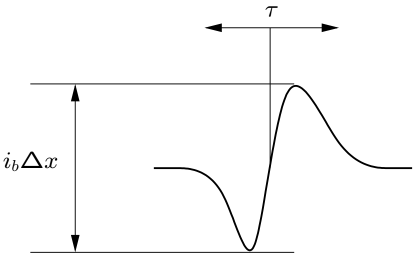
Advanced Signal Processing for APS-U

D. Teytelman

Dimtel, Inc., San Jose, CA, USA

February 16, 2018

Conventional RF Front-End Signal Processing



- Horizontal difference signal derived from four buttons;
- At zero offset amplitude goes to zero;
- Replicate the pulse two or more times;
- Spaced by detection frequency period;
- For analysis can replace the complex shape with a sinusoidal burst at $M\omega_{\mathrm{rf}}$;
- Detected signal after filtering.

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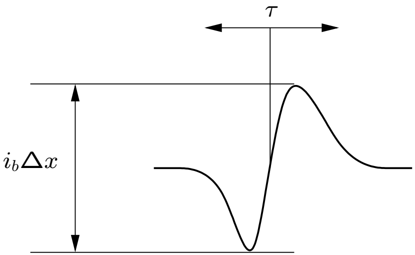

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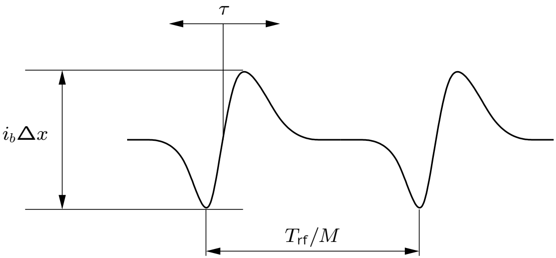

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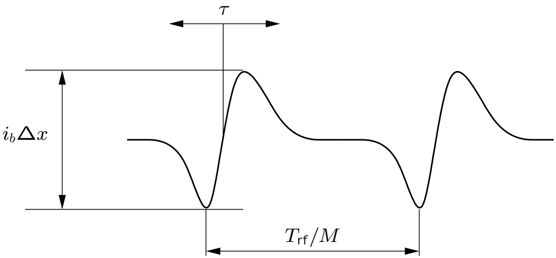

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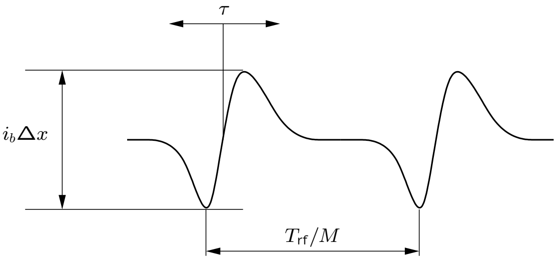

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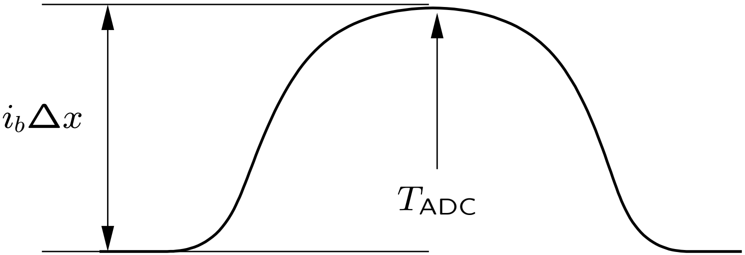

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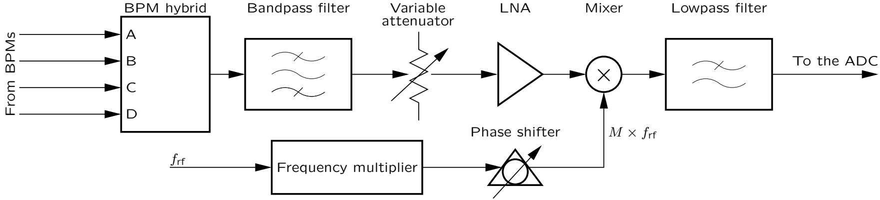
Energy Sensing Analysis



- Conventional front-end with ΔX input;
- Model signal at detection frequency as $v(t) = A(x_0 + \Delta x)\sin(M\omega_{\rm rf}(t + \tau))$;

Parameter	Definition
x_0	Orbit offset
Δx	Horizontal oscillation $D\epsilon/E_0$
M	Detection harmonic
τ	Time oscillation

Adding Synchrotron Oscillation

- Assume energy oscillation $\epsilon = \epsilon_0 \cos \omega_s t$;
- Dispersion term is $\Delta x = D\epsilon_0 / E_0 \cos \omega_s t$;
- Time domain oscillation is $\tau = \frac{\alpha \epsilon_0}{E_0 \omega_s} \sin \omega_s t$;
- Pickup gain factor $A = Q_b g_0 M$, assuming relatively low RF harmonics;
- Mixing $v(t)$ with $\cos M\omega_{\mathrm{rf}} t$ and $\sin M\omega_{\mathrm{rf}} t$ for phase/amplitude detection respectively;
- Amplitude signal, after low-pass filtering is $A/2(x_0 + \Delta x) \cos M\omega_{\mathrm{rf}} \tau$;
- Further downconvert baseband output of the amplitude detector relative to synchrotron reference to extract phase shift.

