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# Fiber-Enhanced GNSS Distribution:

## Achieving Precision, Reliability, and Scalability

# Fiber-Enhanced GNSS Distribution

## Architecture and Project overview

**Project scope:** GNSS **Reference signal transport** to the timing appliance.

### Architecture:

- Utilized **RFoF and Power over fiber** technology to transport reference signal to timing appliance.
- Optical transmission of GNSS signals via fiber
  - Support for long distances (> 100m)
  - Support for high splitting ratios
  - Immune to EMI along cable runs
  - Use of Power-over-Fiber technology to supply antenna
    - No additional power outlet at antenna site required
    - Reduced lightning protection requirements
- Electrical transmission of GNSS signals via RF cable
  - Use on the last meters
  - Support of legacy hardware (without optical input)

### Application illustration

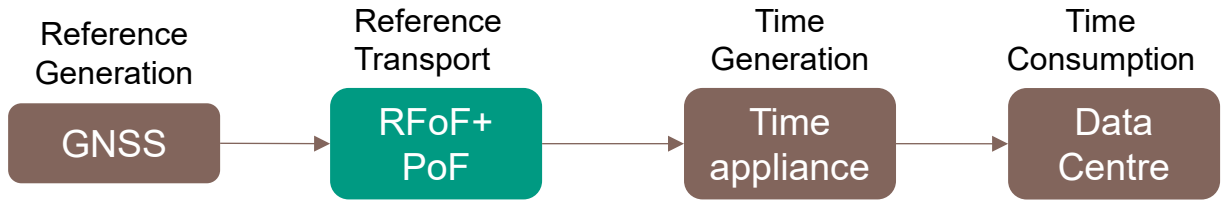



Fig-1 Project scope

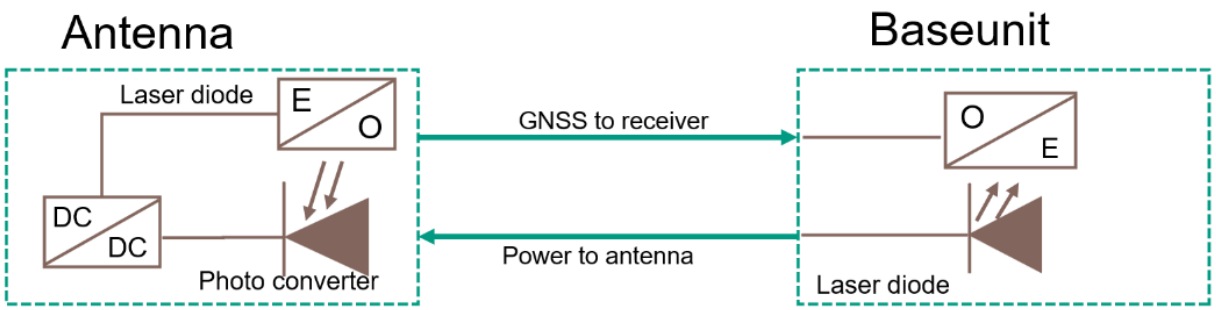



Fig-2 Reference transport design

# Fiber-Enhanced GNSS Distribution

## Reliability

- Identify and mitigate jamming and spoofing attacks
- Continuous monitoring of GNSS signal quality
  - Create alarm messages
  - Switch to another signal source
- Use multiple antennas over large areas
  - Check delays (use of similar fiber lengths)
  - Alternatively: Prepare PTP servers before switching between GNSS signal sources

