Sub-Harmonic Locked Oscillators for Neuromorphic Computing

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Oscillators are ubiquitous in the physical word and interconnected oscillators display complex, emergent dynamics behaviors. This makes them excellent candidates for non-Boolean computing models that may exploit their complex dynamics for computation [1]. The oscillator behaviors, however, are rather sensitive to the parameters of individual oscillators, and physical oscillators are always subject to manufacturing variations, making realization challenging.

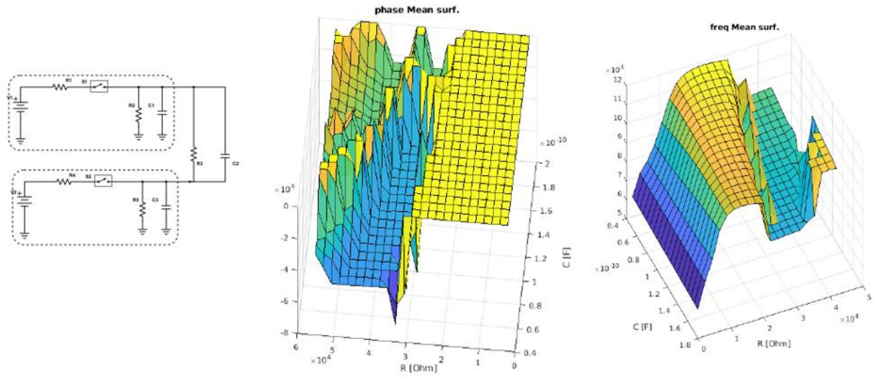
A possible solution to this problem is using sub-harmonic injection locking (SHIL), i.e. pumping the oscillator with a frequency that typically is an n integer multiple of its natural frequency [2]. This stabilizes oscillator frequencies, and allows n number of distinct steady-state phases. The nonlinearity of the oscillations, and how strongly they are pulled toward the attractors, can be tuned by the strength of the pumping field.

In this work, we study ring oscillators and vanadium-oxide-based relaxation oscillators in SHIL-based computing systems. Both oscillators naturally support n=3,5 (odd harmonic) pumping, and we show how they can be redesigned for two-state systems. We study the construction of Hopfield-type networks using both ring oscillators and relaxation oscillators. Hopfield networks show excellent recognition capability with a basic Hebbian learning scheme, and we show an iterative algorithm for adjusting the weights to improve results. We will also demonstrate that adjustable coupling between ring oscillators can be achieved by simple, transistor-based interconnections.

SHIL-controlled relaxation and ring oscillators are very simple circuits, yet seem to be a promising hardware toolbox for realizing a number of computing functions. Importantly, SHIL control makes them much less susceptible to device-to-device parameter variations. This means that potentially large, complex computing circuits can be built from compact and imprecise circuit elements.

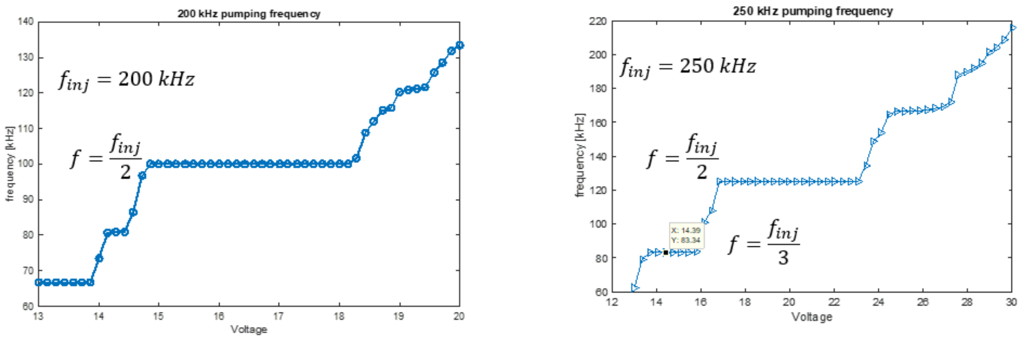
[1] Raychowdhury, Arijit, et. al. Computing With Networks of Oscillatory Dynamical Systems Proceedings of the IEEE (2018).

[2] Csaba, et. al. ”Neural network based on parametrically-pumped oscillators.” In Electronics, Circuits and Systems (ICECS), 2016 IEEE International Conference on, pp. 45-48. IEEE, 2016.



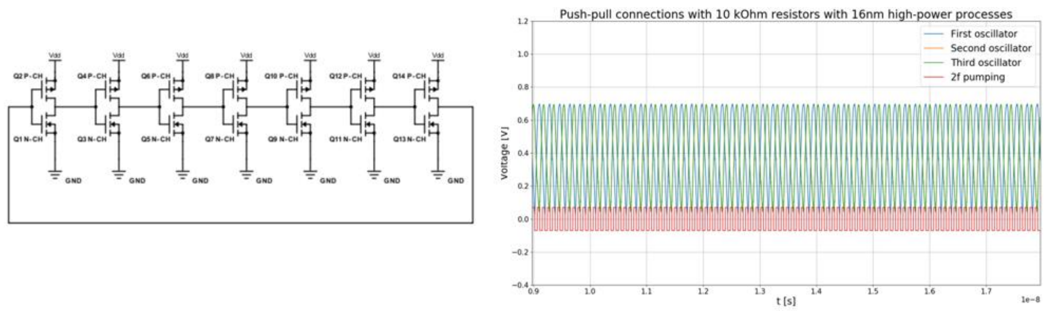
a) b) c)

Figure 1. Synchronization regions for two VO2-based relaxation oscillators, interconnected by an RC element (a). Depending on the connections, various synchronized regions appear (b,c)



a) b)

Figure 2. Relaxation oscillators act as voltage-controlled oscillators, and an externally injected oscillatory signal will injection-lock them to a fixed frequency. Here, the plateaus correspond to subharmonic locking to f/2 and f/3.



a) b)

Figure 3. a) We designed a ring oscillator using highly asymmetric transistors, which can efficiently lock to 2f injection (b) – this network acts as a Hopfield network in the phase space.