Don Keele, Sept. 26, 2008

BRIEF OVERVIEW OF CBT THEORY

DBK Associates and Labs

1.1. A Brief CBT History

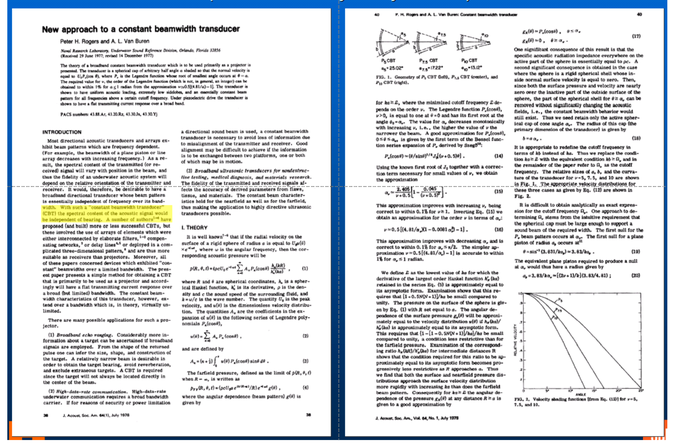
CBT or constant beamwidth transducer theory is based on un-classified military under-water transducer research done in the late 1970s and early 80s [1 - 3]. This research describes a curved-surface transducer in the form of a spherical cap with frequency-independent Legendre shading that provides wide-band extremely-constant beamwidth and directivity behavior with virtually no side lobes.

The theory was applied to loudspeaker arrays by Keele in 2000 [4] where he extended the concept to arrays based on circular-arc line arrays and toroidal-shaped curved surface arrays. Keele also extended the concept to straight-line and flat-panel CBT arrays with the use of signal delays [5]. The 3D sound-field of CBT circular-arc line arrays was analyzed by Keele in 2003 [6]. In 2003 Keele also described the practical implementation of CBT circular-arc line arrays [7].

- First formulated in JASA papers published in 1978 and 1983 describing underwater transducers based on shaded spherical caps (U.S. Naval Research Labs)
  - P. H. Rogers, and A. L. Van Buren, "New Approach to a Constant Beamwidth Transducer," J. Acous. Soc. Am., vol. 64, no. 1, pp. 38-43 (1978 July).
  - A. L. Van Buren, L. D. Luker, M. D. Jevnager, and A. C. Tims, "Experimental Constant Beamwidth Transducer," J. Acous. Soc. Am., vol. 73, no. 6, pp. 2200-2209 (1983 June).
- Applied to loudspeaker arrays in five AES papers by Keele in 2000, 2002, 2003, and 2005
  - [1] "The Application of Broadband Constant Beamwidth Transducer (CBT) Theory to Loudspeaker Arrays," presented at the 109th convention of the Audio Engineering Society, Preprint 5216 (Sept. 2000).
  - [2] "Implementation of Straight-Line and Flat-Panel Constant Beamwidth Transducer (CBT) Loudspeaker Arrays Using Signal Delays," 113th Convention of the Audio Engineering Society, Preprint 5653 (Oct. 2002).
  - [3] "The Full-Sphere Sound Field of Constant Beamwidth Transducer (CBT) Loudspeaker Line Arrays," J. Aud. Eng. Soc., vol. 51, no. 7/8., pp. 611-624 (July/August 2003).
  - [4] "Practical Implementation of Constant Beamwidth Transducer (CBT) Loudspeaker Circular-Arc Line Arrays," presented at the 115th Convention of the Audio Engineering Society, New York (Oct. 2003).
  - [5] "Ground-Plane Constant Beamwidth Transducer (CBT) Loudspeaker Circular-Arc Line Arrays," Presented at the 119th Convention of the Audio Engineering Society, New York (Oct. 2005). (Co-authored with Doug Button of JBL Pro.)

Rogers & Van Buren 1978

(Lots of heavy-duty math!)



Highlighted Text

- "With such a 'constant beamwidth transducer' (CBT) the spectral content of the acoustic signal would be independent of bearing."

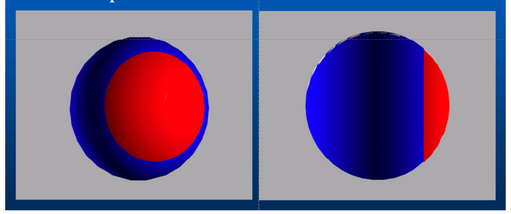
These arrays require no complex DSP processing! Just frequency independent shading (attenuation) applied to the speakers which are mounted on a circular arc.

