Refresher of LMN Resampling

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LArTPC samplings

Detector	T (ns)	F (MHz)	ADC (bits)
past (PD-1,MB)	500	2.000000	12
DUNE FD			
VD TDE	500	2.000000	14
VD BDE	512	1.953125	14
HD	512	1.953125	14

Proposal

Inside the **offline WCT Noise Filter** we will **upsample** the waveforms:

$$T = 512\,\mathrm{ns} \rightarrow T = 500\,\mathrm{ns}$$

Comments:

- Upsampling is **information-lossless** from a sampling-theory view.
  - The particular technique must take care to minimize **time-domain artifacts**.
- Can be performed **cost-free** inside existing WCT NF frequency domain and with a “trick”.
- Apply **far-upstream** to provide $500\,\mathrm{ns}$ to (almost) all offline software.
  - Allows field-response and simulation to be at $500\,\mathrm{ns}$.

Conventional resampling $N \to N'$

"rational interpolation" = "integral upsample" + "integral downsample".

- **integral upsample** $N \to N^{iu} = LN$
- **integral downsample** $N \to N^{id} = N/M$
- **rational interpolation** $N \to N^{ri} = RN,\ R \equiv \frac{L}{M}$

Comments

- Integral downsample allows for non integer N/M by selecting every M^{th} time sample and ignoring the fact that the last selection represents fewer discarded samples than prior selections.
- Depending on original signal bandwidth, downsampling may require a low-pass filter to avoid aliasing.

The LMN trick

Choose N to minimize L and M while keeping $\frac{LN}{M} \in \mathbb{N}$.

We want to shift the Nyquist frequency by:

$$\Delta F = F_{nyquist} - F'_{nyquist} = \frac{T - T'}{2TT'}$$

And we want that shift to be covered by an integral number n of bins of size $\delta F = \frac{1}{NT}$.
So, we want $n \cdot \delta F = \Delta F$ which is solved by:

$$N = \frac{2nT'}{T - T'} = \frac{n}{3} \cdot 250$$

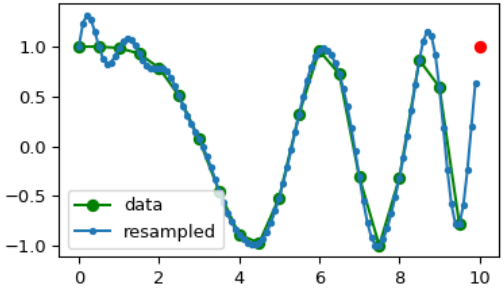
With the last term having plugged in DUNE numbers.
Thus for N any multiple of 250, we can assure the downsampling will be exactly integral.

LMN procedure

1. Calculate a desired N and n.
2. Truncate or pad original signal to N while mitigating **artifacts**.
3. Apply DFT.
4. Insert $2n$ $(R > 1)$ or remove $2n$ $(R < 1)$ frequency samples.
5. Apply DFT^{-1}.
6. Fix normalization.

Resampling artifacts

- Any interpolation produces artifacts in time or frequency or both.
- Fourier-based interpolation does not distort frequency domain spectrum (other than the intentional spectral truncation/extension) but can distort time domain waveform.
  - Violating periodicity assumptions can lead to artifacts near endpoints.
  - Mitigate by padding via simple linear/cubic time-domain extension of waveform?



https://docs.scipy.org/doc/scipy/reference/generated/scipy.signal.resample.html

Links

repo
https://github.com/BNLIF/lmn/
paper
https://www.overleaf.com/project/65525feda20cdec448ee4390