# Indoor GPS: Tightly Coupled Opportunistic Navigation

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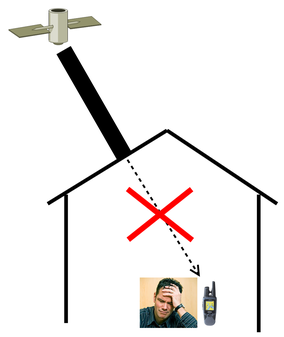
## The Problem

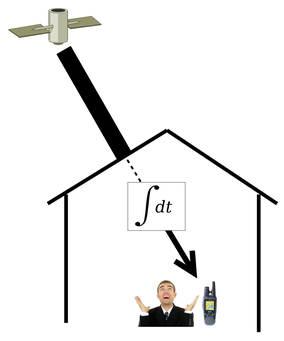
GPS signals attenuate **30–50 dB** indoors:



GPS receivers can't acquire or track indoors with a $\mathbf{C/N_0} \approx \mathbf{7\ dB\text{-}Hz}$.

## Solution: Just Wait!

**Coherently integrate** long enough to recover signal power:




Given a $C/N_0$ of 7 dB-Hz, a coherent integration duration of 5 seconds is required.

**Key Issue:** The receiver's local reference oscillator must maintain phase errors to a fraction of a cycle over those 5 seconds.

## How long must we wait?

Rule-of-thumb from detection theory:

$$\mathbf{SNR_{PD}} = \langle C_{\text{coh}}^2(T) \rangle \cdot \frac{C}{N_0} \cdot T \geq \mathbf{14\ dB}$$

for fixed $P_{\text{d}} = 0.95$ and $P_{\text{fa}} = 0.001$

## Oscillator Model & Stability

An oscillator with a sinusoidal, time-varying voltage $V(t)$ can be modeled as:

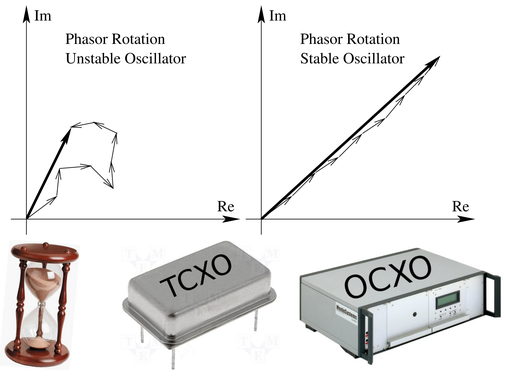
$$V(t) = \cos(2\pi\nu_0 t + \phi(t))$$

A useful metric for comparing oscillators is the coherence function $C_{\text{coh}}$:

$$C_{\text{coh}}(T) = \left| \tfrac{1}{T} \int_0^T e^{j\phi(t)} dt \right|, \quad 0 \leq C_{\text{coh}}(T) \leq 1.$$

This function expresses the effects of phase variations $\phi(t)$ during the coherent integration interval