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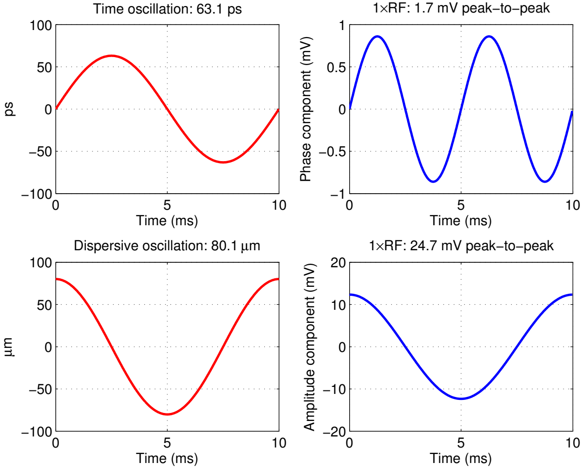

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- 704 MHz;
- 1056 MHz;
- 1408 MHz;
- 1760 MHz;
- Linear scaling for amplitude, quadratic for phase, just as expected.

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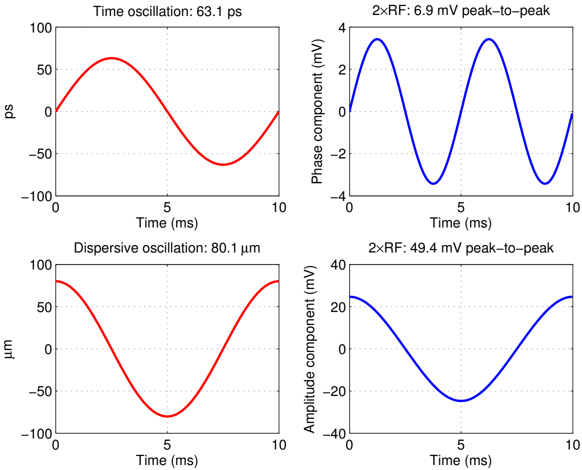

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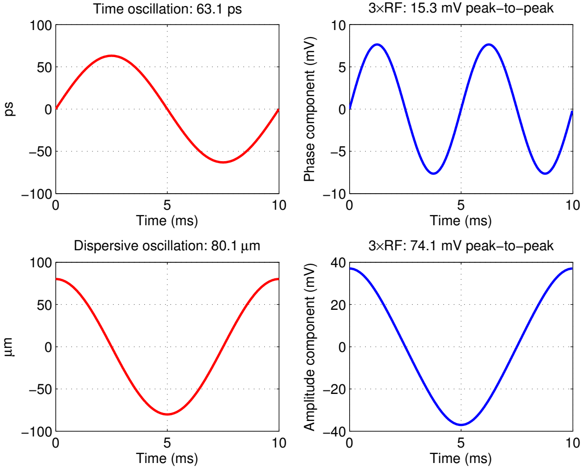

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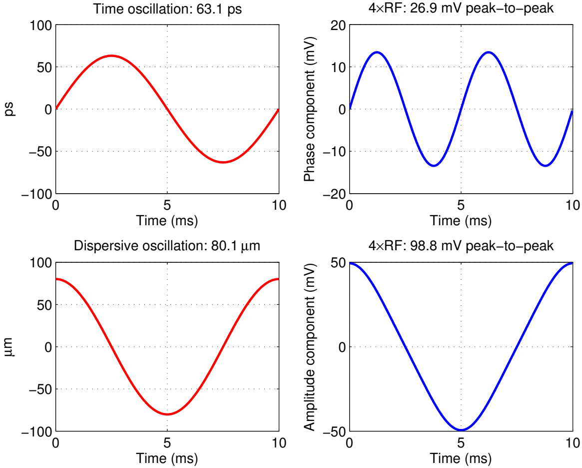

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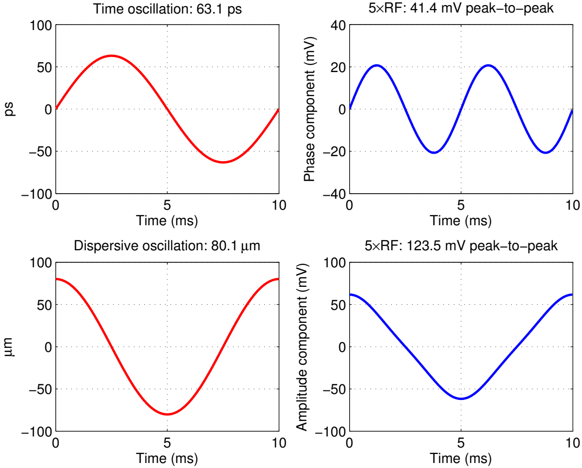

