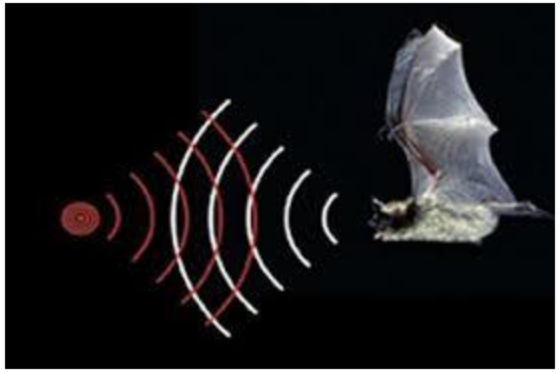
UWB Passive SAW Sensors Based on Hyperbolic Frequency Modulation (HFM)

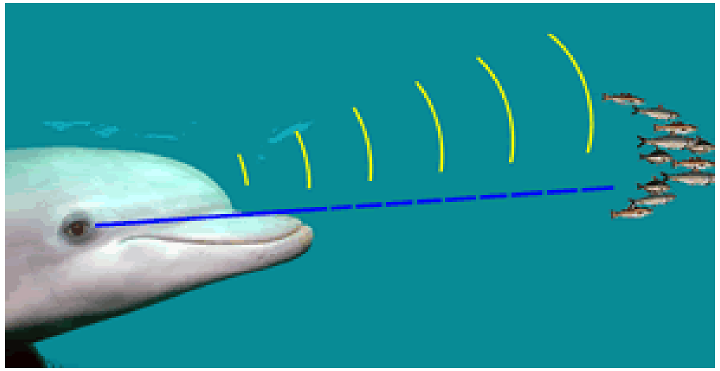
Victor Plessky

Thanks to Marc Lamothe

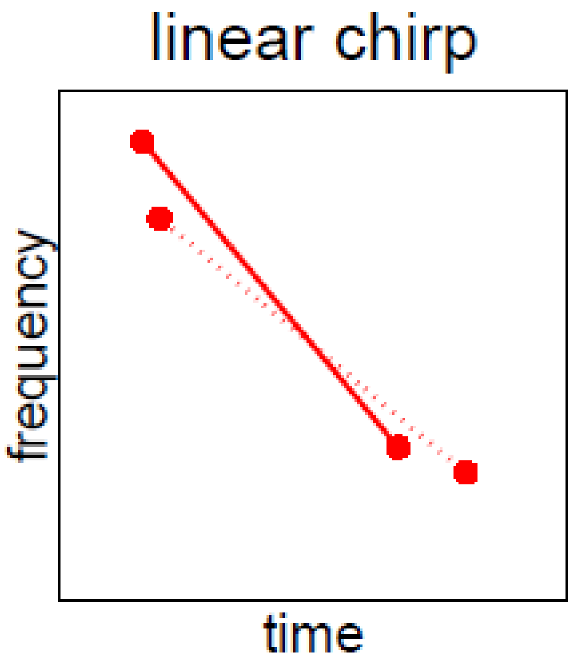
PWST Workshop, 10-12 Oct. 2017

Montreal, Canada



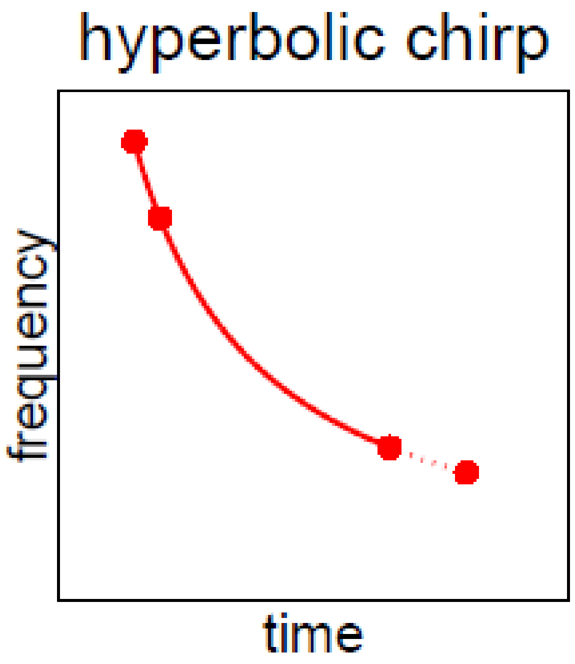


But do the bats and dolphins use LFM chirps?

