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# RF-Photonics for Positioning, Navigation, and Timing

## S&T Campaign: Materials Research
*Photonics*

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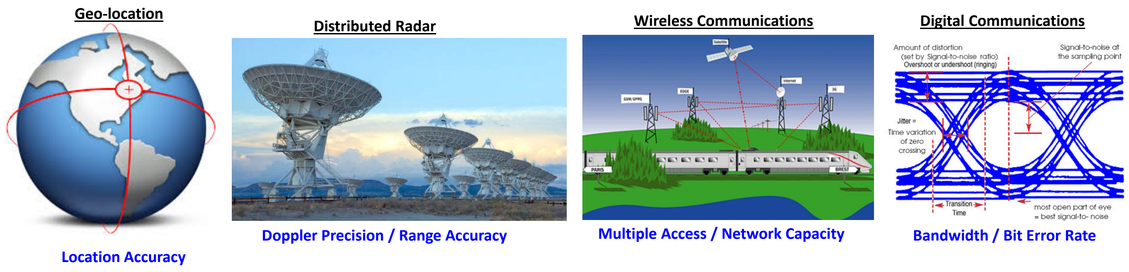
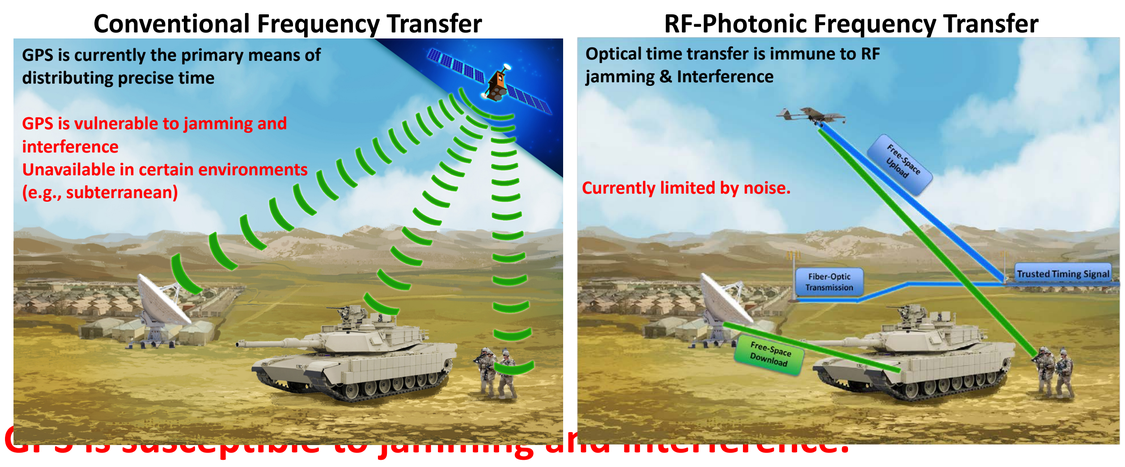
## Research Objective

- Precise frequency references are crucial for several Army-relevant applications.



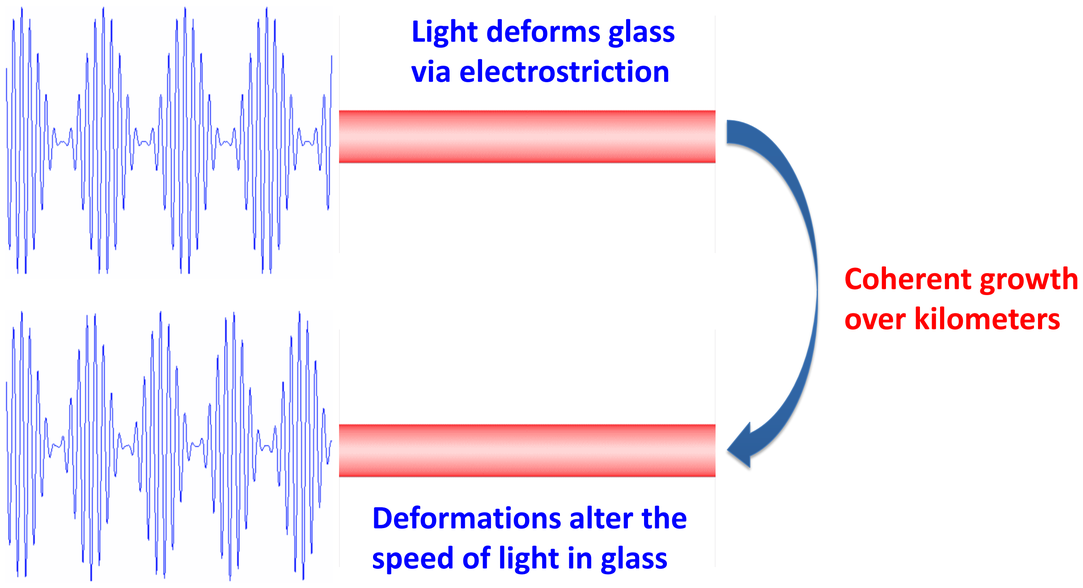

- GPS is the conventional means of transferring frequency references.