**Detect → Alarm → Switch → Maintain service continuity**

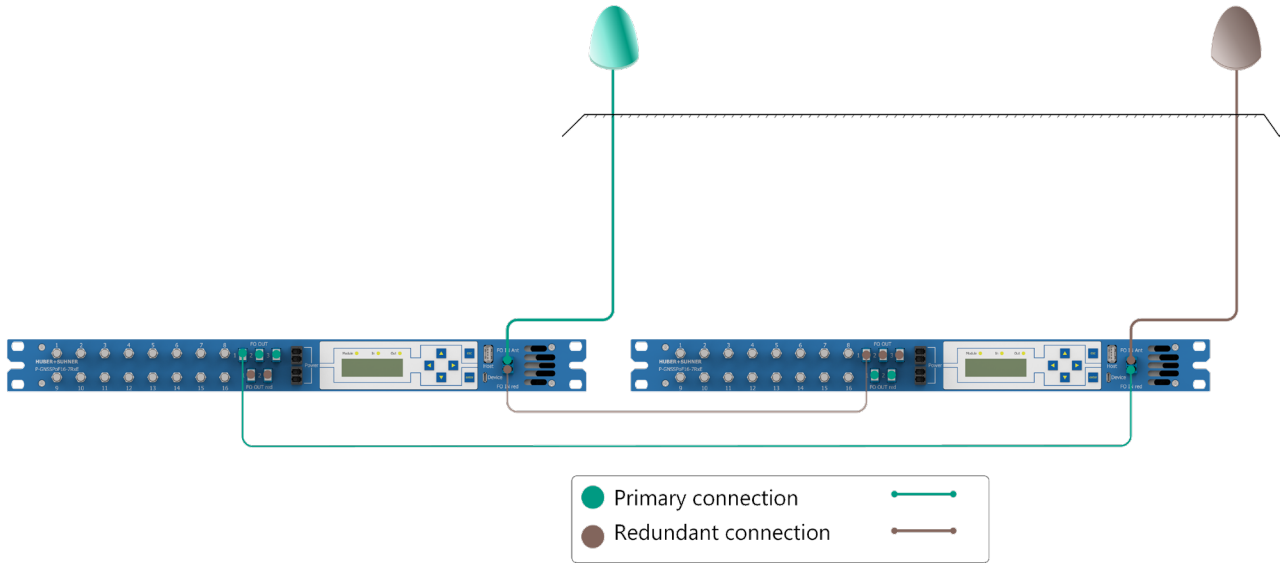



Fig-3 Cross connect system with Spatial diversity

# Fiber-Enhanced GNSS Distribution

## **Precision-** Time Delay compensation

- **Propagation speed in optical fibre is typically ~2/3 c** (determined by the effective refractive index of the fibre)

  Example: ITU-T G.652 fibre @ 1550 nm

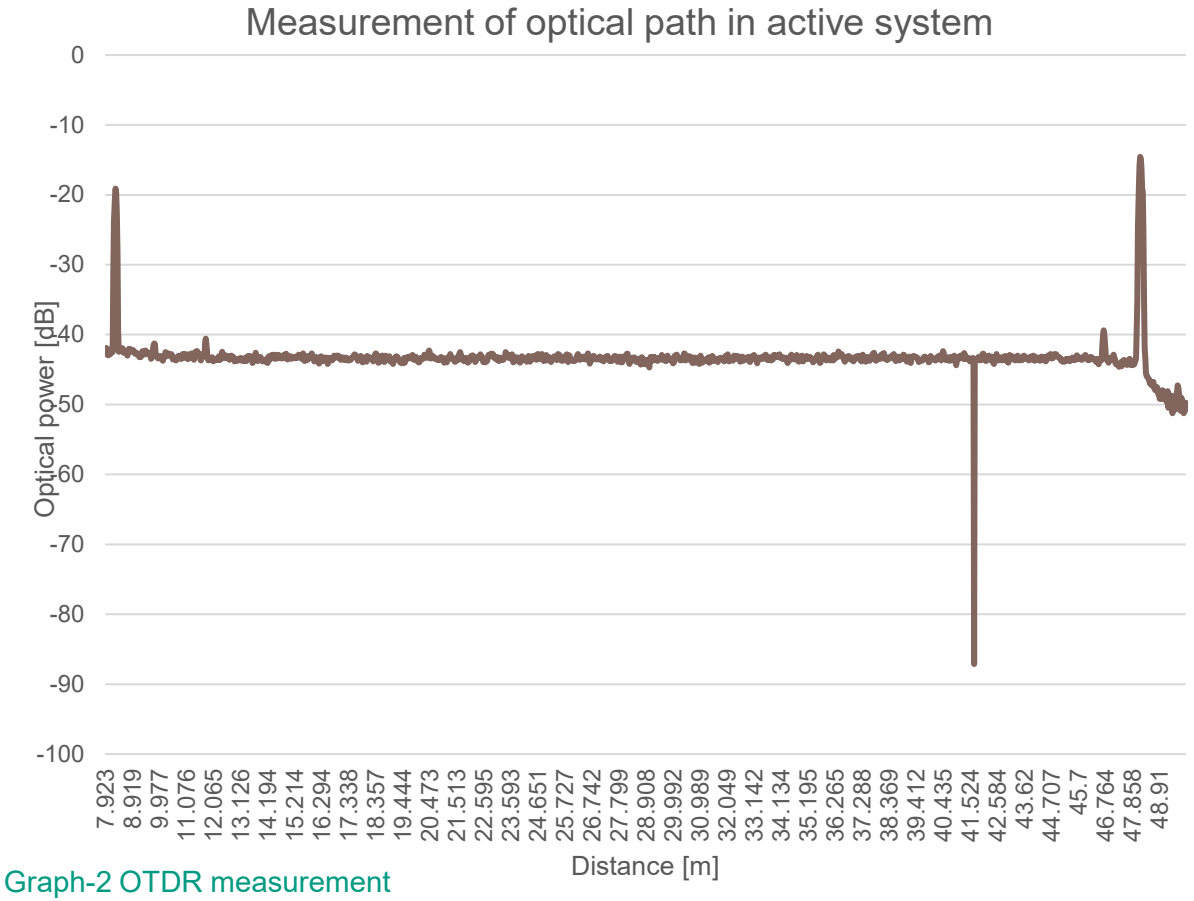
  Effective group refractive index: **n ≈ 1.467**