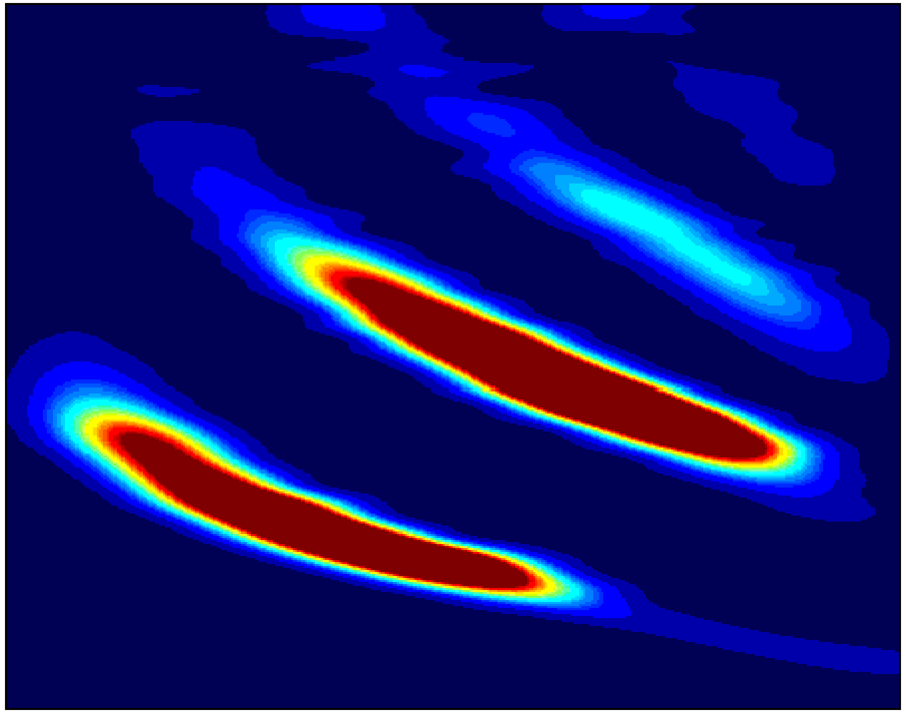


$$B*T*(K-1) > 1$$

(K- scaling factor)
LFM signal compression deteriorates significantly



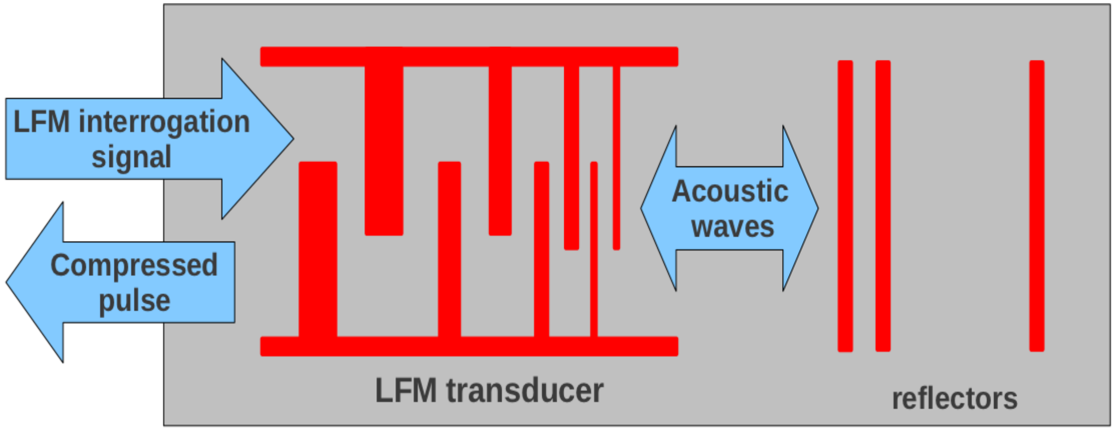
No visible deterioration of compressed pulse



horizontal axis: time (0-2.5ms), vertical axis: frequency (0-70kHz)

vplesski@resonant.com

Purely geometric problem



If the period of an array increases linearly with coordinate, how can the coordinate x_n of *n-th* element of this array be calculated?
For the geometric structure of electrodes (strips, grooves, etc.) with period linearly changing with coordinate *x* one can write the following relation:

$$x_{n+1} - x_n = p_0 + \varepsilon \cdot x_n$$

This formula can be treated as an equation in integer numbers, which has unique solution:

$$x_n = \frac{(1+\varepsilon)^n - 1}{\varepsilon} \cdot p_0$$

For algebra amateurs (1)

Or, calculating the *n-th* period:

$$\boldsymbol{p_n = x_{n+1} - x_n = (1+\varepsilon)^n \cdot p_0}$$

Two parameters p_0 and ε completely determine the array.

If we fix the first period p_0 and the last period x_{N+1}- x_N =p_{end} we can find that

$$\varepsilon = (\frac{p_{end}}{p_0})^{\frac{1}{N}} - 1$$

and re-write the formulas (2) and (3) in the following form:

$$x_n = \frac{(\frac{p_{end}}{p_0})^{\frac{n}{N}-1}}{(\frac{p_{end}}{p_0})^{\frac{1}{N}-1}} \cdot p_0 \quad , \boldsymbol{p_n = (\frac{p_{end}}{p_0})^{\frac{n}{N}} \cdot p_0}$$

For algebra amateurs (2)

If the total length $L{=}x_N$ of the structure is known the number of periods N:

$$\left(\frac{p_{end}}{p_0}\right)^{\frac{1}{N}} = 1 + \frac{p_{end}-p_0}{L}; \quad x_n = L \cdot \frac{p_0}{p_{end}-p_0} \cdot \left\{\left(\frac{p_{end}}{p_0}\right)^{\frac{n}{N}} - 1\right\}$$

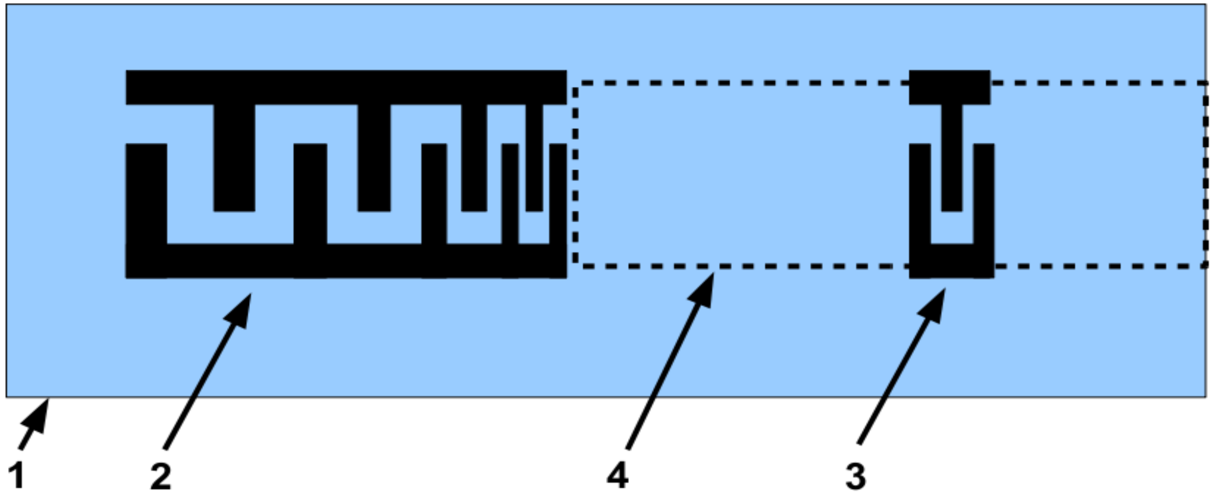
If our structure corresponds to a SAW propagating with velocity V,
and the periods of the structure are related to frequency as

$$p_0 = \frac{V}{(F_0-\frac{B}{2})}, \quad p_{end} = \frac{V}{(F_0+\frac{B}{2})}$$

(here F_0 is the centre frequency, $|B|$- the frequency band) ,
introducing $L{=}\,x_N$ – total length, for the case when there is 1 element per period (RACs):

