FULLY WIRELESS COLLABORATIVE BEAMFORMING USING A THREE-ELEMENT COHERENT DISTRIBUTED PHASED ARRAY

delta
Distributed Electromagnetics Theory and Applications

emrg
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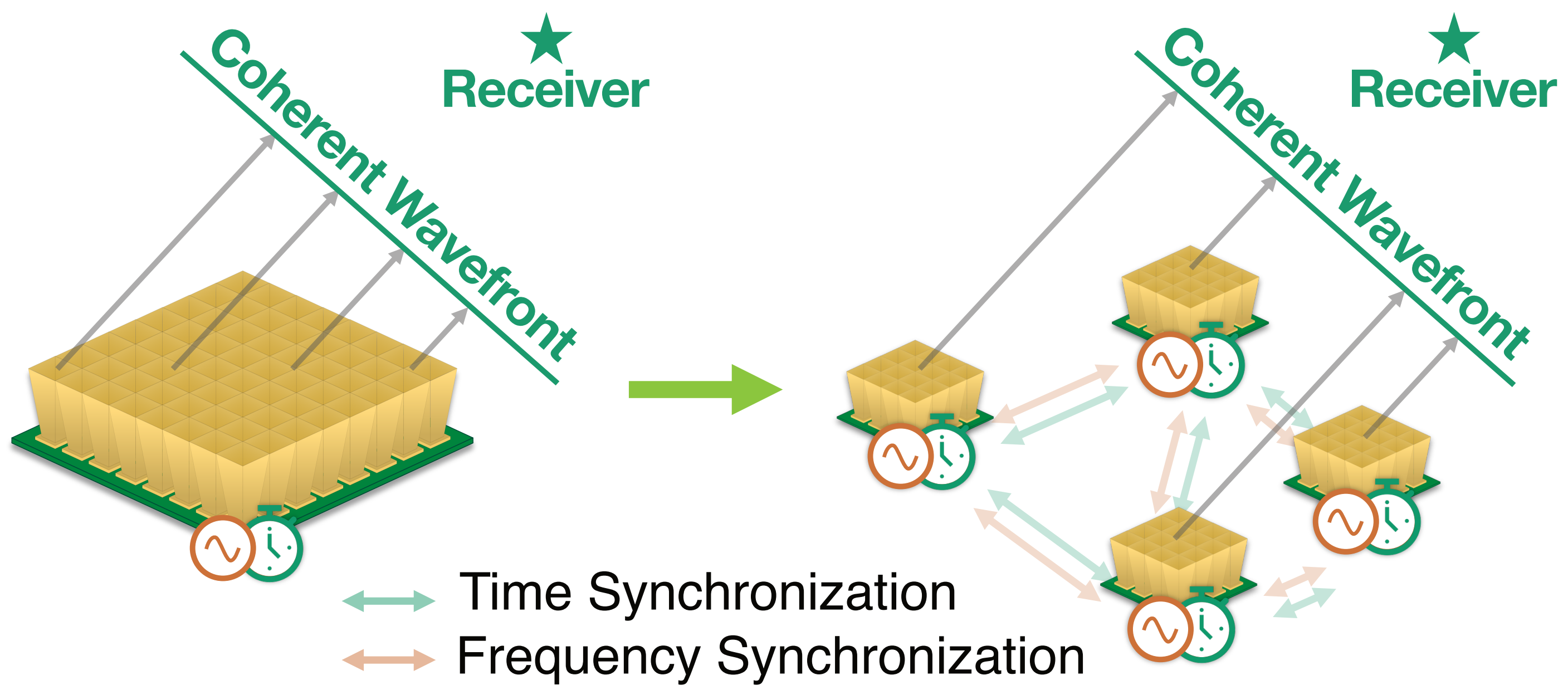
PROJECT SUMMARY

A wirelessly coordinated three-element coherent distributed phased array performing beamforming and steering to a far-field target at 1.05 GHz for use in GNSS-denied environments is demonstrated using a distributed compute system architecture and fully-wireless communication links. Experiments yield a beamforming gain of 9.32 dB (95%) with a sub-60 ps inter-element timing accuracy.