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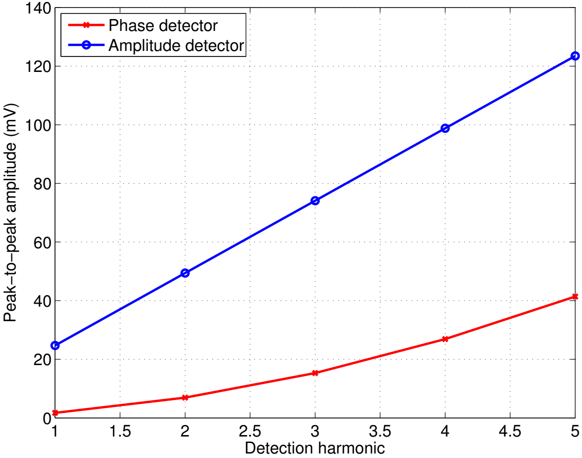

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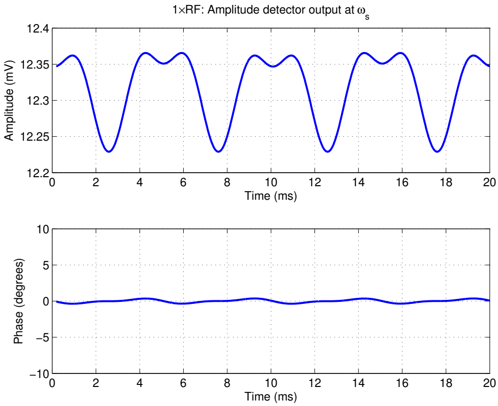
Amplitude and Phase Relative to Synchrotron Reference



- Calculated output of amplitude detector is numerically downconverted relative to synchrotron oscillation reference;
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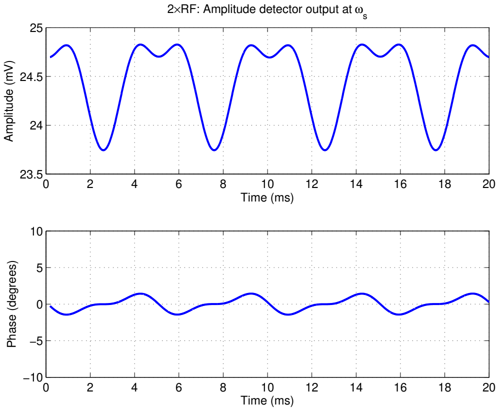

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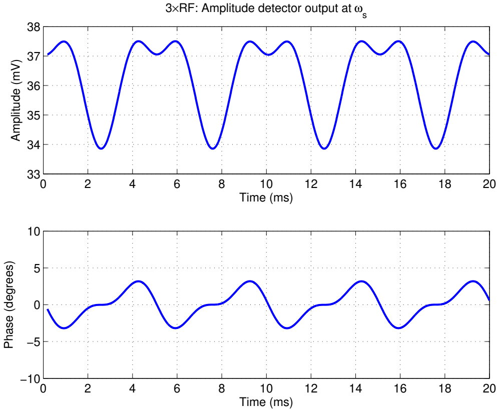

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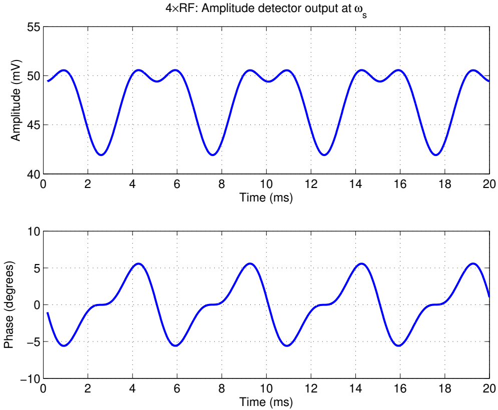

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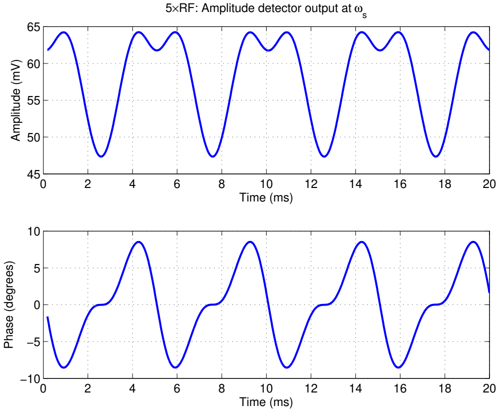

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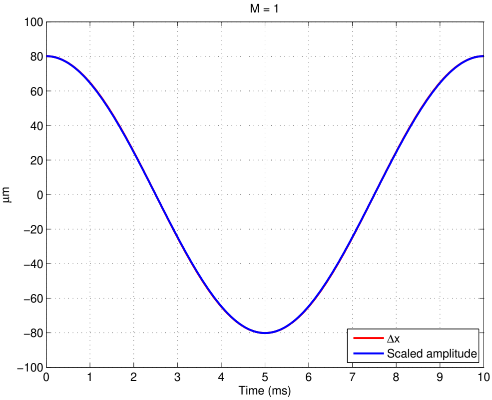
Distortion Due to Phase Modulation



- Original oscillation and detected signal;
- Nearly perfect at RF;
- Deviations from original at peak phase excursions;
- Larger effect at the third harmonic;
- And fourth;
- As well as fifth;
- Generating odd harmonics, can be harmful with wide tune spreads.