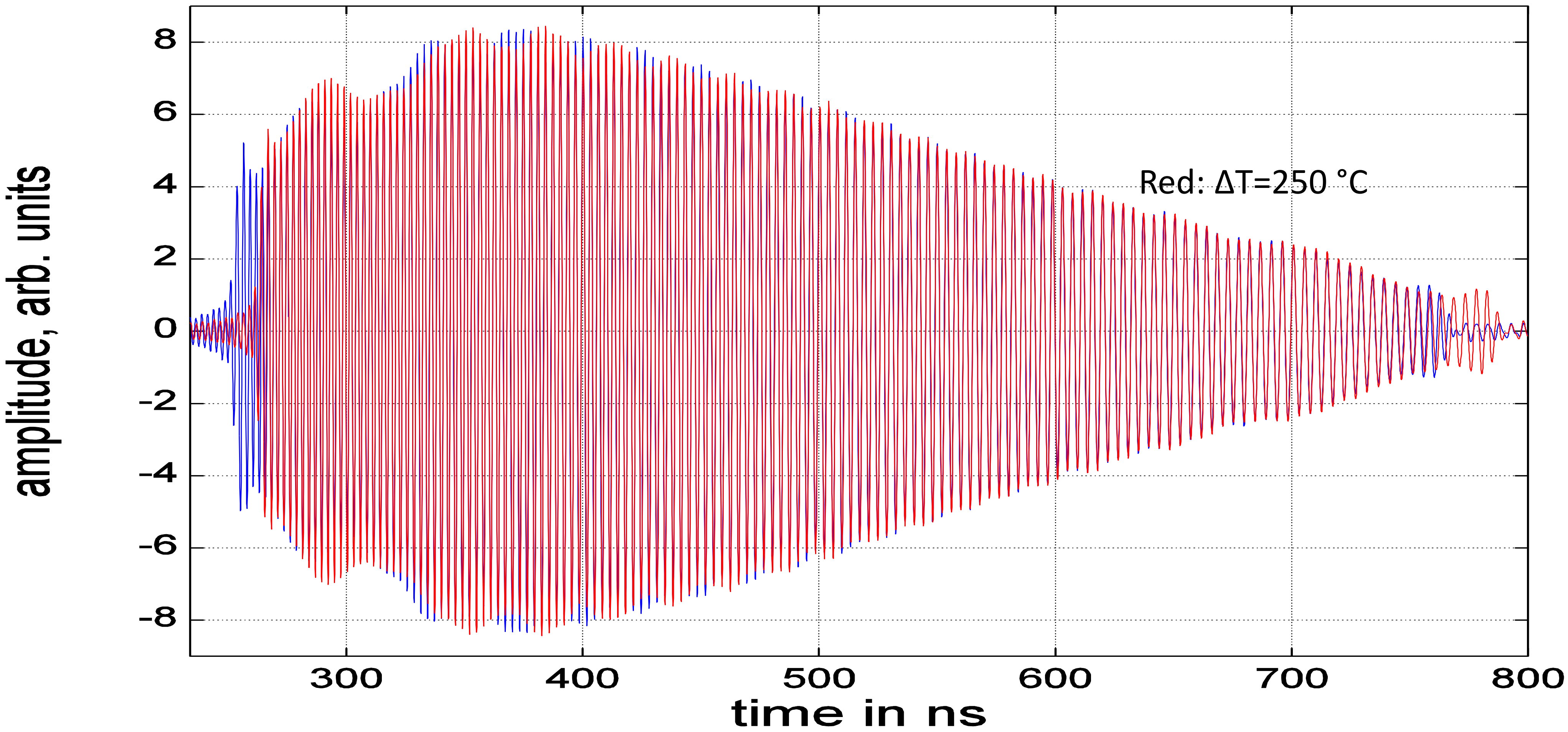
$$x_n = -L \cdot \frac{F_0+B/2}{B} \cdot \left\{\left(1 - \frac{B\cdot V}{L\cdot\left(F_0^2-\left(\frac{B}{2}\right)^2\right)}\right)^n - 1\right\}$$

Numeric simulations



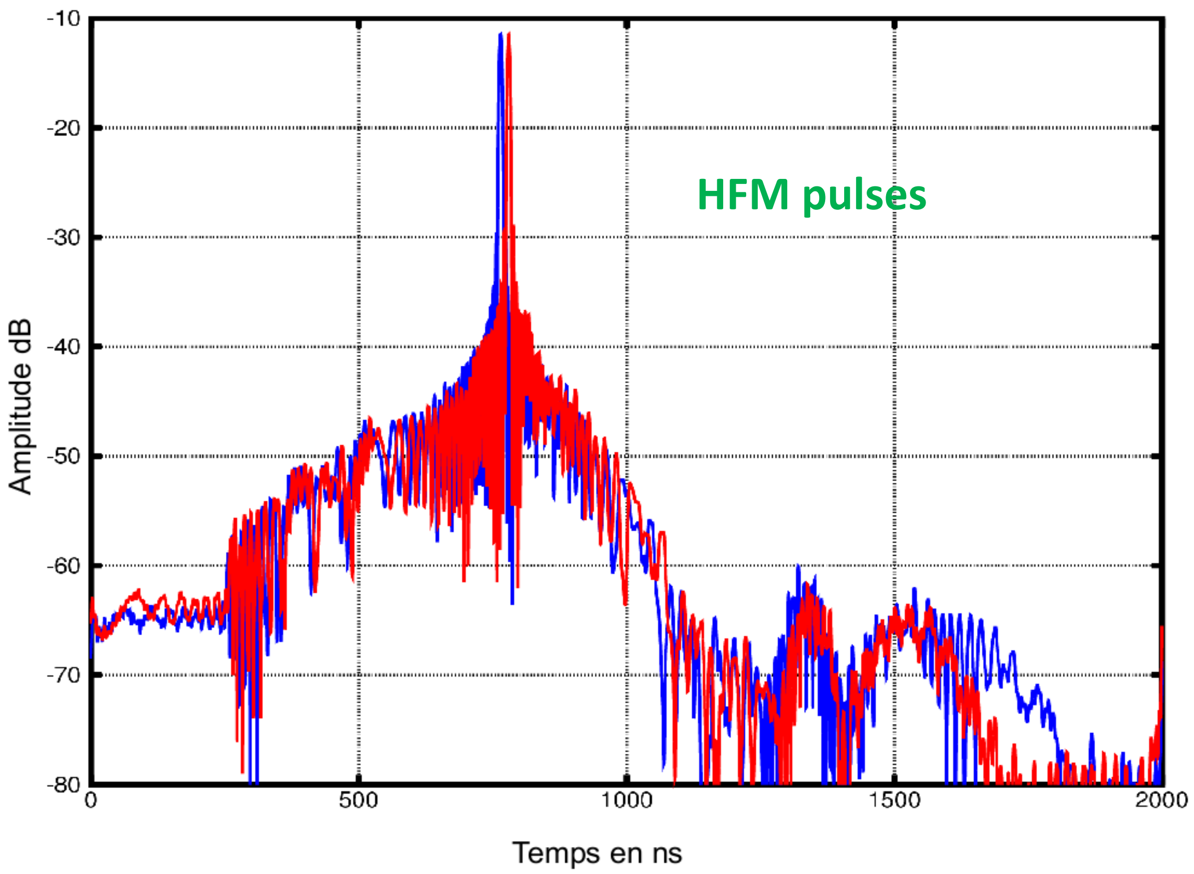
$128°$-$LiNbO_3$
frequency range 200MHz-400MHz
The dispersive delay time ***T*** is equal to 0.5 µs, B*T product thus being B*T=100
P_0=19.2 µm, p_N=9.6 µm
N=279