DISTRIBUTED PHASED ARRAY OVERVIEW

Traditional Phased Array

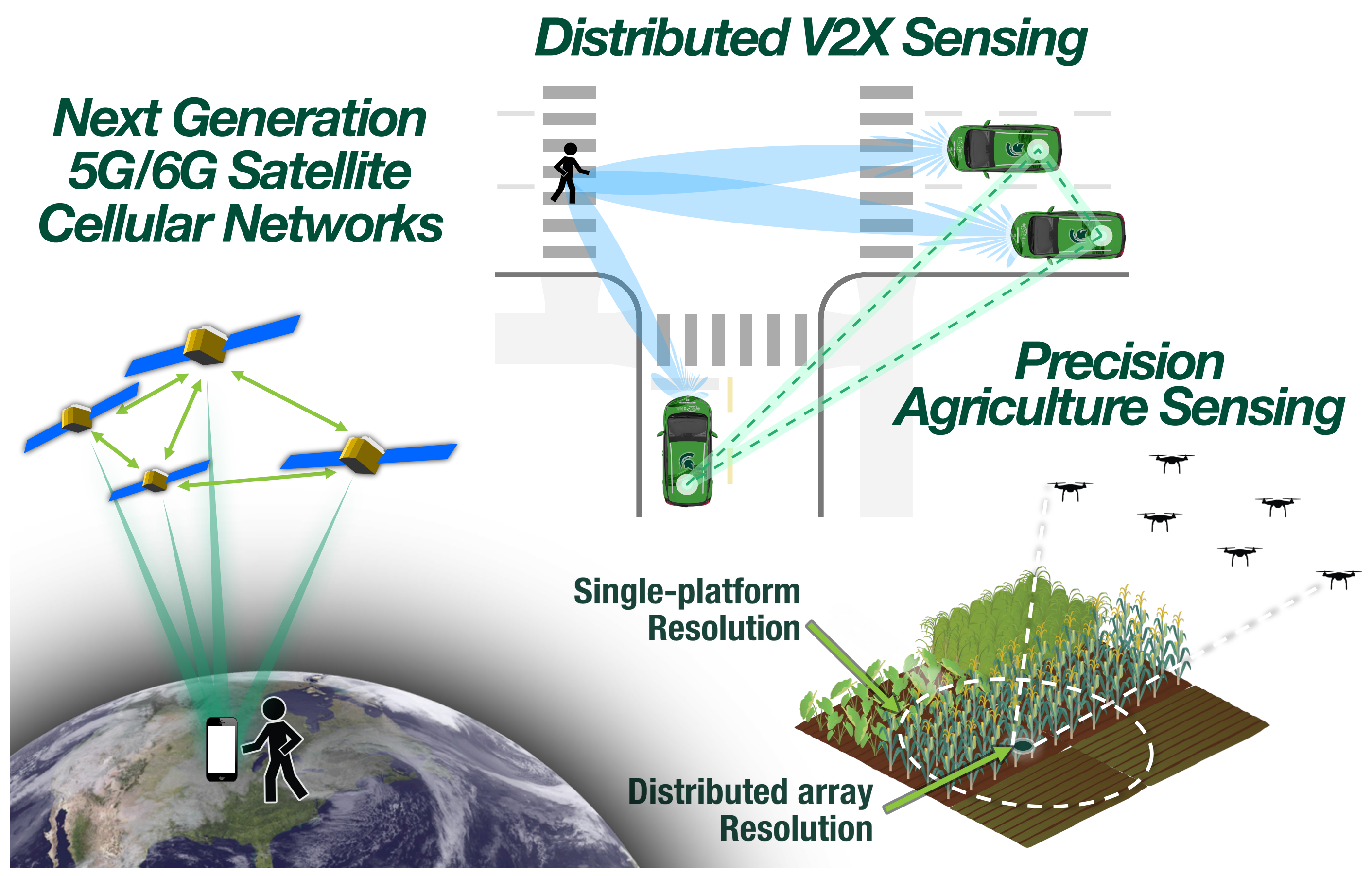
Distributed Phased Array



Benefits of Distributed Phased Arrays

- **Reduced deployment cost**
- **Resilient to antenna / node failure**
- **Larger array sizes possible**
- **Increased gain and throughput**
- **Efficient wideband operation**
- **Decreased thermal management**

APPLICATIONS



ELECTRICAL STATE ALIGNMENT

System Time and Carrier Model

Effective system time at the output of the RF signal path

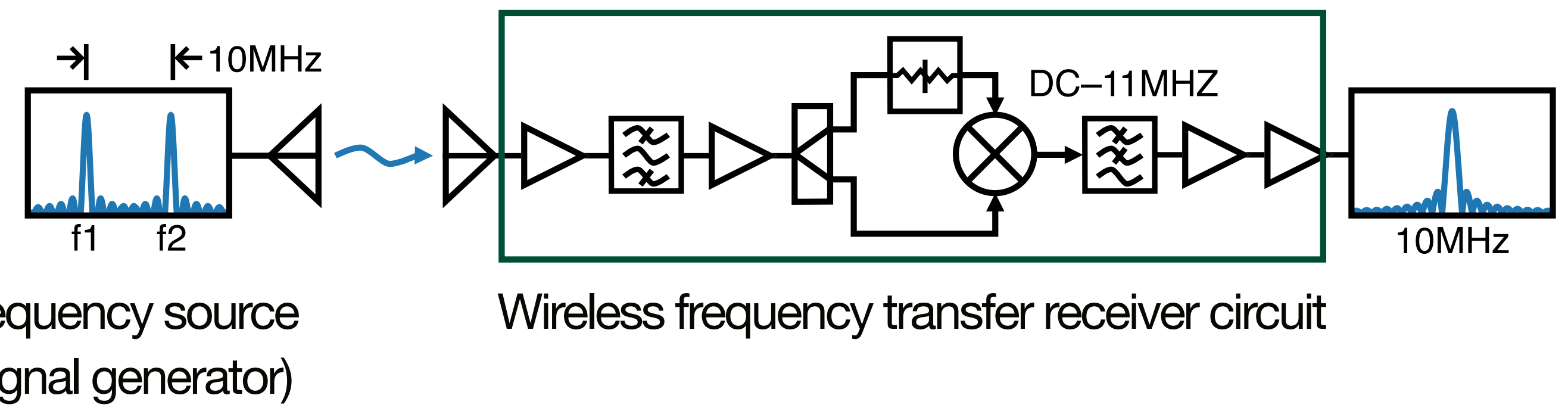
$$T_{\mathrm{TX}}^{(n)}(t) = \sum_{p=0}^{1} \alpha_{p,\mathrm{TX}}^{(n)}(t)t^p + \nu_{\mathrm{TX}}^{(n)}(t)$$

