Source distance information and frequency shifts by chirp decomposition

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APS Meeting 2006.03.15

motivation

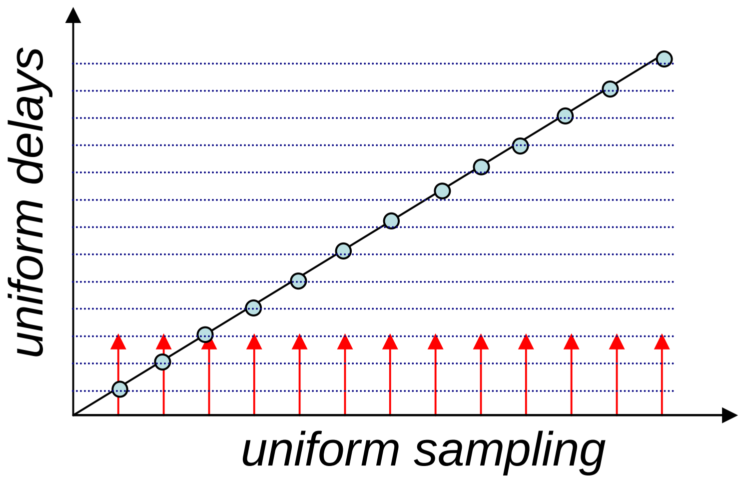
- *Fourier analysis is more than macroscopic*
  - *requires* multiple samples ~ point observations
  - samples must be spread over time*
  - perfectly uniform sampling is impossible….

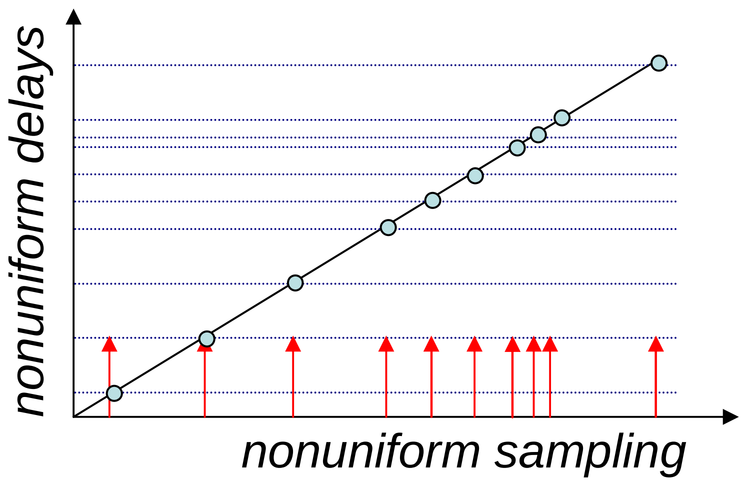
    there could be uncorrected systematic errors

- *What are the effects of sampling nonuniformity?*
  - communication: only discrete rate variations used
  - equivalent to chirps, but chirp techniques still novelty
  - turns out ~ surprising new wave effect