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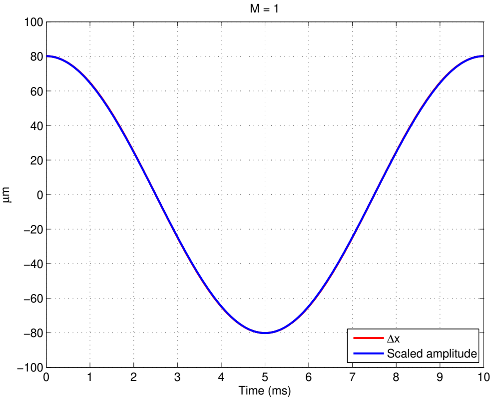

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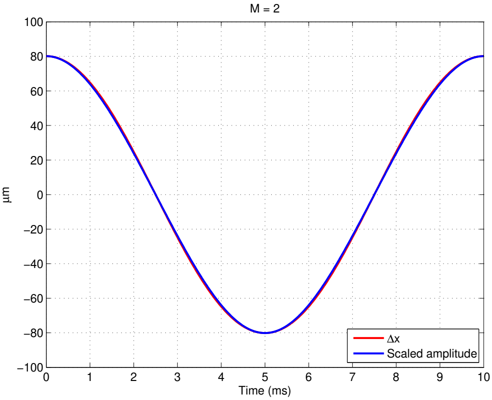

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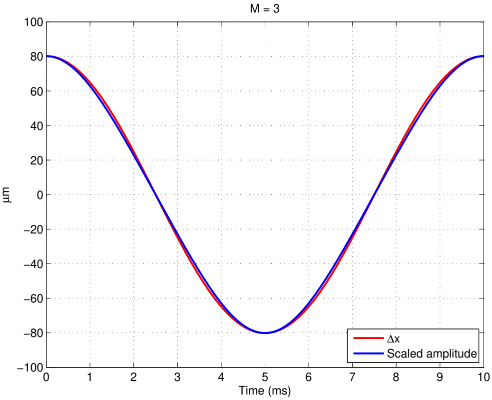

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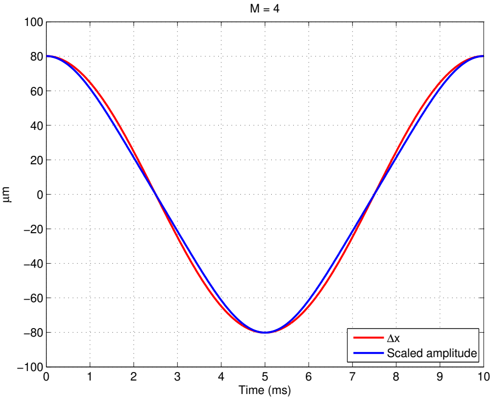

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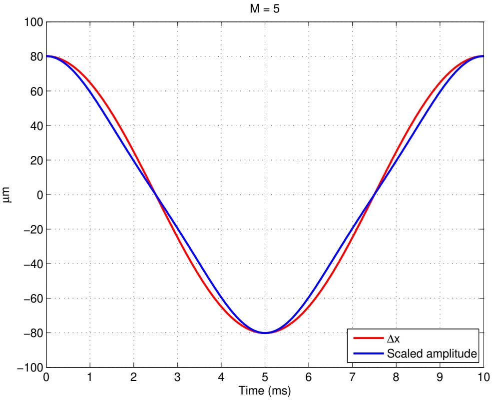

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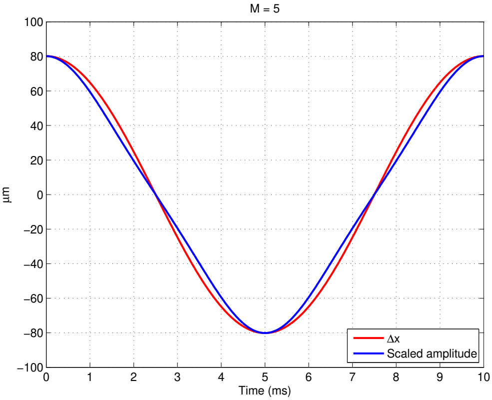

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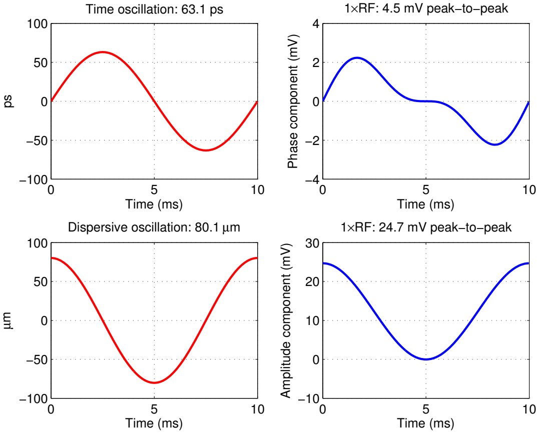

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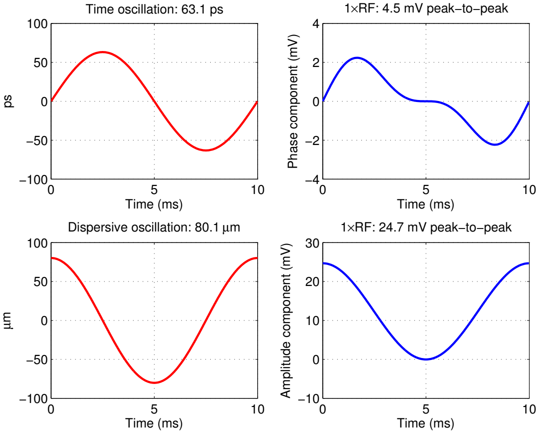

