Introduction to CBT Loudspeaker Arrays

A Presentation Given to a Joint Meeting of the Boston Sections of the Audio Engineering Society, Acoustical Society of America, and the Boston Audio Society.

January 14, 2010

By

Don Keele

Introduction to CBT Loudspeaker Arrays

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Feel free to interrupt me with questions at any time!

But Wait, Before We Start………….

Are any of you runner?

Keele's A Runner Now!

- Started about two and half years ago.
- Last year I've done 28 competitive events mostly road races: 5K (3.1 mile), 4.5 mile, and 10K distances including five half marathons (13.1 miles); with a triathlon, and a 38-floor stair climb thrown in for good measure!
- Great fun!! My wife thinks I'm crazy!
- Pretty good for a guy who's 69 now!

Last year I ran a half marathon at Big Bear Lake, California. Altitude 6800 feet!

(Sept. 12, 2009)

My goal was to beat 3 hrs. I did it in 2 hrs 50 mins!

Half Marathon Route Map

Took Lots of Pictures Along the Way!

And now back to our regularly scheduled presentation……..

Broadband Constant Directivity

It's Magic!

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Is This Broadband Constant Directivity?

Is This Broadband Constant Directivity?

Nope!

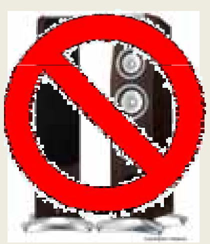
Is This Broadband Constant Directivity?

Is This Broadband Constant Directivity?

Nope!

Is This Broadband Constant Directivity?

Is This Broadband Constant Directivity?



Nope!

Is This Broadband Constant Directivity?

Is This Broadband Constant Directivity?

Nope!

Is This Broadband Constant Directivity?





Is This Broadband Constant Directivity?

Sort of!

In horn’s range only!

Is This Broadband Constant Directivity?






Is This Speaker Broadband Constant Directivity?

Maybe, But Unlikely

Is This Broadband Constant Directivity?

Is This Broadband Constant Directivity?

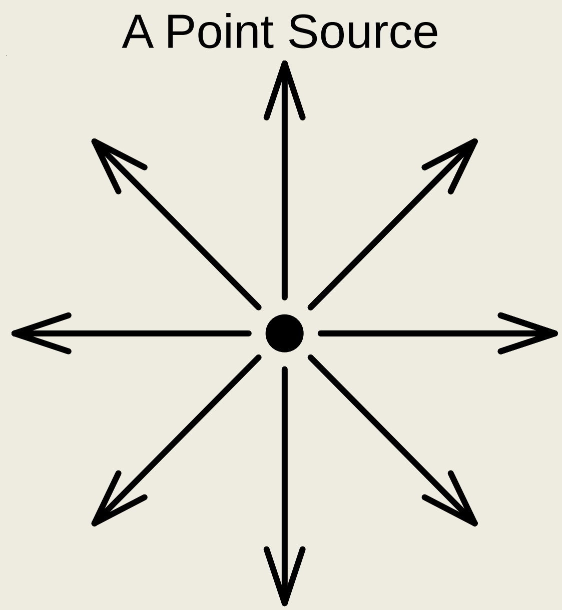




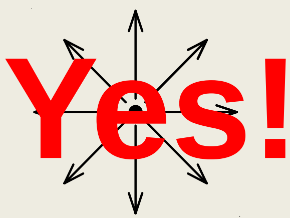


A Big Nope!

Is This Broadband Constant Directivity?

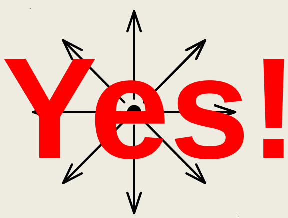


Is This Broadband Constant Directivity?



A Big Yep!

Is This Broadband Constant Directivity?



Neumann U87 Ribbon Mic.
(Figure Eight Pattern)

Is This Broadband Constant Directivity?

Absolutely Yes!

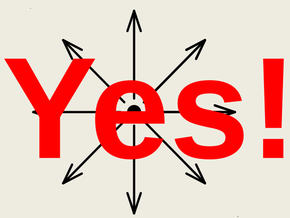
(Depending on design details.)

Is This Broadband Constant Directivity?

Is This Broadband Constant Directivity?





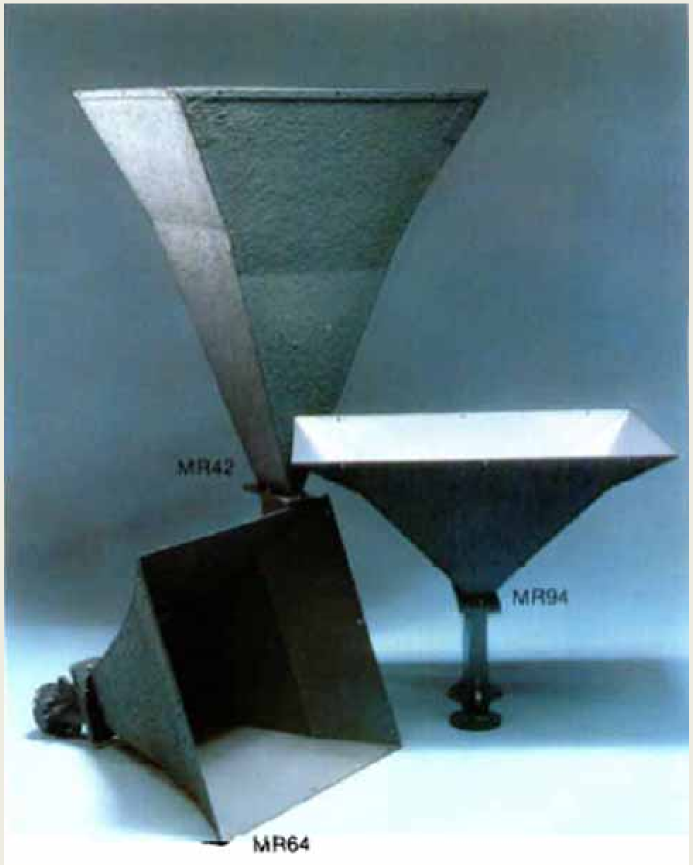




A Qualified Yes!

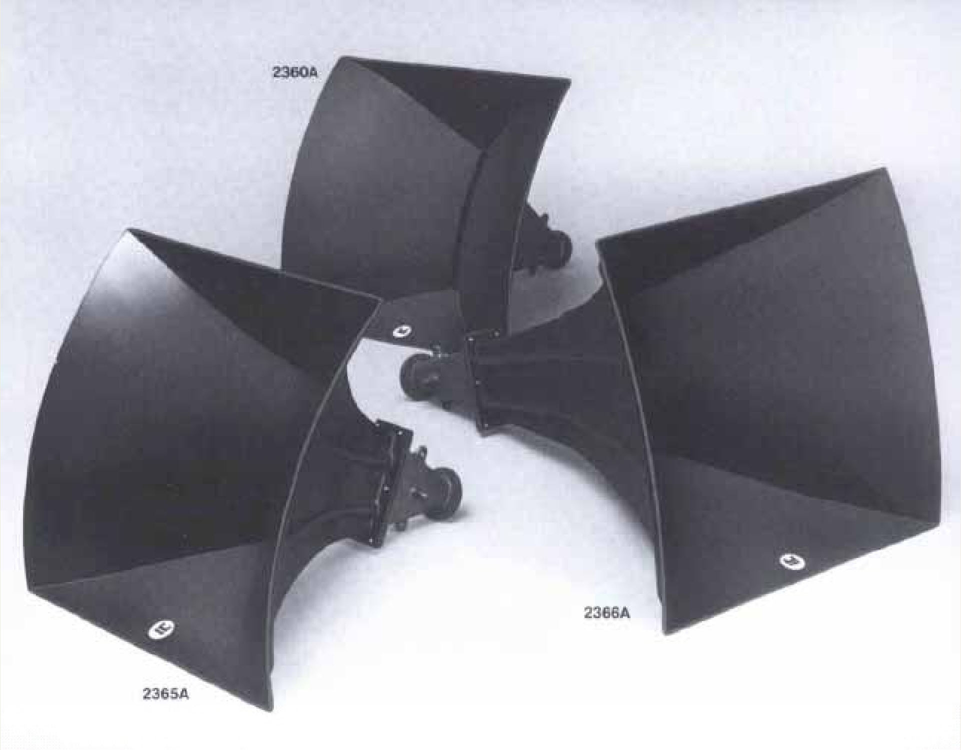
(If the horn’s big enough!)

Is This Broadband Constant Directivity?

Altec Mantaray Pro Horns (Circa 1978)



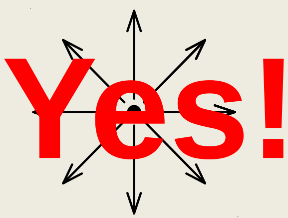
JBL Bi-Radial Pro Horns (Circa 1980)



Is This Broadband Constant Directivity?






A Qualified Yes!

(If the horn's big enough!)

Is This Broadband Constant Directivity?

Keele’s CBT Arrays

Is This Broadband Constant Directivity?

Absolutely Yes!

Caution!! You are About to Enter the Keele “No Spin” Zone

(with due credit to Bill O’Reilly of Fox News)

Remember that what I am going to talk to you about this evening is the topic of two pending Harman CBT patents which will issue soon !

Pending Harman CBT Patents

US 20040240697A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2004/0240697 A1**
Keele, JR. (43) **Pub. Date: Dec. 2, 2004**

(54) **CONSTANT-BEAMWIDTH LOUDSPEAKER ARRAY**

(76) Inventor: **D. Broadus Keele JR.**, Bloomington, IN (US)

Correspondence Address:
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(21) Appl. No.: **10/701,256**

(22) Filed: **Nov. 4, 2003**

Related U.S. Application Data

(60) Provisional application No. 60/473,513, filed on May 27, 2003.

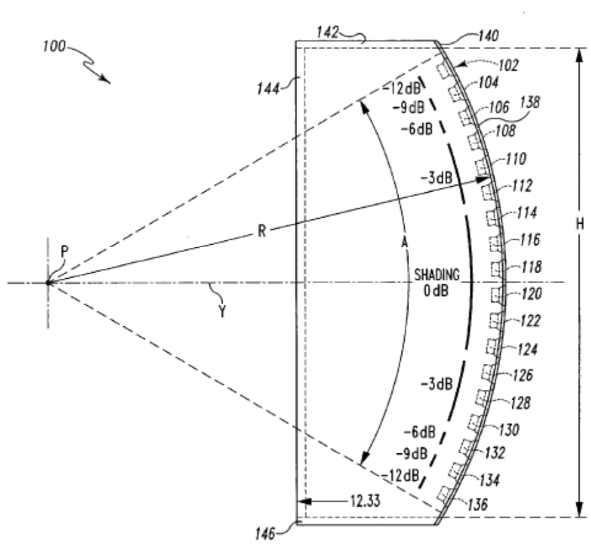
Publication Classification

(51) **Int. Cl.**[7] **H04R 25/00**; H04R 1/02

(52) **U.S. Cl.** **381/336**; 381/335; 381/182

(57) **ABSTRACT**

A loudspeaker is provided for receiving an incoming electrical signal and transmitting an acoustical signal that is directional and has a substantially constant beamwidth over a wide frequency range. The loudspeaker may include a curved mounting plate that has curvature over a range of angles. The loudspeaker may include an array of speaker drivers coupled to the mounting plate. Each speaker driver may be driven by an electrical signal having a respective amplitude that is a function of the speaker driver's respective location on the mounting plate. The function may be a Legendre function. Alternatively, the loudspeaker may include a flat mounting plate. In this case, the respective electrical signal driving each speaker may have a phase delay that virtually positions the speaker onto a curved surface.



US 20060153407A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0153407 A1**
Keele, JR. et al. (43) **Pub. Date: Jul. 13, 2006**

(54) **REFLECTIVE LOUDSPEAKER ARRAY**

(76) Inventors: **D. Broadus Keele JR.**, Bloomington, IN (US); **Douglas J. Button**, Simi Valley, CA (US)

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(21) Appl. No.: **11/371,538**

(22) Filed: **Mar. 8, 2006**

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/701,256, filed on Nov. 4, 2003.

(60) Provisional application No. 60/659,673, filed on Mar. 8, 2005. Provisional application No. 60/473,513, filed on May 27, 2003.

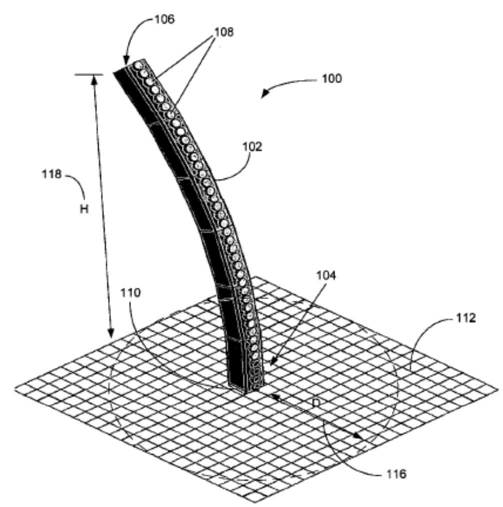
Publication Classification

(51) **Int. Cl.**
H04R 25/00 (2006.01)

(52) **U.S. Cl.** **381/182**

(57) **ABSTRACT**

A reflective loudspeaker array is cooperatively operable with an acoustically reflective planar surface to provide a constructive combination of direct and reflected sound waves that produces a uniform sound field. The uniform sound field provides a controlled sound field in the vertical and horizontal direction, and also provides uniformity from distances close to the reflective loudspeaker array to far way. The direct and reflected sound waves are advantageously and constructively combinable to generate a focused beamwidth of soundwaves. The reflective loudspeaker array includes a plurality of loudspeakers coupled to a surface of the reflective loudspeaker array. The surface may be formed to include at least one curve with a radius of curvature. The reflective loudspeaker array may be placed adjacent an acoustically reflective planar surface such that a frontal plane of a loudspeaker adjacently located closest to the acoustically reflective planar surface is aligned perpendicularly, and a frontal plane of a loudspeaker spaced away from the acoustically reflective planar surface is not aligned perpendicularly.



Military Prior Art

- CBTs first formulated in JASA papers published in 1978 and 1983 describing underwater transducers based on shaded spherical caps.
  - [1] W. J. Trott, “Design Theory for a Constant-Beamwidth Transducer,” Naval Research Laboratory Report 7933 (1975 Sept.)
  - [2] 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).
  - [3] J. Jarzynski, and W. J. Trott, “Array Shading for a Broadband Constant Directivity Transducers,” J. Acous. Soc. Am., vol. 64, no. 5, pp. 1266-1269 (1978 Nov.).
  - [4] 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).

Quote from Introduction:

"It would, therefore, be desirable to have a broadband directional transducer whose beam pattern is essentially independent of frequency over its bandwidth. With such a "constant beamwidth transducer" (CBT) the spectral content of the acoustic signal would be independent of bearing."

New approach to a constant beamwidth transducer

Peter H. Rogers and A. L. Van Buren

Naval Research Laboratory, Underwater Sound Reference Division, Orlando, Florida 32856

(Received 29 June 1977; revised 14 December 1977)

The theory of a broadband constant beamwidth transducer which is to be used primarily as a projector is presented. The transducer is a spherical cap of arbitrary half angle α shaded so that the normal velocity is equal to $U_0 P_\nu(\cos\theta)$, where P_ν is the Legendre function whose root of smallest angle occurs at $\theta=\alpha$. The required value for ν, the order of the Legendre function (which is not, in general, an integer) can be obtained to within 1% for $\alpha \le 1$ radian from the approximation $\nu \simeq 0.5[(4.81/\alpha)-1]$. The transducer is shown to have uniform acoustic loading, extremely low sidelobes, and an essentially constant beam pattern for all frequencies above a certain cutoff frequency. Under piezoelectric drive the transducer is shown to have a flat transmitting current response over a broad band.

PACS numbers: 43.88.Ar, 43.20.Rz, 43.30.Jx, 43.30.Yj

INTRODUCTION

Most directional acoustic transducers and arrays exhibit beam patterns which are frequency dependent. (For example, the beamwidth of a plane piston or line array decreases with increasing frequency.) As a result, the spectral content of the transmitted (or received) signal will vary with position in the beam, and thus the fidelity of an underwater acoustic system will depend on the relative orientation of the transmitter and receiver. It would, therefore, be desirable to have a broadband directional transducer whose beam pattern is essentially independent of frequency over its bandwidth. With such a "constant beamwidth transducer" (CBT) the spectral content of the acoustic signal would be independent of bearing. A number of authors[1-6] have proposed (and built) more or less successful CBTs, but these involved the use of arrays of elements which were either interconnected by elaborate filters,[1-3] compensating networks,[3] or delay lines[4,5] or deployed in a complicated three-dimensional pattern,[6] and are thus more suitable as receivers than projectors. Moreover, all of these papers concerned devices which exhibited "constant" beamwidths over a limited bandwidth. The present paper presents a simple method for obtaining a CBT that is primarily to be used as a projector and accordingly will have a flat transmitting current response over a broad (but limited) bandwidth. The constant beamwidth characteristics of this transducer, however, extend over a bandwidth which is, in theory, virtually unlimited.

