CLIC Fine Timing System

Update on specifications

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Goal of this presentation

In scope

- Recap usual timing performance specification methods.
- Cast (some) existing requirements into this language.

Out of scope

- In-depth review of requirements from all clients.
- Solution space.

The imperfect sine wave

With both amplitude and phase noise

$$a(t) = A(1 + \alpha(t))\sin(\omega t + \varphi(t))$$

If we use hard-limiters, AGCs, etc.

$$a(t) = A\sin\left(\omega\left(t + \frac{\varphi(t)}{\omega}\right)\right)$$

Phase noise Power Spectral Density (PSD)

Parseval's theorem

$$\int_{-\infty}^{+\infty} |\varphi(t)|^2 \, dt = \int_{-\infty}^{+\infty} |\Phi(f)|^2 \, df$$

Truncated signal

$$\Phi_T(f) = \int_{-T/2}^{+T/2} \varphi_T(t) e^{-j2\pi ft} dt$$

Truncated Parseval

$$\frac{1}{T} \int_{-T/2}^{+T/2} |\varphi_T(t)|^2 \, dt = \int_{-\infty}^{+\infty} \frac{|\Phi_T(f)|^2}{T} df$$

Phase noise Power Spectral Density (PSD)

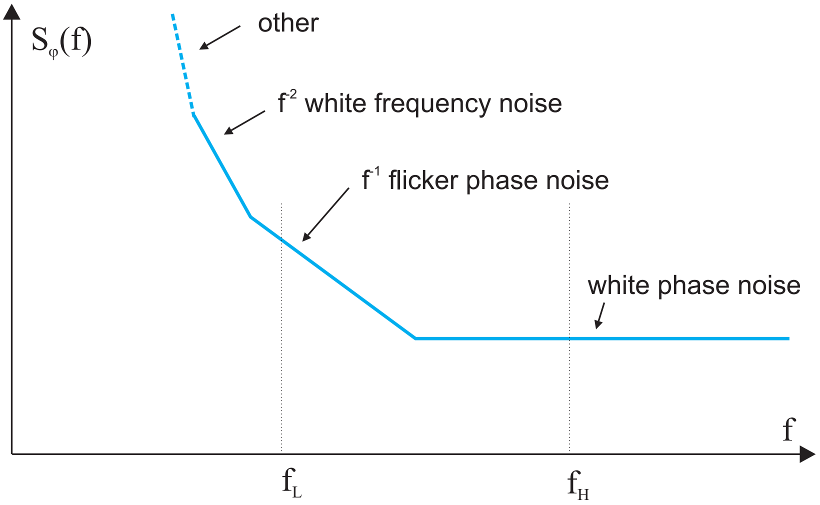
Wiener-Khintchine theorem

$$S_{\varphi}^{II}(f) = \lim_{T\to\infty} \frac{1}{T} \left|\Phi_T(f)\right|^2$$

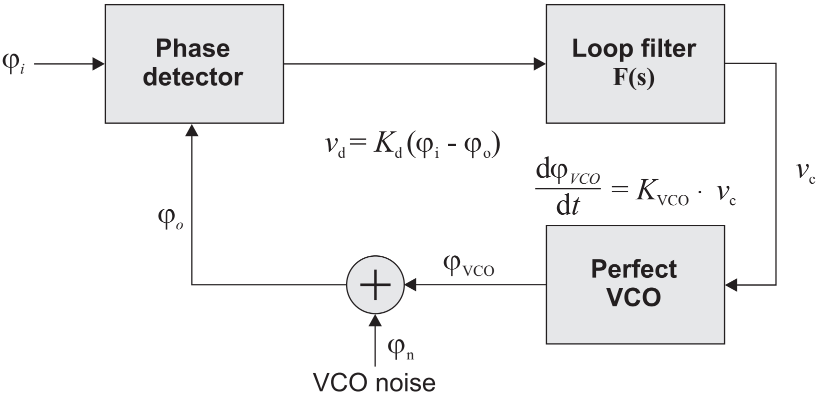
In practice

$$S_{\varphi}(f) \approx \frac{2}{T} \left\langle \left|\Phi_T(f)\right|^2 \right\rangle_m$$