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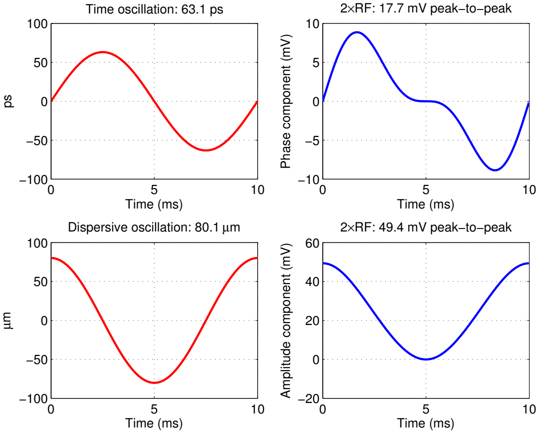

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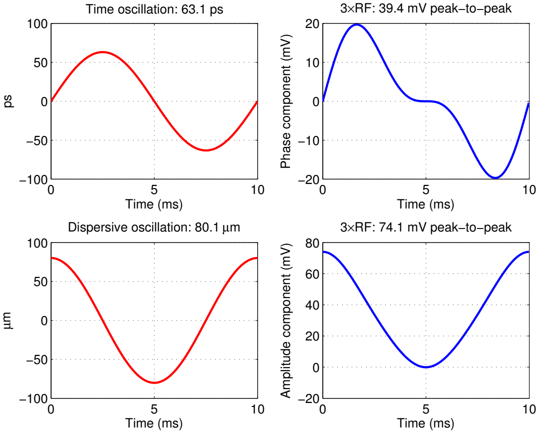

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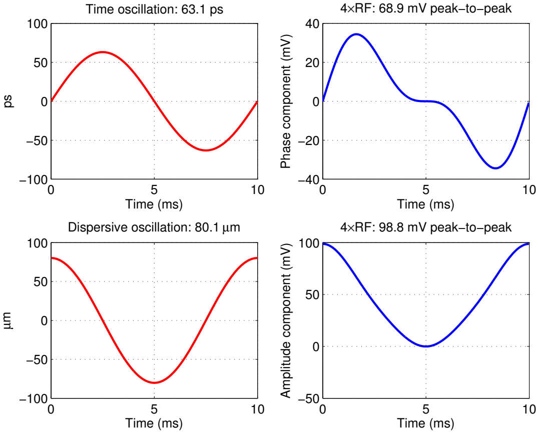

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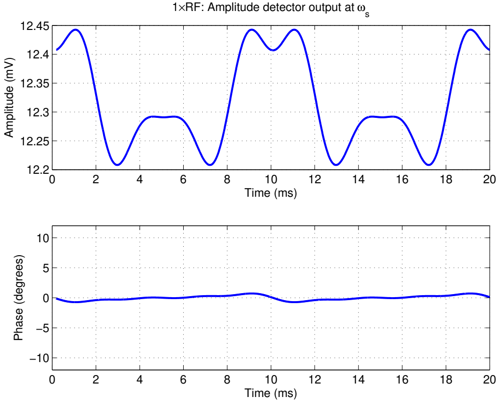

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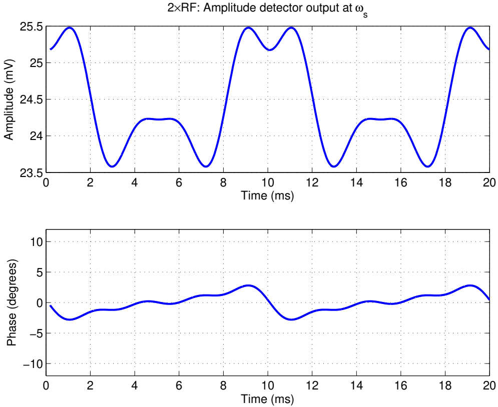

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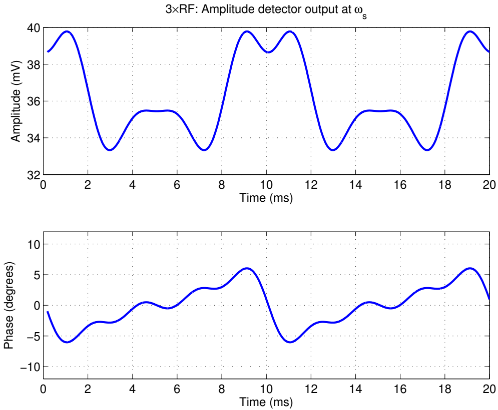

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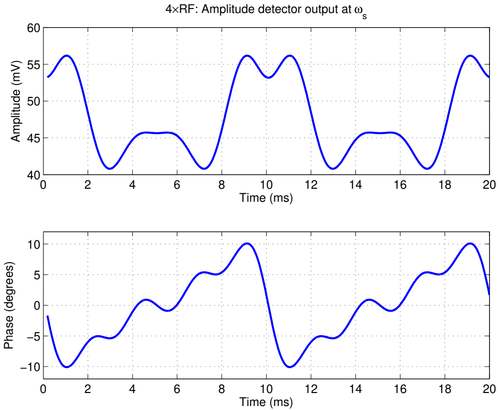