There are many possible applications for such a projector.

(1) *Broadband echo ranging.* Considerably more information about a target can be ascertained if broadband signals are employed. From the shape of the returned pulse one can infer the size, shape, and construction of the target. A relatively narrow beam is desirable in order to obtain the target bearing, avoid reverberation, and exclude extraneous targets. A CBT is required since the target will not always be located directly in the center of the beam.

(2) *High-data-rate communication.* High-data-rate underwater communication requires a broad bandwidth carrier. If for reasons of security or power limitation a directional sound beam is used, a constant beamwidth transducer is necessary to avoid loss of information due to misalignment of the transmitter and receiver. Good alignment may be difficult to achieve if the information is to be exchanged between two platforms, one or both of which may be in motion.

(3) *Broadband ultrasonic transducers for nondestructive testing, medical diagnosis, and materials research.* The fidelity of the transmitted and received signals affects the accuracy of derived parameters from flaws, tissue, and materials. The constant beam characteristics hold for the nearfield as well as for the farfield, thus making the application to highly directive ultrasonic transducers possible.

I. THEORY

It is well known[7-9] that if the radial velocity on the surface of a rigid sphere of radius a is equal to $U_0 u(\theta) \times e^{-i\omega t}$, where ω is the angular frequency, then the corresponding acoustic pressure will be

$$p(R,\theta,t) = i\rho c U_0 e^{-i\omega t} \sum_{n=0}^{\infty} A_n P_n(\cos\theta) \frac{h_n(kR)}{h_n'(ka)} , \qquad (1)$$

where R and θ are spherical coordinates, h_n is a spherical Hankel function, h_n' is its derivative, ρ is the density and c the sound speed of the surrounding fluid, and $k=\omega/c$ is the wave number. The quantity U_0 is the peak velocity, and $u(\theta)$ is the dimensionless velocity distribution. The quantities A_n are the coefficients in the expansion of $u(\theta)$ in the following series of Legendre polynomials $P_n(\cos\theta)$,

$$u(\theta) = \sum_{n=0}^{\infty} A_n P_n(\cos\theta) , \qquad (2)$$

and are defined by

$$A_n = (n+\tfrac{1}{2}) \int_0^{\pi} u(\theta) P_n(\cos\theta) \sin\theta \, d\theta . \qquad (3)$$

The farfield pressure, defined as the limit of $p(R,\theta,t)$ when $R \to \infty$, is written as

$$p_{FF}(R,\theta,t) = (\rho c U_0 a e^{ik(R-a)}/R) e^{-i\omega t} g(\theta) , \qquad (4)$$

where the angular dependence (beam pattern) $g(\theta)$ is given by

Keele CBT References

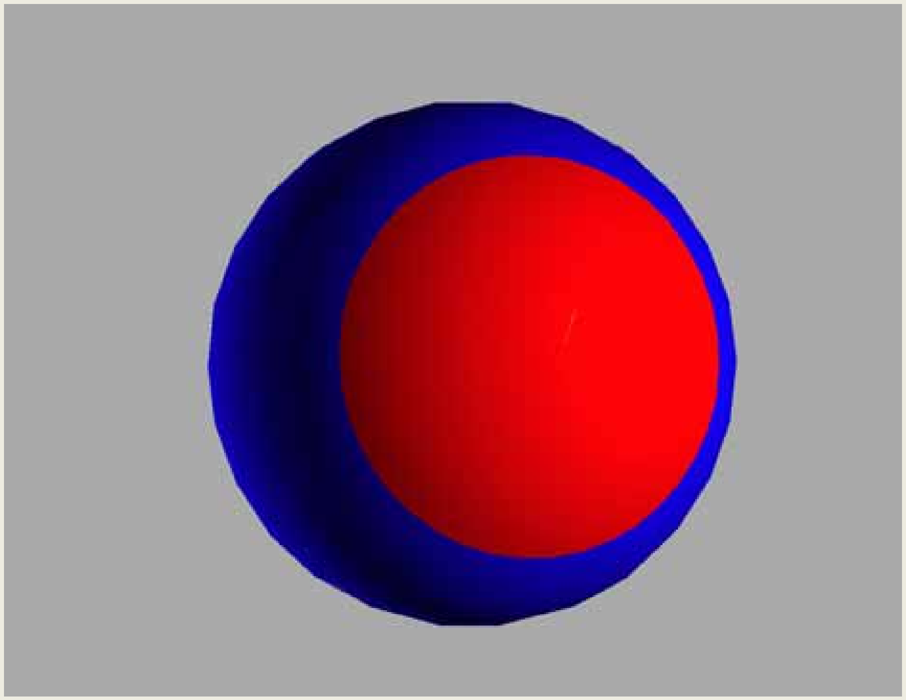
- Keele Five AES CBT Papers (2000-2005):

  - [1] D. B. Keele, Jr., “The Application of Broadband Constant Beamwidth Transducer (CBT) Theory to Loudspeaker Arrays,” 109th Convention of the Audio Engineering Society, Preprint 5216 (Sept. 2000).
  - [2] D. B. Keele, Jr., “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] D. B. Keele, Jr., “Full-Sphere Sound Field of Constant Beamwidth Transducer (CBT) Loudspeaker Line Arrays,” J. Audio Eng. Soc., vol. 51, no. 7/8 (July/August 2003).
  - [4] D. B. Keele, Jr., “Practical Implementation of Constant Beamwidth Transducer (CBT) Loudspeaker Circular-Arc Line Arrays,” 115th Convention of the Audio Engineering Society, Preprint 5863 (Oct. 2003).
  - [5] D. B. Keele, Jr. and D. J. Button, “Ground-Plane Constant Beamwidth Transducer (CBT) Loudspeaker Circular-Arc Line Arrays,” 119th Convention of the Audio Engineering Society, Preprint 6594 (Oct. 2005).

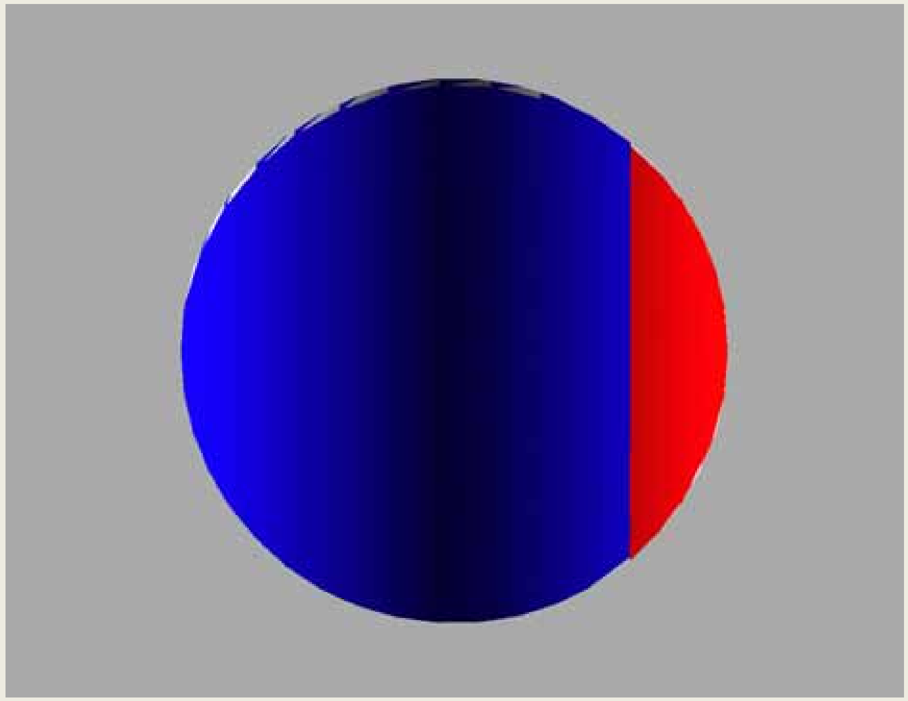
Spherical Cap Transducers

- 100° Circular Spherical Cap

Oblique View



Side View



Shaded Spherical Cap

- Legendre Function Shading

$$u(\theta) = \begin{cases} P_v(\cos\theta) & \text{for} \quad \theta \le \theta_0 \\ 0 & \text{for} \quad \theta > \theta_0 \end{cases}$$

where

$u(\theta)$ = radial velocity distribution

θ = elevation angle in spherical coordinates,

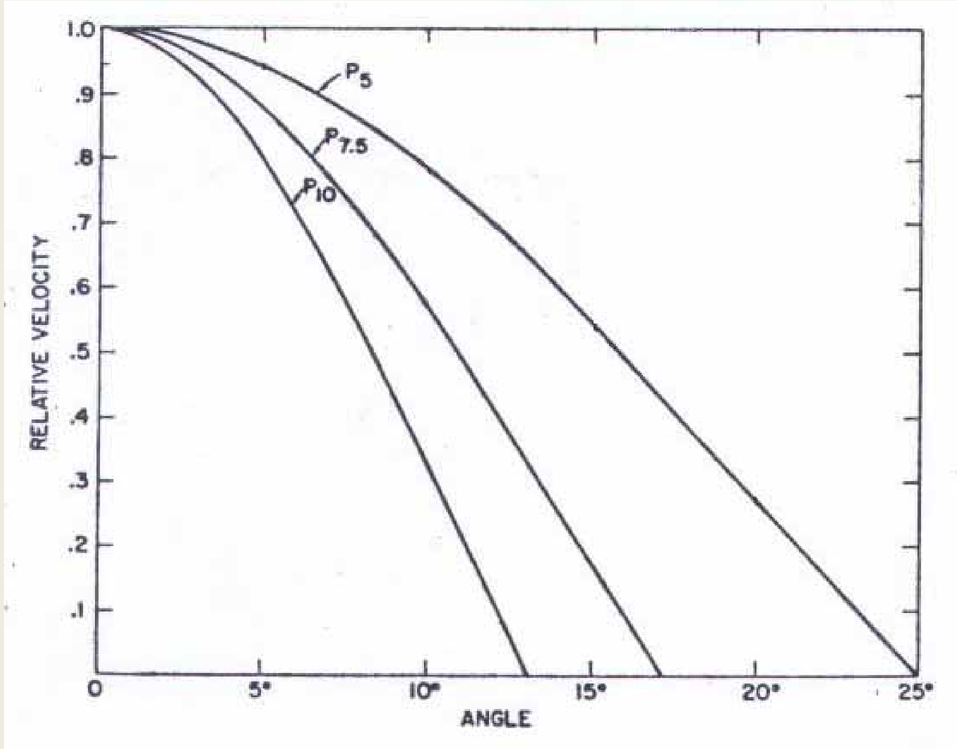
($\theta = 0$ is center of circular spherical cap)

θ_0 = half angle of spherical cap

$P_v(x)$ = Legendre function of order v ($v > 0$) of argument x,

Shaded Spherical Cap

- Velocity shading functions for Legendre orders of v = 5, 7.5, and 10. (Reproduced from Rogers and Van Buren [2]):



Shaded Spherical Cap

- Approximation to Farfield Pressure Pattern

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

where

$$p(\theta) = \text{radial pressure distribution.}$$

QED: Surface pressure distribution, nearfield pressure pattern, and farfield pressure pattern are all essentially the same, i.e. no nearfield!! Polar pattern is independent of distance!!

Shaded Spherical Cap

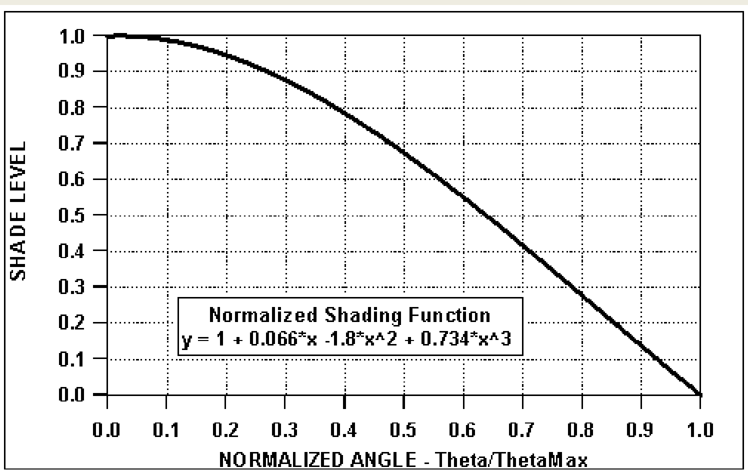
- Power Series Approximation of Legendre Shading Function (Keele):

$$U(x) \approx \begin{cases} 1 + 0.066x - 1.8x^2 + 0.743x^3 & \text{for} \quad x \le 1 \\ 0 \quad \text{for} \quad x > 1 \end{cases}$$

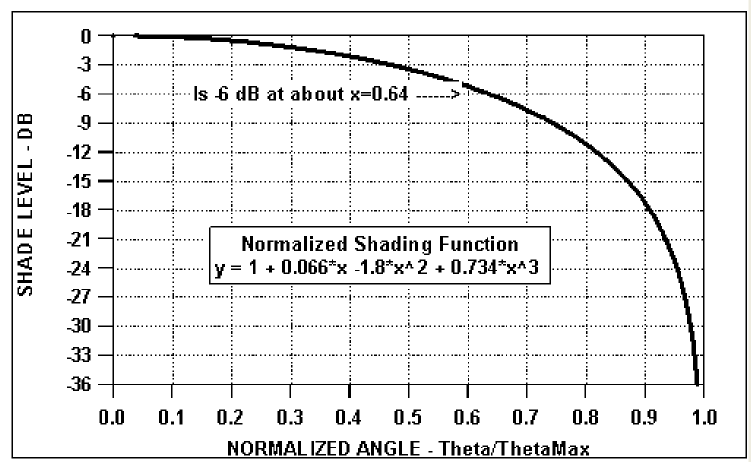
where

$$x = \text{normalized angle} \left(\frac{\theta}{\theta_0} \right)$$

(a)



(b)



Legendre Shading

Reproduced from Van Buren [4].

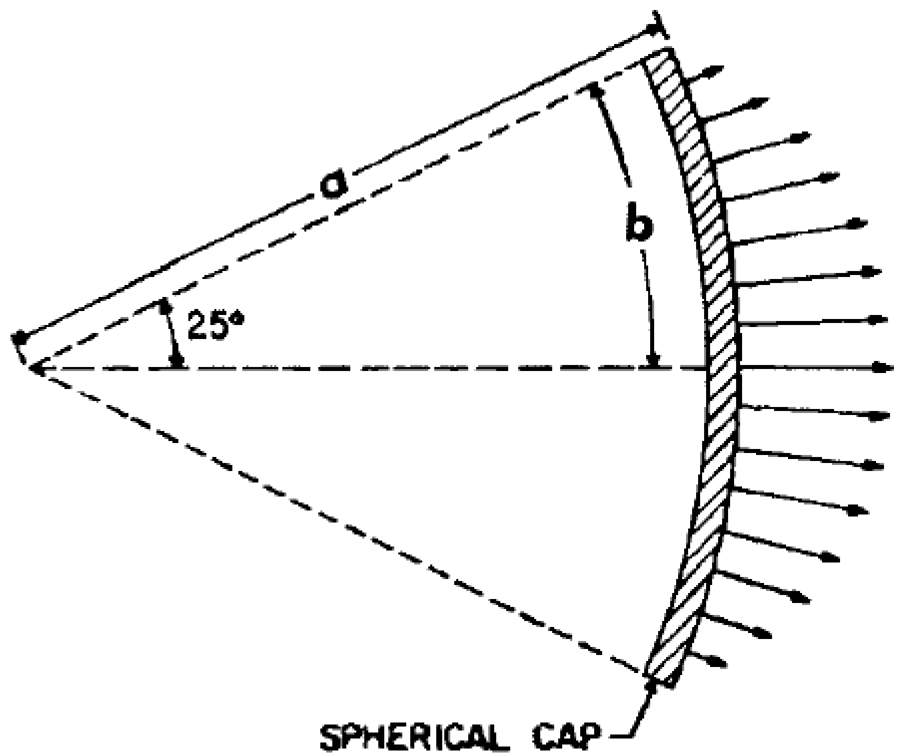
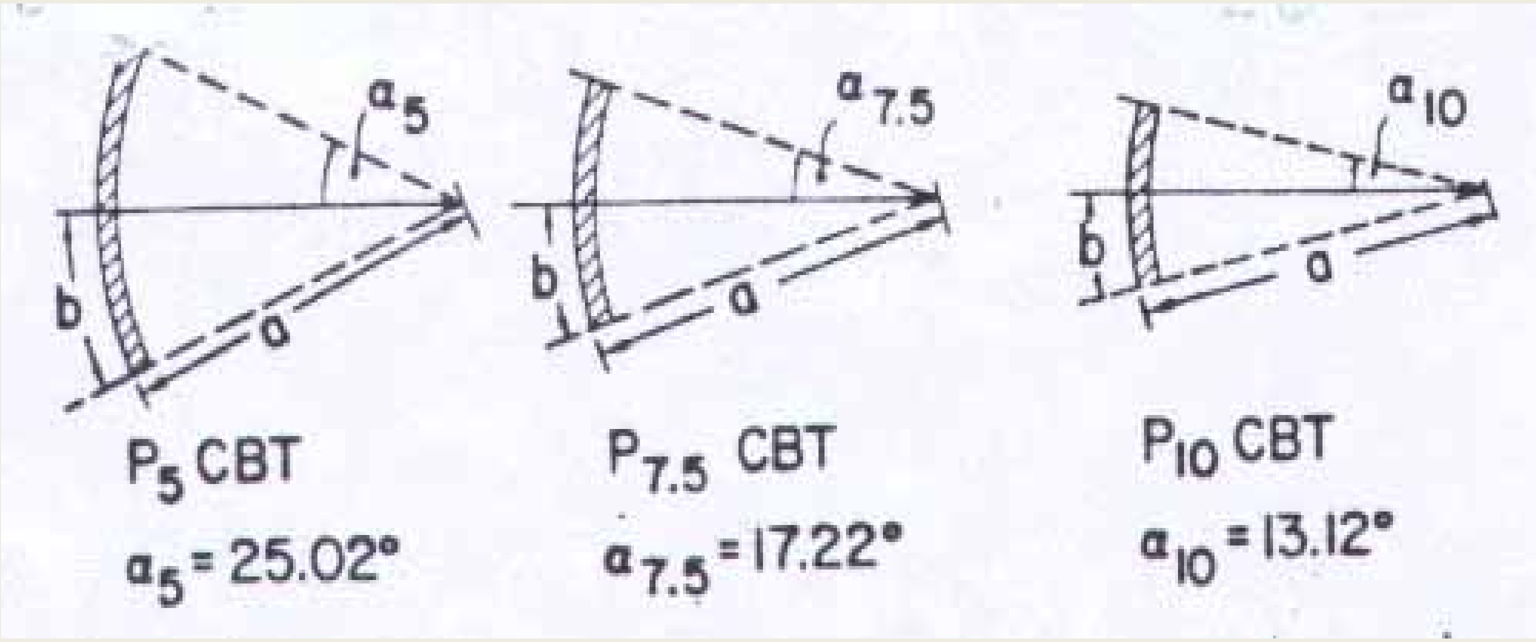