Transmitted waveform with time, frequency, and phase offsets

$$s_{\mathrm{TX,RF}}^{(n)}(t) = s_{\mathrm{b}}\left(T_{\mathrm{TX}}^{(n)}(t)\right) \exp\left\{j2\pi \cdot f_{\mathrm{RF,TX}} \cdot T_{\mathrm{TX}}^{(n)}(t) + j\phi_{0,\mathrm{TX}}^{(n)}\right\}$$

Analog Frequency Syntonization

Compensating for $\alpha_1^{(n)}$



Digital Time Synchronization

Two-way Time Transfer (TWTT)

One-way time delay estimate

$$\tilde{\tau}^{(n\to m)}[k] = T_{\mathrm{RX}}^{(m)}\left(t_{\mathrm{RX}}^{(m)}[k]\right) - T_{\mathrm{TX}}^{(n)}\left(t_{\mathrm{TX}}^{(n)}[k]\right)$$

Two-way time delay estimate

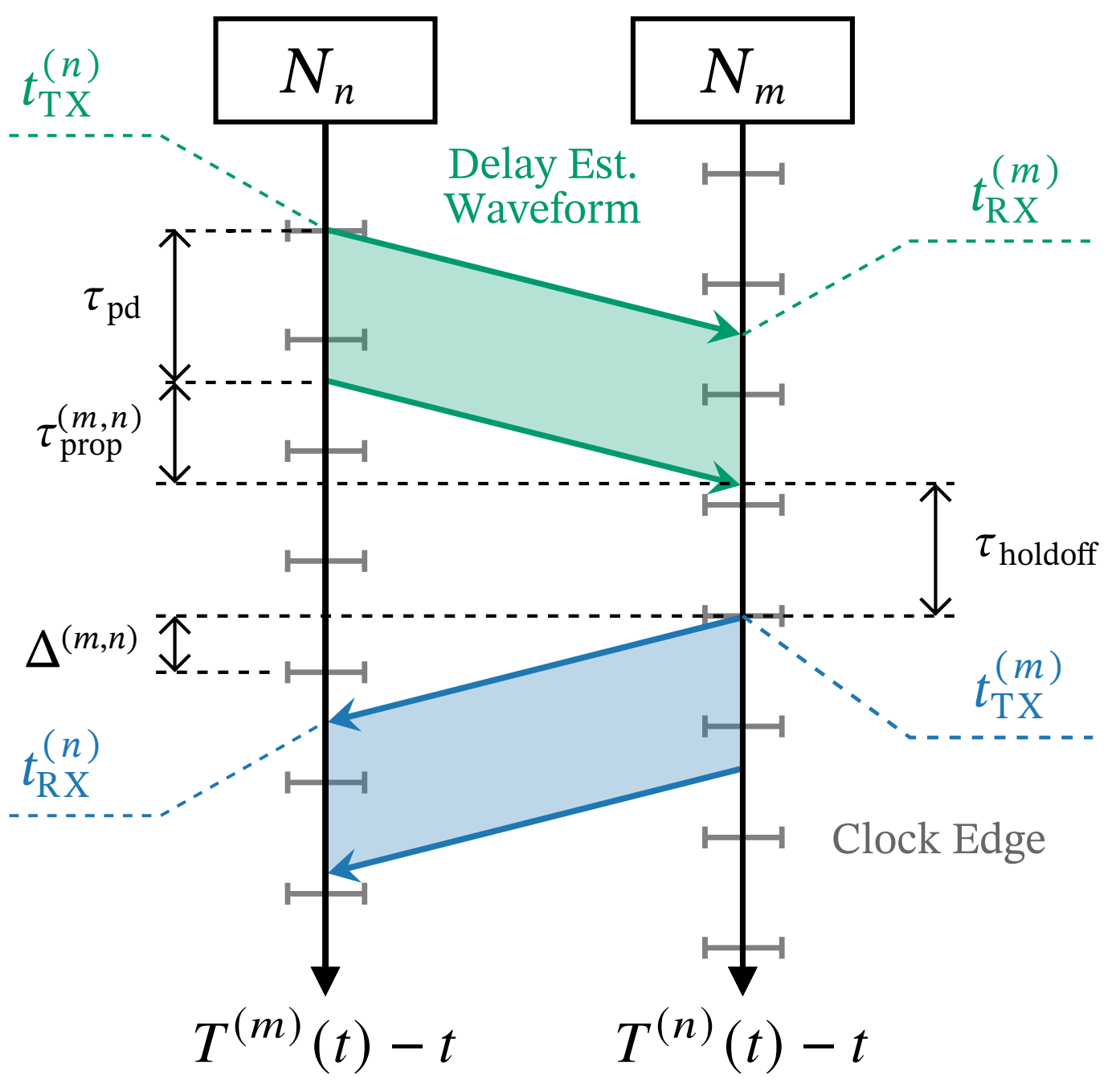
$$\alpha_0^{(m,n)}[k] = \frac{\tilde{\tau}^{(n\to m)}[k] - \tilde{\tau}^{(m\to n)}[k]}{2}$$