**for "temporal frequencies"*

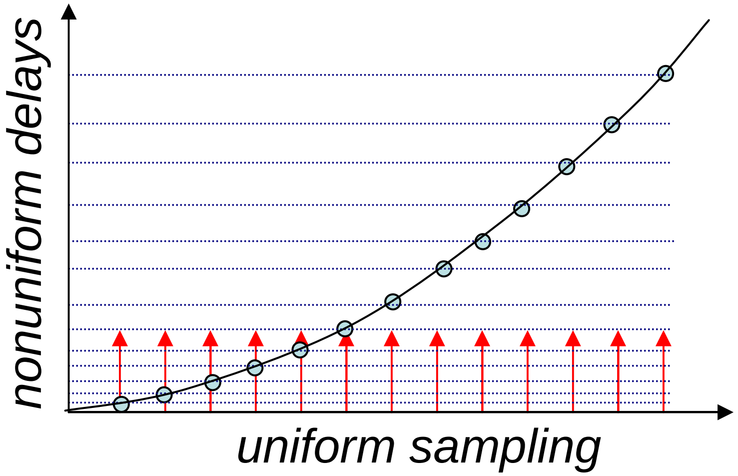
sample-delay profile

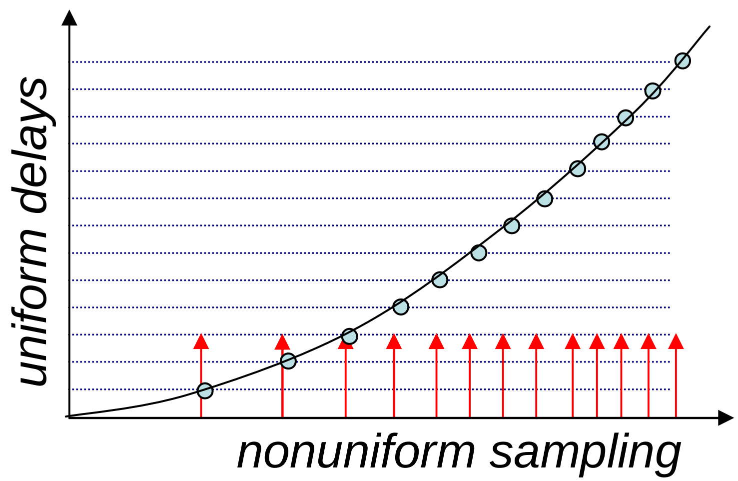




- linear <=> Fourier
- in practice
  - sampling jitters annulled by long integration
  - rate drifts can be corrected by delays to ensure Fourier
- invariably linear
  - wavelets: *static* time scales

chirp sampling profiles

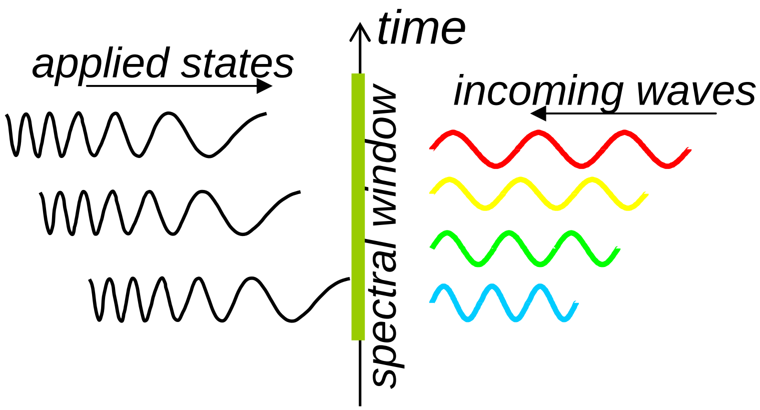


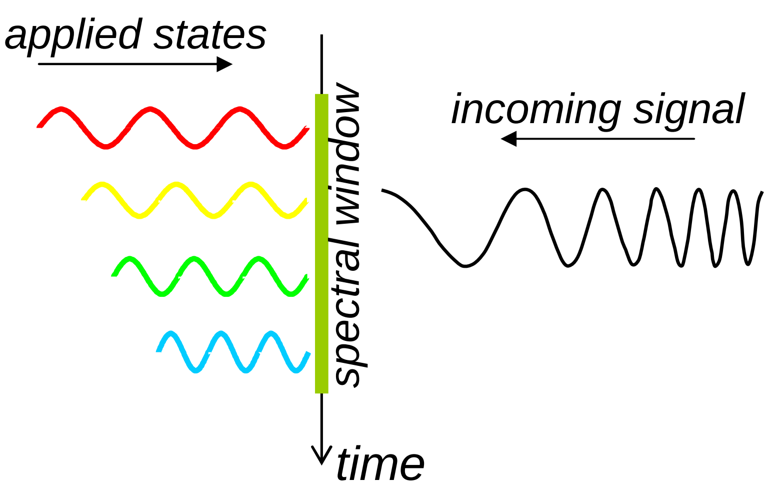


- nonlinear sampling new..
  - at least to signal processing
- chirps *per se* are known
  - radar, radiographic rotations
- chirp sampling: *non Fourier*
  - generator: exponential
  - equivalent to

