TC for Acoustics Ultrasound and Vibration:

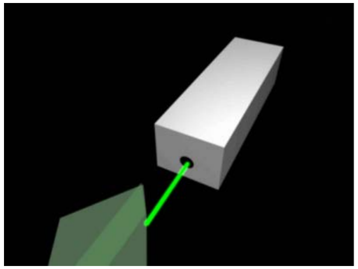
Highlights and Challenges:

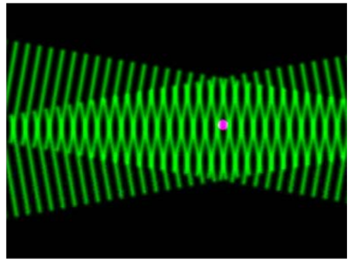
Optically-based primary standards and measurement techniques

Salvador Barrera-Figueroa,
TC AUV Chair

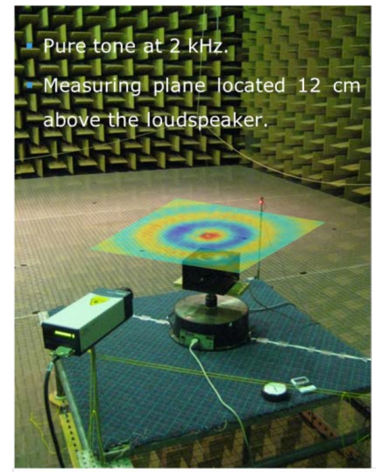
7th EURAMET General Assembly

Reykjavik, May 2013

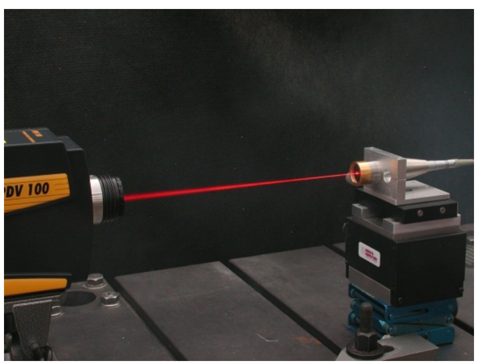




Laser Doppler anemometry + photon correlation



Acousto-optic effect



Optical scanning of transducers

Acousto-optic effect

The acousto-optic effect, that is, the interaction between sound and light, is a novel non-invasive measurement principle capable of fully characterizing an acoustic field. This can be illustrated with three different applications:

- Acoustic imaging
- Beamforming
- Acoustic holography

All the measurements are carried out with a laser Doppler vibrometer (LDV).

Measurement principle

Under the following conditions:

- In air
- Within the audible frequency range
- Levels below the threshold of pain

$$n \cong n_0 + \frac{n_0 - 1}{\gamma p_0} p$$

Refractive index

Refractive index under static conditions

Acousto-optic effect

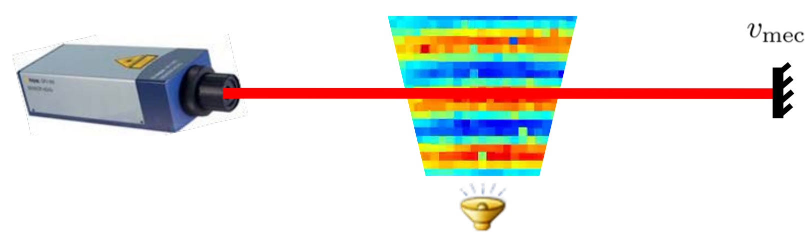
Ratio of specific heats

Static pressure

Acoustic pressure

- No diffraction
- The sound modulates the phase of light
- The pressure is proportional to the refractive index

The acousto-optic effect can be measured with an LDV:



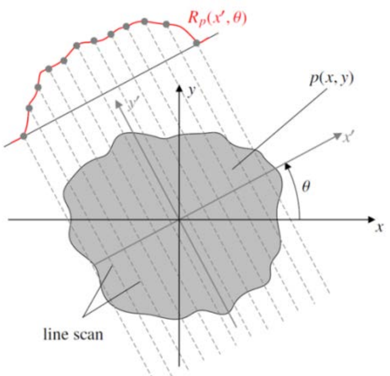
$$v_{\mathrm{LDV}}(t) = \frac{n_0 - 1}{\gamma p_0 n_0} \frac{\mathrm{d}}{\mathrm{d}t} \left(\int_L p(x, y, t) \mathrm{d}l \right)$$

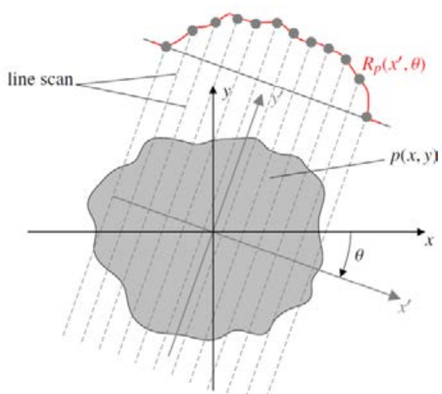
Sound field visualization - Acousto-optic tomography