  Propagation speed: **v = c / n ≈ 2.04 × 10⁸ m/s (≈ 0.68 c)**

  - **Delay per meter: ≈ 4,9 ns**

→ Similar delay for optical and electrical GNSS distribution

- Accuracy in the range of *ns* requires calibrated systems
  - Use of equipment calibrated by manufacturer
  - Use precise OTDR (accuracy ±0.5ns) to measure delay in existing systems
    - Left example: Peaks show back reflections caused by
      - LC/UPC connector (@ 8.2m)
      - Optical Isolator of E/O converter @ antenna site (@ 48.1m)
      - Fibre delay: $(48.1m - 8.2m) \cdot 4.9ns = 39.9m \cdot 4.9ns \approx 195.5ns$
        (Delay of active electronics needs to be added)



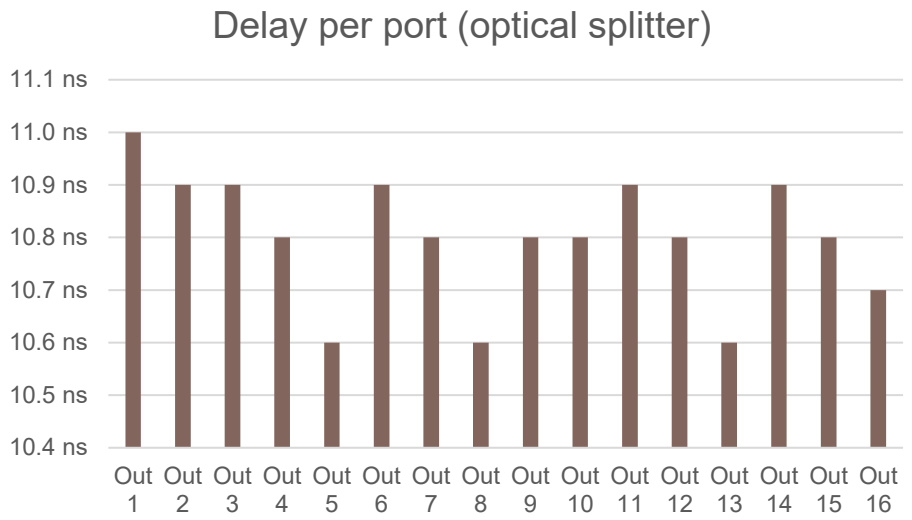

Graph-2 OTDR measurement

# Fiber-Enhanced GNSS Distribution

## **Precision-** Time delay of additional components for optical distribution

**In large GNSS distribution systems, component-induced delay variation dominates fibre delay variability.**

- **Optical Splitter (1:16)**
  - Splitter technology strongly influences port-to-port delay uniformity
  - Accuracy +/- 0.2ns per port
- Splitting technology
  - PLC
  - FBT
- **Optical amplifier**
  - Delay varies between different devices (calibrated devices required)
  - Delay is independent of optical input power