continuously turning
the tuning knob…

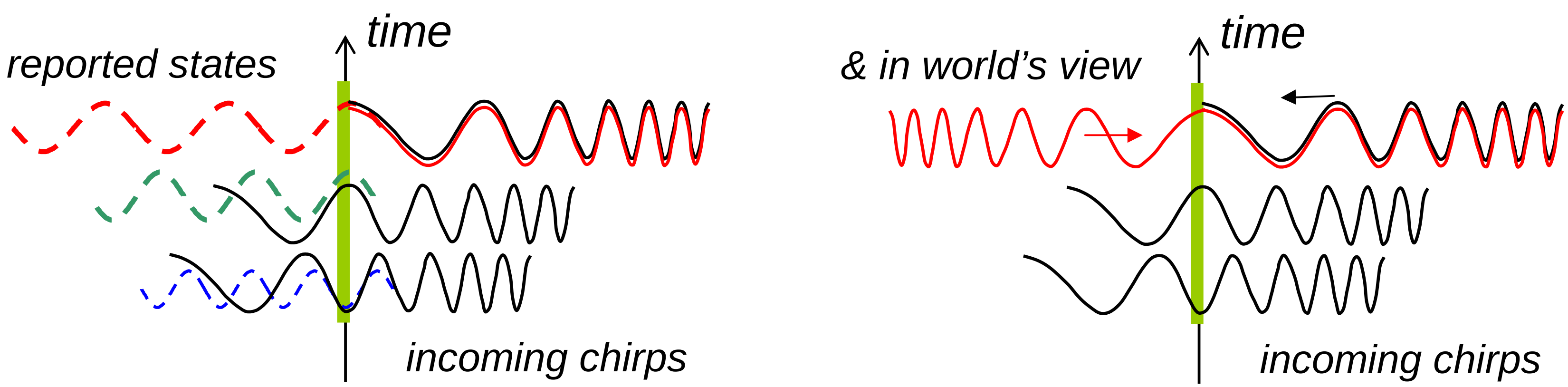
mechanics of integration





- world view:
  - receiver states are chirped
  - states only differ in phase!
  - receiver's "window" moving
- receiver view: world moves
  - world chirps as sinusoids!
  - true world tones vanish!
  - **requires "chirp content"**
- surprise effect
  - world tones scaled
  - *by source distances*

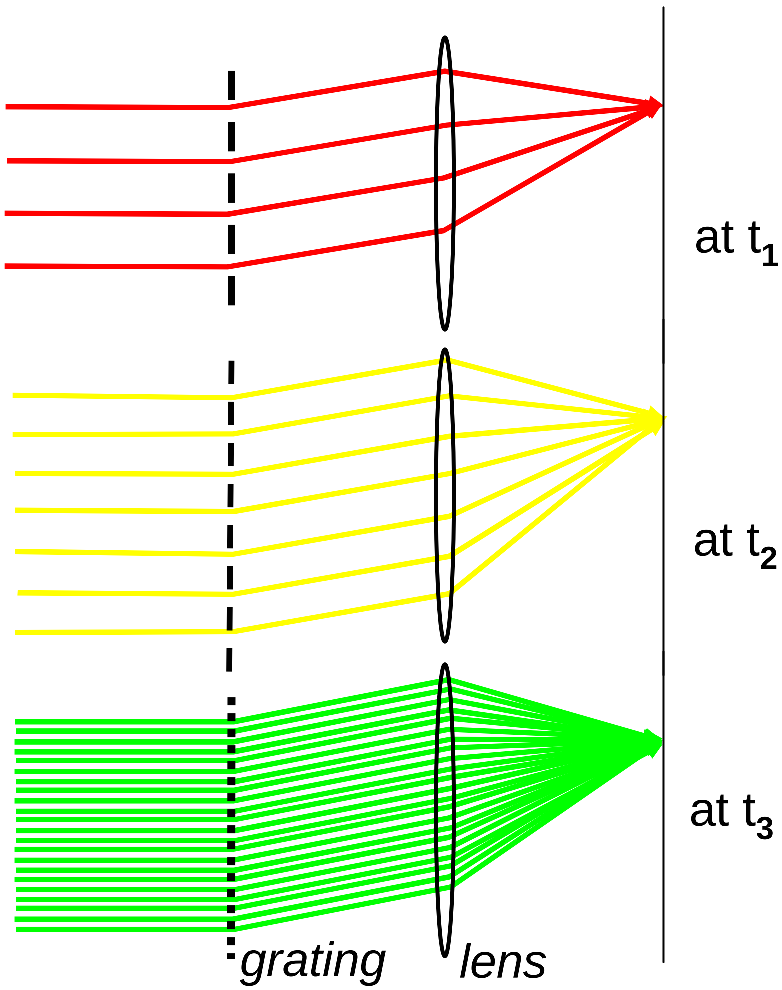
loss of translational invariance



- same chirp seen at different colours
  - varies w/ arrival time/phase ~ assuming fixed starting phase

- related thoughts:
  - same properties should hold for photon amplitudes
  - similar chirps do occur in cosmology [Parker 1968,1969]

same for gratings



- at any diffraction angle
  - continuum of wavelengths
  - in each integral
- detected wavefunctions
  - are all now chirped!

