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1 Objectives

- Better **harmonic distortion characteristics** than Huovilainen's model [2]
- Realistic **self-oscillation**
- Comparable computational cost to [2]

2 Circuit Analysis

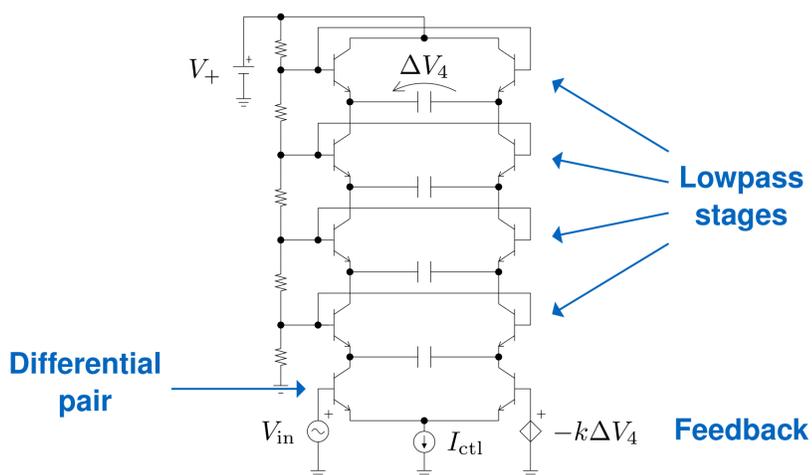


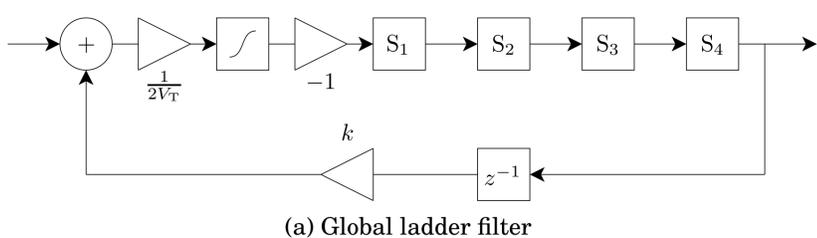
Figure 1: The Moog ladder circuit [1].

Continuous-time large-signal model ($i = 2...4$):

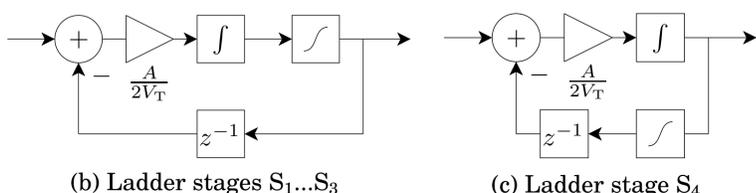
$$\frac{d\Delta V_1}{dt} = -\frac{I_C}{2C} \left[\tanh\left(\frac{\Delta V_i}{2V_T}\right) + \tanh\left(\frac{V_{in} + k\Delta V_4}{2V_T}\right) \right],$$

$$\frac{d\Delta V_i}{dt} = \frac{I_C}{2C} \left[\tanh\left(\frac{\Delta V_{i-1}}{2V_T}\right) - \tanh\left(\frac{\Delta V_i}{2V_T}\right) \right].$$

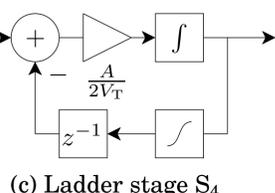
3 Digital Implementation



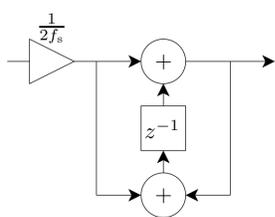
(a) Global ladder filter



(b) Ladder stages $S_1...S_3$



(c) Ladder stage S_4



(d) Bilinear-transformed integrator

Figure 2: Proposed implementation.