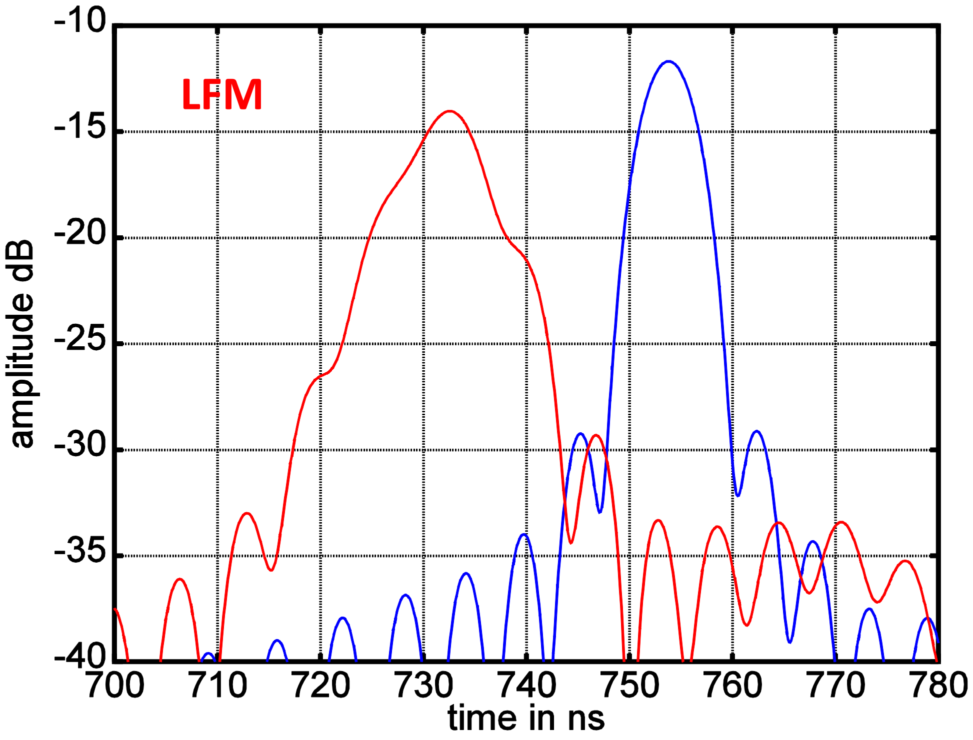
Simulation results



Themain part of this response geometrically is not only similar, but *identical* to the initial response

Compressed peaks



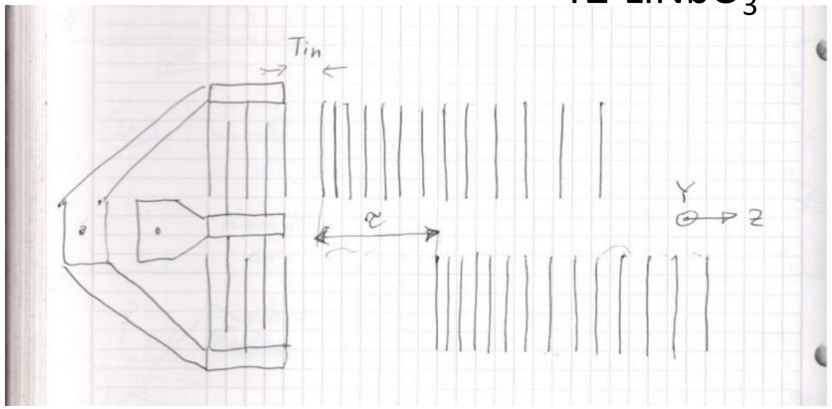


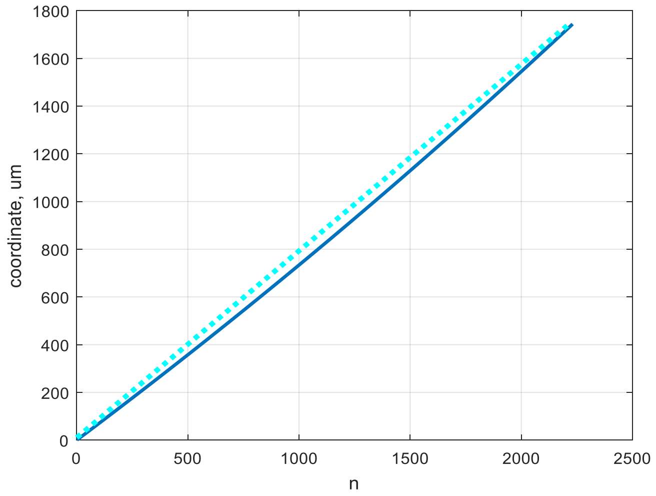
LFM case. Right curve compressed pulse at initial temperature, left curve – 2% expanded chirp.

