

# A software-defined universal frequency counter

Anders E. Wallin, Kalle J. Hanhijärvi, Thomas Fordell, Thomas Lindvall

VTT Technical Research Centre of Finland Ltd, National Metrology Institute VTT MIKES,  
Espoo, Finland

Email: anders.wallin@vtt.fi

We present a software-defined universal frequency counter based on commercially available software-defined radio (SDR) and GNU Radio software algorithms. An Ettus N210 SDR is used to digitize a 1-30 MHz signal at 100 MS/s followed by digital downconversion and decimation to typically 500 kS/s IQ-samples transferred over Ethernet to a host computer running the GNU Radio frequency counter algorithms (Fig. 1). Frequency counting algorithms can be flexibly implemented in software and enable the counter to operate in  $\Pi$ -,  $\Lambda$ -, and  $\Omega$ -counting mode<sup>1</sup> simultaneously, with multiple gate times (e.g. 1 ms to 1 s) if needed. Decimation of  $\Omega$ -counter data<sup>2</sup> requires additional data to be stored with the counted value. Particular attention to the numerical stability of the algorithms is needed, to avoid bias in the counted frequency. Frequency values are output as 64-bit floating point numbers via ZeroMQ, enabling downstream storage of continuous data to a time series database (e.g. InfluxDB with Grafana) or processing/visualization anywhere in our laboratory network with e.g. AllanTools to produce real-time graphs of Allan deviation or other statistics. To validate the software, we compared our counter against multiple commercial frequency counters and found no bias within the statistical uncertainty. For measurement signals with low signal-to-noise ratio (SNR), the frequency counting stage can be preceded with an all-digital tracking oscillator with adjustable bandwidth and loop filter characteristics. We present several applications of the counter, including validation of frequency-comb beat-note measurements by measuring beat notes against comb-mode number  $n$  and  $n+1$  and measuring fiber –noise cancellation on optical fibers or other phase locked loops exhibiting white phase noise where  $\Lambda$ - or  $\Omega$ -counting is beneficial. Multiple SDRs can be synchronized with a common pulse-per-second signal, allowing for simultaneous sampling by more than two counter channels. We plan to publish the developed GNU Radio software under an open-source license.

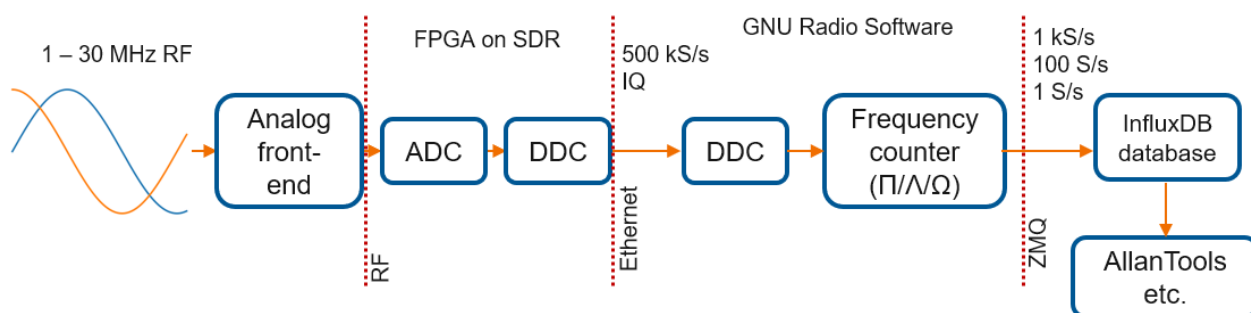


Figure 1. Hardware/Software-stack for frequency counting, visualization, and storage.

<sup>1</sup> E. Benkler, C. Lisdat, and U. Sterr, “On the relation between uncertainties of weighted frequency averages and the various types of Allan deviations,” *Metrologia*, vol. 52, no. 4, pp. 565–574, 2015

<sup>2</sup> M. Danielson, F. Vernotte, and E. Rubiola, “Memory-efficient high-speed algorithm for multi- $\tau$  PDEV analysis,” in *2016 IEEE International Frequency Control Symposium (IFCS)*, 2016, pp. 1–4. doi: 10.1109/IFCS.2016.7546783.