Inter-node time-of-flight estimate

$$\tau^{(m,n)}[k] = \frac{\tilde{\tau}^{(n\to m)}[k] + \tilde{\tau}^{(m\to n)}[k]}{2}$$

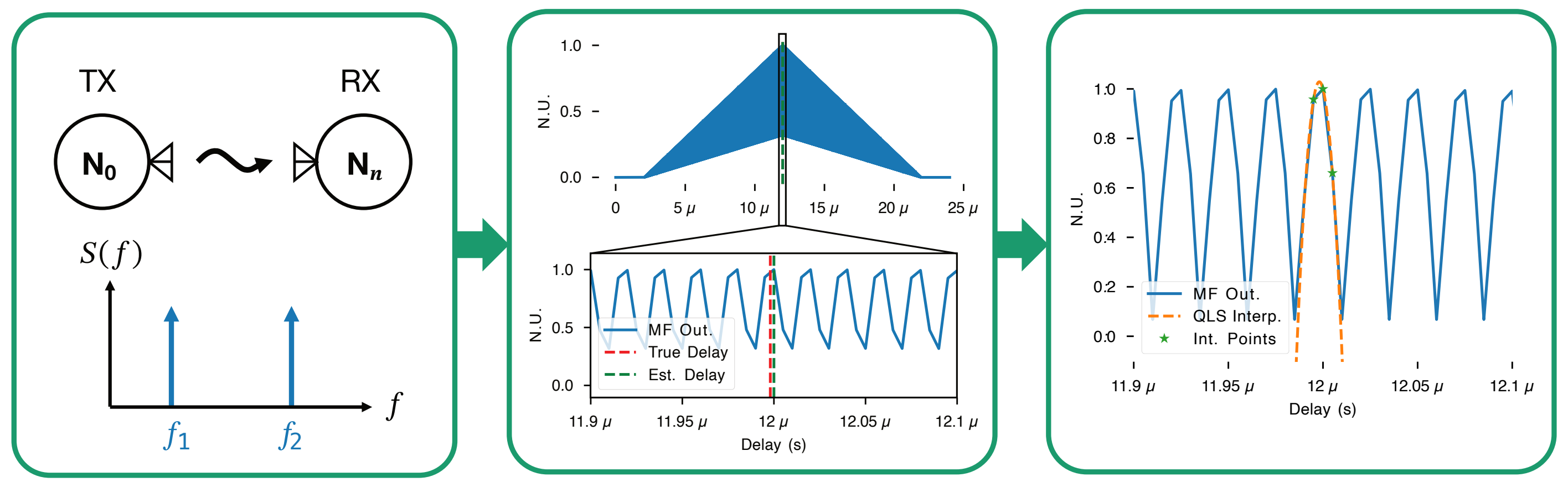
Inter-node range estimate

$$R^{(m,n)}[k] = c \cdot \tau^{(m,n)}[k]$$



Time of Arrival Estimation

Pulsed Two-Tone Transmission | **Matched Filter** | **Quadratic Least Squares (QLS) Peak Refinement**