FIG. 6. Cross-sectional view of the spherical cap for a P_5 CBT. Arrows indicate the relative surface velocity distribution. The cap radius b is measured on the outer spherical surface.

Shaded Spherical Cap

- Geometry of spherical cap constant-beamwidth transducers. (Reproduced from Rogers and Van Buren [2]):

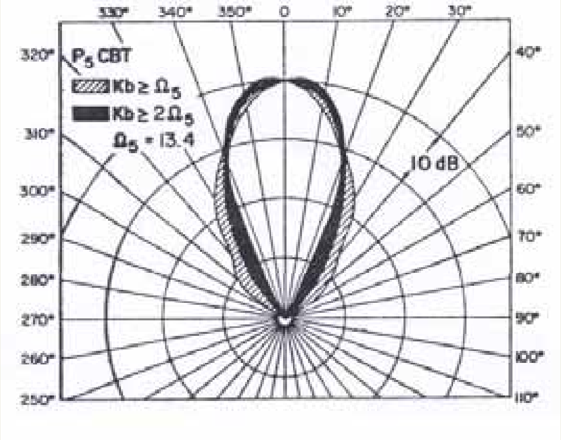
P_5 CBT 50°　　$P_{7.5}$ CBT 34°　　P_{10} CBT 26°



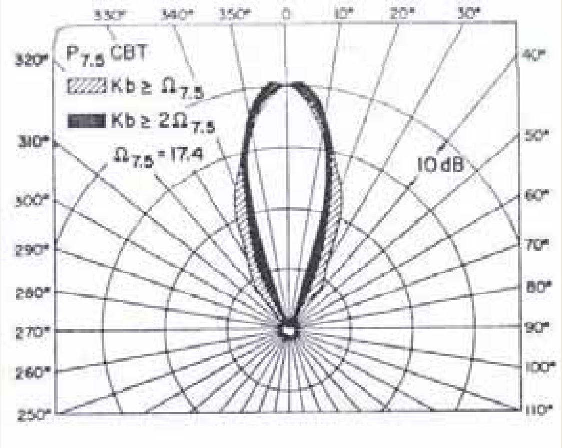
Shaded Spherical Cap

- CBT polar patterns (Reproduced from Rogers and Van Buren [2]):

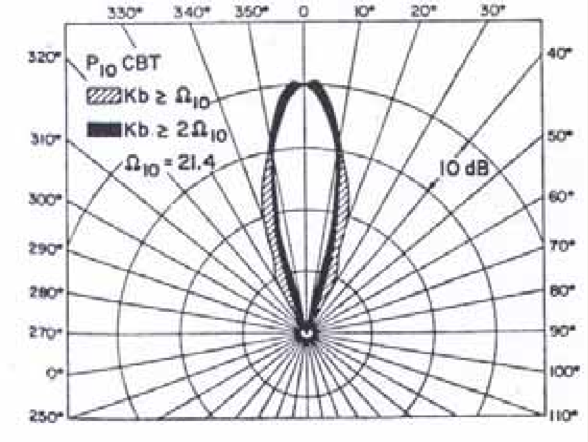
P_5 CBT



$P_{7.5}$ CBT

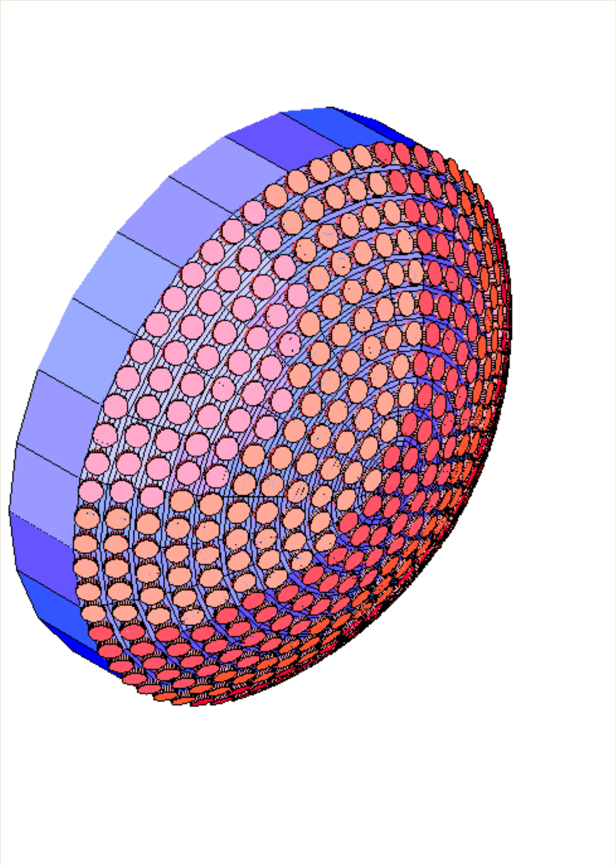


P_{10} CBT

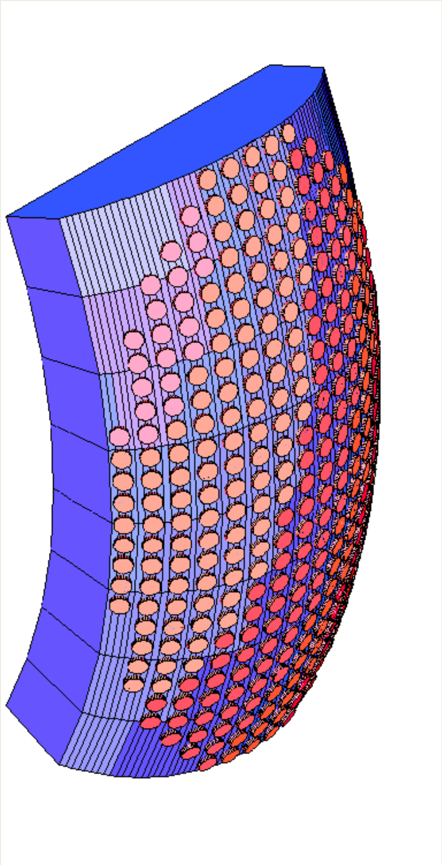


Apply CBT Theory to Loudspeaker Arrays
(From Keele 2000 [2])

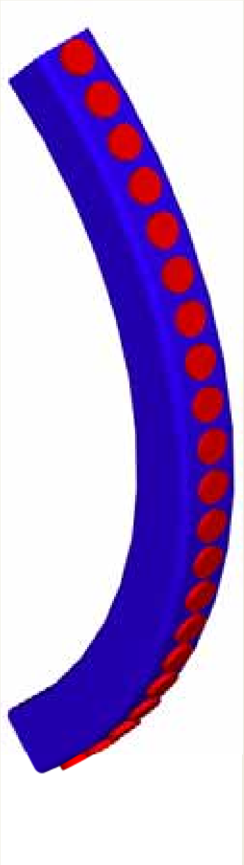
Circular Spherical -Cap Array



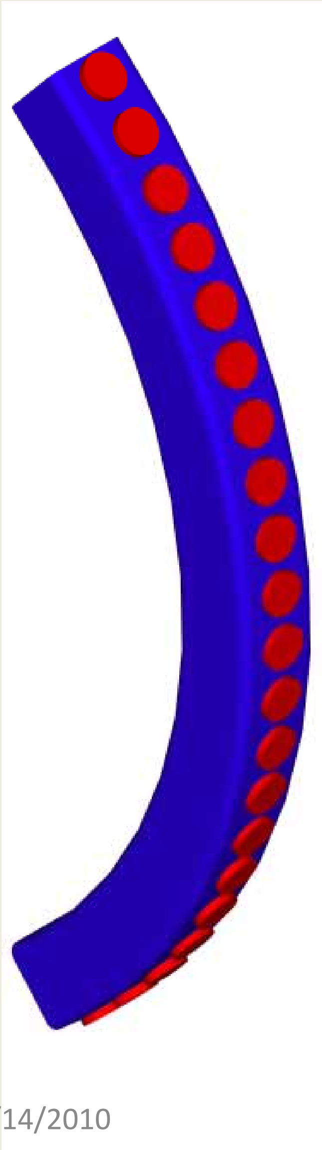
Elliptical Toriodal-Cap Array



Circular-Arc Line Array



Apply CBT Theory to Loudspeaker Line Arrays



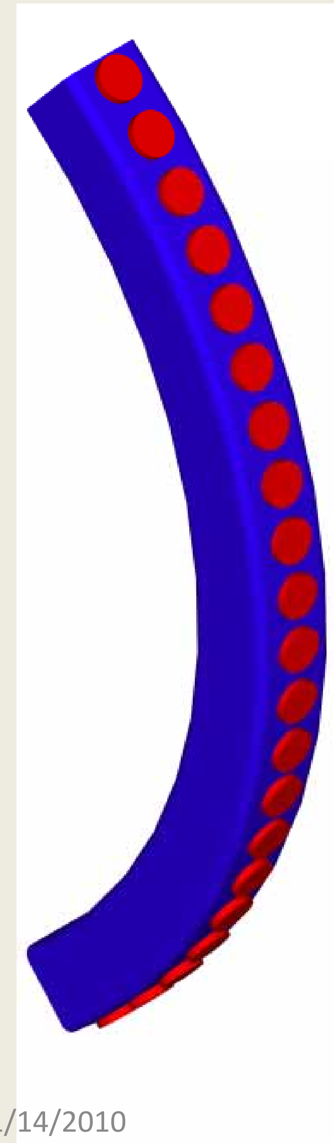
Curved Line Source:

(Arrange speakers around a circular arc and apply frequency-independent Legendre shading.)

Simulate 21 Sources around a 100° circular arc. (Height is one-wavelength high at 1 kHz).

Simulate with and without shading.

Apply CBT Theory to Loudspeaker Line Arrays



Curved Line S

(Arrange speake
and apply frequency-in
Legendre shading.)

No DSP!!
Shading can be implemented passively!!

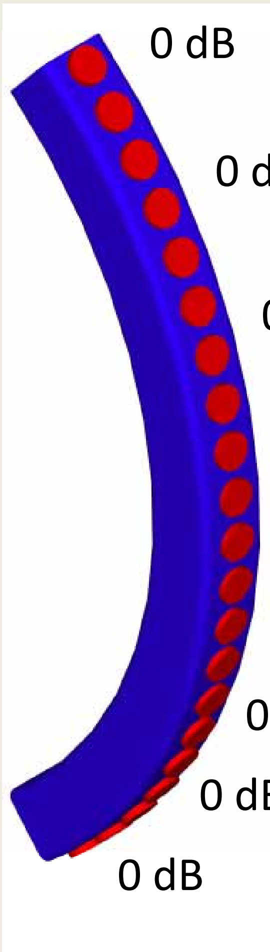
Simulate 21 Sources around a 100° circular arc. (Height is one-wavelength high at 1 kHz).

Simulate with and without shading.

Shading

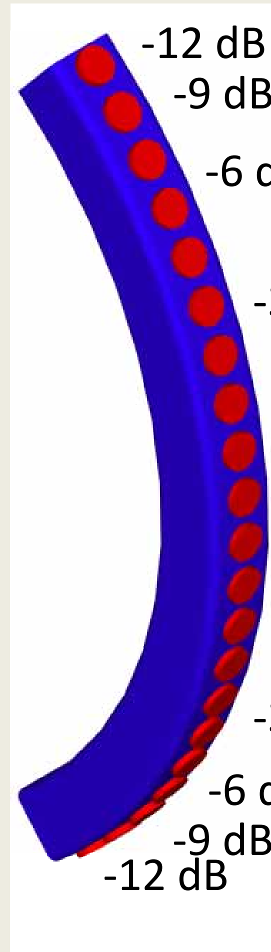
(Show Level in dB)

No Shading



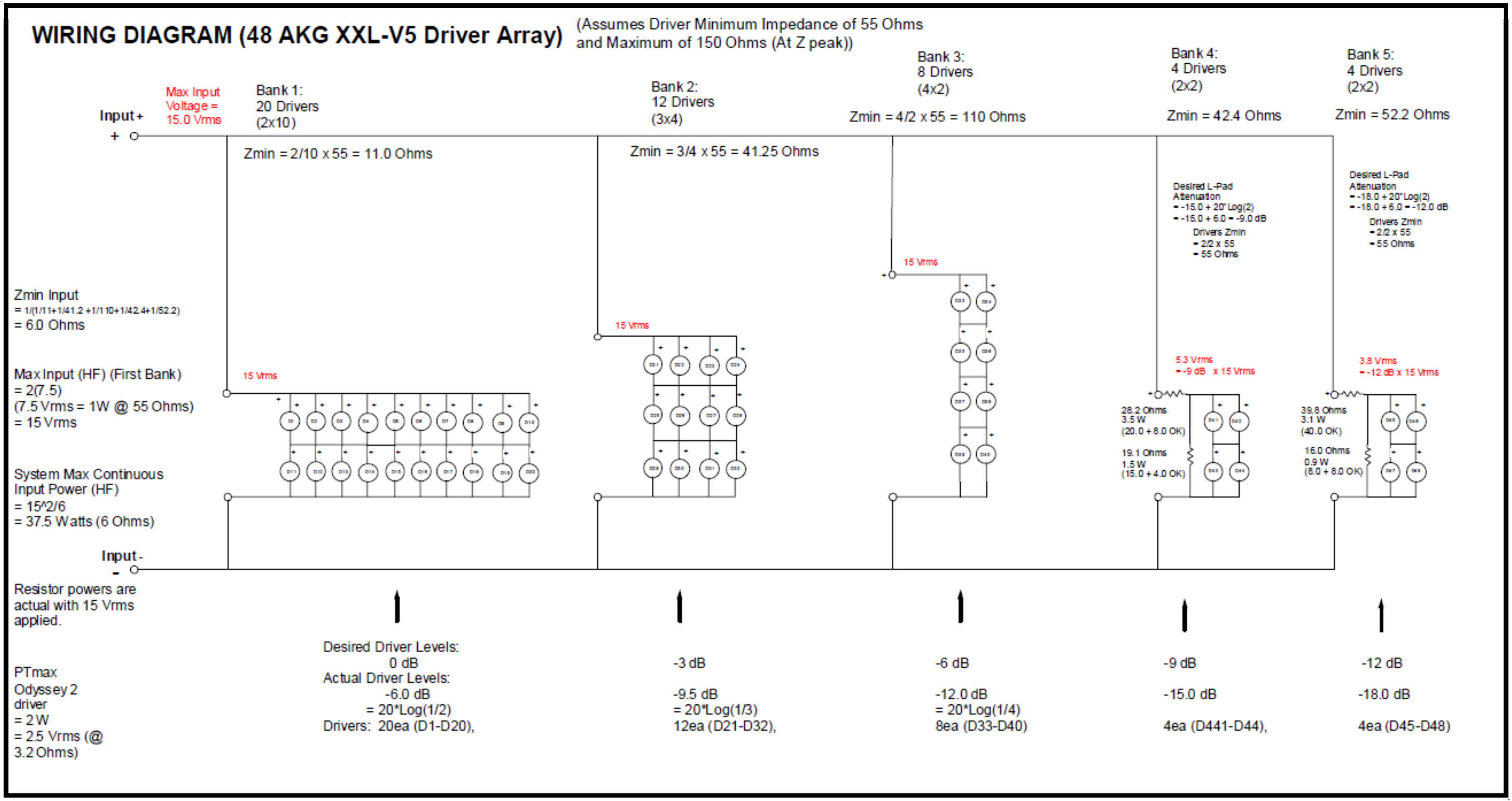
With Legendre Shading

(-12 dB Truncated and Stepped)