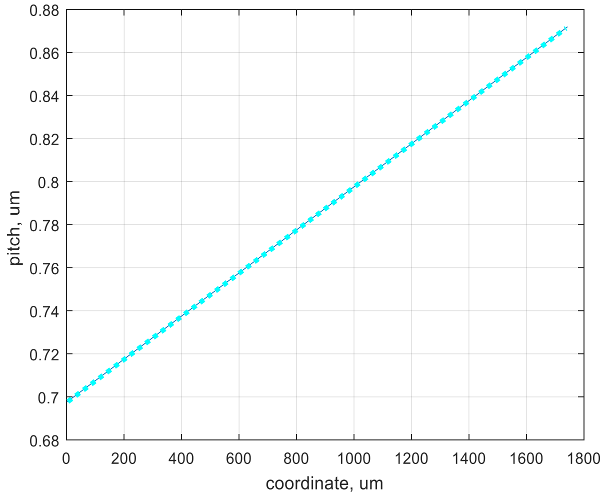
vplesski@resonant.com

Swiss-Lithuanian Project
Eurostars No E!10640 UWB_SENS

YZ-$LiNbO_3$







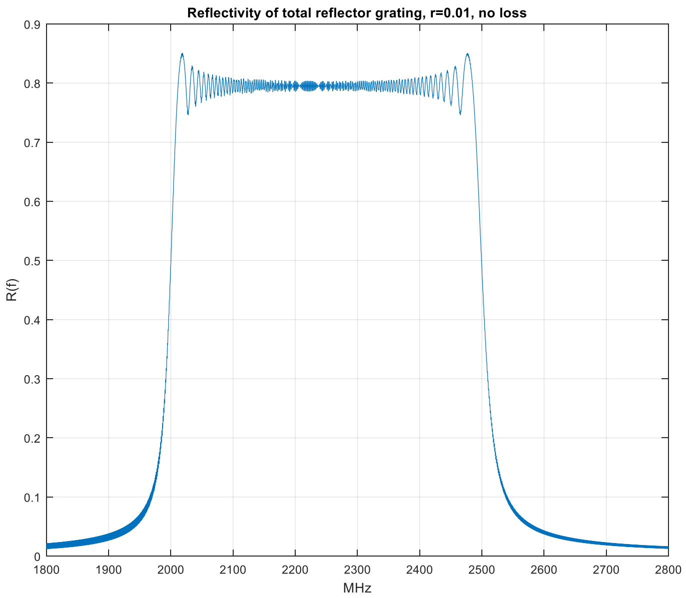
F= 2000 MHz to 2500MHz,
p_0=*697.6 nm, pN =872.0 nm*
N=2231 grooves, for T=1000ns
$$L = V * \frac{T}{2} = 1744\ \mu m$$

The coordinate of the grove reflector center
is non-linear function of its number,
while the pitch of the grating **is** linear function
of the coordinate of reflecting element.

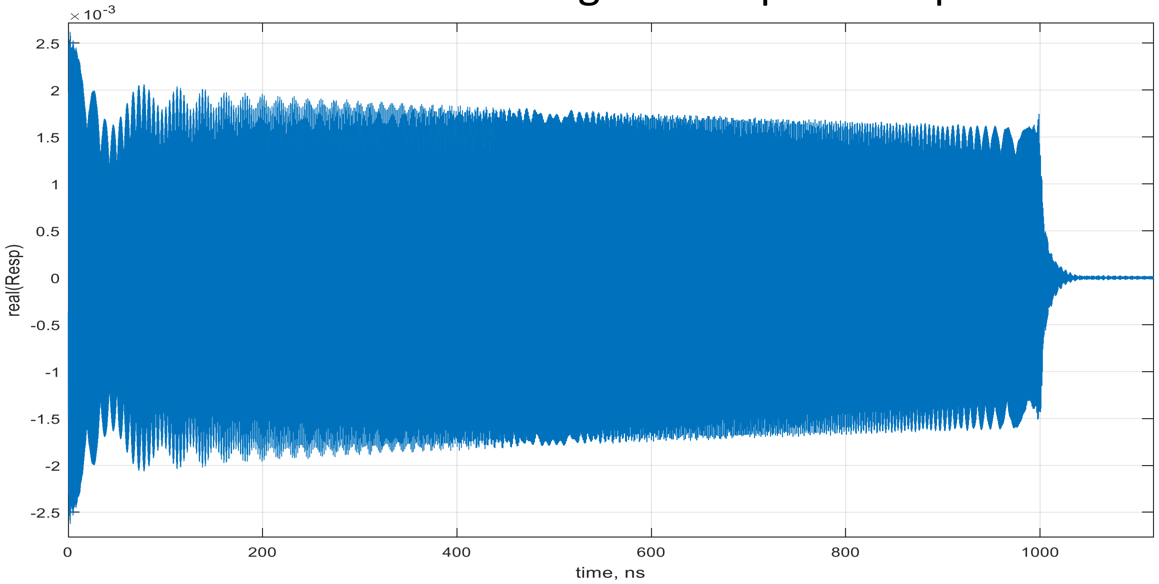
Reflectivity of the chirp grating (no loss included)