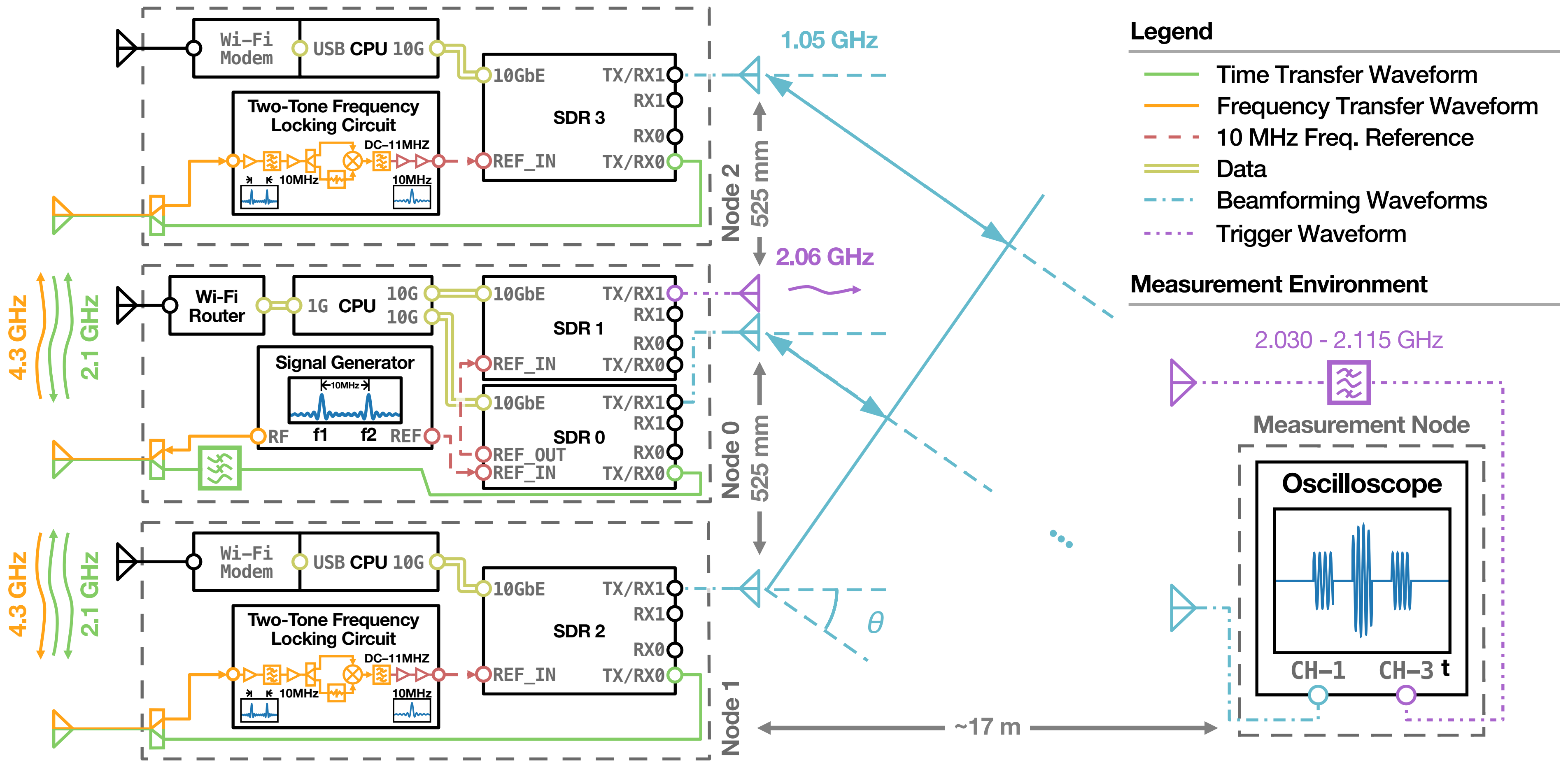


Digital Waveform Compensation

Baseband waveform resampled at correct time offset, with carrier phase compensation

