MULTI-PURPOSE CONSTANT-DELAY OPTICAL LINK

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Abstract: An electro-optical system for a multi-purpose user signal distribution with a temperature-drift compensation of a fiber link is presented. The delay drift is measured by a RF phase comparison. (CWDM technology is used for combining compensation and user signals. Temperature and other delay variations (e.g. vibrations) are compensated by an internal heated/cooled fiber spool and/or piezo-controlled fiber stretcher. A delay stability better than 1 ps peak-peak in a 24 hour period has been measured using a dedicated measurement setup. The system uses standard commercially available telecommunication optical components.

Principle of Operation

- **Master unit**
- **Slave unit**
- **Temperature-controlled aluminium bobbin with 360 m of Duca SMF fiber**
- **Piezo-controlled fiber stretcher with 40 m of SMF-28 fiber**
- **RF Wilkinson splitter 1:2**
- **Constant optical & RF power (comp. signal)**
- **Temperature-controlled electronics (+/-0.01 °C )**
- **Optical-path compensation:**
  - Piezo-controlled fiber stretcher
  - Compensation-fiber-temperature control

Compensation range

1. Temperature control of the compensation spool - $T_{comp}$
   - $\Delta T = \pm 40 \, ^\circ C$
   - SMF length $L = 150 \, m$
   - Time-delay difference $\Delta t = 600 \, ps (9 \, K_{fiber} \approx 42 \, fs/(m\cdot K))$
   - Control BW $< 0.01 \, Hz$
   - $L_{comp} = 8 - 10^7 \, \mu m$ (temperature coefficient of the spool material)
   - $K_{fiber} = 7.5 - 10 \, ^\circ C$ (temperature expansion coefficient of the glass-fiber length)

   $$ \Delta t = \frac{L - \Delta T_{comp} \cdot (k_n + k_f)}{c} $$

2. Piezo-controlled fiber stretcher
   - $K_{Piezo} = \pm 10 \, ps/V$ on 4 piezo-strecher buttons
   - AU = 500 V (400 V)
   - SMF length $L = 43 \, m$
   - Time-delay difference $\Delta t = 28 \, ps (0.7 \, ps/m)$
   - Control BW $< 1 \, kHz$

   $$ K_{comp} = 44 \, fs/(m\cdot K) $$
   $$ K_{max} = 0.92 \, fs/(V/m) $$

Encouraged by good results from the prototype instrument, InLambda BDT d.o.o. has industrially reconfigured the optical-synchronization system which is now available as the InLambda ODSS Instrument.

Link-stability measurements

- **Reference path:** 3 GHz RF signal over Sucoform S404 cables
- **Constant-delay-path:** 3 GHz RF signal over link-stabilization system + 948 m fiber
- **Uncompensated path:** 3 GHz RF signal over 948 m of fiber

Brief description:
- The optical carrier $\lambda_{opt}$ is directly modulated by the reference RF clock signal at 1200 MHz. The modulated signal is then propagated to the slave unit, where the signal is reflected on a Faraday mirror, demodulated on the photodiode PD and compared with the reference signal. The phase-error signal directly controls the temperature of the internal compensation-fiber spool and/or piezo-controlled fiber stretcher.
- $\Delta t = \Delta T_{comp} \cdot (k_n + k_f)$
- $c = 2.998 \times 10^8 \, m/s$

Brief description:
- The master-RF oscillator signal was compared to the signal transferred over the 948 m long compensated optical link with an independent, custom made phase detector (based on Gilbert-cell AD8302). The phase difference was sampled every 1 second with a running average of 10.

Industrialization

- 19'' 1U rackmount enclosure
- Temperature-controlled SMF-28
- $\Delta T = \pm 1 \, kHz$
- $\Delta t = \pm 6 \, ps$ (948 m fiber)
- Temperature coefficient of the glass-fiber length
- $K_{fiber} = 7.5 - 10 \, ^\circ C$

Control BW $< 0.01 \, Hz$
- Frequency stability $< 0.01 \, Hz$
- $K_{fiber} = 7.5 - 10 \, ^\circ C$
- $T_{comp} = \pm 40 \, ^\circ C$

Type of time-delay device

- Temperature controlled: SMF-28
- Single mode fiber wound on a piezo-strecher button
- Temperature controlled $< 1 \, kHz$
- $K_{comp} = 44 \, fs/(m\cdot K)$
- $K_{max} = 0.92 \, fs/(V/m)$
- $T_{comp} = \pm 40 \, ^\circ C$


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