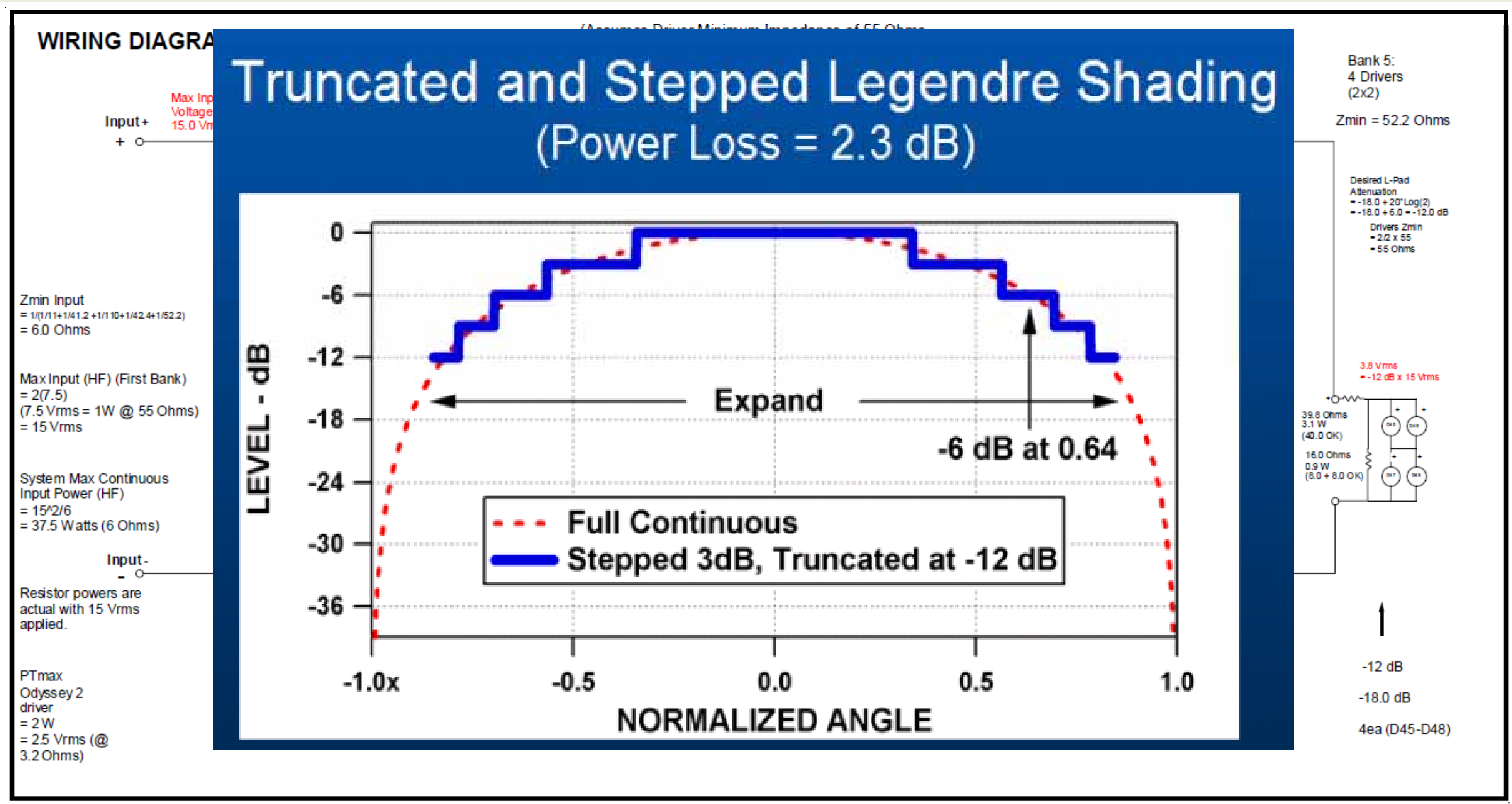
Truncated and Stepped Shading Implemented Passively

(Five Banks: 0, -3, -6, -9, -12 dB)



Truncated and Stepped Shading Implemented Passively

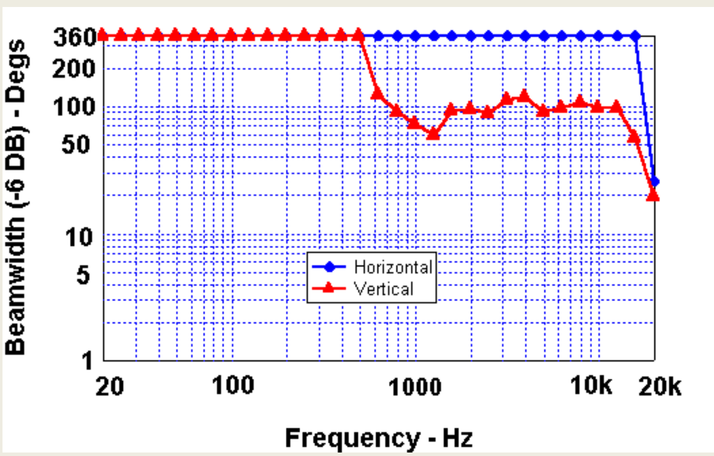
(Five Banks: 0, -3, -6, -9, -12 dB)



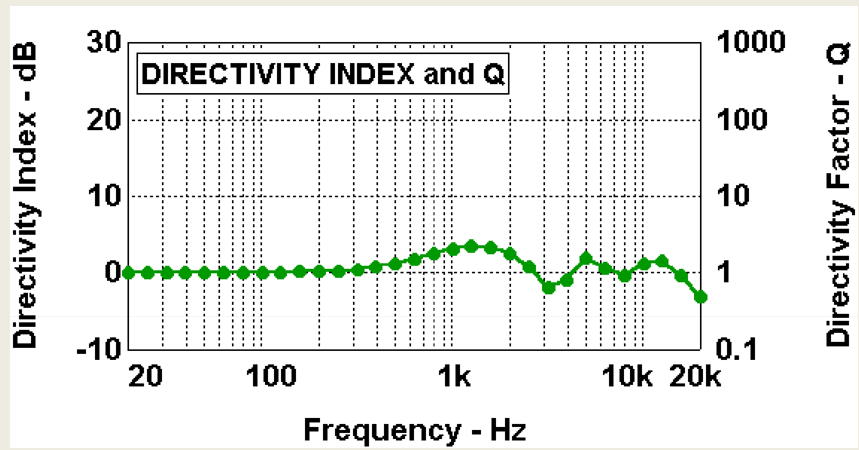
Simulation Results

- Curved Line Source (100° Circular-Arc)
  - No Shading (Equal drive levels)

BEAMWIDTH

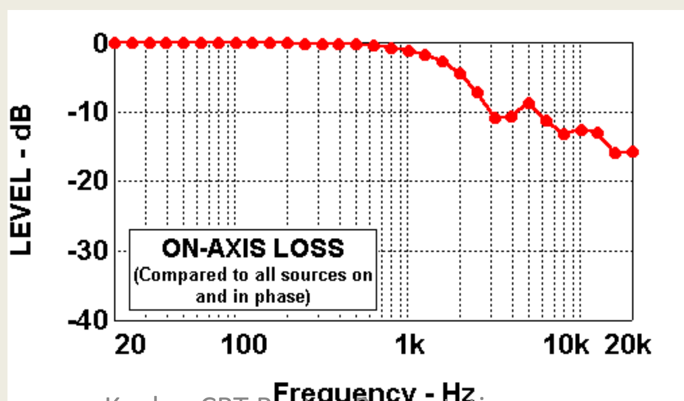


DIRECTIVITY



ON-AXIS

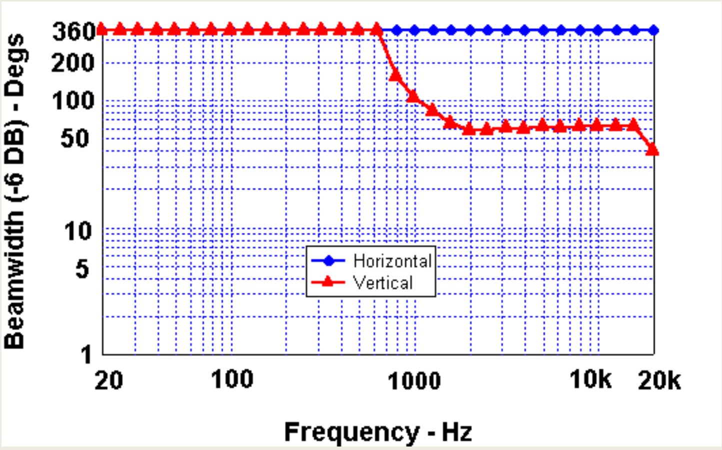
LOSS



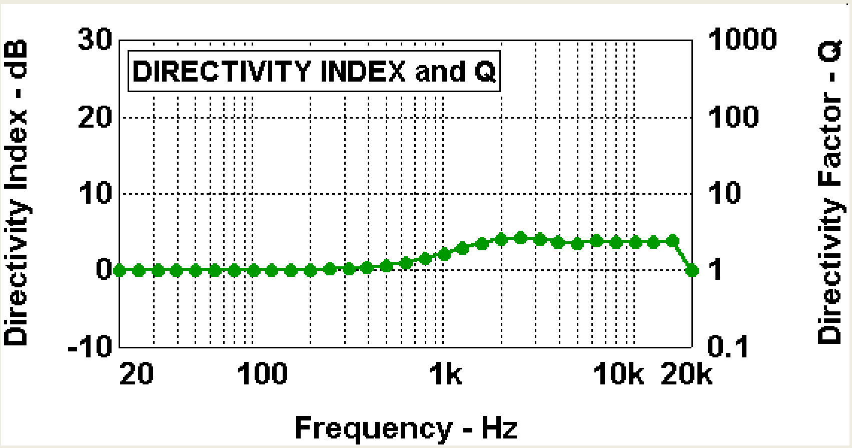
Simulation Results

- Curved Line Source (100° Circular-Arc)
  - With Full Legendre Shading

BEAMWIDTH

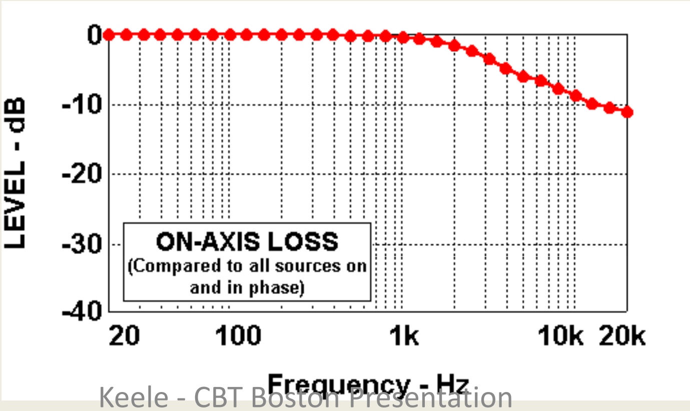


DIRECTIVITY



ON-AXIS

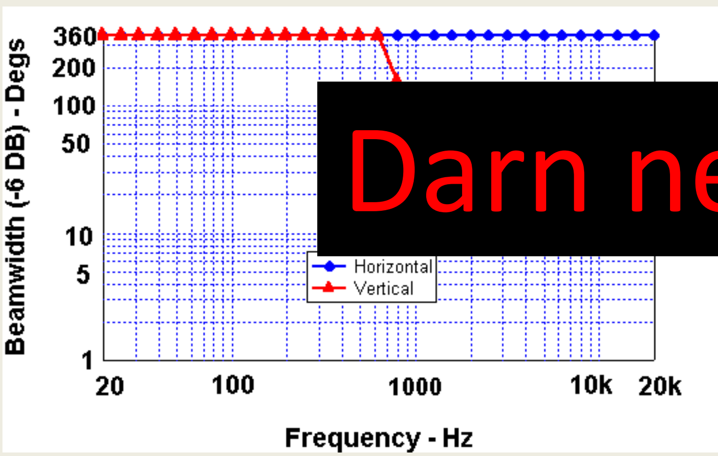
LOSS



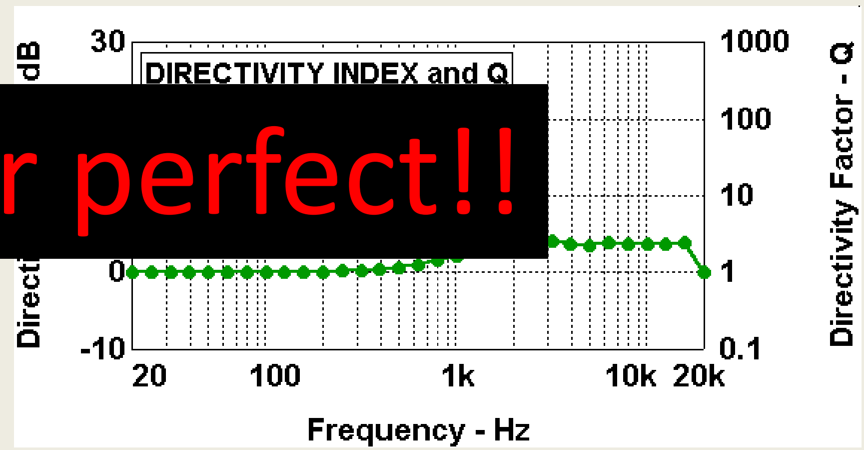
Simulation Results

- Curved Line Source (100° Circular-Arc)
  - With Full Legendre Shading

BEAMWIDTH



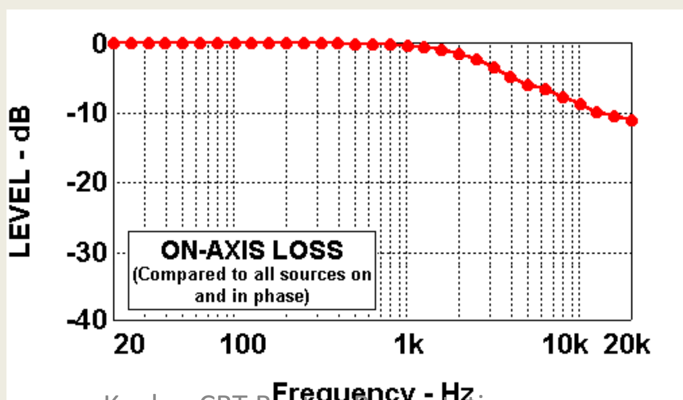
DIRECTIVITY



Darn near perfect!!

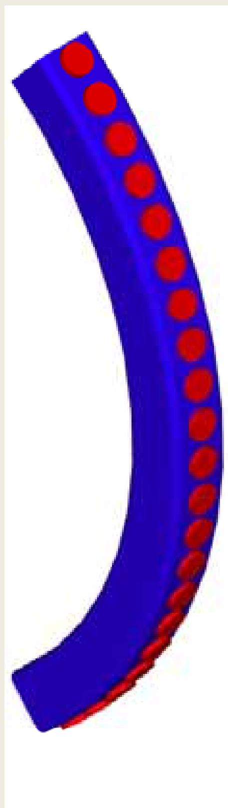
ON-AXIS

LOSS



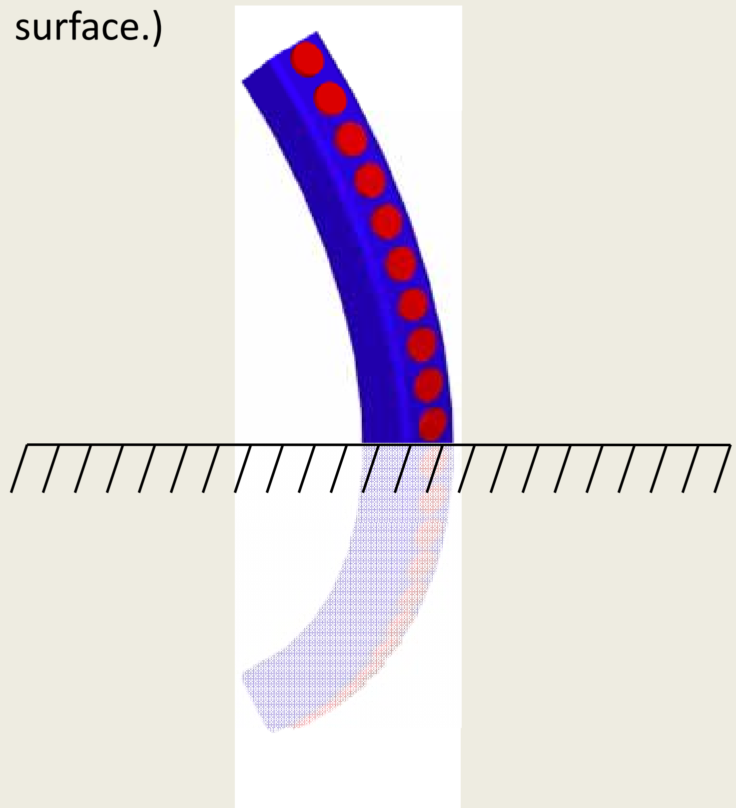
Two CBT Line-Array Versions

Free-Standing Version



Ground-Plane Version

(Cutoff the bottom half of the array and place the bottom on a reflective surface.)