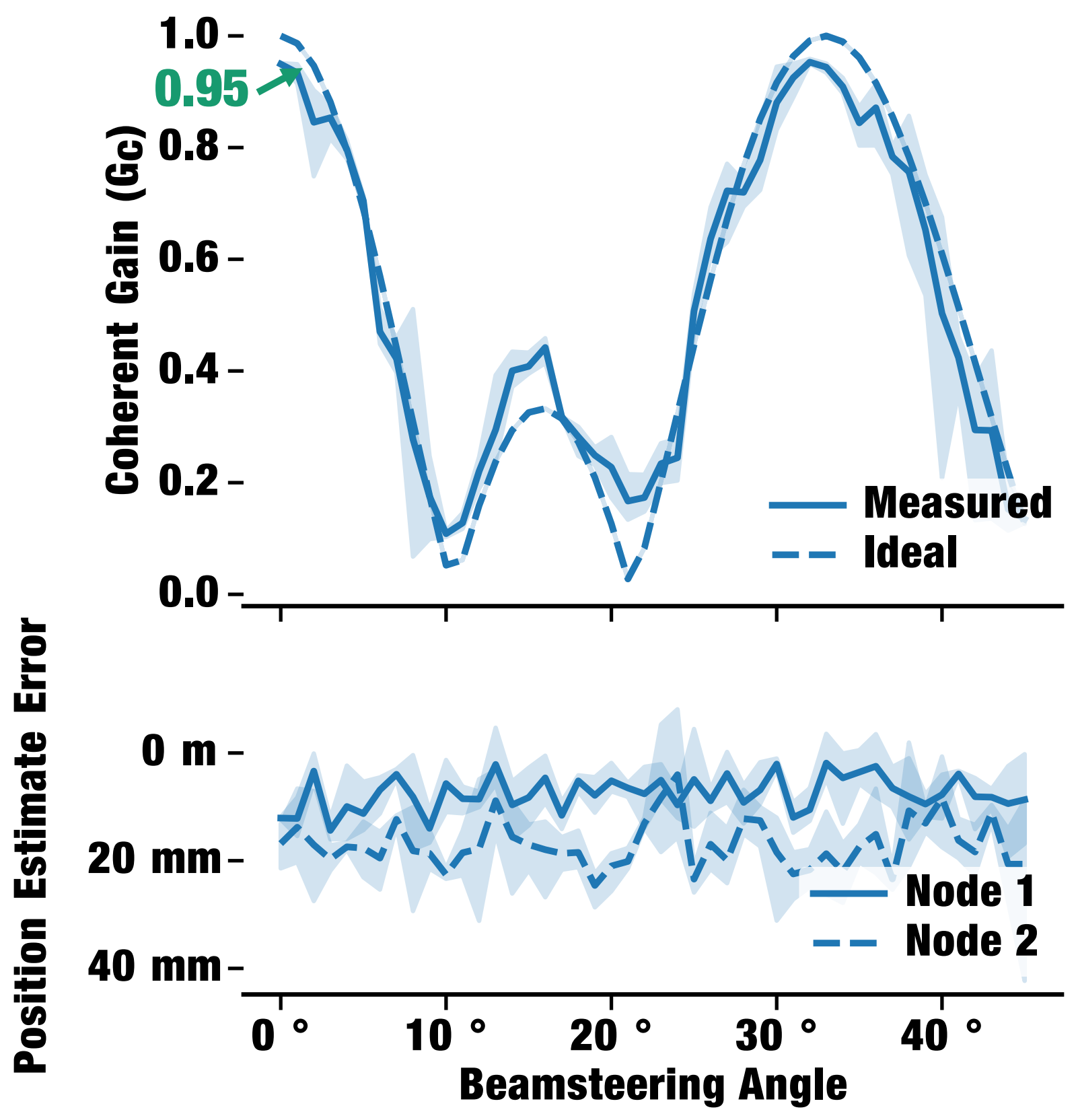
$$s_{\mathrm{b}}^{(n)}[i] = s_{\mathrm{m}}\left(t_{\mathrm{s}}[i] + \alpha_{0,\mathrm{TX}}^{(n)}[k]\right) \exp\left\{-j\left(2\pi \cdot f_{\mathrm{RF,TX}} \cdot \alpha_{0,\mathrm{TX}}^{(n)}[k] + \phi_{0,\mathrm{TX}}^{(n)}\right)\right\}$$