Spherical-Cap CBT Transducers

Overview

100° Circular Spherical Cap

Oblique View | Side View

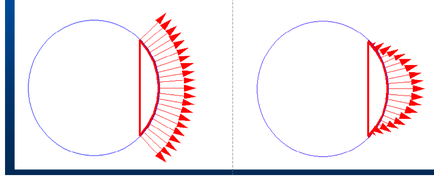


Spherical-Cap CBT Transducers

Overview Cont.:
Legendre Shading of Surface Pressure

No Shading | With Shading

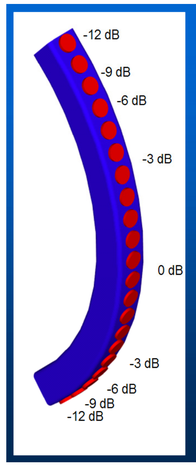
$$p(\theta)=\begin{cases}1 & \text{for} \quad \theta \le \theta_0 \\ 0 & \text{for} \quad \theta > \theta_0\end{cases} \qquad p(\theta)=\begin{cases}P_n(\cos\theta) & \text{for} \quad \theta \le \theta_0 \\ 0 & \text{for} \quad \theta > \theta_0\end{cases}$$



Spherical-Cap CBT Transducers

Overview Cont.: Observations

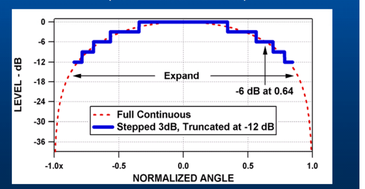
- Provides extremely uniform polars above a certain frequency which are independent of distance
- Beamwidth = 0.64 x Cap Angle
- Surface pressure distribution, nearfield pressure pattern, and farfield pressure pattern are all essentially the same! No nearfield!
- Don't need the rest of the sphere!



Applied to Circular-Arc Line Arrays

CBT Curved Line Source
(Circular Wedge)

Truncated and Stepped Legendre Shading
(Power Loss = 2.3 dB)

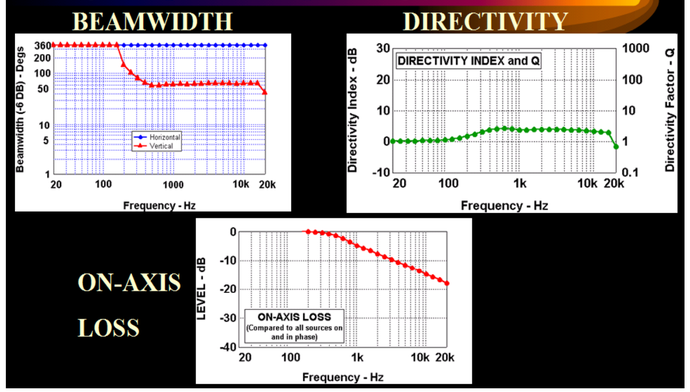


These line arrays provide incredibly even coverage with wide-band constant beamwidth and directivity! Right-left, up-down and near-far! These arrays essentially have no nearfield. The pattern is essentially independent of distance!

Simulation Results

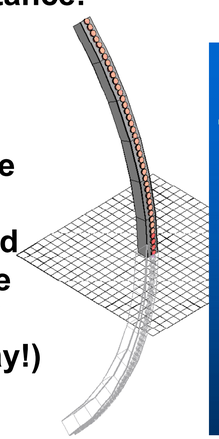
- Curved Line Source (Circular Wedge) *Cont.*
  - 81 points, Legendre shading, 100°, 54" high (one wavelength at 250 Hz)

BEAMWIDTH | DIRECTIVITY



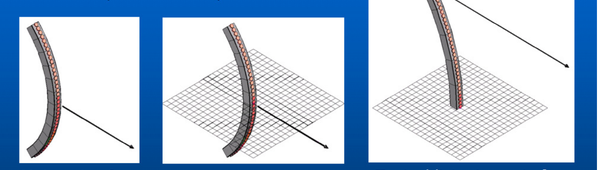
ON-AXIS LOSS

Applied to Ground-Plane Circular-Arc Line Arrays (Uses the ground plane to recreate the other half of the missing array!)



Working Off the Side of the Pattern

- At specific heights, the variation of near-far SPL is minimized because the trajectories approximately coincide with specific constant-pressure contours.



Main axis of free-standing CBT array. | Main axis of ground-plane CBT array. Axis grazes the ground-plane! | Typical listening axis for a ground-plane CBT array. The listener listens on an axis that is offset from the main axis of the array.

Conclusions: Advantages of CBT Ground-Plane Array

- Minimizes/eliminates detrimental floor reflections.
- Extremely uniform coverage: up-down, right-left, and near-far.
- Can be implemented without DSP, passive speaker-level shading can be used.
- Minimizes near-far variation of SPL at certain heights.
- The beneficial effects of the ground-plane can be taken advantage of in two ways:
  - Increase Effective Size:
    - Doubles effective array height.
    - Doubles array sensitivity (+6 dB).
    - Doubles array maximum sound pressure level (SPL) capability (+6 dB).
    - Extends operating bandwidth down by an octave (or two depending on how the beamwidth is defined).
  - Decrease Physical Size:
    - Can half the physical height of the array but maintain the same performance as the full-size free-standing array when a ground plane is available.
  - Or a combination of the two!