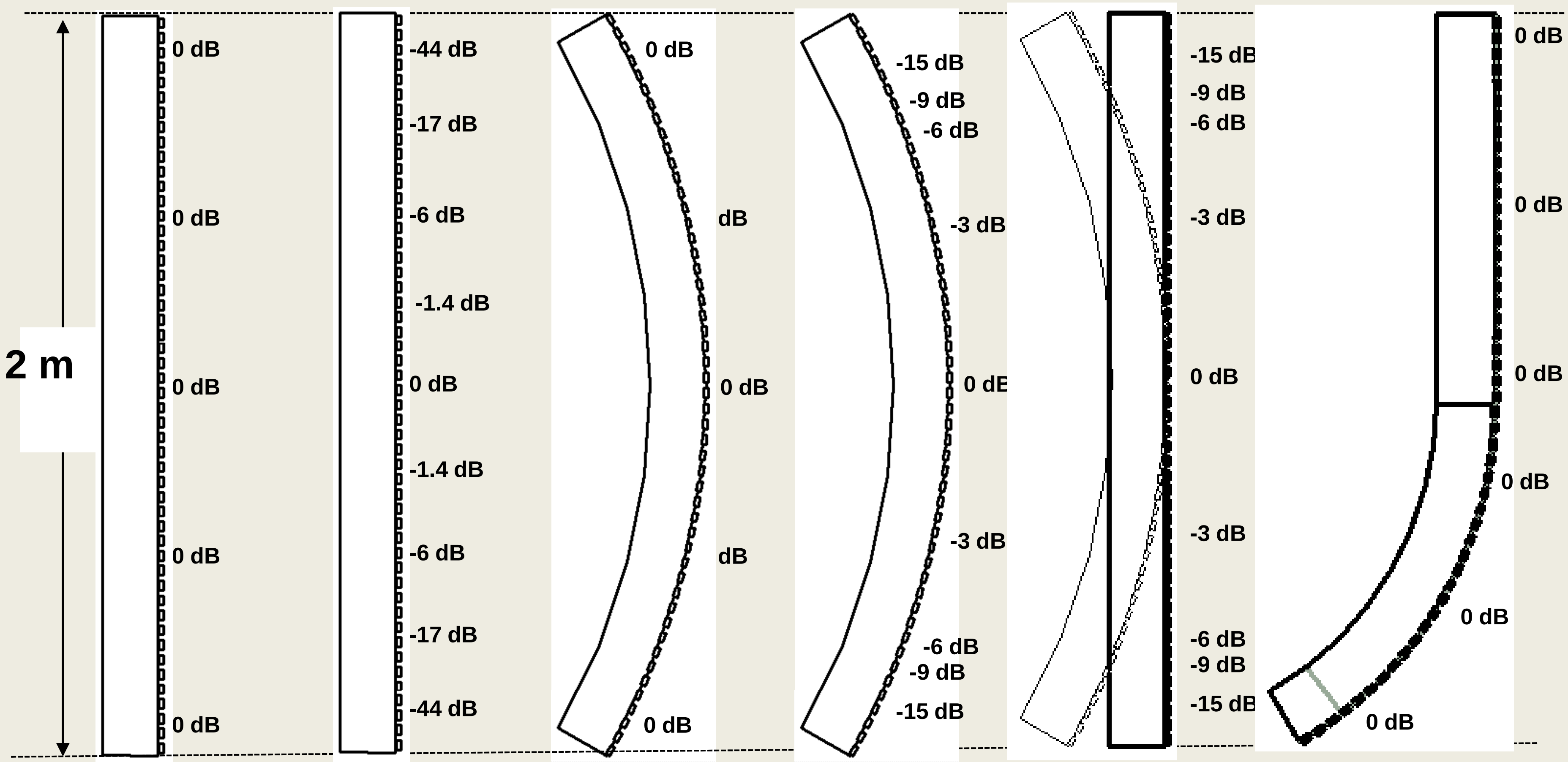
A Comparison of the Simulated Vertical-Plane Sound Field of Six Different Types of Line Arrays

- Types of Arrays:
  - 1. **Straight-Line Array:**
    - No Shading
  - 2. **Straight-Line Array:**
    - With Shading (Hann)
  - 3. **Curved-Line Array:**
    - 60° Circular-Arc, No Shading (Provides a coverage angle of about 60° at high frequencies)
  - 4. **CBT Curved-Line Array:**
    - 60° Circular-Arc, With Shading (Legendre) (Provides a coverage angle of about 40° at high frequencies)
  - 5. **Straight-Line Array, CBT Delay-Curved:**
    - Generates a 60° Circular-Arc, With Shading (Legendre) (Provides a coverage angle of about 40° at high frequencies)
  - 6. **"J" Line Array:**
    - No Shading, Straight Top Half , 60° Circular-Arc Curved Bottom Half

Six Different Types of Arrays Compared

All arrays are composed of 100 wide-band omni-directional point sources. Source center-to-center spacing is about 20mm (0.8 in). (Only 50 sources shown on each array here.)

1) Straight-Line Array No Shading | 2) Straight-Line Array With Shading | 3) 60° Curved-Line Array No Shading | 4) 60° Curved-Line Array With Shading | 5) Straight-Line Array 60° Delay Curved With Shading | 6) J-Line Array No Shading



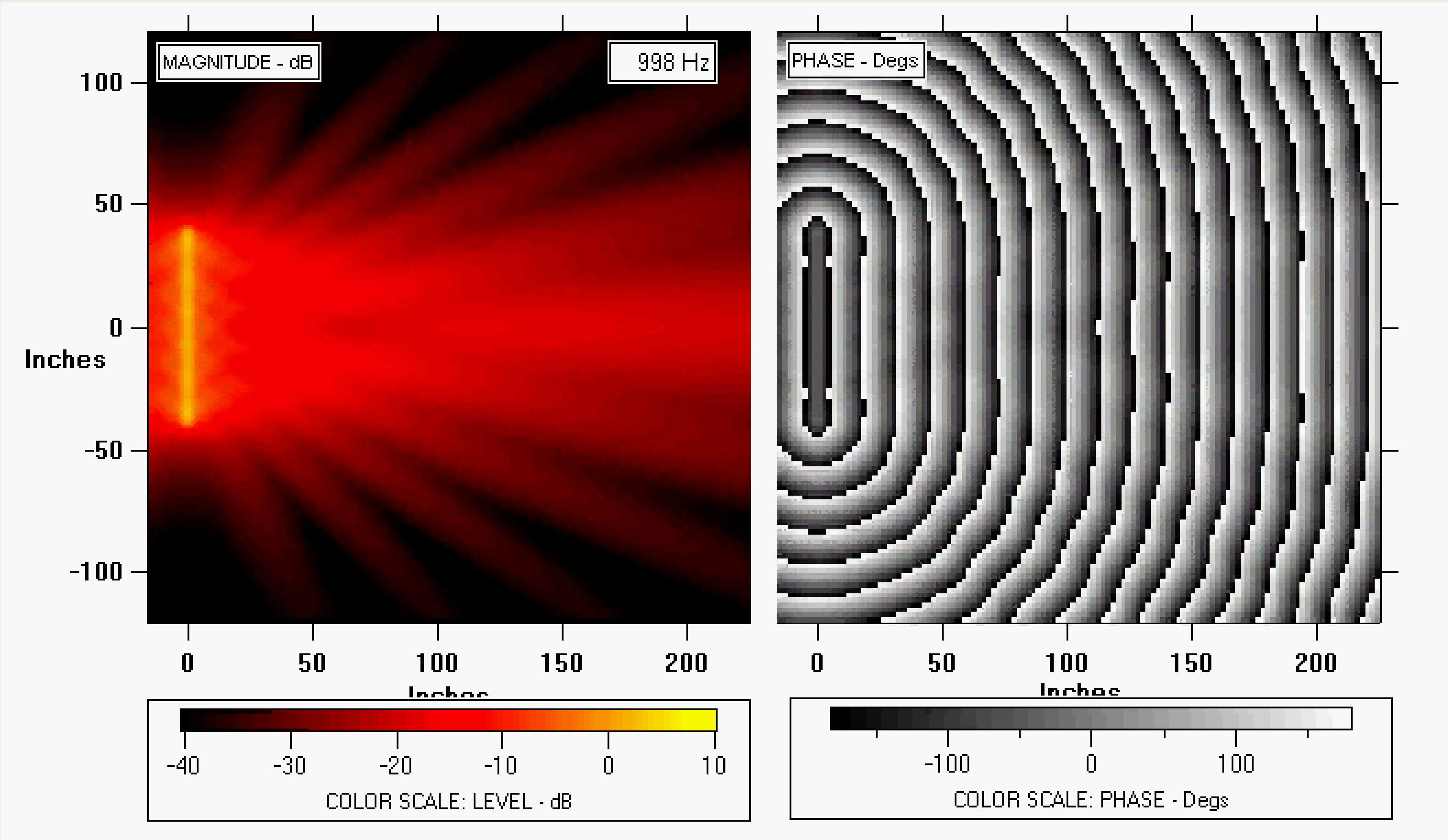
Simulation Conditions

Conditions:

- Straight-line array is located at origin. Curved-line arrays are located with center of curvature at origin.
- The vertical sound field is plotted in a region of 6 x 6 m (240 in, 20 ft) with origin on left at (0, 0).
- The soundfields are plotted at all 3rd-octave center frequencies from 50 Hz to 20 kHz.
- All arrays are equalized flat on axis at 6 m (240 in, 20 ft).
- SPL magnitude is plotted on the left and phase on the right. *Note that phase plot is only accurate up to roughly 2 kHz and exhibits visual aliasing at all higher frequencies.*