EXPERIMENTAL SYSTEM CONFIGURATION

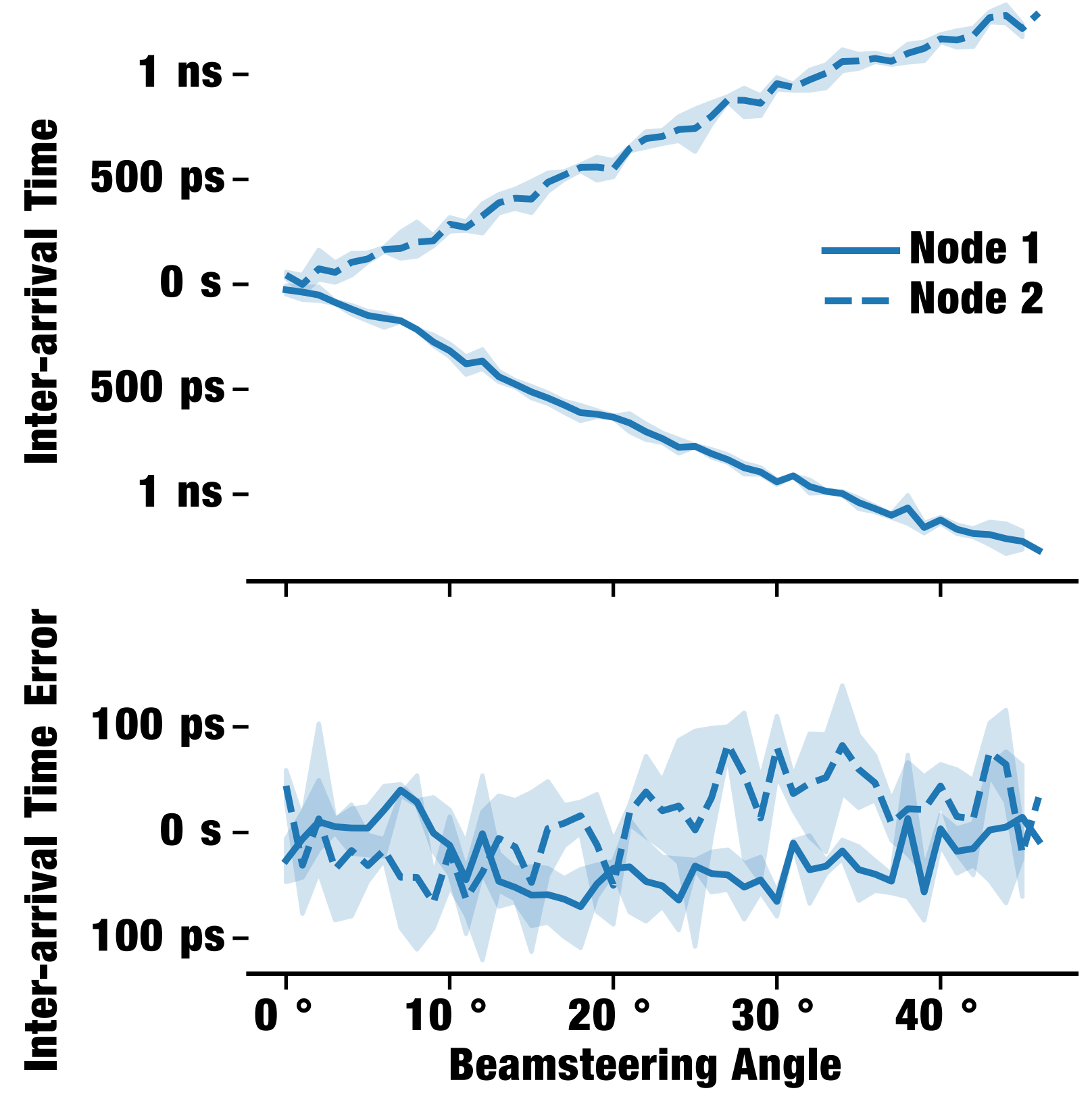


EXPERIMENTAL BEAMFORMING MEASUREMENT RESULTS

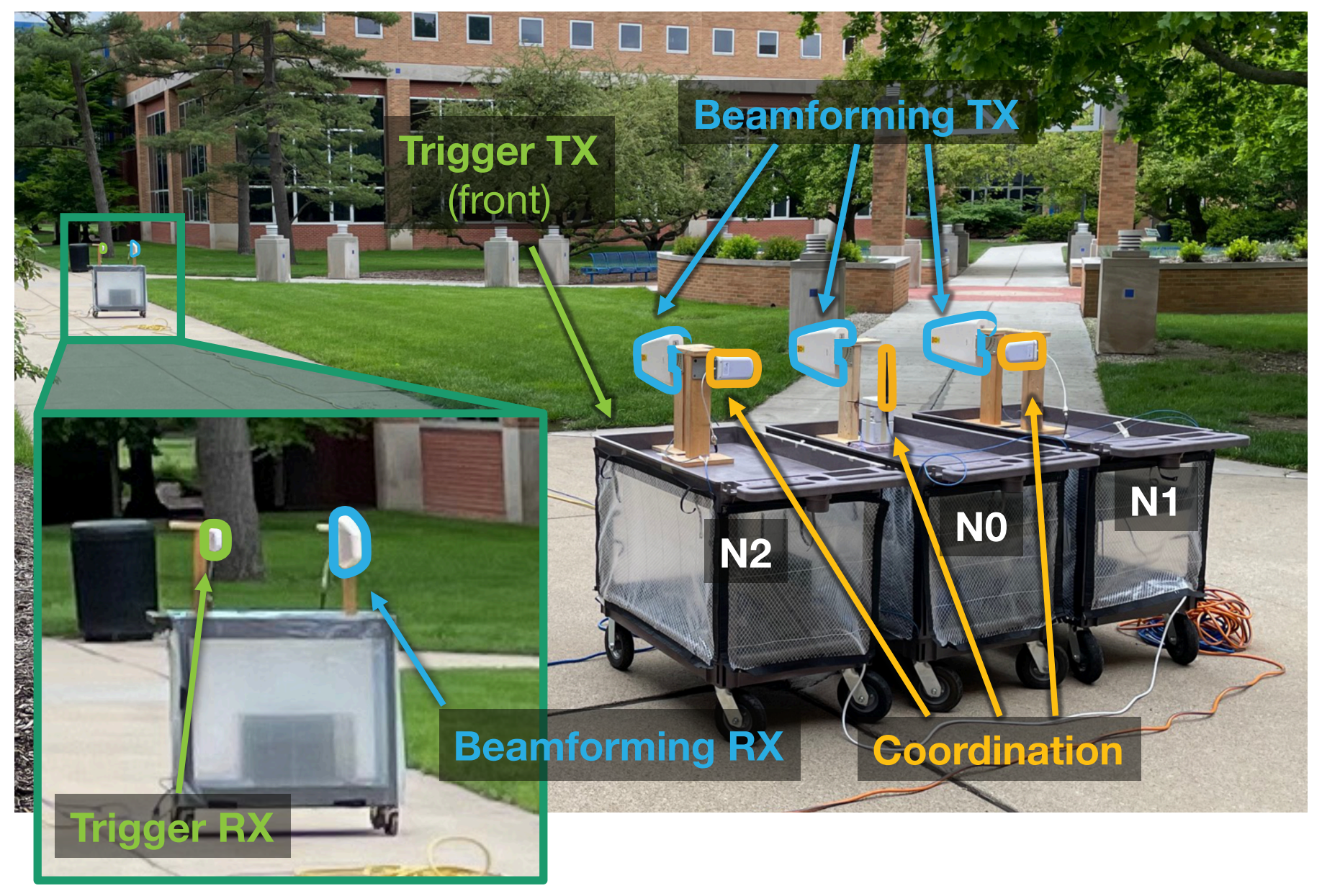
Coherent Gain (Broadside) vs. Beamsteering Angle