Graph-2 Time delay measurement

| Opt. PIN | Opt. POUT | Time Delay |
|---|---|---|
| 2,2 dBm | 17 dBm | 79,65ns |
| 2,2 dBm | 13 dBm | 79,66 ns |
| -8,0dBm | 17 dBm | 79,74 ns |

Table-1 Time delay for Optical amplifier

# Fiber-Enhanced GNSS Distribution

## Scalability- Basic System

- Support of up to 3 Levels

| | Source * | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Optical Input Power [dBm] | - | 2.4 | -4.9 | -12.3 |
| No. of sats | 12 | 12 | 12 | 12 |
| C/N GPS | 45 | 45 | 45 | 42 |
| C/N Galileo | 42 | 42 | 42 | 40 |
| Dilution of Precision (HDOP) | 0.96 | 0.95 | 0.95 | 1.1 |
| 3D accuracy (MRSE) [m] | 1.8 | 1.8 | 1.9 | 3.4 |

- 64 RF output with same performance or upto 100 RF ports with slightly degraded performance
  - Level 1: 16x RF out
  - Level 2: 48x RF out
  - Level 3: 36x RF out

→ Beginning signal degradation in Level 3 due to **optical power budget** and **reduced C/N** after multiple splits

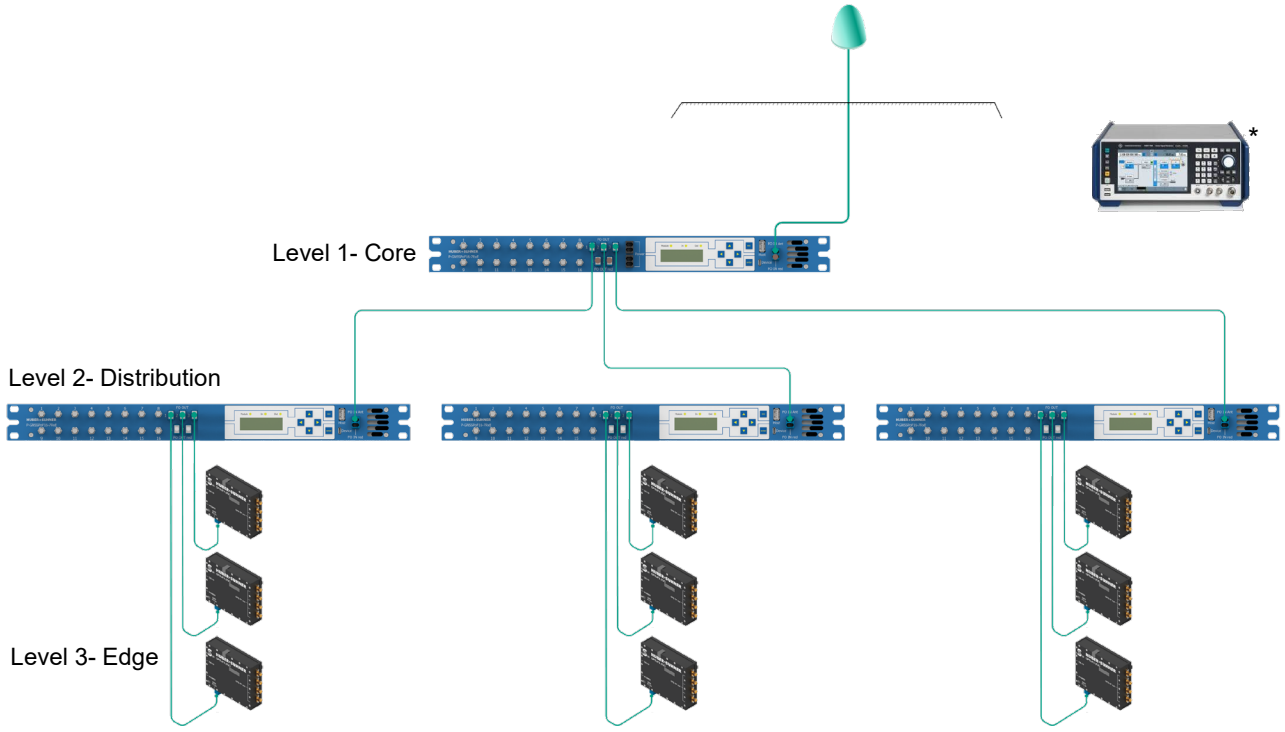



Fig-4 Basic system with 3 layer

* Source: SMBV100B (Rohde & Schwarz)

