GNURadio as a digital signal processing environment: application to acoustic wireless sensor measurement and time & frequency analysis of periodic signals

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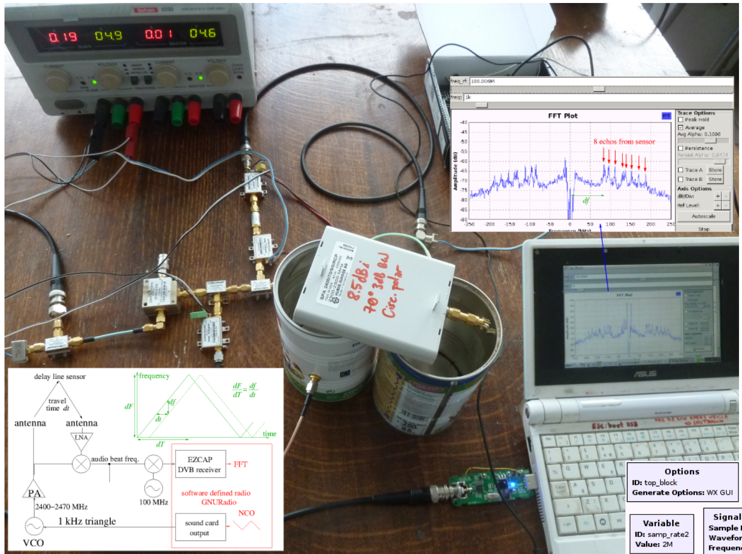
Digital signal processing: reconfigurable, stable, flexible (develop hardware once, implement algorithms), accurate

Application to radiofrequency signals: record raw analog RF signals and process datastream.

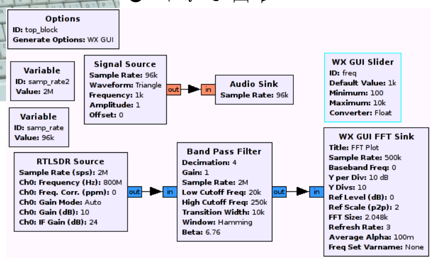
Practically: ADC limited to 1 GS/s so still a need for RF front-end (LNA + mixer)

Wireless passive sensor probing

- FMCW strategy: simple hardware, complex software (VCO sweep, FFT)
- a VCO frequency is swept over bandwidth dF during dT
- echoes delayed by dt generate a beat signal with VCO of $df = dt \cdot (dF/dT)$
- if $df = 50$ MHz and $dt = 10$ ms, then $dt \leq 5$ μs (CTR delay line) $\Rightarrow$ $df \leq 25$ kHz
- sound card/DVB-R record processed using GNURadio for *real time* display
- software defined frequency sweep compensates for VCO non-linear frequency output with input voltage



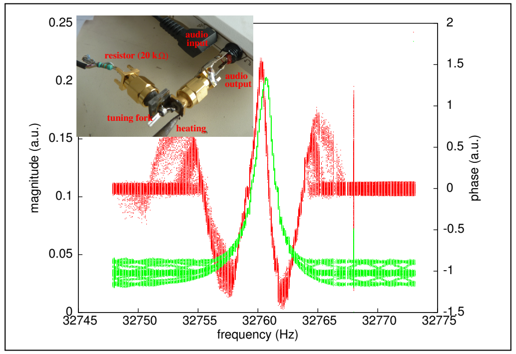
G.L. Charvat, A.J. Fenn, B.T. Perry, *The MIT IAP radar course: Build a small radar system capable of sensing range, Doppler, and synthetic aperture (SAR) imaging*, IEEE Radar Conference, (2012) pp.138–144
Web site: `http://ocw.mit.edu/resources/` under Lincoln Lab entry

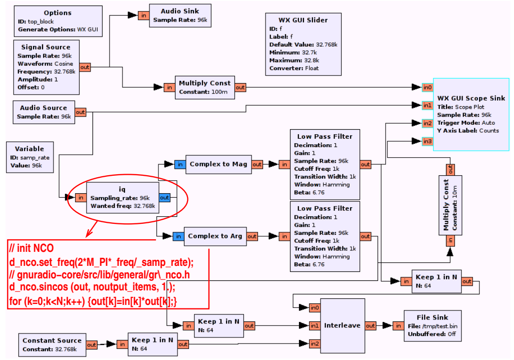


- digital signal processing blocks available for most common operations (display, FFT, filter)
- opensource environment: learn from the source code and add processing blocks (C or Python)

Time & frequency metrology analysis

- Software frequency counter & phase noise analysis in a receiver only configuration
- Full duplex operation allows for network analyzer operation
- Stable frequency source suitable for teaching/training (tuning fork characterization)





Question: computation resolution to reach a given noise floor ? Phase noise calculation:

1. sample sine wave from oscillator and generate local oscillator using a Numerically Controlled Oscillator (NCO),
2. mixer = multiplication, possibly sign change if NCO is a square wave,
3. low pass filter and decimator to reach twice the carrier offset maximum Fourier frequency

$\{I,Q\} = \frac{1}{N}\sum_N \overbrace{(lo_k \cdot s_k)}^{mixer} \times lpf_{N-k} \Rightarrow d(I,Q) \simeq \frac{3\times 2^{-M}}{\sqrt{N}}$ if all terms are coded on M bits, & $S_\varphi = \frac{\sigma_\varphi^2}{BW} \Rightarrow \sigma_\varphi = \sqrt{S_\varphi \cdot BW} \Rightarrow M = -\log_2 \sqrt{(N \cdot S_\varphi \times BW)}/3$. Since $S_\varphi = 10^{S_{dB}/10}$, $BW = 9$ kHz (1000 points in the 1-10 MHz decade), then -180 dBrad^2/Hz $\Rightarrow M \simeq 21$ bits and -160 dBrad^2/Hz $\Rightarrow M \simeq 19$ bits

$\Rightarrow$ challenging resolution to meet metrological requirements

$\Rightarrow$ effect of square wave NCO (harmonics ? but $dlo = 0$), aliased sampling ?

Conclusion:

1. **Flexible** environment for implementing various **signal processing** tools for sensor characterization to TF metrology or digital protocol decoding
2. **Real time** display of computation result (as opposed to post-processing using Matlab-GNU/Octave)
3. Wide range of **input sources and output sinks** from kHz to GHz
4. **Opensource** best suited for adding processing block and learning from source code + hardware schematics for most peripherals
5. Still limited by ADC resolution and sampling rate for UHF oscillator characterization

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