Integrating PSD: jitter



PLL block diagram



PLL transfer functions

Total output phase spectrum

$$\Phi_o(s) = H(s) \cdot \Phi_i(s) + E(s) \cdot \Phi_n(s)$$

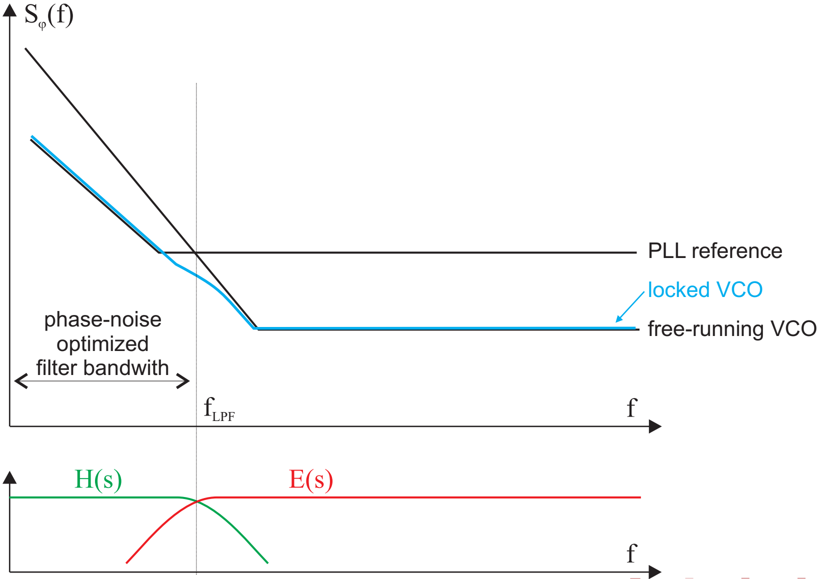
System transfer function (low pass)

$$H(s) = \frac{K_{VCO} K_d F(s)}{s + K_{VCO} K_d F(s)}$$

Error transfer function (high pass)

$$E(s) = 1 - H(s) = \frac{s}{s + K_{VCO} K_d F(s)}$$

Jitter optimization



Some representative clients

Drive beam RF system

Drive beam phase jitter $< 0.02^\circ$ at 1 GHz ($\approx$ 50 fs).

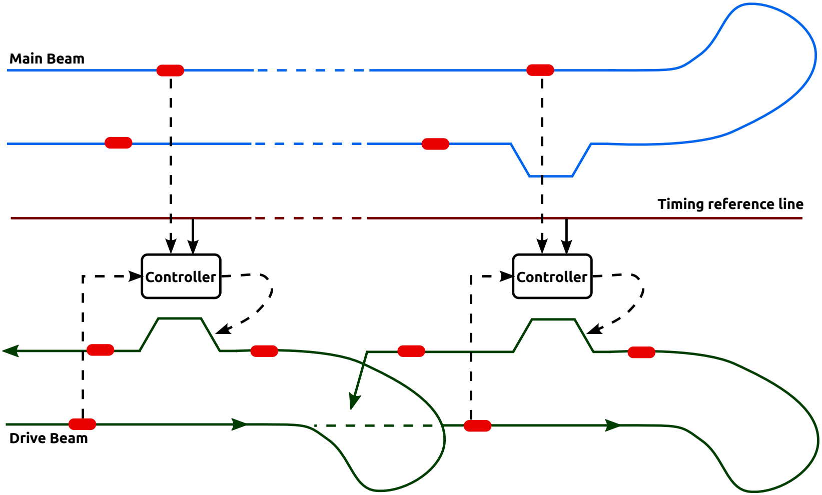
Inter-beam synchronization using kickers

Similar requirements. See D. Schulte's talk.

Beam-based pulse-to-pulse feedback

Need for coherent time-tagged data. Precision tbd.

Inter-beam synchronization using kickers



Drawing inspired by D. Schulte's.

PSD integration limits

Lower limit

Perturbations below $\sim$ 5 Hz can be corrected through pulse-to-pulse feedback.

Upper limit

Set by the active element with the highest bandwidth (kickers, cavities...). Currently estimated to lie in the MHz region.

A peek at available technologies

Low noise oscillators

Many promising options for both master oscillator and VCO on receiving side. See e.g. F. Ömer İlday's talk in CLIC09.

Fiber link stabilization

Proposed schemes guarantee noise of master oscillator up to the kHz region (limited by speed of light in fibers). Two types, pulsed and CW, have gone under 50 fs but not over 25 km.

Conclusions

Preliminary work

Started casting existing requirements into phase noise PSD language.

Figures so far

In the tens of femtoseconds realm, have been realised elsewhere but not over 25 km.

Outlook

Finish specifications

Complete client list and get more precise figures.

Launch studies to evaluate promising technologies

Cost optimization and the ability to synchronize over 25 km fiber links are the key subjects for study.