- GPS is susceptible to jamming and interference.
- **RF-Photonic transmission is potentially covert, precise, and resistant to jamming.**

## Challenges

- Existing optical communications cannot provide the frequency precision required for positioning, navigation, and timing.
- Conventional fiber-optic systems are limited by noise.
- Fiber-induced noise dominates at distances of 1 km or more.
- ARL determined that Rayleigh scattering is a dominant source of fiber-induced noise.[1]



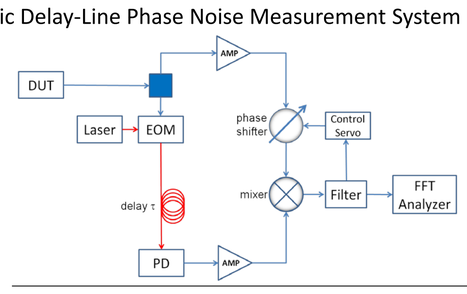

- **Conventional noise suppression requires two-way active feedback (not conducive to scaling to communications networks).**
- **Alternative means of suppressing fiber-induced noise are required make RF-photonic frequency transfer practical for Army positioning, navigation, and timing applications.**

Recent Awards for the above research.
1. 2013 Army Research and Development Achievement Award.
2. 2014 International Frequency Control Symposium Best Student Paper Award.
3. 2014 OSD Scientist of the Quarter Award for the 3rd Quarter.

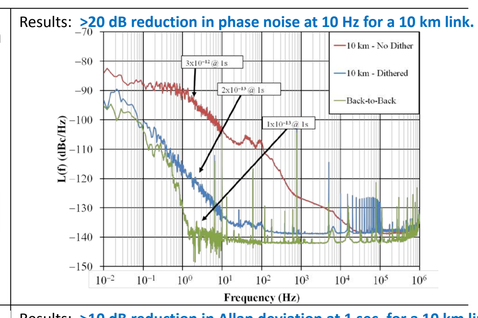
## ARL Facilities and Capabilities Available to Support Collaborative Research

- **Precision metrology:**
  - RF-photonic delay-line phase noise test system
  - Digital Allan Deviation measurement system

Photonic Delay-Line Phase Noise Measurement System

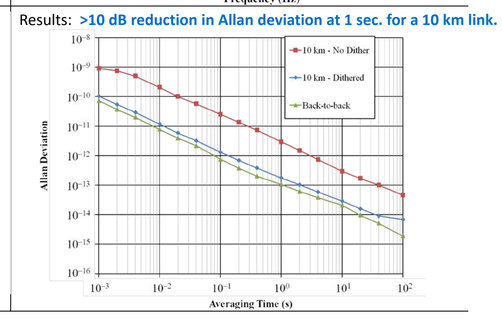



Results: >20 dB reduction in phase noise at 10 Hz for a 10 km link.




Precision Allan Deviation Measurement System

Results: >10 dB reduction in Allan deviation at 1 sec. for a 10 km link.




- **Recent achievements:**
  - **Discovery that laser frequency dithering suppressed fiber-induced noise.**
  - **Demonstration of 10x better than GPS frequency distribution over 10 km of optical fiber without two-way active feedback.[2,3]**

Performance Comparison: **~10 dB better than GPSDO at 1 second.**

| Oscillator Type | Rubidium | Cesium | GPSDO | Fiber Link |
|---|---|---|---|---|
| Stability at 1 second | $5 \times 10^{-11}$ to $5 \times 10^{-12}$ | $5 \times 10^{-11}$ to $5 \times 10^{-12}$ | $1 \times 10^{-10}$ to $1 \times 10^{-12}$ | $1 \times 10^{-13}$ (1 m) $2 \times 10^{-13}$ (10 km) |
| Stability at 1 day | $5 \times 10^{-12}$ | $8 \times 10^{-14}$ to $2 \times 10^{-14}$ | $8 \times 10^{-13}$ to $5 \times 10^{-14}$ | TBD |
| Phase noise (dbc/Hz, 10 Hz from carrier) | −90 to −130 | −130 to −136 | −90 to −140 | −135 (10 km) −140 (1 m) |
| Produces on-time pulse without additional synchronization | No | No | Yes | No (requires optical combs) |
| Cost (USD) | $2,000 to $10,000 | $30,000 to $75,000 | $3,000 to $15,000 | $6,000 to $10,000 |

Data from NIST Technical Paper

## Complementary Expertise/ Facilities/ Capabilities Sought in Collaboration

- **Modeling of acoustic and thermal phonons in fused-silica fibers and air.**
- **Modeling of thermodynamic scattering in fused-silica fibers and air.**
- **Modeling of amplitude-to-phase noise conversion in high-speed photodiodes.**
- **Design and construction of low-noise, high-linearity photoreceivers.**
- **Design and construction of efficient and low-chirp electro-optic modulators.**

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