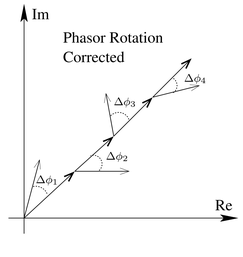
## Oscillator Comparison




a) $10^{-1} s/s$ b) $10^{-9} s/s$ c) $10^{-12} s/s$

## What are some options?

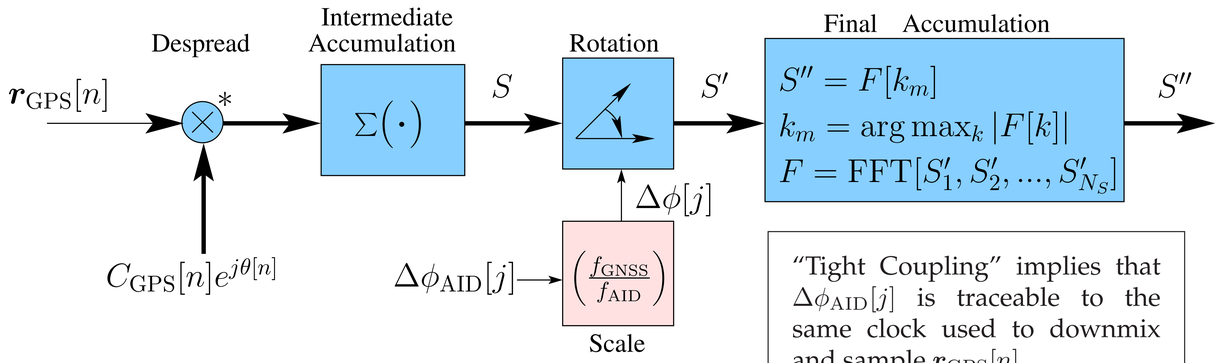
1. ~~Carry an atomic clock~~ → heavy!
2. ~~Use small, portable OCXOs~~ → expensive!
3. **Capture the stability of ambient "signals of opportunity"**




Use this stability to periodically correct for local oscillator phase variations, $\phi(t)$.

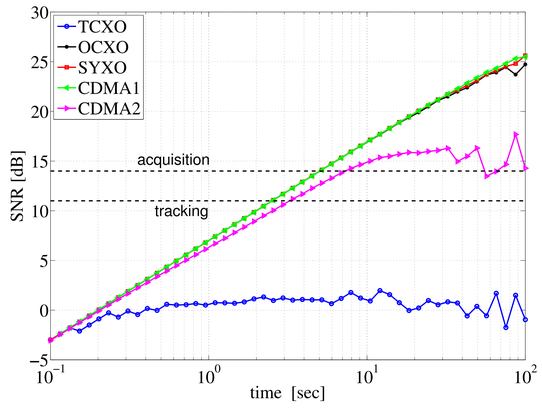
## Frequency Stability Transfer Model

Frequency stability transfer is the exercise of compensating for the local oscillator's phase instability by applying phase corrections derived from a tightly coupled stable aiding signal:

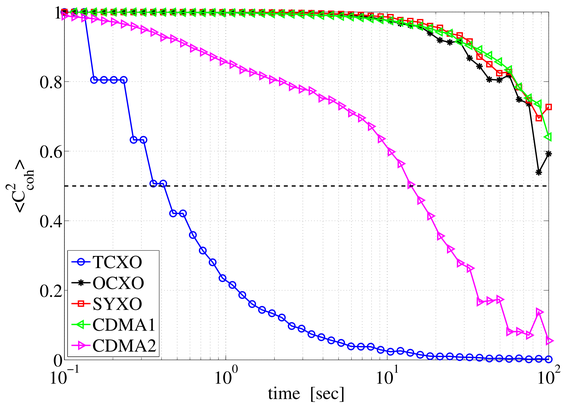



"Tight Coupling" implies that $\Delta\phi_{\text{AID}}[j]$ is traceable to the same clock used to downmix and sample $\boldsymbol{r}_{\text{GPS}}[n]$.

## Results: TCXO vs OCXO vs CDMA Aiding




Pre-detection SNR for TCXO-, OCXO-, and CDMA-generated carrier phase estimates for an assumed $C/N_0$ = 7 dB-Hz.




Mean-squared coherence of the TCXO-, OCXO-, and CDMA-driven carrier phase

Both the OCXO and the CDMA-aided oscillator **WILL** meet the $\text{SNR}_{\text{PD}}$ in less than 10 seconds. Additionally both of these oscillators remain coherent past 10 seconds. The TCXO will not.

These plots show that a GPS receiver which uses an unaided TCXO will **not** be able to coherently acquire or track indoors. However, a receiver which uses a TCXO **aided** by stable CDMA signals will be able to.

## Conclusion

Indoor GPS tracking and acquisition **is possible** with **commercial GPS receivers** using stable ambient signals of opportunity!

## References

[1] K. Wesson, K. Pesyna, J. Bhatti, T. Humphreys. "Opportunistic Frequency Stability Transfer for Extending the Coherence Time of GNSS Receiver Clocks," *ION 2010*