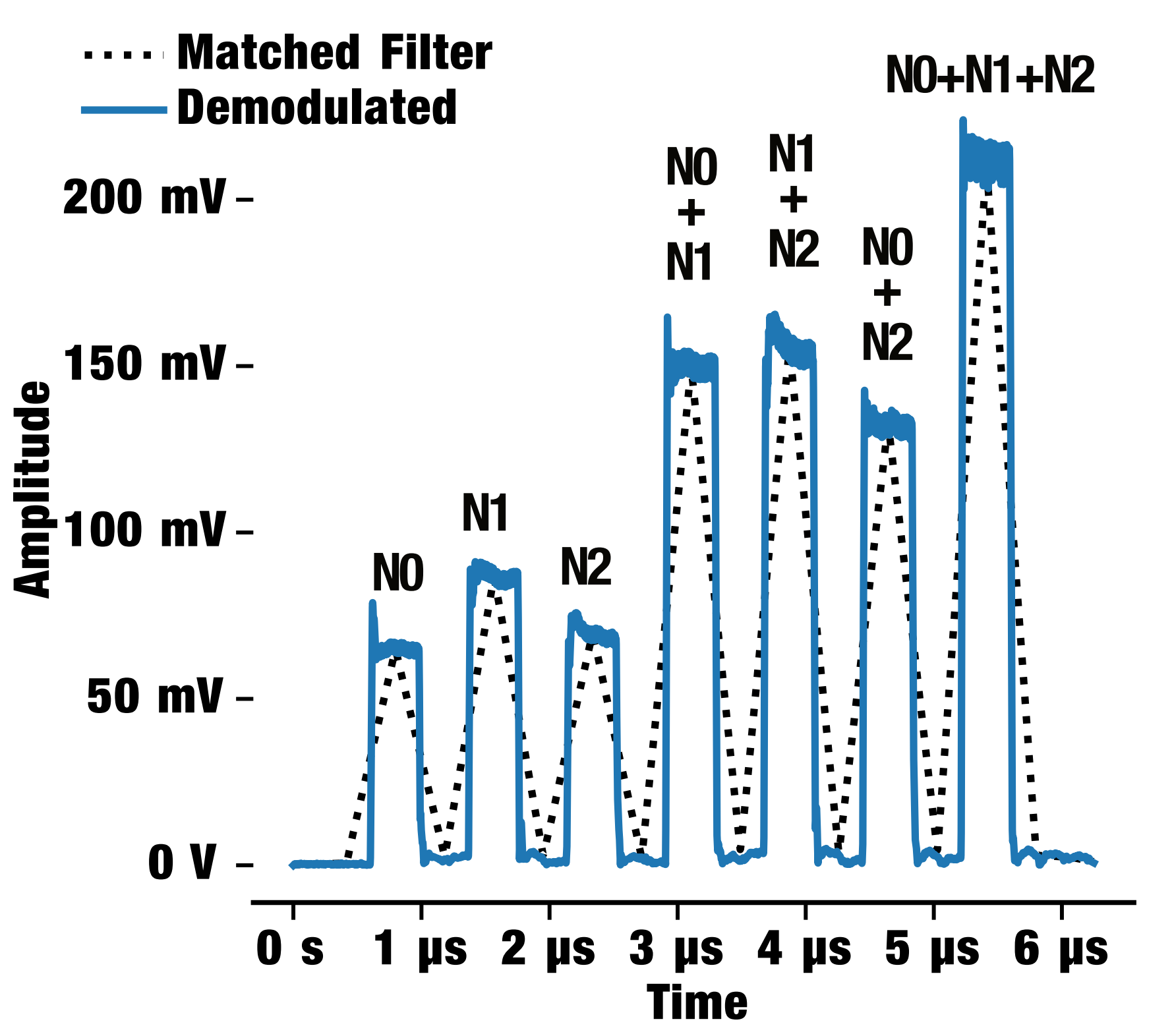
LFM Pulse Inter-arrival Time vs. Beamsteering Angle



Experimental Setup



CW Pulse Train Matched Filter



Measurement Summary

Beamforming Gain	Beamforming Standard Dev.	Theoretical Throughput*
9.32 dB (95%)	< 60.00 ps	~1.6 Gbps

*Based on Monte-Carlo simulations of BPSK data