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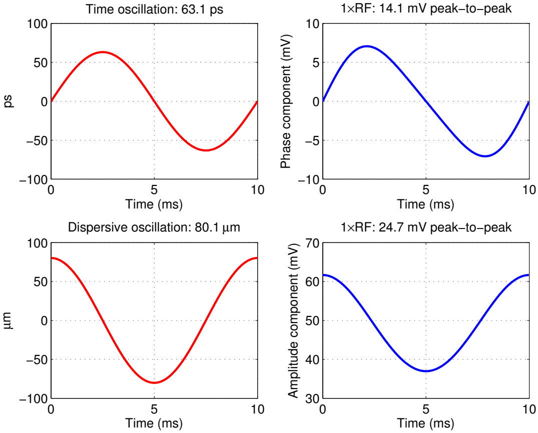

- 320 µm offset;
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- Very high distortion.

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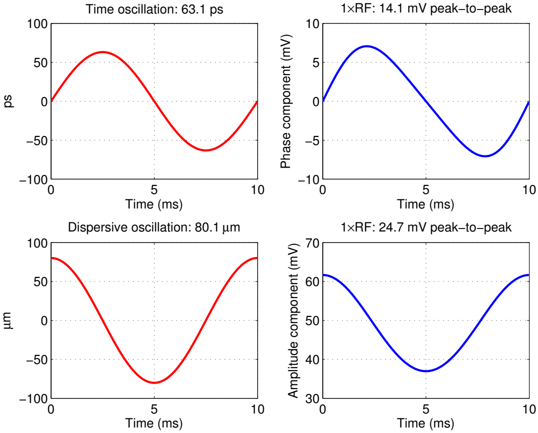

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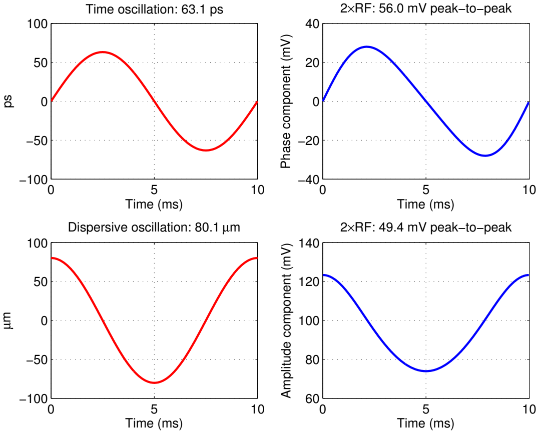

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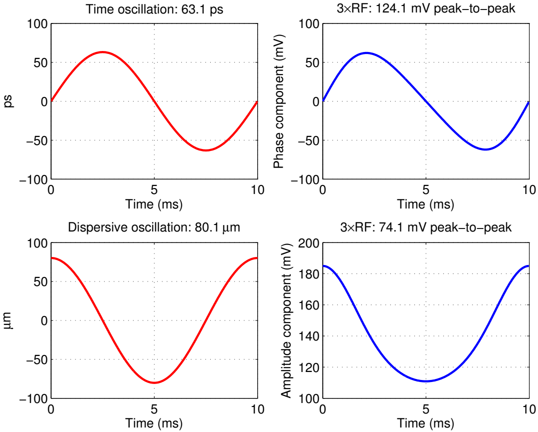

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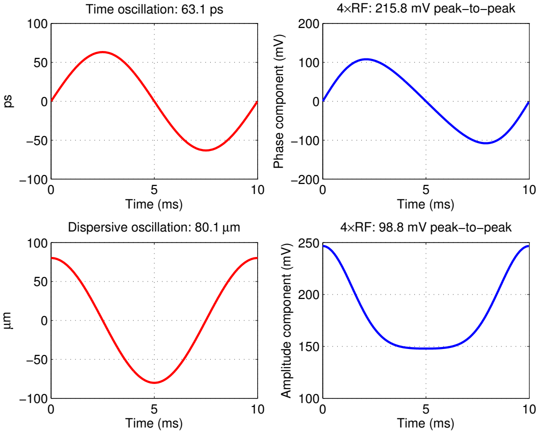

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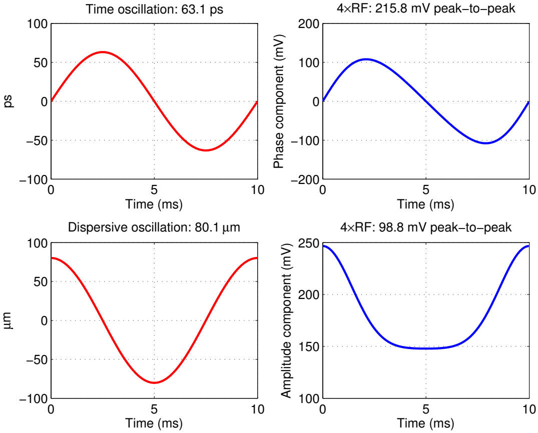

