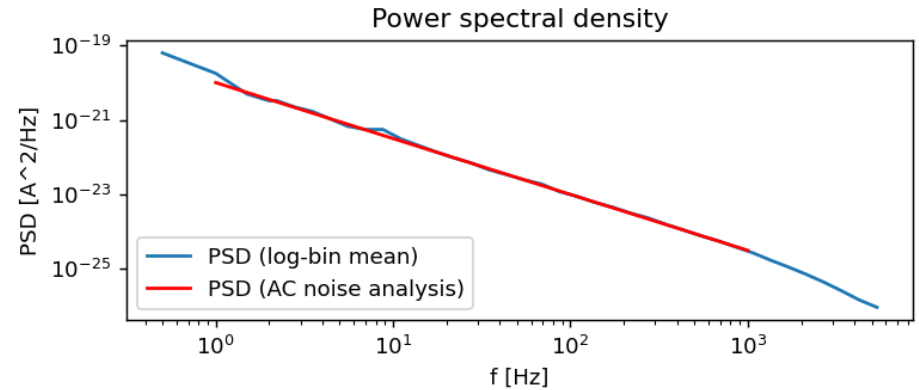
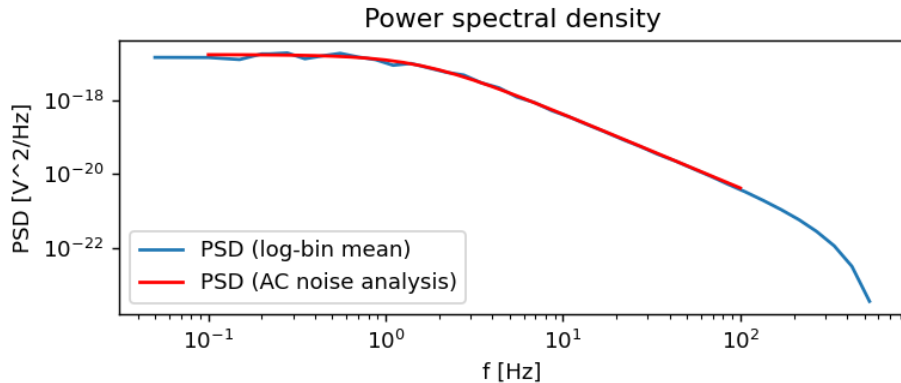
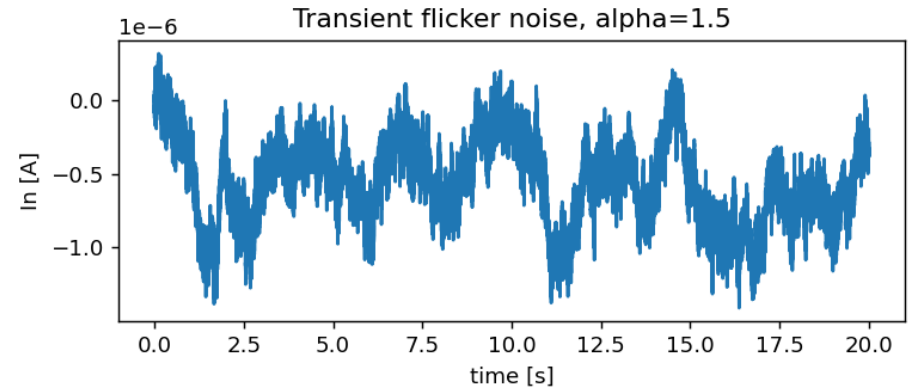
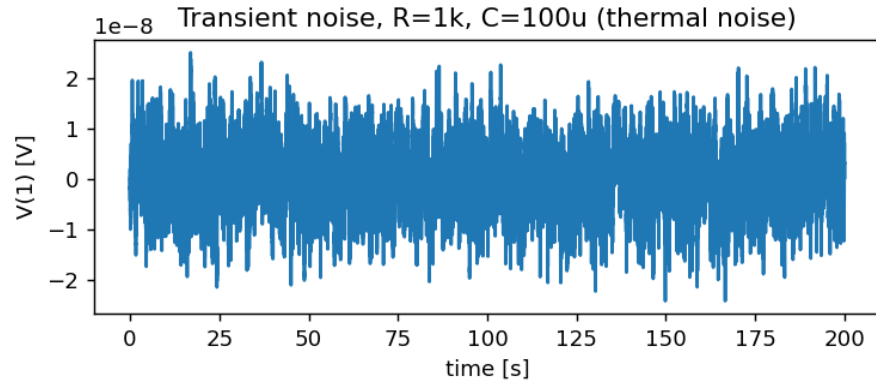
- PSD

$$S_i(f) = \frac{2\sigma_i^2}{\omega_i^2 + (2\pi f)^2} = \frac{2\sigma_i^2/\omega_i^2}{1 + (f/f_i)^2}$$

