Indoor GPS: Tightly Coupled Opportunistic Navigation
KEN PESYNA, KYLE WESSON, JAHSHAN BATTI, AND TODD HUMPHREYS

THE PROBLEM
GPS signals attenuate 30–50 dB indoors:

GPS receivers can’t acquire or track indoors with \(C/N_0 \approx 7 \text{ dB-Hz}\).

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:

\[
\text{SNR}_{PD} = (C_{coh}(T)) \cdot C \cdot N_0 \cdot T \geq 14 \text{ dB}
\]

for fixed \(P_0 = 0.95\) and \(P_{ta} = 0.001\)

OSCILLATOR MODEL & STABILITY
An oscillator with a sinusoidal, time-varying voltage \(V(t)\) can be modeled as:

\[
V(t) = \cos(2\pi f_0 t + \phi(t))
\]

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

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

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

frequey 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:

\[
S'' = F[k_m] = \arg \max_k |F[k]|
\]

“Tight Coupling” implies that \(\Delta \phi_{AID}[j]\) is traceable to the same clock used to downmix and sample \(r_{GPS}[n]\).

FREQUENCY STABILITY TRANSFER MODEL

RESULTS: TCXO VS OCXO VS CDMA AIDING

Pre-detection SNR for TCXO-, OCXO-, and CDMA-generated carrier phase estimates for an assumed \(C/N_0 = 7 \text{ dB-Hz}\).

Both the OCXO and the CDMA-aided oscillator WILL meet the SNR_{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