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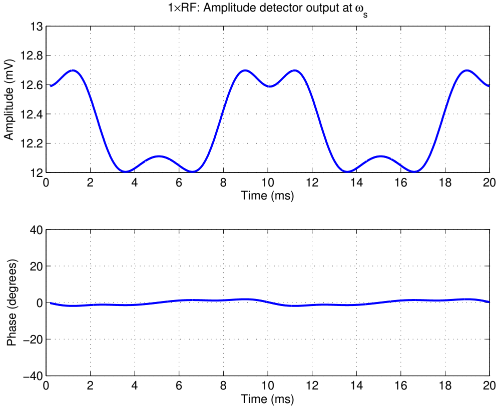

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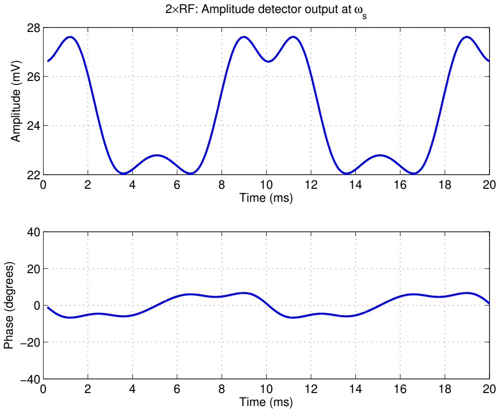

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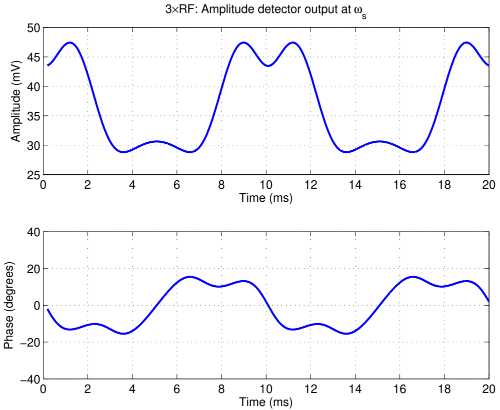

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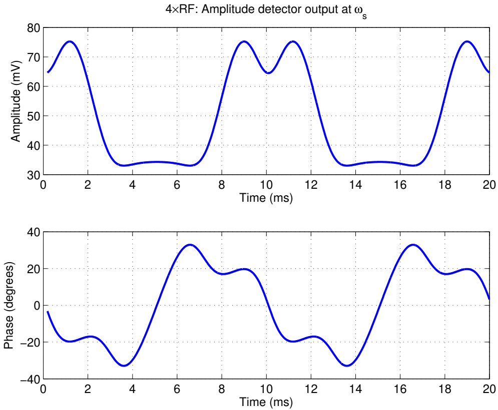
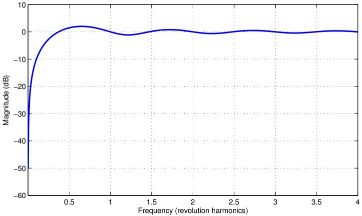
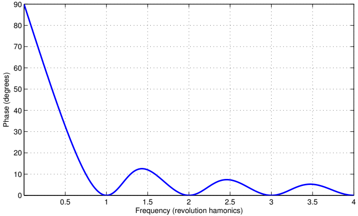


- 352 MHz;
- 704 MHz;
- 1056 MHz;
- 1408 MHz;
- Extreme amplitude and phase modulation!

Filtering Out Mode 0





- A 1296 tap FIR filter acting on consecutive buckets;
- Signal for the turn-by-turn feedback filter is current bunch signal minus the average over the full turn;
- High rejection of low frequencies, close to unity gain by the first revolution harmonic;
- Gain is nearly perfect near revolution harmonics;
- Ripple between revolution harmonics should not be a problem;
- Efficient CIC implementation.

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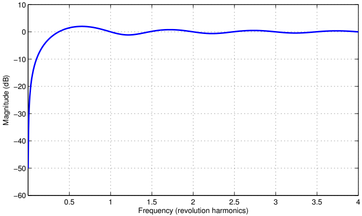

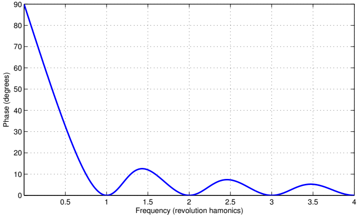

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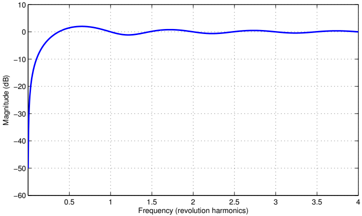

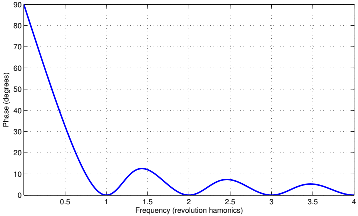

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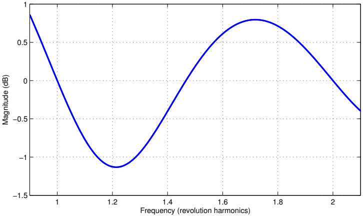