PSD of an Ornstein-Uhlenbeck process

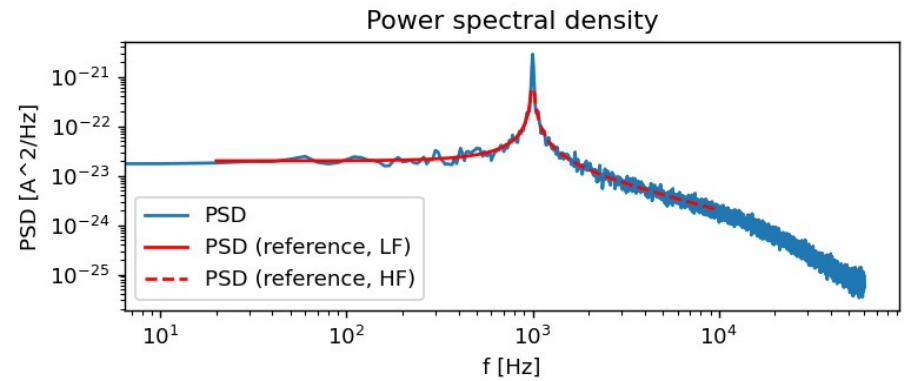
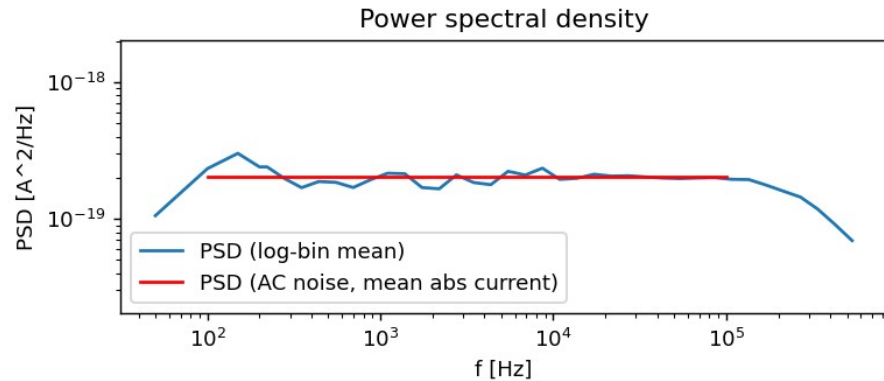
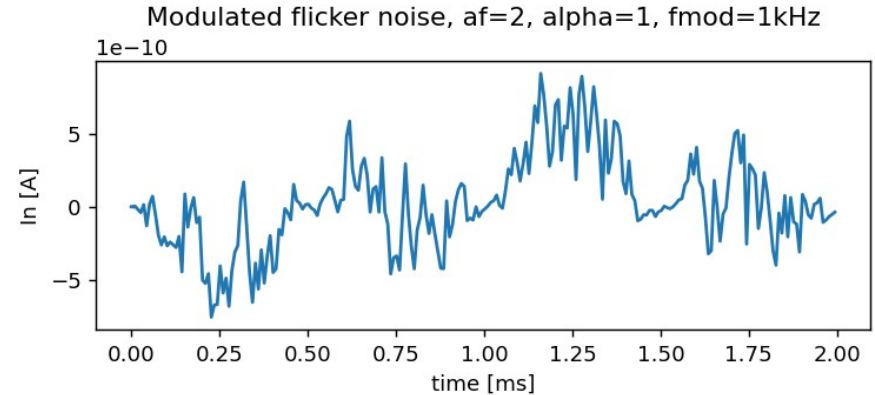
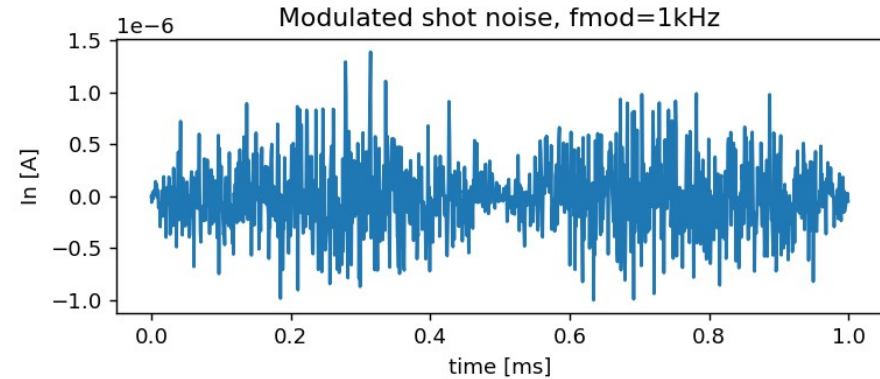