4 Evaluation

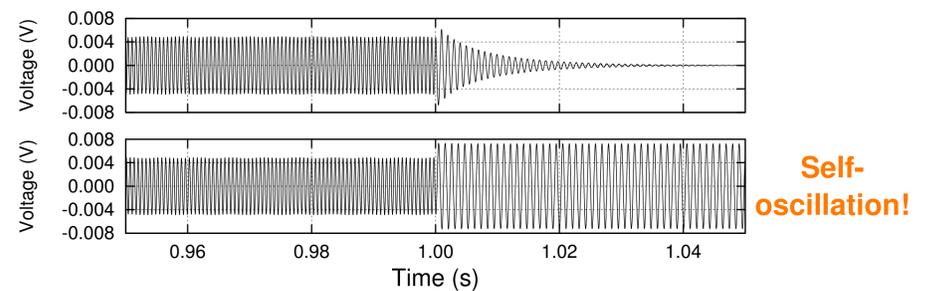
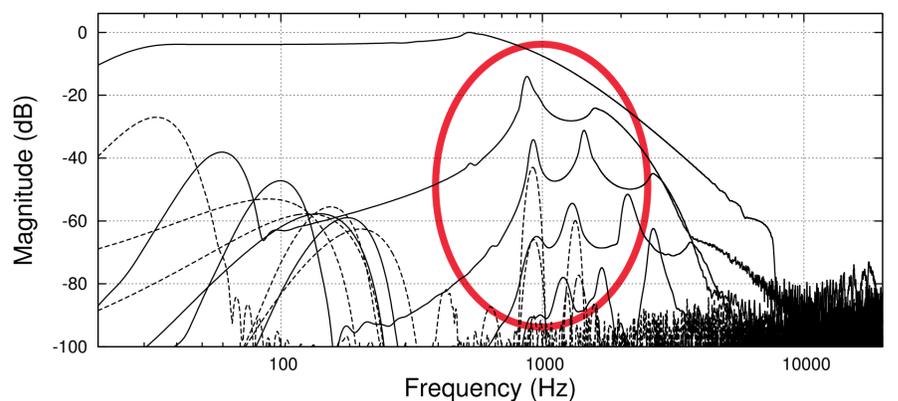
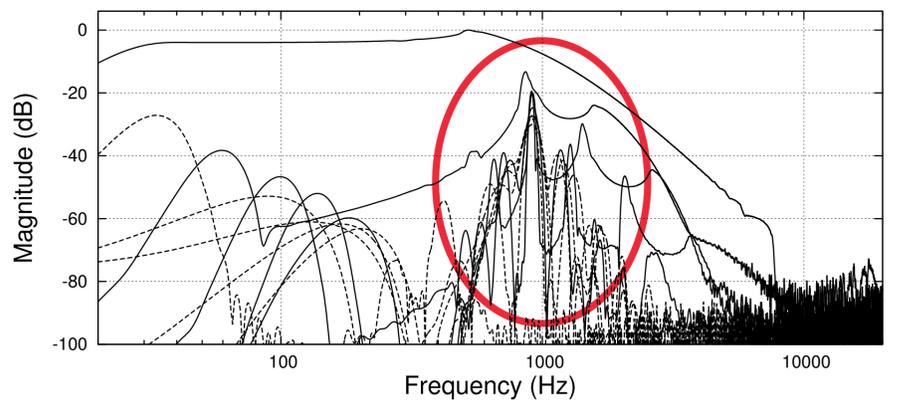


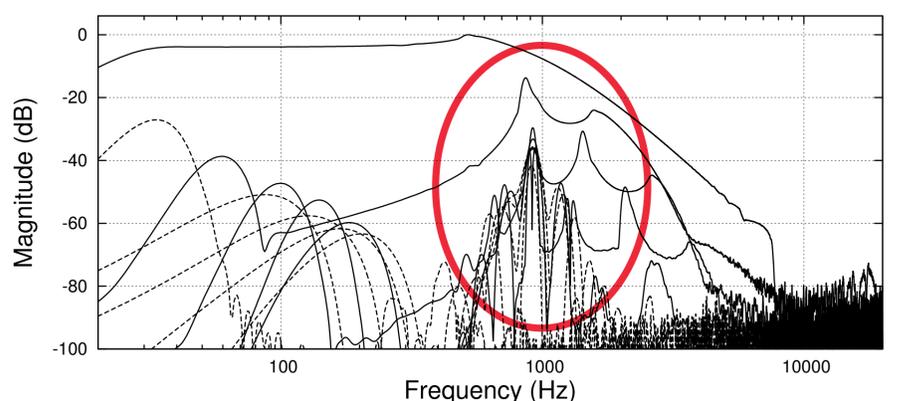
Figure 3: Outputs from the previous model [2] (top) and the new model (bottom) in barely self-oscillating mode.



(a) Previous model [2]



(b) New model



(c) SPICE simulation

Figure 4: Normalized harmonic spectra up to the 10th harmonic.

References

- [1] R. A. Moog, "A voltage-controlled low-pass high-pass filter for audio signal processing," in *17th AES Convention*, New York, USA, Oct. 1965.
- [2] A. Huovilainen, "Non-linear digital implementation of the Moog ladder filter," in *Proc. 7th Intl. Conf. Digital Audio Effect*, Naples, Italy, Oct. 2004, pp. 61–64.
- [3] A. Farina, "Simultaneous measurement of impulse response and distortion with a swept-sine technique," in *Proc. 108th AES Convention*, Paris, France, Feb. 2000.