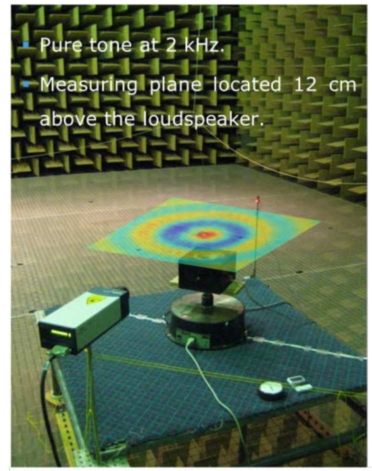
By identifying the line integral of the pressure as the Radon transform of the acoustic field,

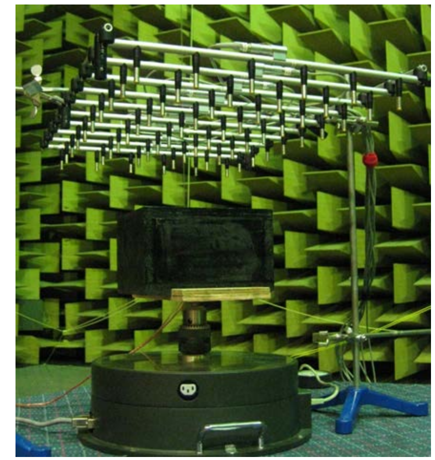
$$R_p(x', \theta) = \int_0^L p(x, y)\mathrm{d}x$$

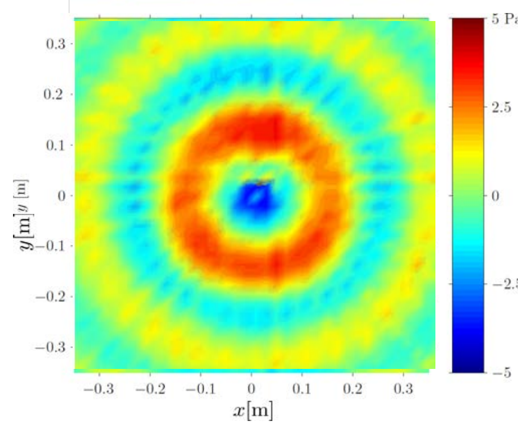
an arbitrary sound field can be reconstructed using tomographic techniques. For instance, one can use parallel scan configuration and probe the sound field in different angles of projection θ:

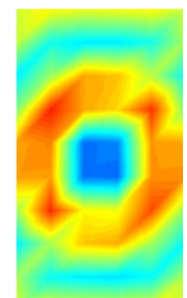








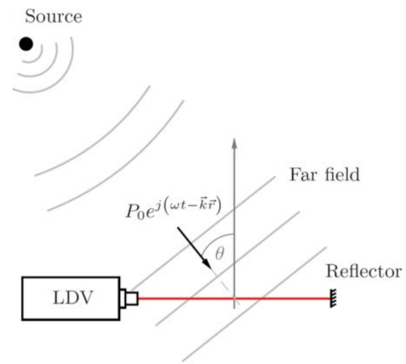


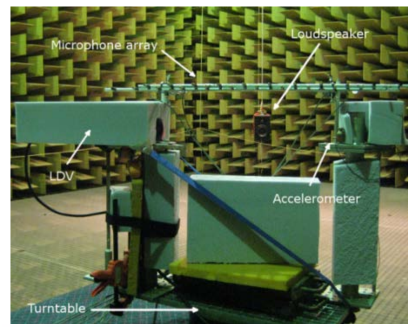


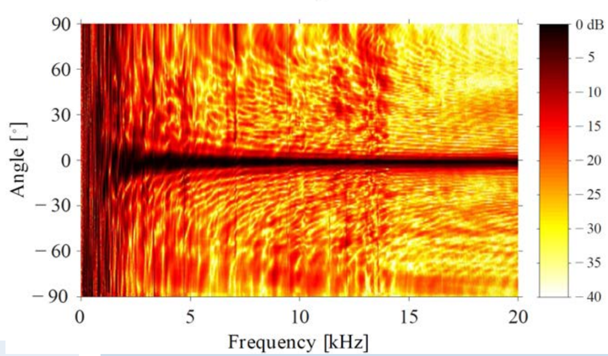
Sound source localization

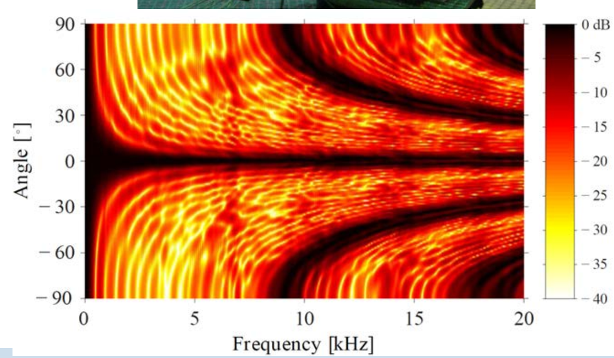
Any beamforming technique based on microphone arrays is limited at high frequencies by spatial aliasing. Theoretically, this limitation could be overcome if an infinite number of microphones were located infinitely close to each other:

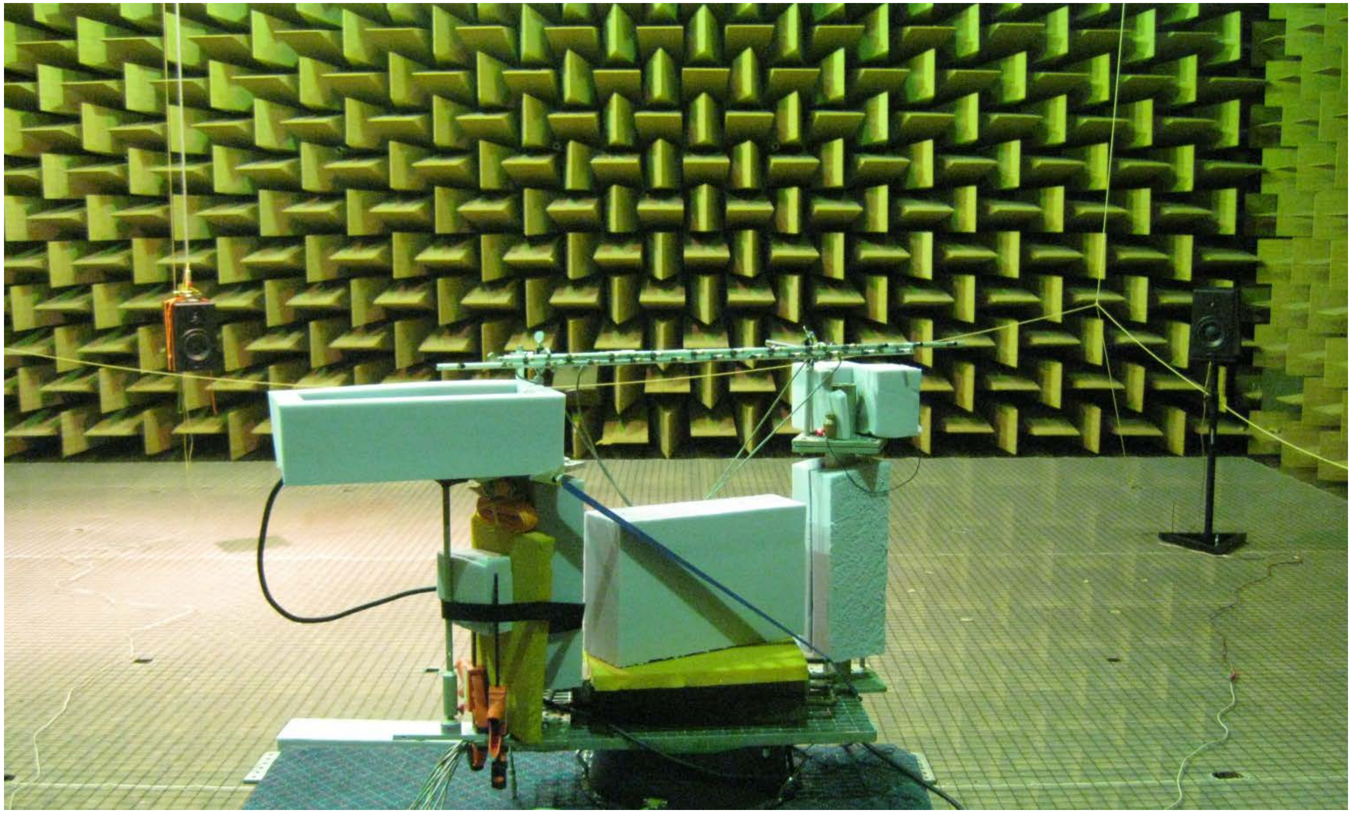
$$\lim_{M\to\infty}\sum_{m=0}^{M-1}\tilde{p}_m d = \int_0^{L_0} P(x,y,\omega)\mathrm{d}l \qquad V_{LDV}(\omega) = j\omega\frac{n_0-1}{\gamma p_0 n_0}\left(\int_{\mathbf{L}} P(x,y,\omega)\mathrm{d}l\right)$$











LDV $\theta = 90^\circ$ | Microphone | LDV $\theta = 30^\circ$