Distributed Temperature Sensing (DTS): an Introduction

Christine E. Hatch
University of Nevada, Reno
Roadmap

• What is DTS?
• How Does it Work?
• What Can DTS Measure?
• Applications
What is Distributed Temperature Sensing (DTS)?

- Temperature measurement using only the properties of a fiber optic cable.
- The fiber optic cable serves as the thermometer; a laser serving as the illumination source.
- Measurements of temperature every 1-2 meters distributed along cables as long as 30 km can be resolved, every 1-60 minutes, with temperature resolution of 0.01-0.5°C.
How does it work?

• 99.999% of the light energy travels down the fiber optic cable without loss.
• However, Rayleigh, Raman and Brillouin scattering all occur as light is passed through a fiber optic cable.
• Most of the scattering is Rayleigh scattering, in which the scattered light returns at the same wavelength (like a mirror!).
Construction of Optical Fiber

\[ \theta_a = \text{Acceptance Angle} \]

*** Total Internal Reflection
Light enters fiber optic cables, refracts off interface between core and cladding glass, and returns...
General construction of optical fiber

- **Cladding glass**: Typical diameter: 125 μm
- **Primary coating (plastic)**: Typical diameter: 250 μm
- **Core glass**: Typical diameter: 50 to 62.5 μm
“Normal” Uses of Raman Spectra

• Raman shifting is commonly used to infer molecular structure
• Raman Spectroscopy is used routinely to identify concentrations in fluids, and also for speciation states of surface sorption.
• The principal of DTS is to illuminate the material, look at the wavelengths of light that bounce back.
• Compare the (frequency) “spectra” with “libraries” of responses of known materials.
Raman Scattering for Temperature

- Thermal energy drives oscillations within the lattice of the doped amorphous glass making up the fiber.

- When excited by photons (from the laser illumination), the interactions between the photons and the electrons of the solid occurs, and results in light being scattered (re-emitted) is shifted to higher frequencies (spectra).

- The light is shifted in frequency equivalent to the resonant frequency of the oscillating lattice (a constant for any particular molecular structure)

- For us, the energy in the shifted frequency is related to the temperature of the scattering source.
Anti-Stokes Stokes shifts with temperature

Brillouin in frequency

Raman Scattering

Rayleigh Scattering

Brillouin in frequency

Raman (Stokes) in intensity

The Raman wavelengths are predictable and symmetric.

The anti-Stokes (energy gaining) is strongly temperature dependant, but the Stokes is relatively independent of the temperature of the colliding molecule.

The temperature of the scatterer is calculated from the ratio of the anti-Stokes/Stokes Intensity.
Example Traces

Amplitude/Intensity vs. Distance along cable (m)

- Cable on spool
- Cable enters stream
- Ice – slush calibration bath

Legend:
- Red: Stokes
- Blue: Anti-Stokes
How do we know where the scattered light came from?

- The scattered light returns to the detector at the speed of light. So by counting the number of nanoseconds between our laser pulse and the returned signal, the distance is simply:

\[ X = \frac{1}{2} c \times \text{time} \]

since the laser was fired

- Where \( c \) is the speed of light in the fiber (\( \frac{1}{2} \) because time is two-way travel time)

- The light pulse travels about 2 meters in typical glass fibers every 10 nanoseconds.
Currently used in fire monitoring, oil pipeline monitoring, high tension electrical transmission cables, down-hole oil production well monitoring, dam seepage applications…

- Cable lengths up to 30 km
- Resolution of Temperature every 1-2 meters!
- Temperature accuracy up to 0.01 °C
How DTS works (continued)

1. Begin measurement: send laser pulse down fiber

2. Light is backscattered (Raman scattering) along fiber

3. Detect Stokes and Anti-Stokes frequencies of light

4. Convert and amplify electrical signals

5. Acquisition and Analysis (convert to temperatures)

6. Repeat until measurement time is done and send to PC
Advantages of DTS

• The cable serves as the measuring device
• Fiber optic cable is relatively inexpensive ($0.50-$10/meter) and robust (more on that later!) and have small thermal inertia.
• Once installed, continuous measurements do NOT disturb the fluid column (wells) or soils.
• Very high resolution and long cables can provide high density coverage of a landscape, lake, or groundwater reservoir.
• Installations can be temporary or permanent.
Why Study Temperature?

• Many hydrologic, geologic and environmental processes are governed by temperature or
• These processes can be inferred from time/distance series of temperature.
• *Examples:*
  – Deep groundwater flows
  – Geothermal reservoir behavior
  – Soil heat flux
  – Limnology and lake mixing
  – Cave circulation
More Reasons!

• Heat capacity of water >> heat capacity of earth materials

More Applications…

– Surface water - groundwater interaction
– Temperature is key biochemical control
– Acid mine drainage
– Dam and canal seepage
– Evaporation and turbulent heat transport in the atmosphere
– Groundwater inflow in streams– distinct temp signature
– Leachate signatures from landfills
– Snow Hydrology
Details!
(Signal Generator/Detector)

• Calibration is always required, and often challenging for our environmental applications
• The Stokes and Anti-Stokes signals propagate at different speeds they are a function of wavelength and we are interested in their ratio from a specific location!
• Power requirements need to be considered
• Drift and temperature stability?
Details!
(Sensor, the cable)

• Fiber optic cables must be chosen for your environment
• What is it you are really measuring? 
  cable, sunlight, boundary layers?
• Connectors and field repairs
  (this gets easier, believe us!)
• Spurious noise or real signal?
• *Is the cable where you think you left it?* Critical for soils and stream work, where spatial registration is used for calculation of fluxes and moisture content.
• Others
Installing fiber optic cable in Andrews Experimental Forest, Oregon
Distributed Temperature Sensing (DTS) in Agricultural Settings
Splicing connectors onto cable near the Truckee River, California
Installing fiber optic on the shore of Lake Tahoe, California
PASEO – PASI Workshop in a Salt Marsh at Villa del Mar, Argentina!!!