For ¦r¦=0.01 – reflection coefficient by a single groove

For *YZ-LN* $r=0.6*(h/\lambda)$; $\lambda \approx 1.55\mu m$, $h \approx 250Å$

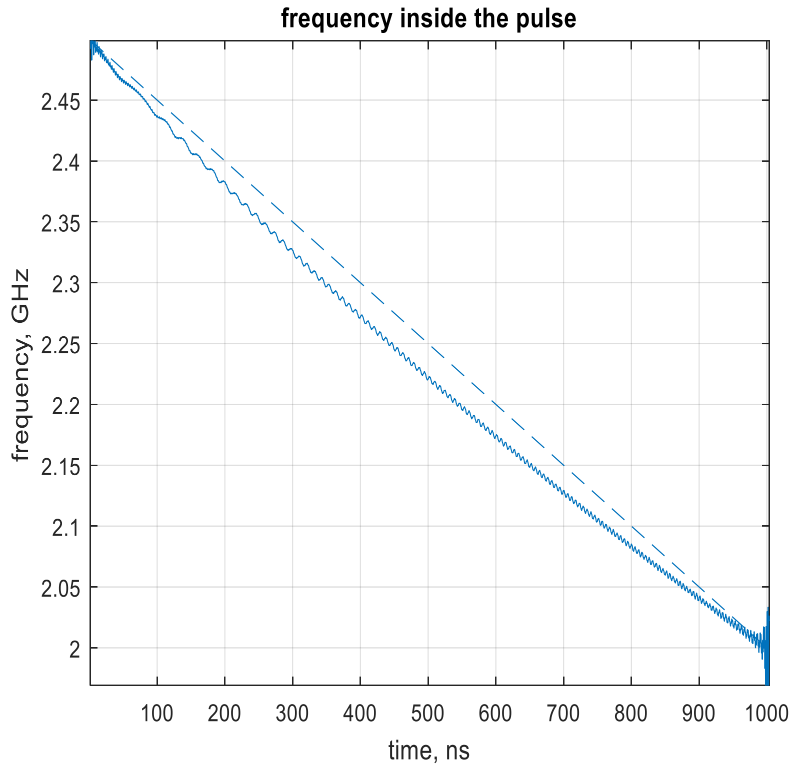


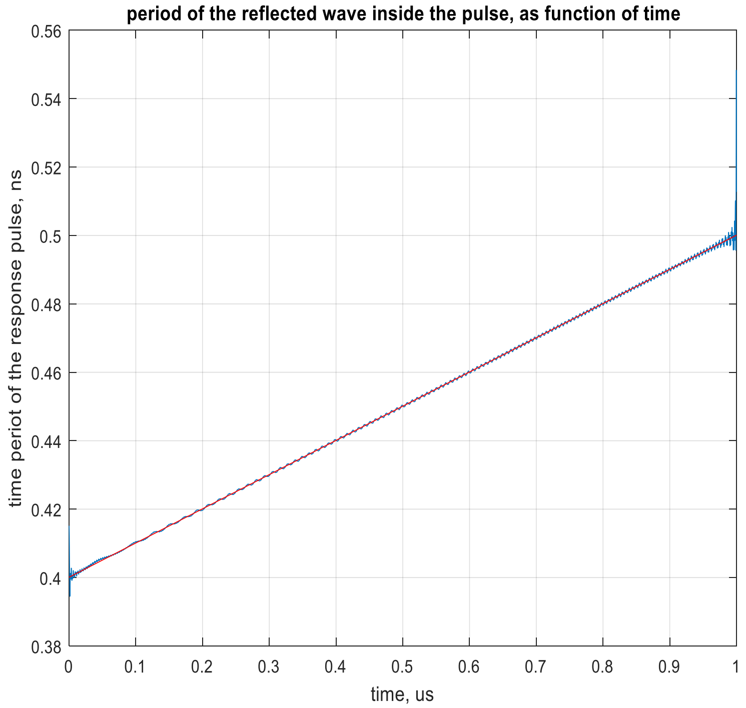
Using Inverse Fast Fourier Transform (IFFT) we can get an impulse response



We have used Nfr=2001 frequency points, fr=[1800:0.5: 2800];

Hyberbolic Frequency Modulation

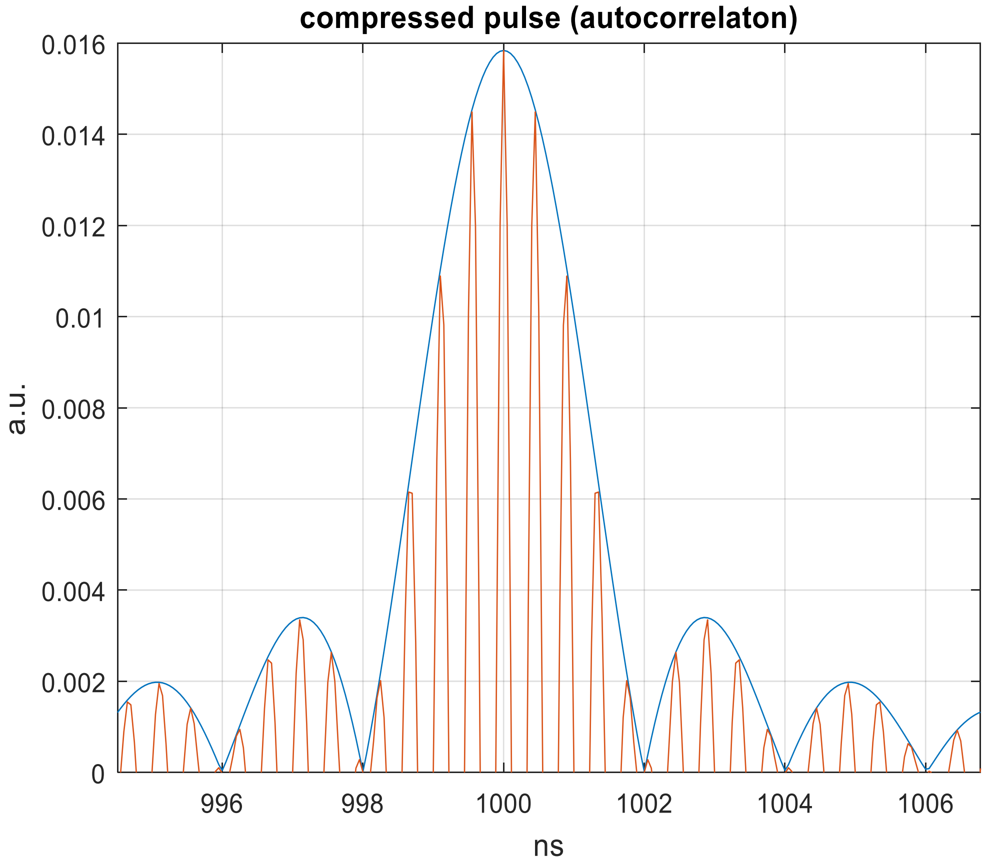




Linear increase of time period (1/f); red line – ideal fitted straight line.
Polynomial fit is
y=0.4001+0.1*t
with the correct beginning period **0.4 ns**= 1/ 2.5 GHz, end period
0.5 ns = 1 /2.0 GHz, and expected rate coefficient (2.5-2.0)/1.0 =0.1.

For comparison:
– dotted straight line

Simulated compressed pulse



The compressed pulse has form close to sinx/x with the width around 1/500MHz = 2 ns. Its form (red line shows *real* part of the signal) is unique, and its position can be determined without uncertainty of phase (2 π). If in a sensor response we will have 2 such pulses, by correlation method we will find the distance between this peaks.

