AEROSPACE

TIME TRANSFER TESTBED

Resilient Timing for the Missions that Matter

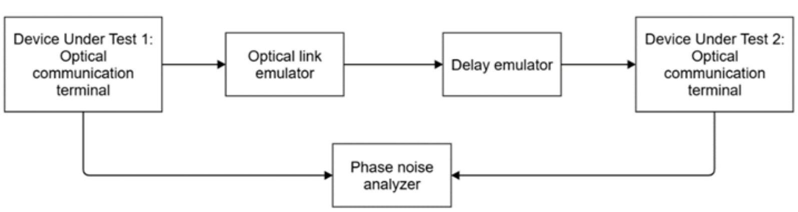
In an era where distributed architectures, contested environments and precision timing are mission-critical, there is a growing need for resilient, GNSS-independent time transfer solutions. Time transfer systems are used to measure the time offset of a local clock to a distant reference, enabling clock synchronization or correction, correlated observations, and communications handoffs. The Aerospace Corporation's Time Transfer Testbed addresses this need with a state-of-the-art capability for evaluating, emulating and validating time synchronization techniques across RF and optical links.

Designed to support spaceborne and terrestrial systems, the testbed provides a controlled environment to assess the accuracy, stability and robustness of one-way and two-way time transfer protocols. Backed by Aerospace's deep technical expertise in timing, synchronization and space system validation, this testbed enables mission-ready solutions.

Application Schematics

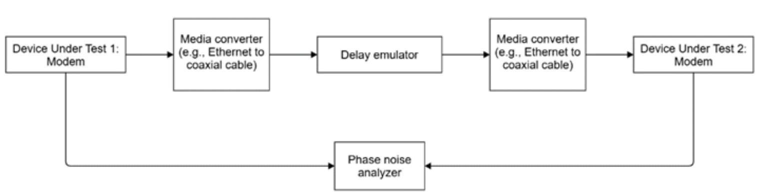
Optical Time Transfer Link Emulation

Simulates spaceborne optical time transfer, incorporating true time delay, fixed and variable optical attenuation for free-space loss and fades, optical amplification, and pointing-and-tracking validation.



Time Transfer Validation

Evaluates the accuracy and stability of one-way and two-way time transfer links, incorporating propagation delay modeling, relativistic corrections and synchronization performance metrics.



Contact

› Matthew Kelley
matthew.j.kelley@aero.org

Key Capabilities and Features

- › Emulates time delays up to 1 second
- › Supports one-way and two-way time transfer (RF and optical)
- › Models propagation effects: attenuation, turbulence, and amplification
- › Validates pointing and tracking for optical synchronization
- › Includes Kalman filtering for improved synchronization accuracy

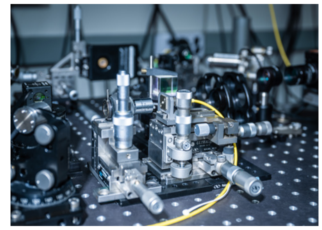
Applications

- › Spaceborne and terrestrial time transfer validation
- › RF and optical network synchronization
- › GNSS-independent precision timing
- › Dynamic range and range rate emulation

AEROSPACE

Specifications

Capabilities	Description
Interfaces	• Differential and single-ended SMA (up to 18 GHz) • SFP+ (up to 16 Gbit/s)
Physical Layer	• Propagation delay emulator o Signal baud rate: 2 GBd o True time delay: 60 µs to 1 s (up to cislunar space) o Doppler shift: < 100 PPM (30 km/s) o Jitter: 6 ps RMSE • Optical channel emulator o Propagation loss (variable optical attenuator): > 50 dB o Atmospheric turbulence (fast variable optical attenuator): > 40 dB o Pre- and post-link amplification (EDFA): up to 23 dBm output o Pointing and tracking: +/– 300 urad added jitter
Measurement Metrics	Allan variance (AVAR), modified Allan variance (MVAR), time interval error (TIE), time variance (TVAR)
Phase Noise Analyzer	• Direct-digital phase noise measurement (COTS) o Frequency range: 1 to 200 MHz o Offset frequency range: 0.001 Hz to 1 MHz o Offset frequency rate: < 10 Hz/s o Allan deviation (t = 1s): 7E-15 (5E-15 typical) • Direct-digital phase noise measurement (SDR) o Frequency range: DC to 6000 MHz o Offset frequency range: 0.001 Hz to 50 MHz o Offset frequency rate: < 100 kHz/s o Allan deviation (t = 1s): 8E-14 (4E-14 typical)
Oscilloscope	• Analog bandwidth (max): 16 GHz • Analog sample rate (max): 50 GSa/s (4-channel) • Waveform memory (max): 20 Mpts (4-channel) • Scope channels: 4
External Reference Clocks	Lock internal timing reference to external reference. External reference inputs: PPS, 10 MHz, GPS Antenna
Internal Reference Clocks	• ADEV typically less than 5E–15 at t = 1s; 1E–16 at t = 1000s • Close-to-carrier phase noise and AM noise at offsets from 0.001 Hz • Single- or dual-reference oscillator inputs allow cross-correlation measurements with noise floor approaching –175 dBc/Hz
Arbitrary Waveform Generator	• Frequency range: 10 MHz to 18 GHz • Analog sample rate: 50 GSa/s • Amplitude range: 25 dBm to -70 dBm at 1 GHz, 18 dBm to -77 dBm at 13 GHz • Accuracy: ± 0.5 dB at 1 GHz, ambient 16 °C to 26 °C • Resolution: 0.01 dB • Amplitude flatness: ± 3 dB, 10 MHz to 10 GHz • Amplifier 1 dB compression: > 25 dBm at 1 GHz, > 22 dBm at 13 GHz



The optical pointing and tracking testbed serves as an optical channel emulator, representing terminal pointing and tracking jitter and signal fades in a coherent optical link.

The digital propagation delay emulator (center rack, top) uniquely enables signal true time delays and Doppler shifts commensurate with the low-Earth to cis-lunar orbits. This technology is based on Aerospace proprietary technology.

View of the time transfer testbed incorporating an optical transceiver interface module and software-defined radio (SDR). The SDR enables phase noise characterization of Doppler-shifted links.

Acronym Definition List

GNSS – Global Navigation Satellite System
RF – Radio Frequency
SMA – SubMiniature version A
SFP – Small Form-Factor Pluggable
PPM – Parts Per Million
RMSE – Root Mean Square Error
EDFA – Erbium-Doped Fiber Amplifier
COTS – Commercial Off The Shelf
SDR – Software-Defined Radio
GPS – Global Positioning System
AM – Amplitude Modulation

The Aerospace Corporation

The Aerospace Corporation is a leading architect for the nation's space programs, advancing capabilities that outpace threats to the country's national security while nurturing innovative technologies to further a new era of space commercialization and exploration. Aerospace's national workforce of more than 4,600 employees provides objective technical expertise and thought leadership to solve the hardest problems in space and assure mission success for space systems and space vehicles. For more information, visit www.aerospace.org.

The Aerospace Corporation | 14745 Lee Road, Chantilly, VA 20151 USA | www.aerospace.org