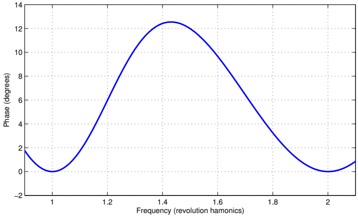

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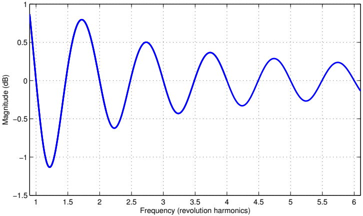

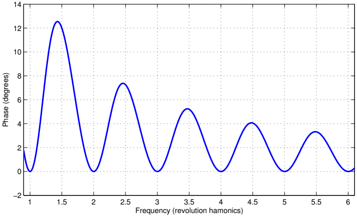

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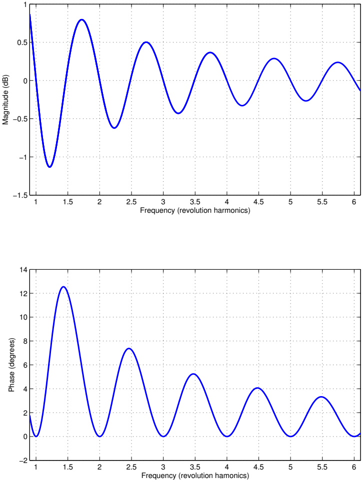

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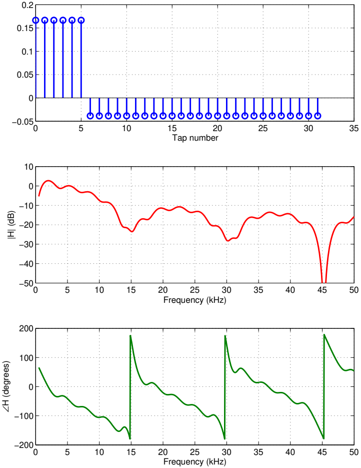
Dispersive Feedback Filter to Test in the APS



- 32-tap FIR, downsampling of 3 — can run in current iGp12 without any modifications;
- Simple-minded design - 6 tap averager to reject horizontal motion;
- Use remaining 26 taps to achieve DC rejection;
- Notch around horizontal frequency (45 kHz);
- Peak gain and nearly zero phase shift at 2.2 kHz;
- Not optimal, just a rough idea.

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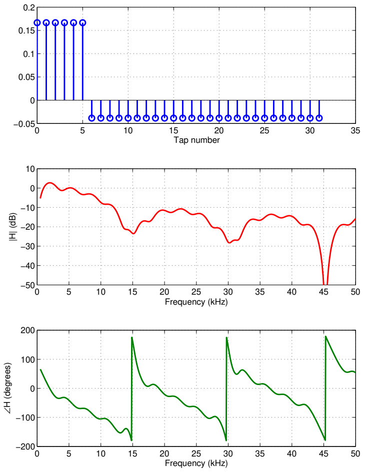

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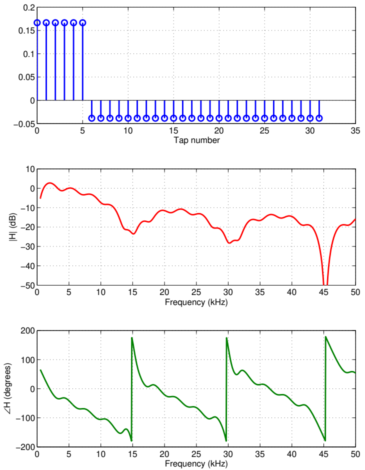

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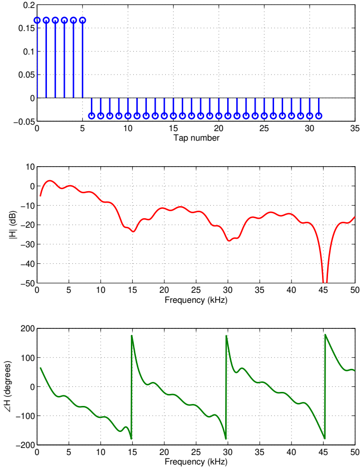

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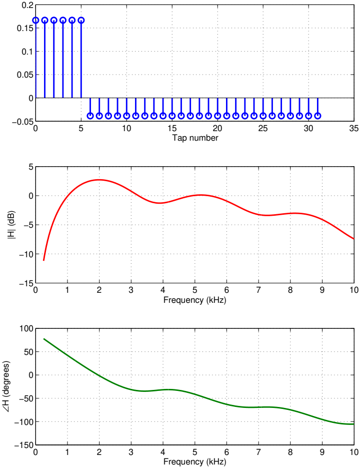

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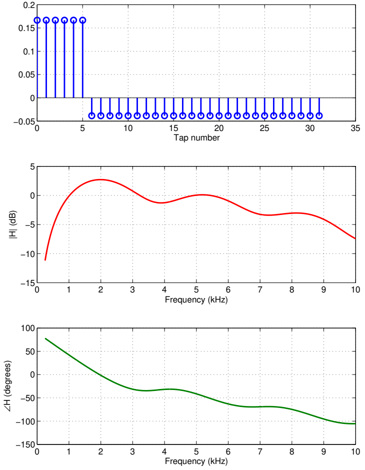

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Summary

- Conventional front-end with amplitude detection should work for energy sensing;
- Need to keep physical and electronic offsets small;
- Detection at 704 MHz is probably a good idea;
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