Unmodulated noise



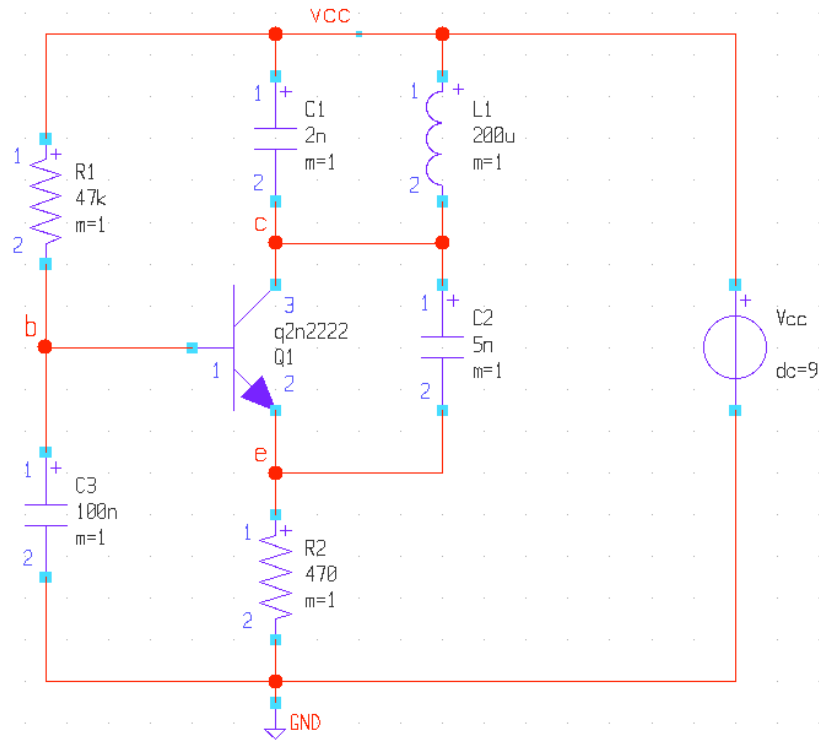
analysis tran1 tran stop=20/fmin noisefmax=fmax noisefmin=fmin oversample=6

Modulated noise



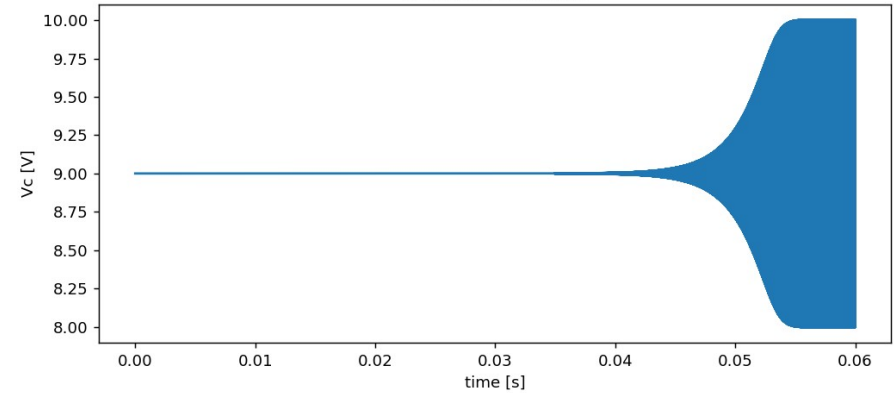
Coram et. al., Flicker Noise Formulations in Compact Models, IEEE TCAD, vol. 39 (2020), pp. 2812-2821.