Theoretical (ideal) HFM signal used for compression of sensor response

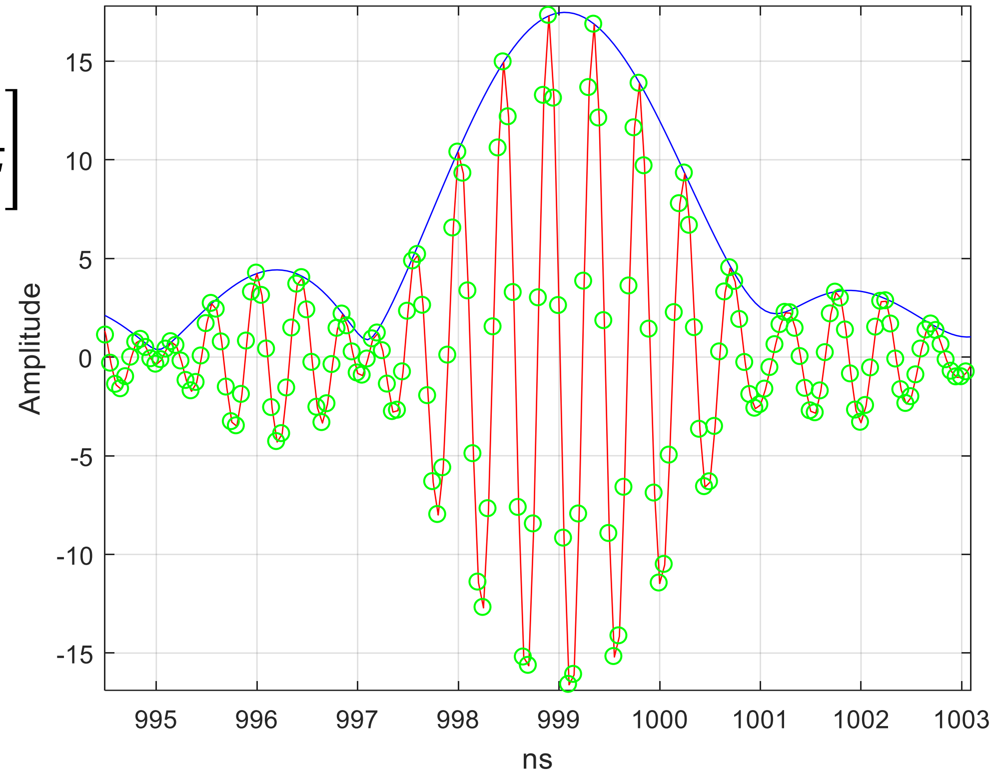
$$T(t) = T_0 + \frac{T_N - T_0}{T} * t$$

Introducing phase

$$\Phi = 2\pi \cdot \int_0^t \frac{dt}{T(t)} = 2\pi \cdot \int_0^t \frac{dt}{T_0 + \frac{\Delta T}{T} \cdot t} = 2\pi \cdot \frac{T}{\Delta T} \cdot ln\left[1 + \frac{\Delta T}{T_0} \cdot \frac{t}{T}\right]$$

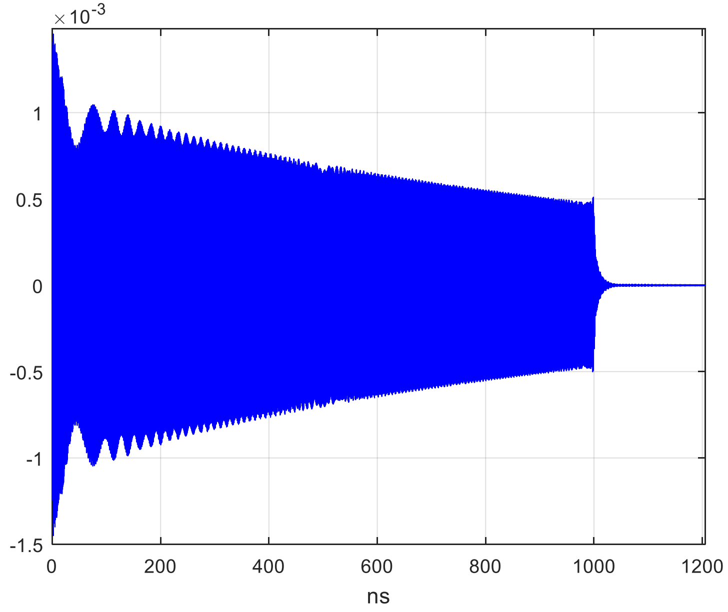
$$\Phi = -2\pi \cdot \frac{T}{B} \cdot (F_0^2 - \left(\frac{B}{2}\right)^2) \cdot \log(1 - \frac{B}{F_0 + B/2} \cdot \frac{t}{T})$$

$$U = 1 \cdot \exp(1i \cdot \Phi)$$

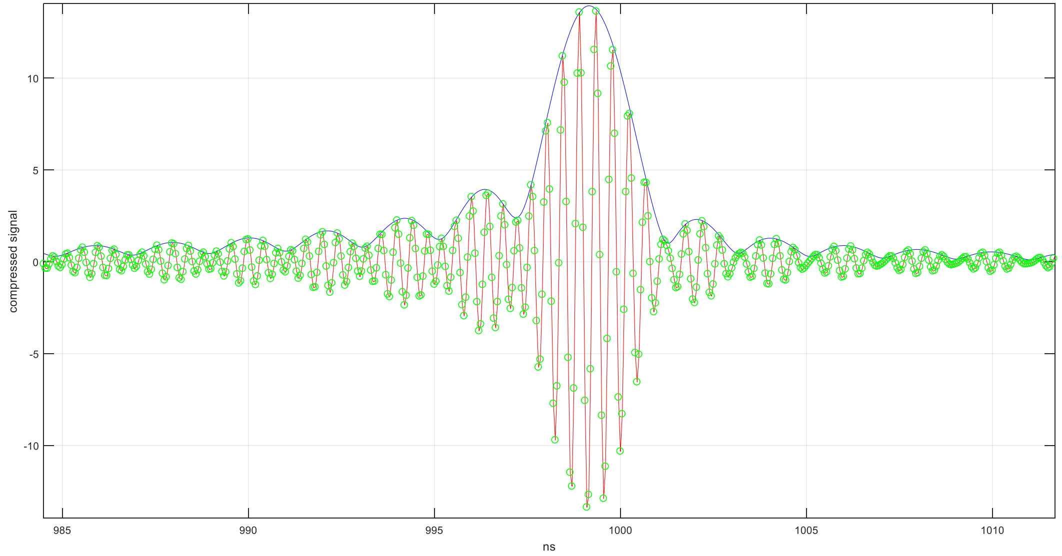


The “compression gain” = 17.5 times, or about 25 dB, which close to ideal value about 10*log10(B*T) = 27 dB