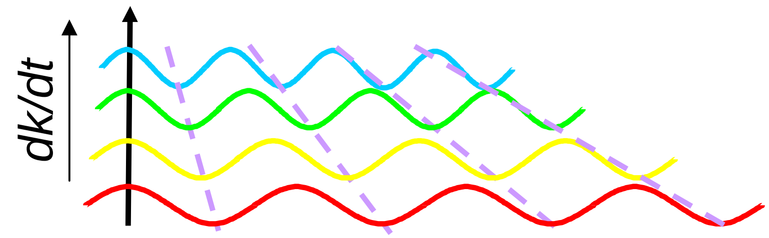
$$n \lambda = l \sin \theta$$

$$n \frac{d\lambda}{dt} = \frac{dl}{dt} \sin \theta$$

$$\frac{1}{\lambda}\frac{d\lambda}{dt} = \frac{1}{l}\frac{dl}{dt} = \boldsymbol{-\beta}$$ **← normalized rate of change**

turning the tuning knob

- adds a rate of change of phase
- this rate *is* a frequency change
- and it is distance-dependent



Wave phase $\varphi = k\,r - \omega\,t$

hence $\Delta\varphi = \Delta(k\,r - \omega\,t)$

$$= \underbrace{r\,\Delta k + k\,\Delta r}_{\text{space part}} - \underbrace{\Delta(\omega\,t)}_{\text{signal part}}$$

$k\,\Delta r$ – the term most responsible in holography, synthetic aperture

$r\,\Delta k$ – imaging in pulsed radars, using the frequency comb

Consider the total rate of change

$d\varphi/dt = r\,dk/dt + k\,dr/dt + \omega$

new term *Doppler* *signal*

The "received" frequency is then

$\omega' \equiv d\varphi/dt = r\,dk/dt + k\,dr/dt + \omega$

With $\beta \equiv k^{-1}\,dk/dt$, the new contribution is

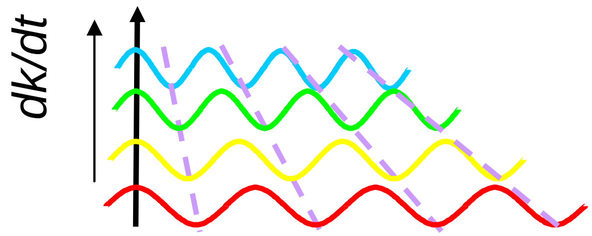
$\Delta\omega' = r\,dk/dt = \beta\,k\,r$

representing a frequency scaling factor

$z \equiv \Delta\omega' / \omega = \beta\,r / c = \alpha\,r \;,\; \alpha \equiv \beta/c$

source distance information

*notice: signal phase profile moves with the waves, but the **kr** component does not* →



- spatial (*kr* ≡ – *ωct* ~ but not *ω* alone)
  - *k* is instantaneous receiver selection/tuning
    => *shifts independent of the signal*
- inverse problem to –ve refractive index
  - not based on dispersion
- assumes
  - a differential continuum of frequencies ~ *any real source*
  - with phases consistent with common source location
    → continuum => eliminates "aliasing" (unlike, e.g pulsed radar)

potential applications

- source location
  - *radar, rescue, navigation*
- communication
  - *multiplies Shannon capacity*
  - *cellular w/o (or orthogonal to) CDMA, etc.*
- devices
  - “universal wave sources” – from THz, IR to UV, X
  - “cross-sensing” – match any band to any sensor
- *calculations are very encouraging*

status, ack

- principle:
  - positive reviews in IEEE WCNC, MILCOM ’05
  - from space radar, SIGINT experts
  - simulation – examples at http://www.inspiredresearch.com

- empirical:
  - “reverse-engineered” from a 1995-1996 astrophysics hunch
    - consistent evidence for a natural error spanning from Type Ia SNe to Pioneer 10, oceanic friction, and GPS base station drifts, for an uncorrected creep-related cause
  - radio wave tests by a SIGINT research group scheduled
  - IR/optical test device half-way (myself)

references

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- K Osterschek and P Hartogh, "A fast, high resolution chirp transform spectrometer for atmospheric remote sensing from space", *Proc. 11th Intl. Geosc. & Rem. Sensing Symp.*, Finland, 1991.
- F A Jenet and T A Prince, "Detection of variable frequency signals using a fast chirp transform", *PRD*, 62(12), Dec 2000.
- C E Shannon, "A mathematical theory of communication", *Bell Sys. Tech. J.*, 27:379-423,623-656, 1948. (available online).