Example Simulation of Straight-Line Array

STRAIGHT-LINE ARRAY, 2m HIGH, 100 SOURCES, EQUAL DRIVE LEVELS (No shading): 1 kHz



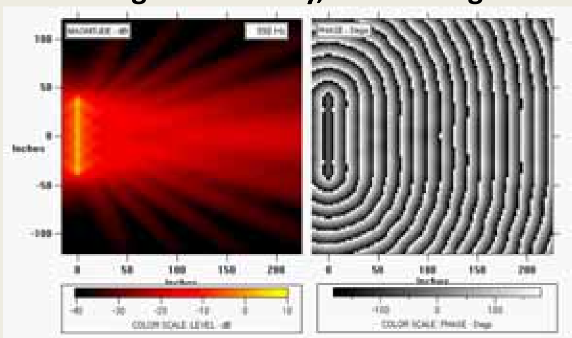
Equalized Flat On Axis

Switch to Straight-Line PPT Demo

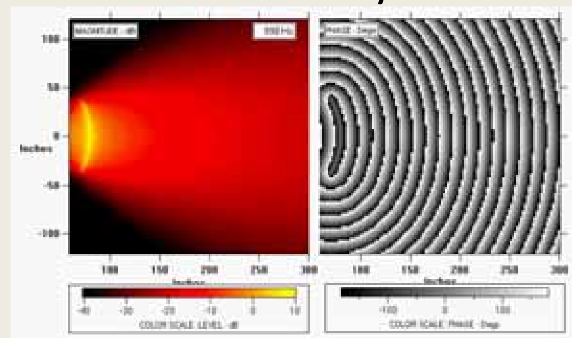
Frequency: 1 kHz

Composite Simulations

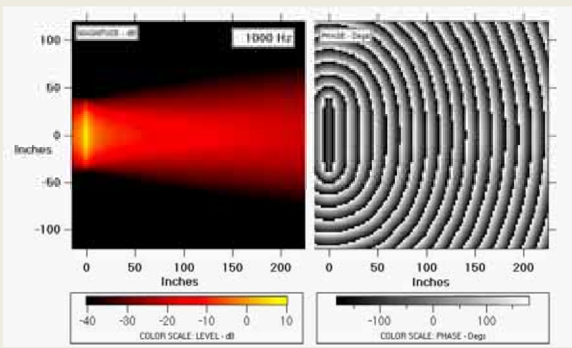
1. Straight-Line Array, No Shading



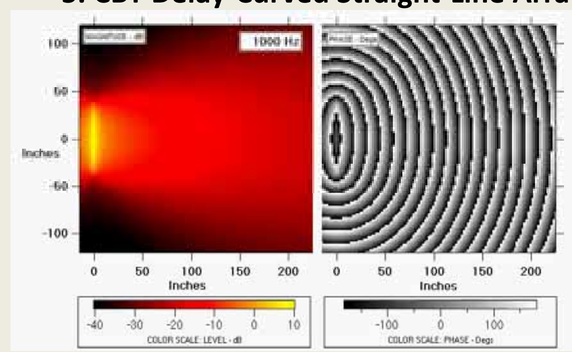
4. CBT Curved-Line Array



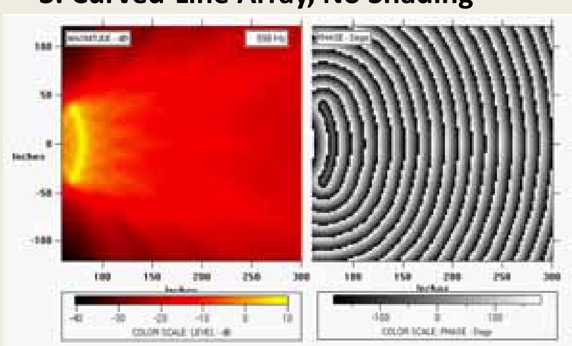
2. Straight-Line Array, With Shading



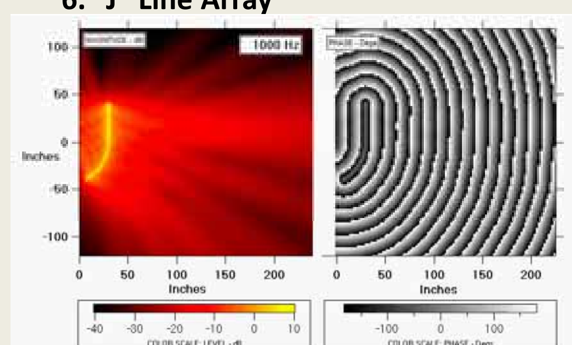
5. CBT Delay-Curved Straight-Line Array



3. Curved-Line Array, No Shading

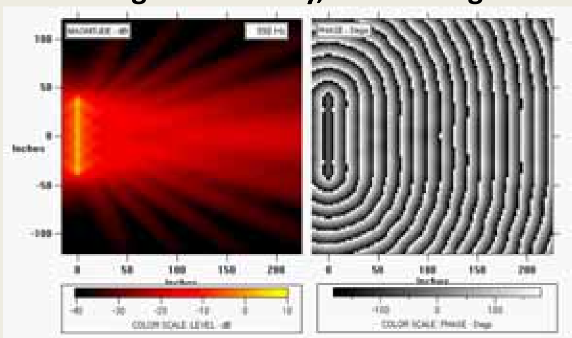


6. "J" Line Array

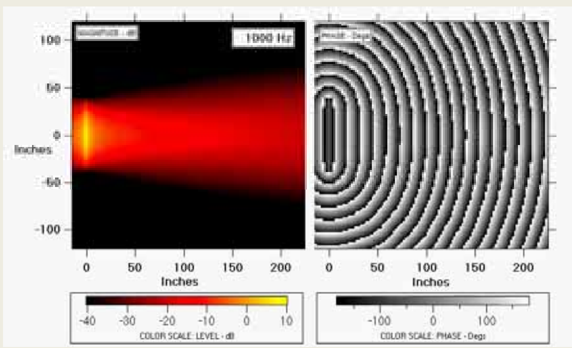


Frequency: 1 kHz Composite Simulations

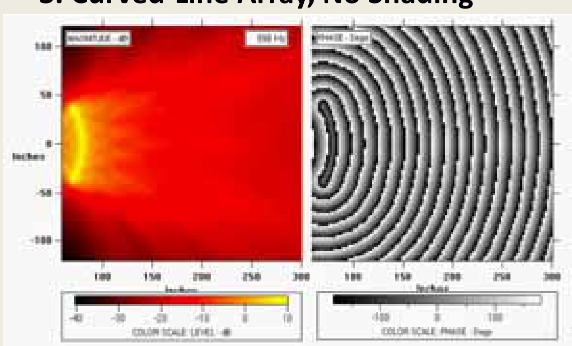
1. **Straight-Line Array, No Shading**



2. **Straight-Line Array, With Shading**

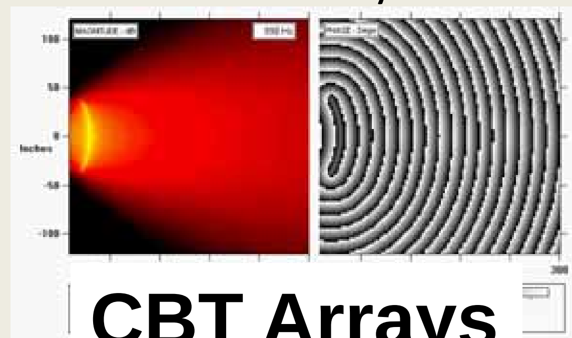


3. **Curved-Line Array, No Shading**

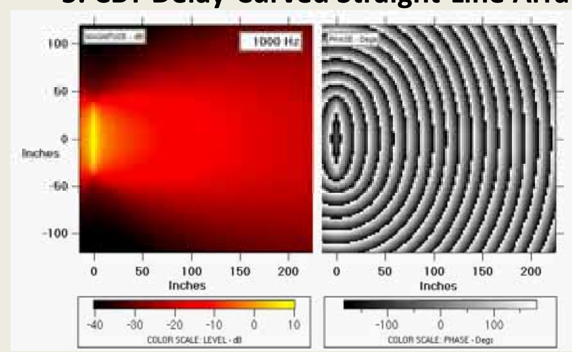


CBT Arrays

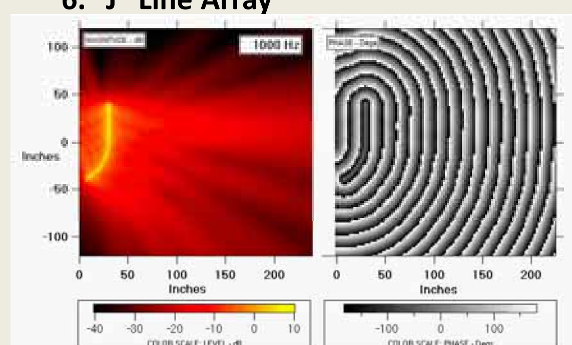
4. **CBT Curved-Line Array**



5. **CBT Delay-Curved Straight-Line Array**



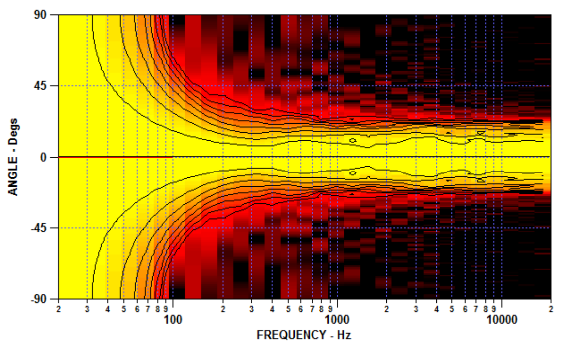
6. **"J" Line Array**



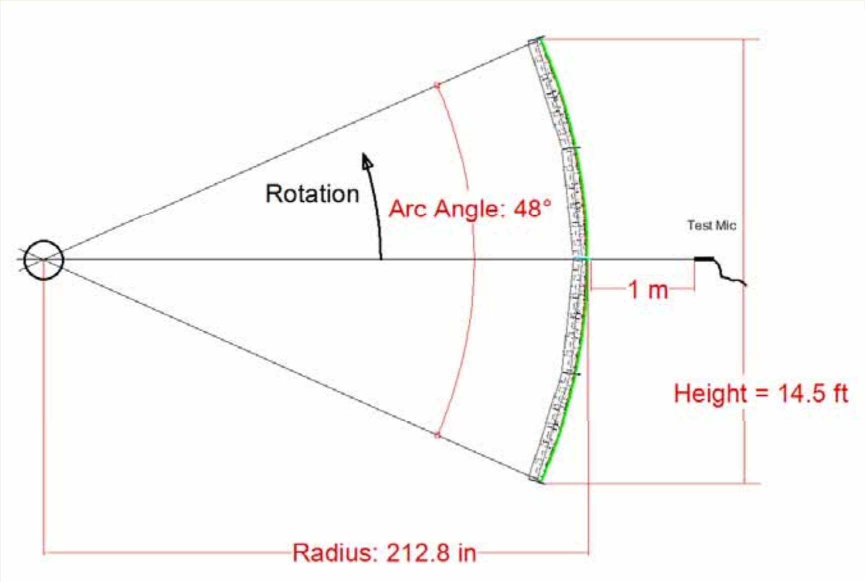
Play Composite Sound-Field Simulation PPT Movie

CBT Array Polar Pattern is Independent of Distance!

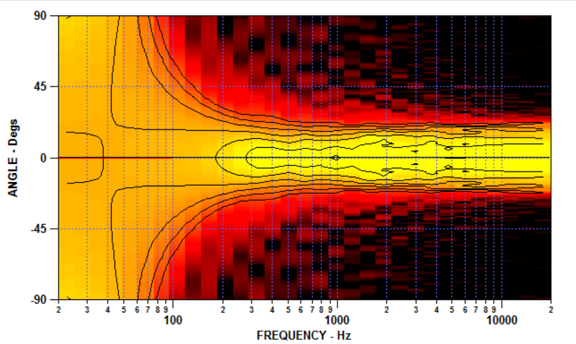
100 m Polar Map



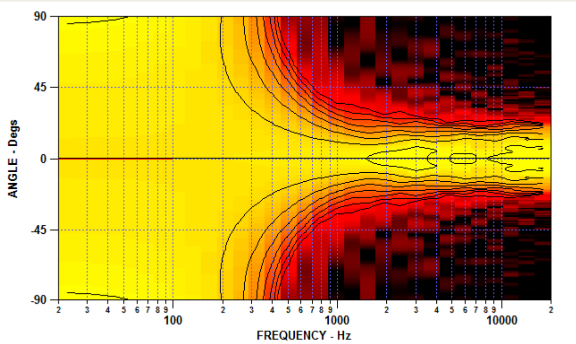
Polar Rotation:



10 m Polar Map



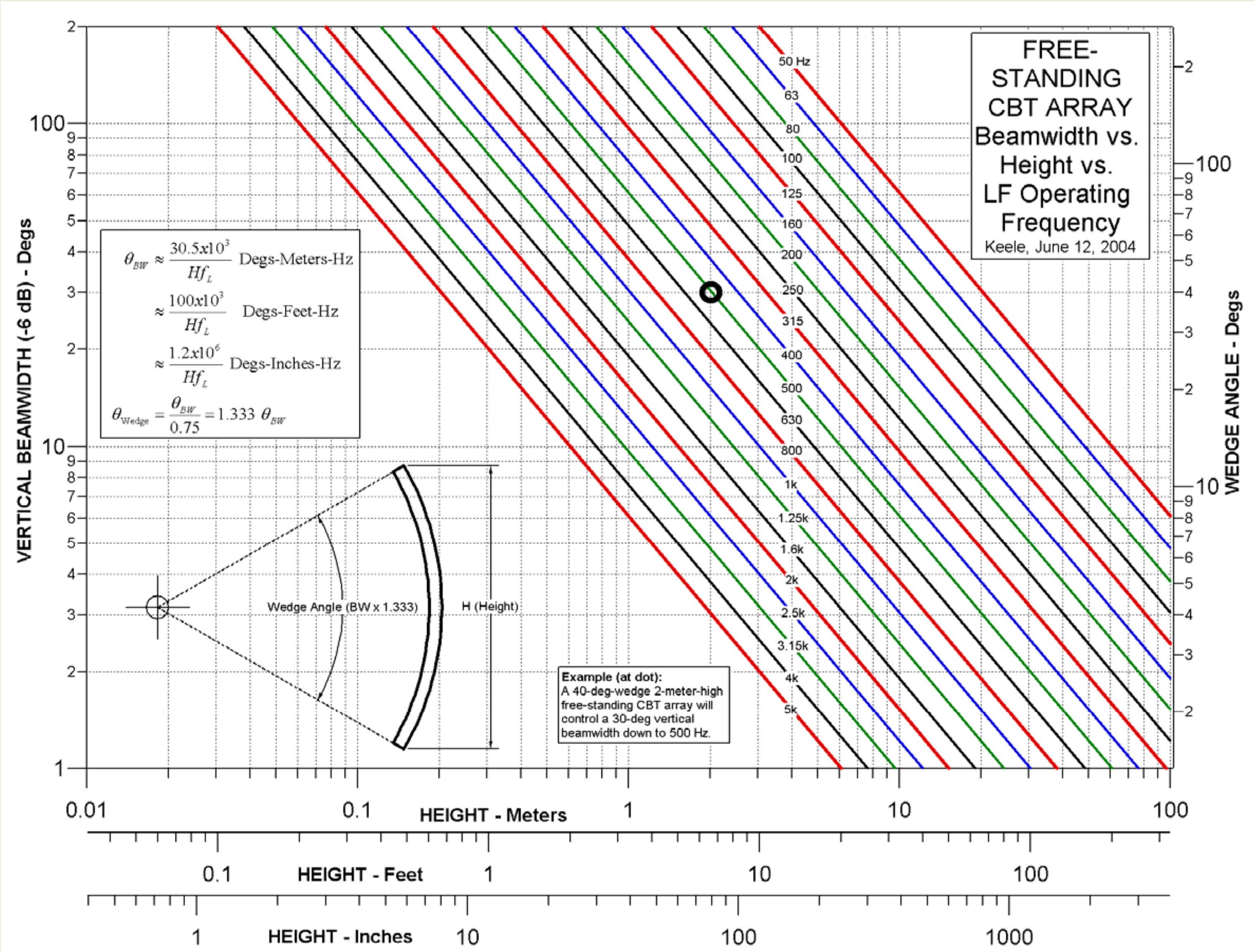
1 m Polar Map



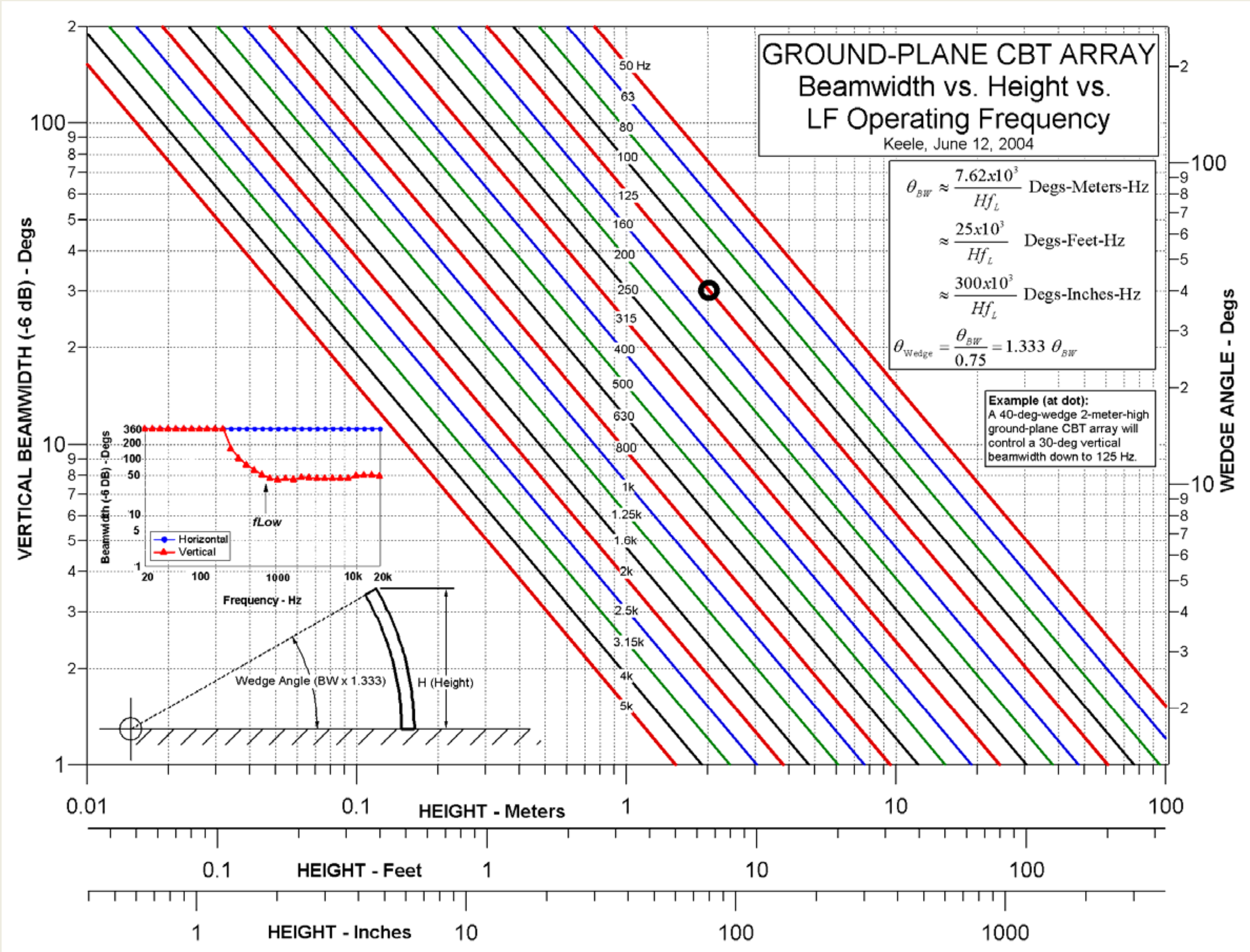
Implementation of CBT Arrays

- Angle vs. Height vs. LF Control Frequency Tradeoffs: Show Nomographs
- Implementation using individual drivers
- Keele Prototypes
- Implementation using systems
- Marshall Kay Church System
- Monte Kay Home Theater Center Channel

FREE-STANDING CBT ARRAY: Angle vs. Height vs. LF Control Frequency



GROUND-PLANE CBT ARRAY: Angle vs. Height vs. LF Control Frequency



Implementation Using Individual Drivers

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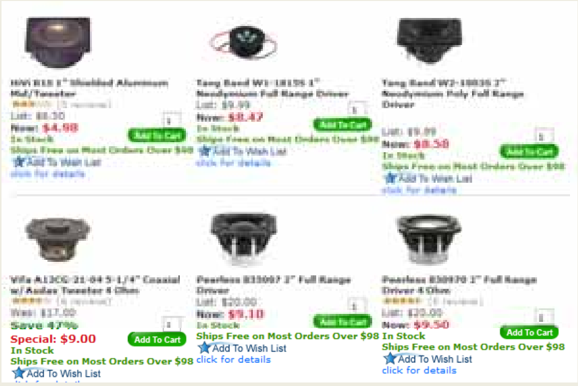
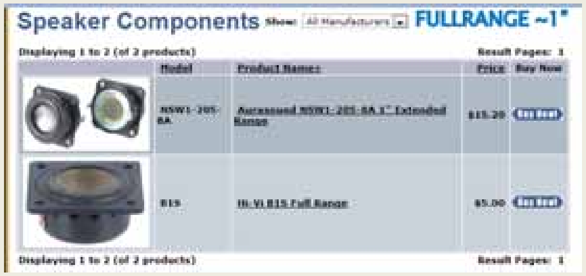
Madisound Speaker Components, Inc.





Implementation Using Individual Drivers

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Regal RS, RM, and RR Series
Micro Speakers and Receivers

Specifications

Features

- *Extremely Small Size*
- *Rugged*
- *Wide Range*
- *High Power (Speakers)*

Applications

- *PDAs*
- *Cell Phones*
- *Annunciator Panels*
- *Handheld Games*

Model	Size (mm)		Imp. (ohms)	Resonant Freq. (f_o)	Freq. Range	Sensitivity	Power Input (watts)		Frame
	Dia.	Hgt.		Hz	Hz	dB (+/-3dB)	Nom.	Max	
Speakers (may also be used as receivers and buzzers)									
RS-1534A-ENL	15	3.4	8	1050	600~20K	77	0.5	1.0	Metal
PDF File: Specifications/drawings (RM-1534A-NL.pdf; 1 page, 63k)									
RM-1332-NL	13	3.2	8	1200	670~20K	81	0.5	0.8	Plastic
PDF File: Specifications/drawings (RS-1332-NL.pdf; 1 page, 50k)									
RM-1543SP-NL (spring contacts)	15	4.3	8	1100	620~20K	78	0.7	1.0	Metal
PDF File: Specifications/drawings (RM-1543SP-NL; 1 page, 57k)									
Receivers									
RR-1000A-NL	10	4.2	32	-	100~4K	110	.01	.05	Metal
PDF File: Specifications/drawings (RR-1000A.pdf; 1 page, 67k)									

Implementation Using Individual Drivers

DRIVERS:

LARGE DRIVER:

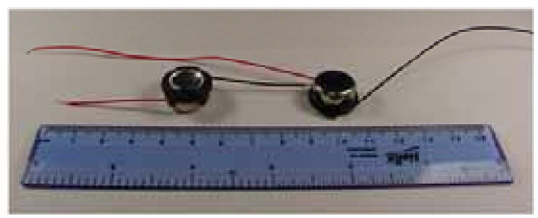
Harman Multimedia 57mm (2.25") Odyssey 7 used in Apple iMac.