# Fiber-Enhanced GNSS Distribution

## Scalability- Enhanced System

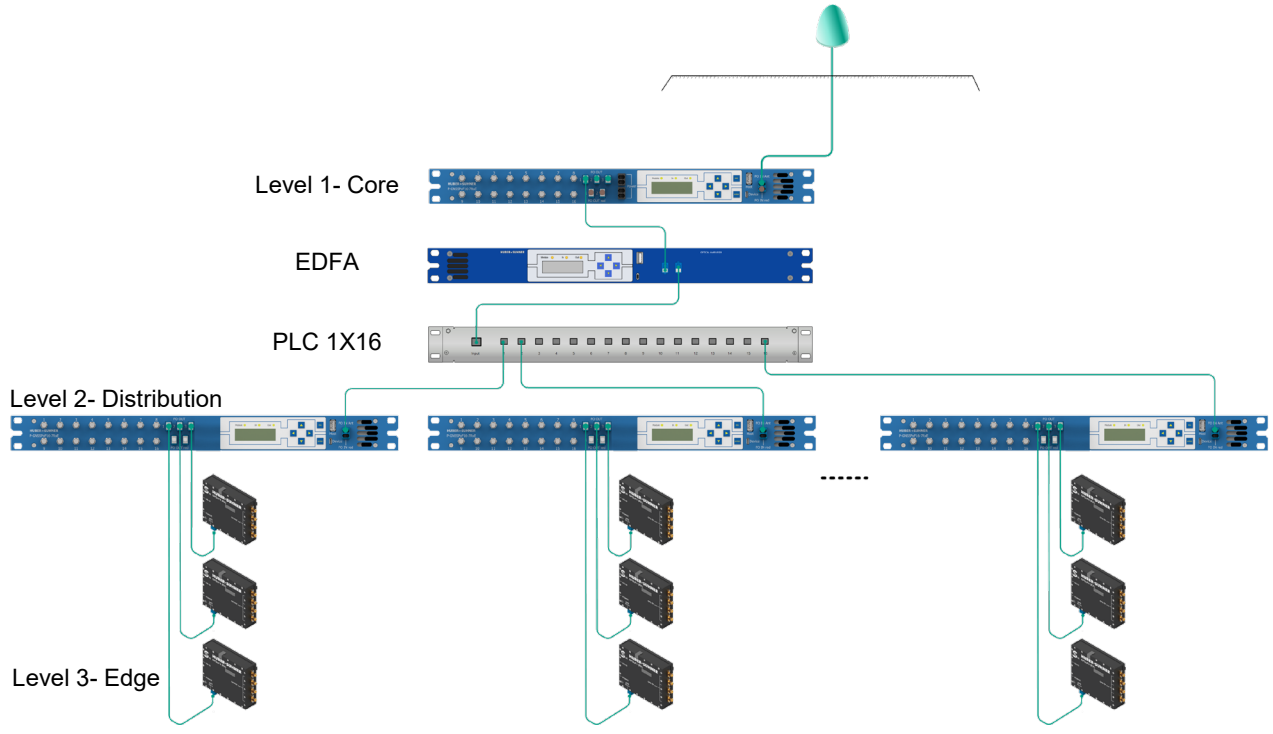
By enhanced system, we mean a fibre GNSS distribution architecture with optical amplification explicitly designed to preserve C/N at scale.