Example: oscillator

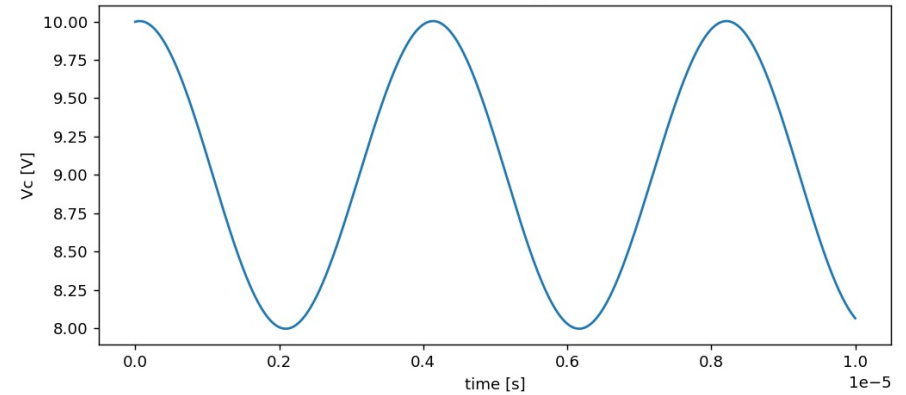


LC oscillator

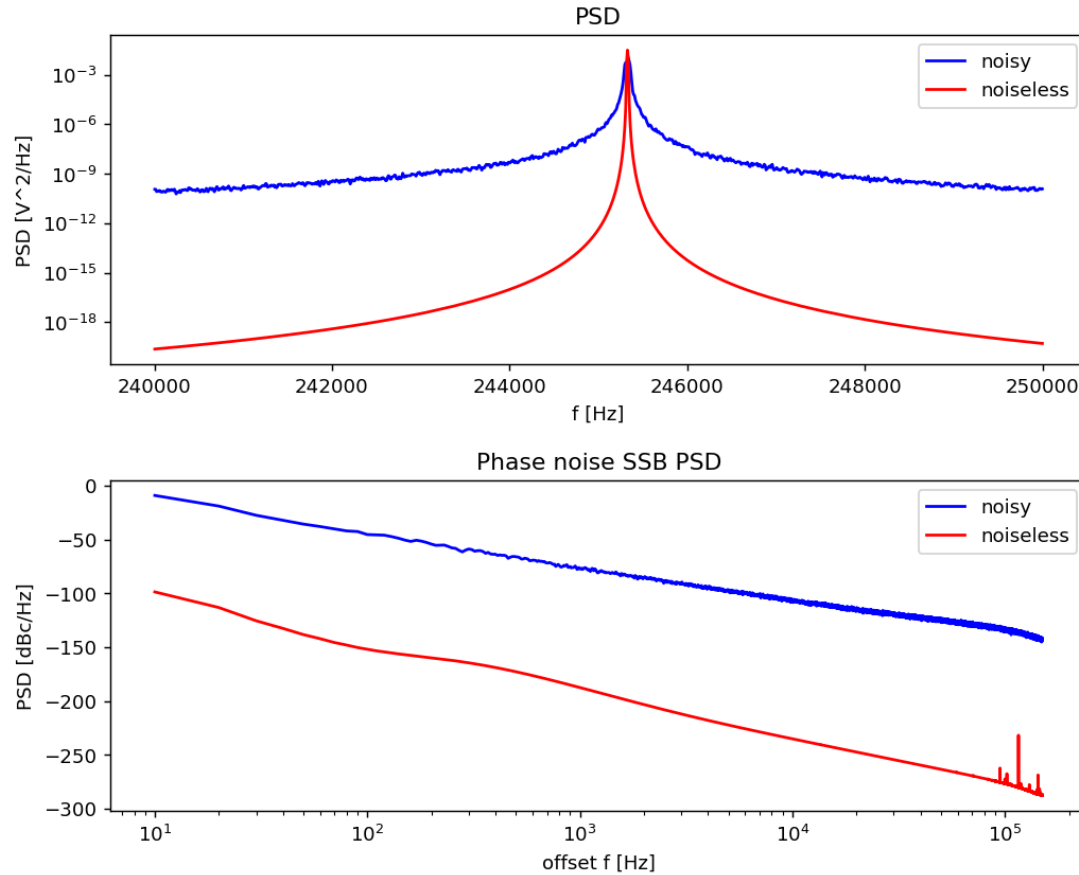
Oscillator response



Oscillator steady state

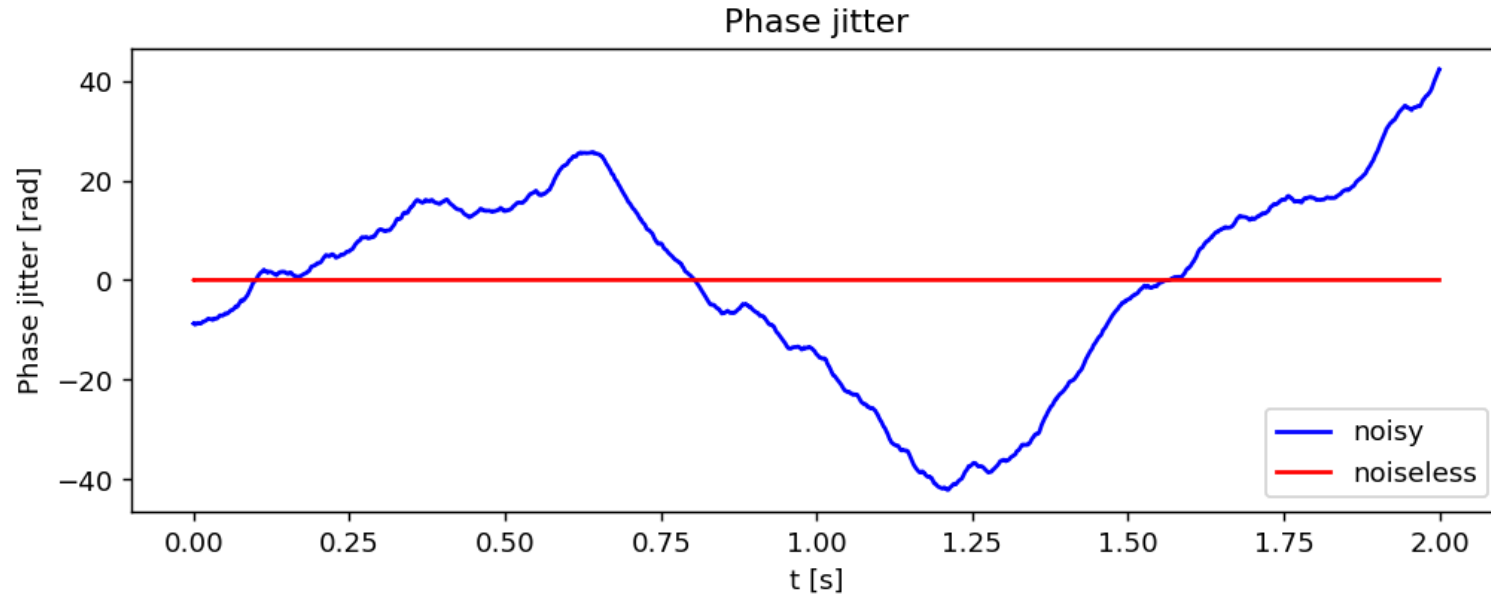


Noise PSD and SSB PSD of phase noise



- 245.4kHz LC oscillator
- Noise: 10Hz .. 400kHz
- $T_{\text{max}}=2\text{s}$, $T_{\text{step}} \leq 25\text{ns}$
- $\text{reltol}=1\text{e-}6$
- 81M points
- 5 minutes
- Welch: 37 segments
- SSB PSD BW=300kHz centered around f_{osc}

Phase jitter



FIR bandpass around f_{osc} (BW=50kHz), Hilbert xform, subtract linear phase

Acknowledgement: Filip Maksimović evaluated transient noise and improved SNR

Thank you.