33mm (1.3") inverted metal dome. (Bandwidth: 100 Hz to 20 kHz)

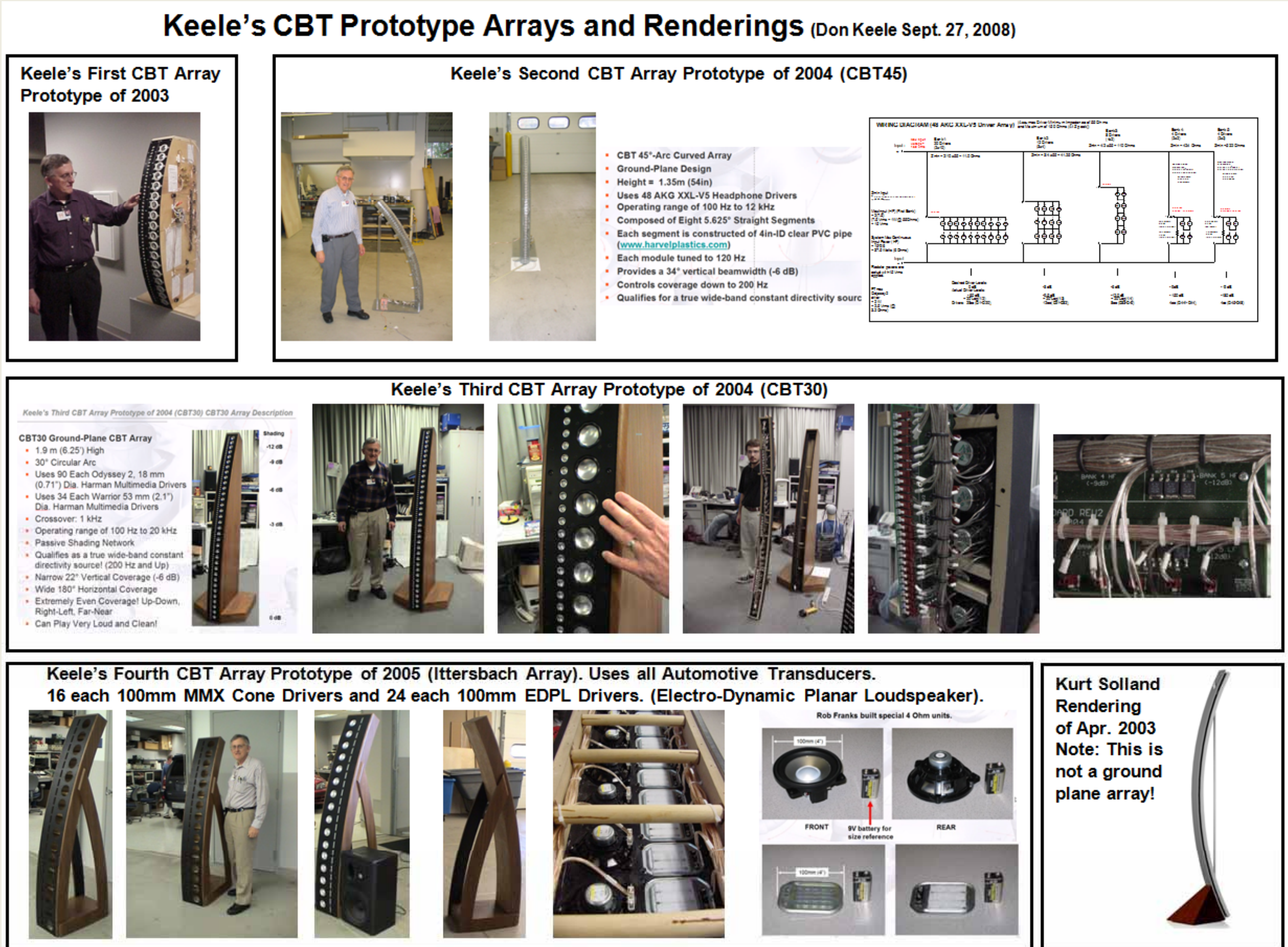
SMALL DRIVER:

Harman Multimedia 19mm (0.75") Odyssey 2 used in Toshiba and Dell Laptop Computers.

12.5 mm (0.5") inverted metal dome. (Bandwidth: 400 Hz to 20 kHz)



Keele's CBT Prototypes



Keele’s First CBT Array Prototype

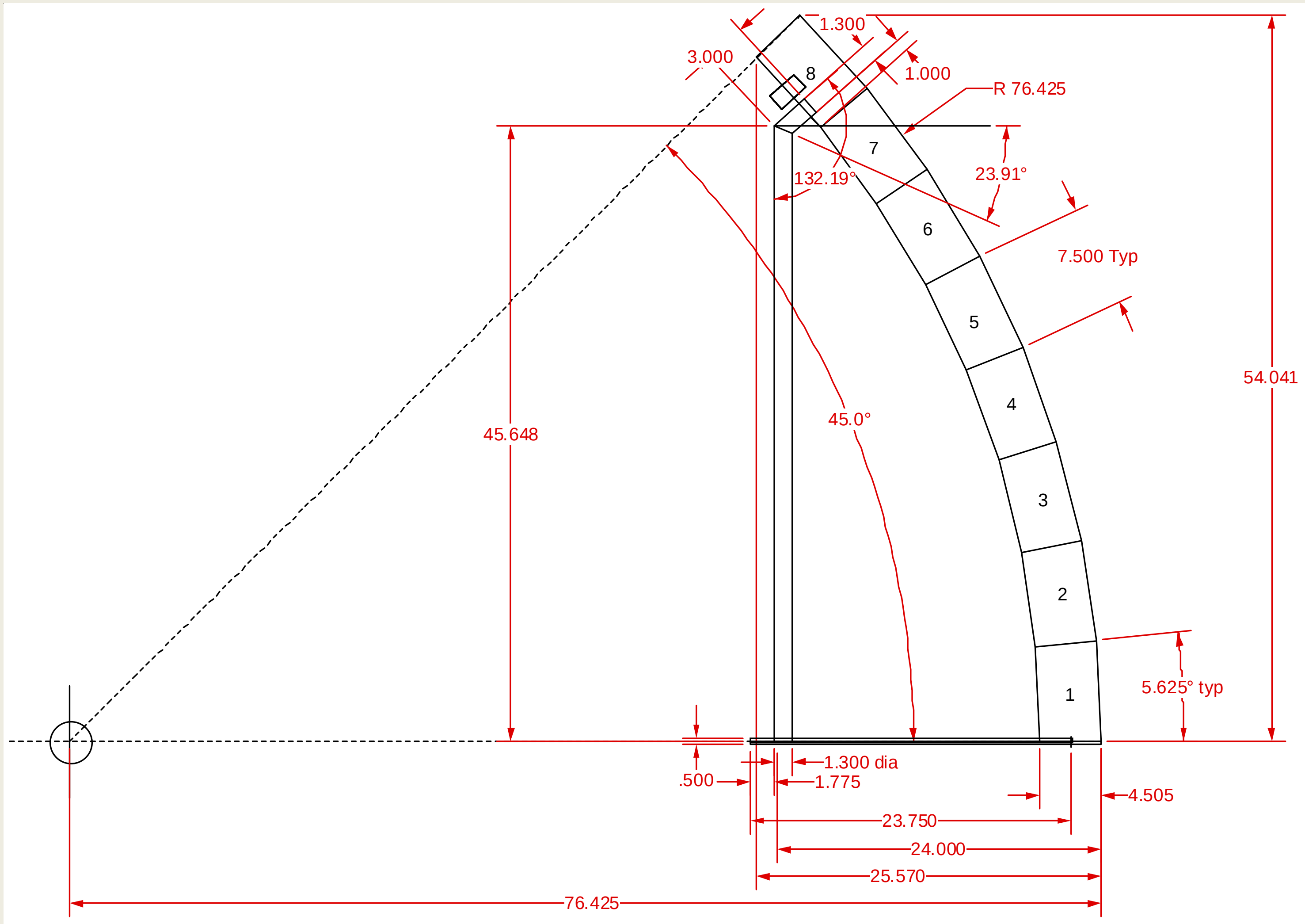
Uses 18 each 2.25” drivers, and 50 each 0.75” dia wide-range drivers (used in Toshiba laptops).

Remember the Harman Kardon Soundsticks PC Multimedia Speakers?

Keele's Second CBT Array Prototype of 2004 (CBT45)

- **DESCRIPTION:**
- CBT 45°-Arc Curved Array
- Ground-Plane Design
- Height = 1.35m (54in)
- Uses 48 AKG XXL-V5 Headphone Drivers
- Operating range of 100 Hz to 12 kHz
- Composed of Eight 5.625° Straight Segments
- Each segment is constructed of 4in-ID clear PVC pipe (www.harvelplastics.com)
- Provides a 34° vertical beamwidth (-6 dB)
- Controls coverage down to 200 Hz
- Qualifies for a true wide-band constant directivity source!

CBT45 Array CAD Drawing



CBT45 Photos

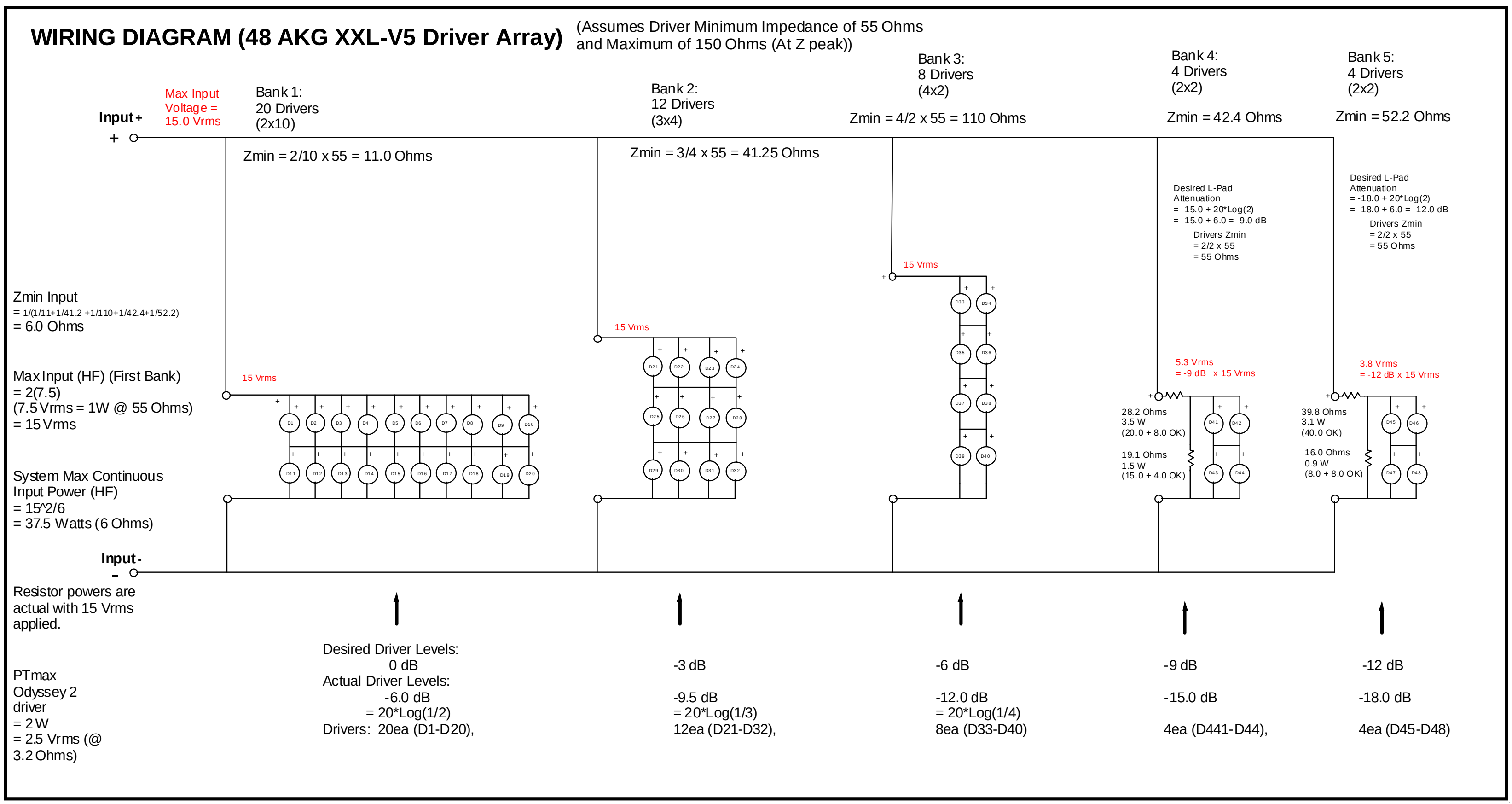
CBT45 Photos

CBT45 Photos

CBT45 Array Wiring Diagram

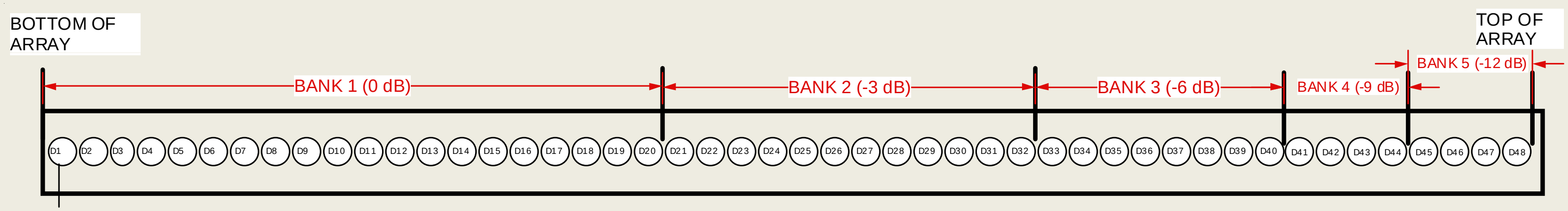
(Implements stepped and truncated Legendre Shading)