- Use of optical amplifier (EDFA) and 1:16 optical splitter for increased optical budget

| | Source * | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Optical Input Power | - | 2.5 | 4.0 | -3.2 |
| No. of sats | 12 | 12 | 12 | 12 |
| C/N GPS | 45 | 45 | 45 | 45 |
| C/N Galileo | 42 | 42 | 42 | 42 |
| Dilution of Precision (HDOP) | 0.96 | 0.95 | 0.95 | 0.96 |
| 3D accuracy (MRSE) [m] | 1.8 | 1.8 | 1.9 | 1.9 |

- 464 RF ports available
  - Level 1: 16x RF out
  - Level 2: 256x RF out
  - Level 3: 192x RF out

→ No GNSS signal degradation




*EDFA (Erbium Doped Fiber Amplifier)

Fig-5 Enhanced system

# Fiber-Enhanced GNSS Distribution

## Key takeaways

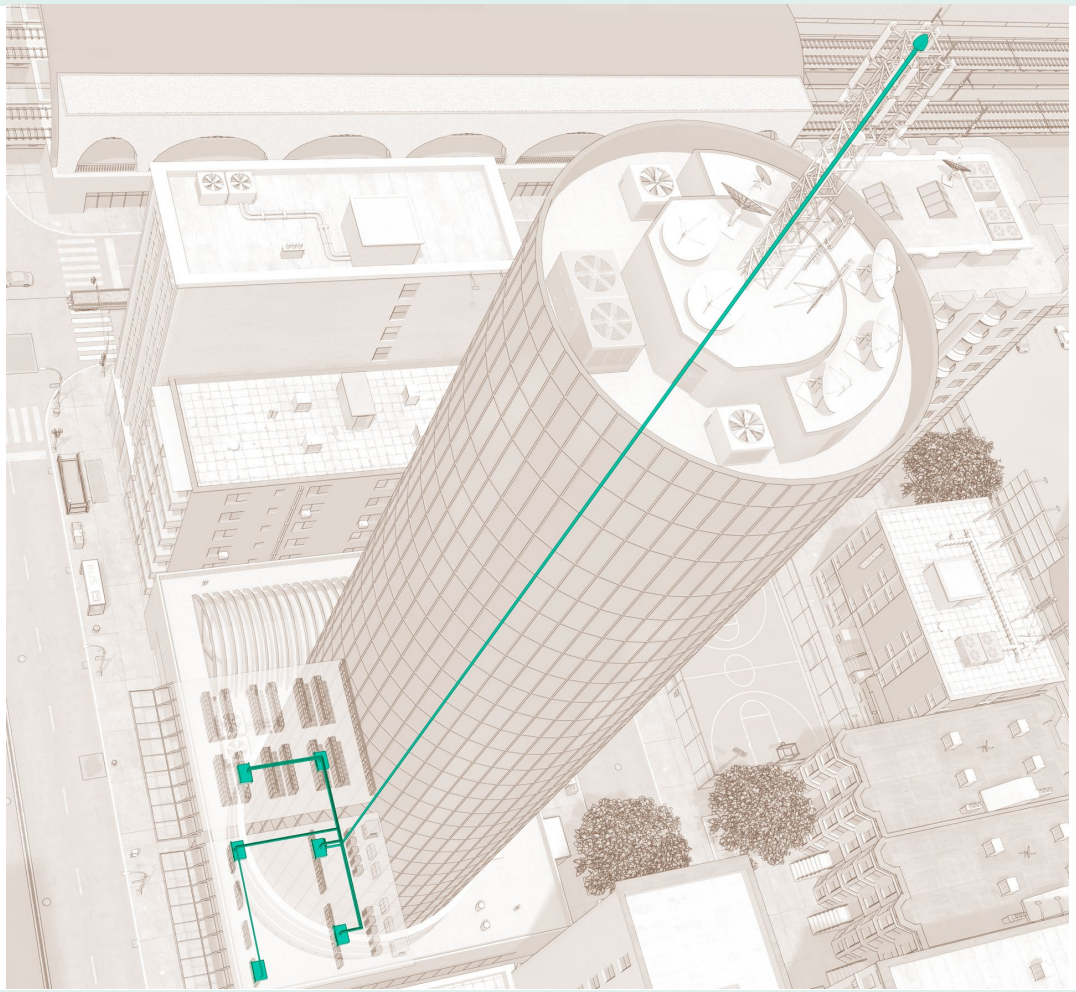
1. GNSS timing performance is defined at system level

2. Fibre enables controlled GNSS distribution at scale

3. Nanosecond accuracy requires delay awareness

4. Scalability depends on architectural choices

5. Future-ready timing infrastructures start with the distribution layer




Connecting – today and beyond

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