SAW attenuation included



6dB/ µs at 2GHz in LiNbO3



The “compression gain” using ideal HFM signal as refernce is about 14 times, or 23 dB

Profile groove etching

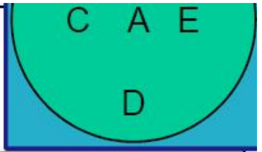
Uniform groove etching

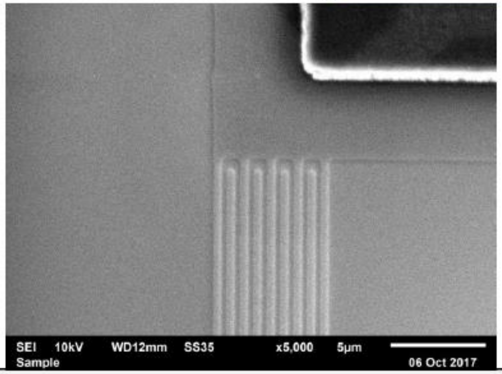
Uniform etching, aperture weighted

GVR Trade SA
A wholly owned subsidiary of RESONANT®

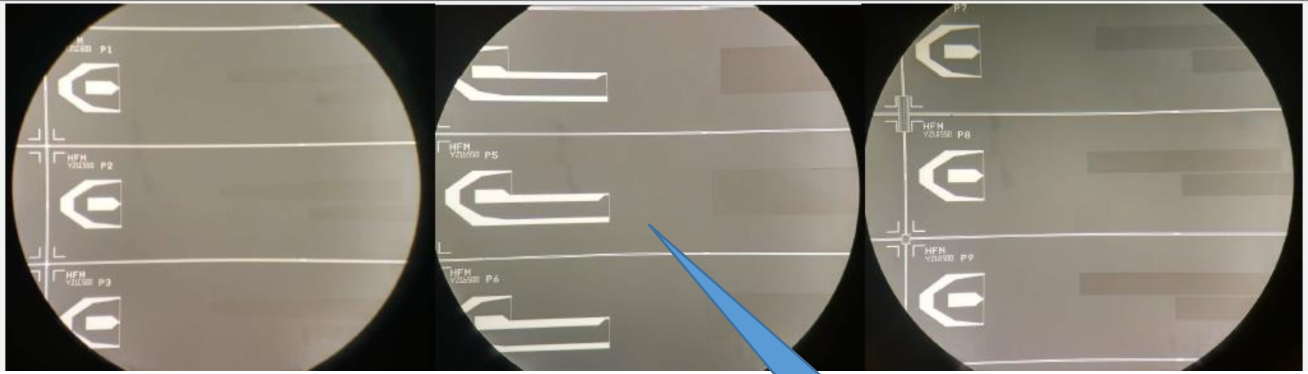
Etching grooves

Thickness/C.D. measurement			
Metal Thickness (nm)		Metal C.D. By SEM 5000x (um) – P1	
A	72.5	A	0.36
B	71.3	B	0.35
C	72.7	C	0.36
D	73.2	D	0.36
E	71.9	E	0.35





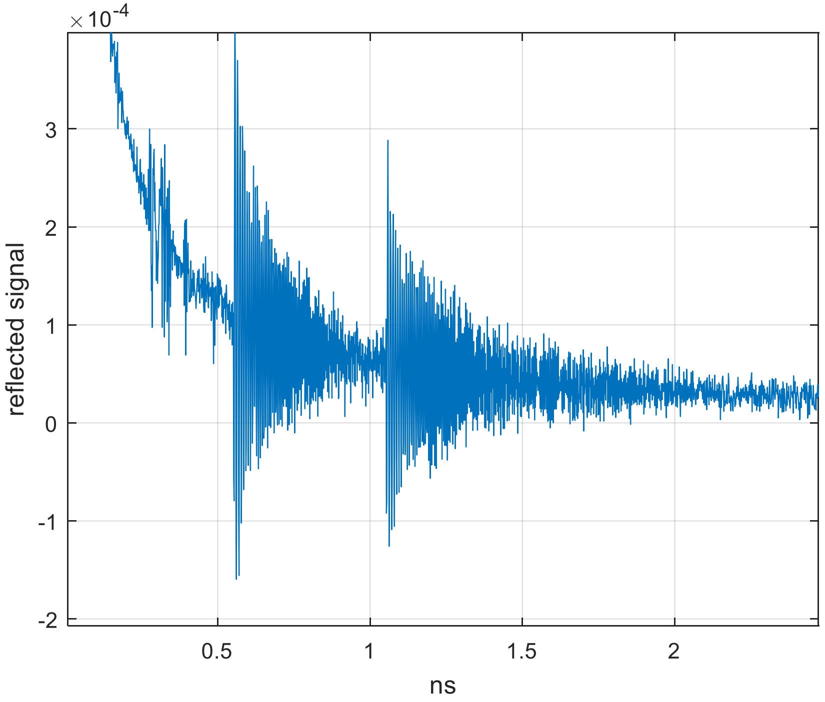
Wafer Picture



P5

First samples manufactured

Reflected chirps (sample P5)



Conclusions

B*T*(K-1) >1

(K- scaling factor)

LFM signal compression deteriorates significantly

The **Hyperbolically Frequency Modulated (HFM)** signals and transducers/reflectors
are ideally suitable for SAW-sensors and SAW-tags,
since compression of such signals, being temperature-invariant,
can be achieved with always the same matched-to-signal filter,
simplifying significantly the interrogation algorithm.

Acknowledgements

This research is co-funded
by the Swiss State Secretariat
for Education, Research and Innovation
in frames of Eurostar Project E!10640 UWB_SENS

Thanks!

Thank you!