Rated Impedance: 8 Ohms
Minimum Impedance: 6.4 Ohms

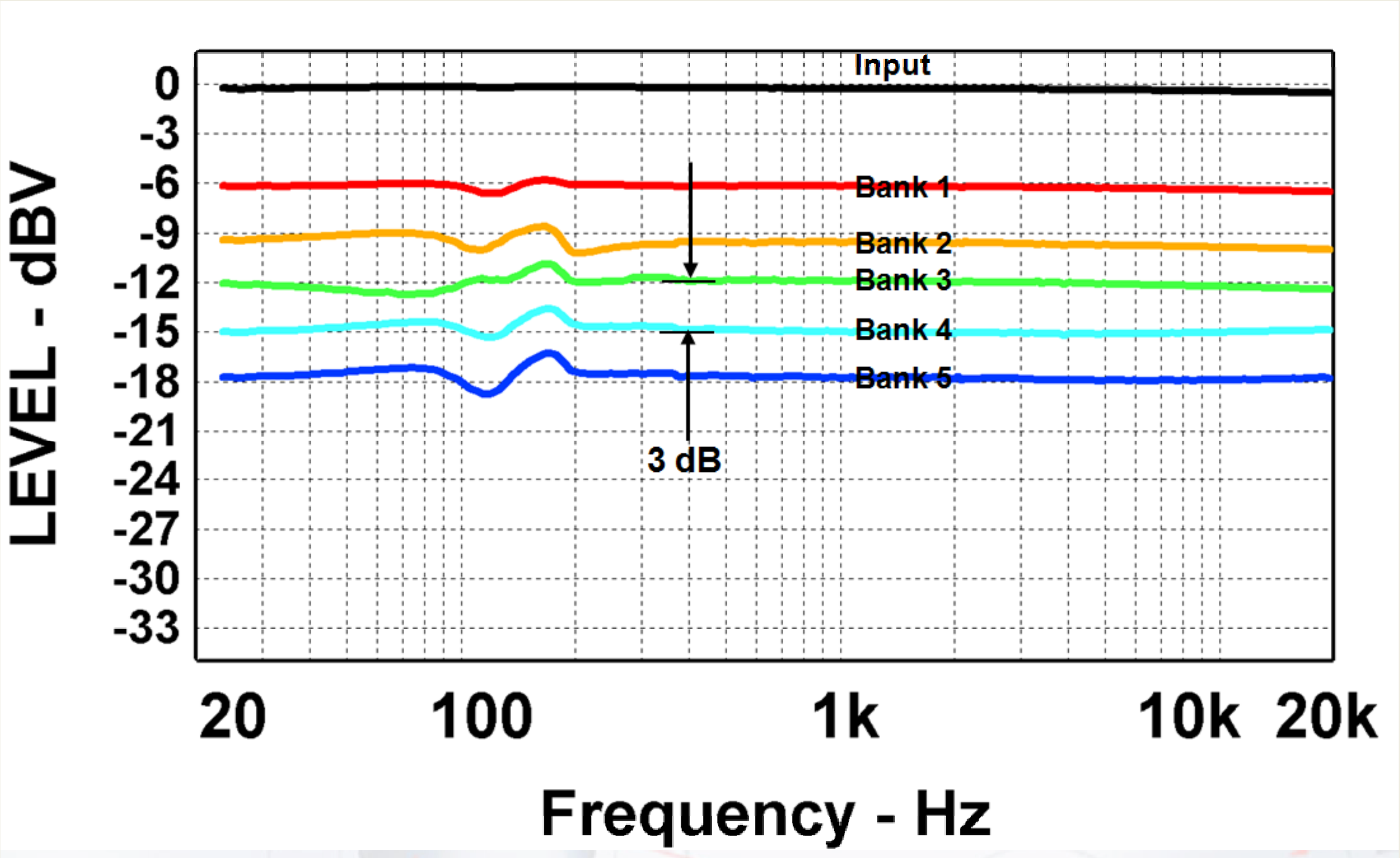


CBT45 Driver Layout and Shading

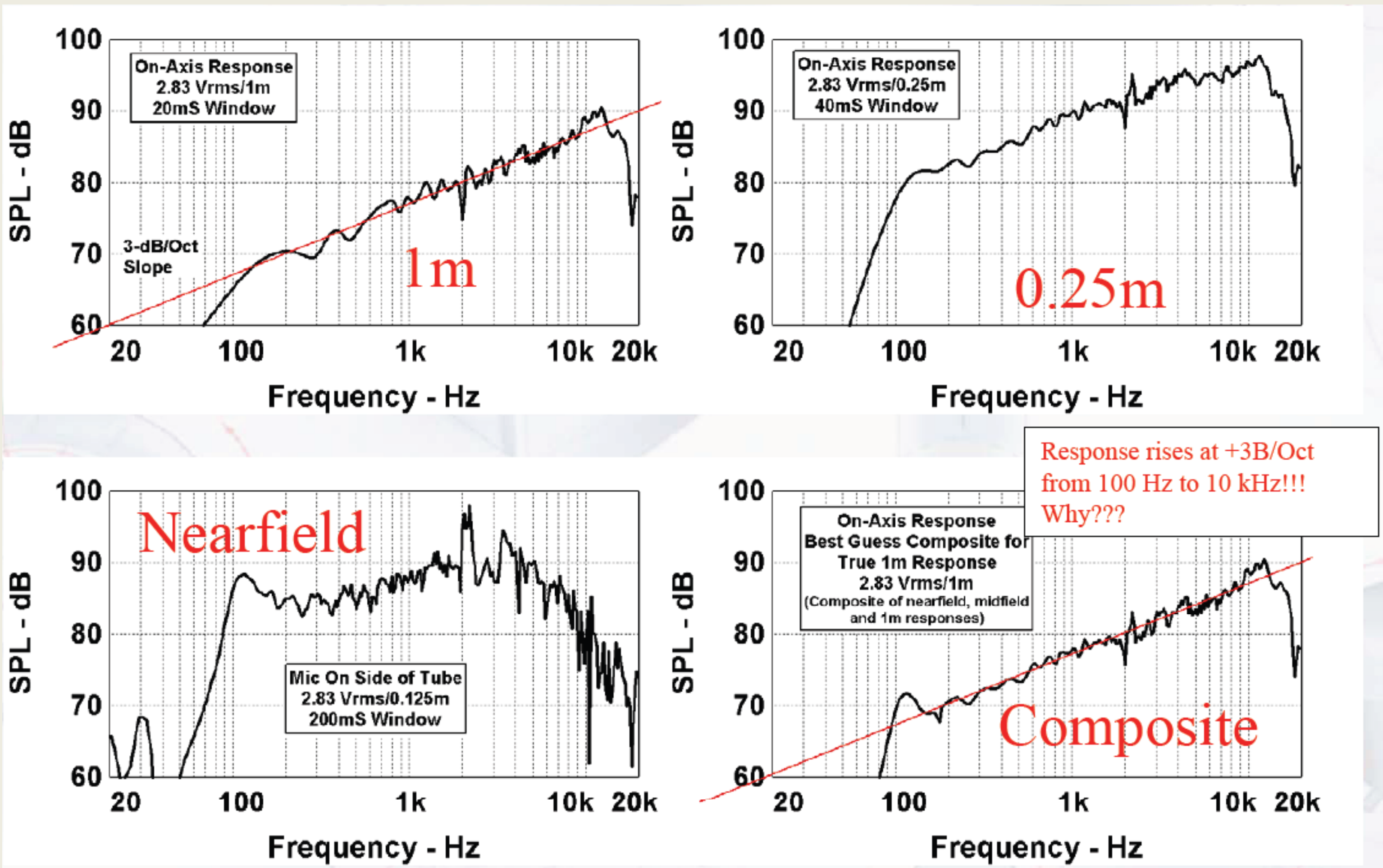
Total of 48 Drivers



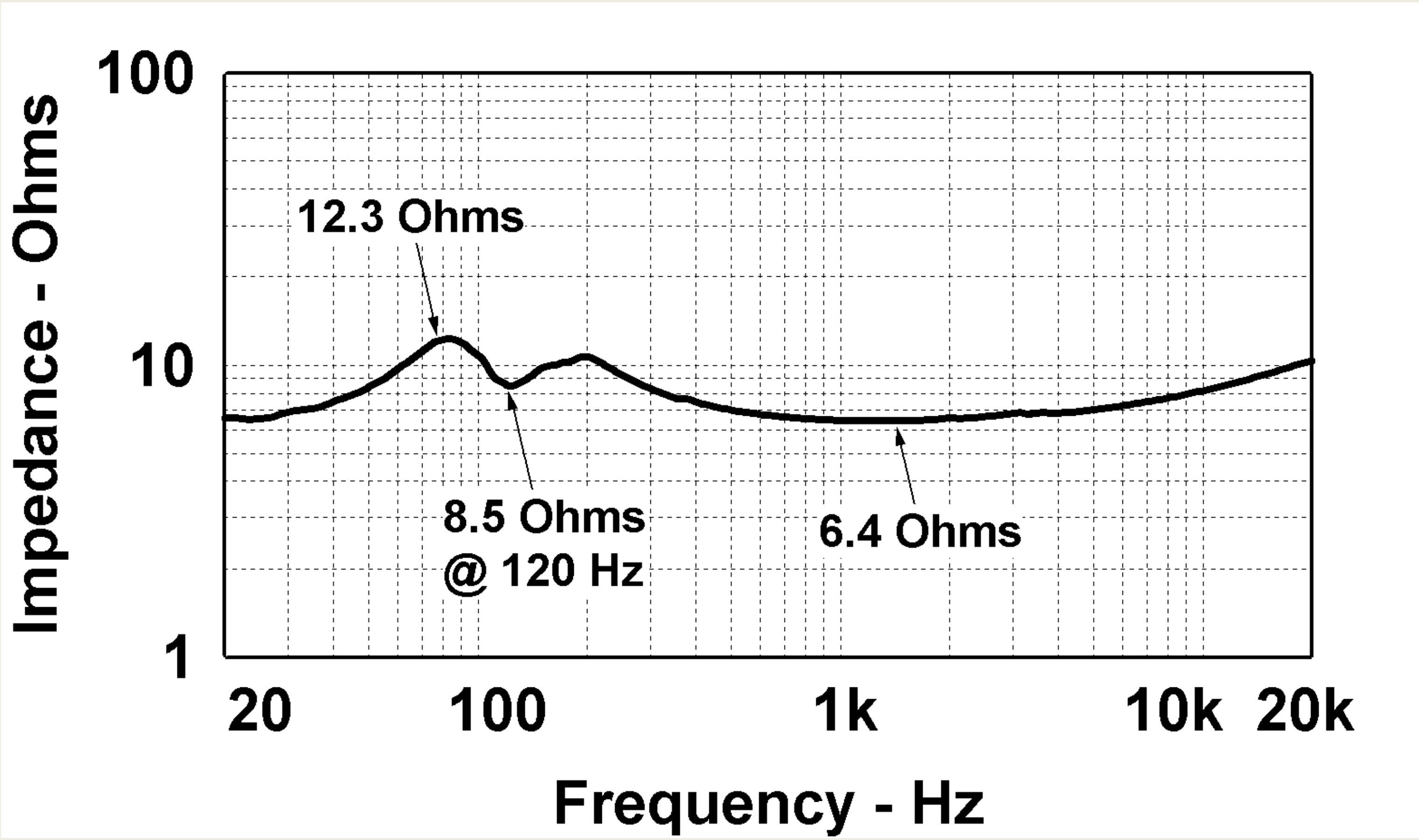
CBT45 Measured Voltage Drive of Shading Network



AKG Headphone Driver Response

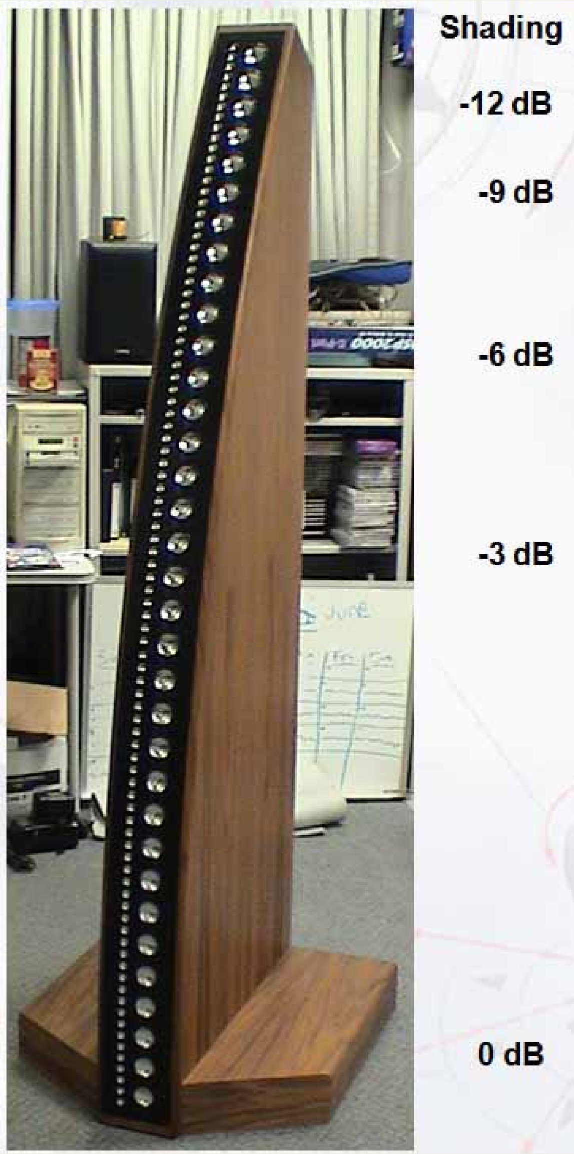


CBT45 Measured System Impedance

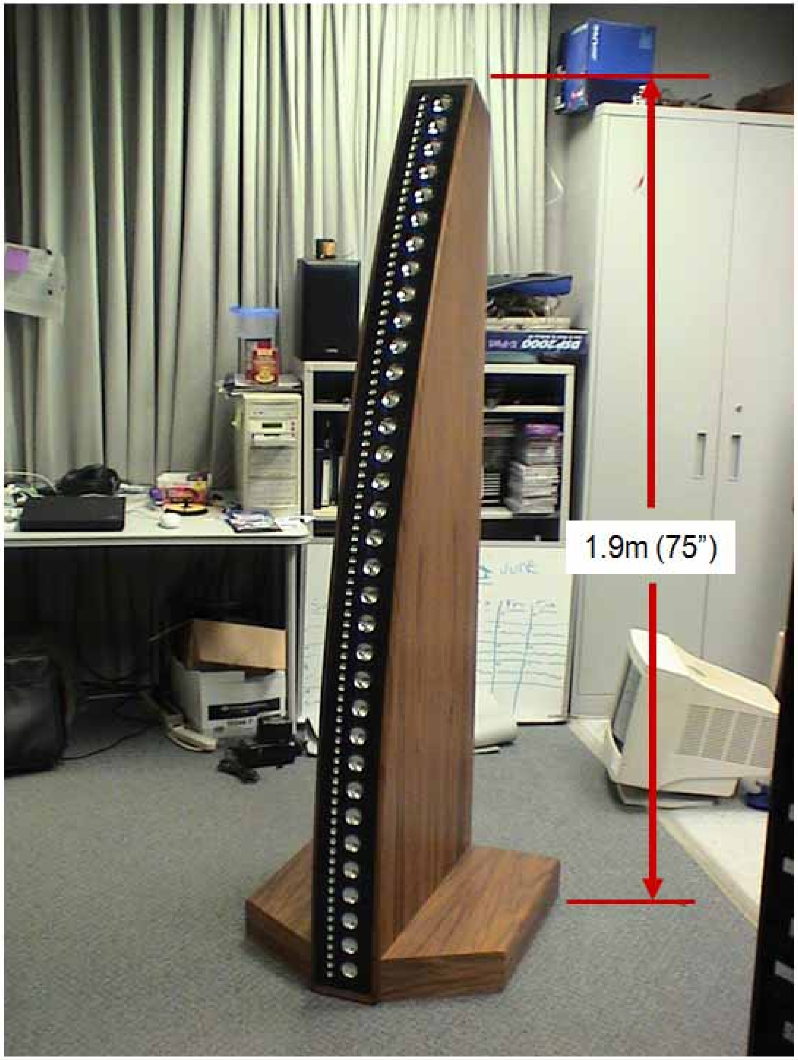


Keele's Third CBT Array Prototype of 2004 (CBT30)

- **CBT30 Ground-Plane CBT Array**
  - 1.9 m (6.25') High
  - 30° Circular Arc
  - Uses 90 Each Odyssey 2, 18 mm (0.71") Dia. Harman Multimedia Drivers
  - Uses 34 Each Warrior 53 mm (2.1") Dia. Harman Multimedia Drivers
  - Crossover: 1 kHz
  - Operating range of 100 Hz to 20 kHz
  - Passive Shading Network
  - Qualifies as a true wide-band constant directivity source! (200 Hz and Up)
  - Narrow 22° Vertical Coverage (-6 dB)
  - Wide 180° Horizontal Coverage
  - Extremely Even Coverage! Up-Down, Right-Left, Far-Near
  - Can Play Very Loud and Clean!

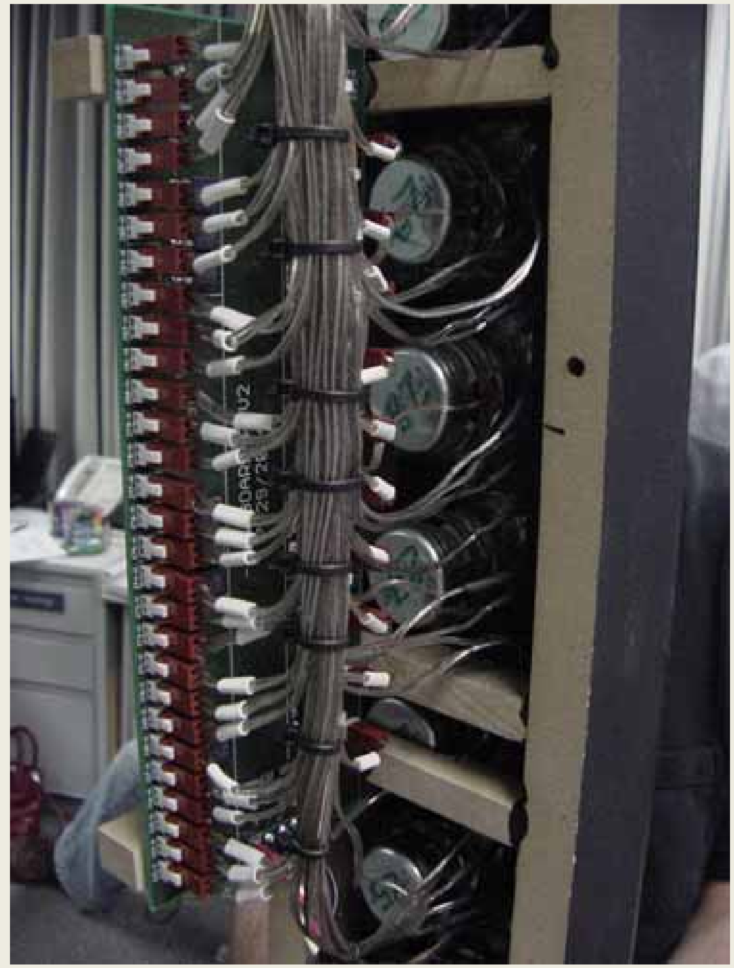


Keele's Third CBT Array Prototype of 2004
CBT30

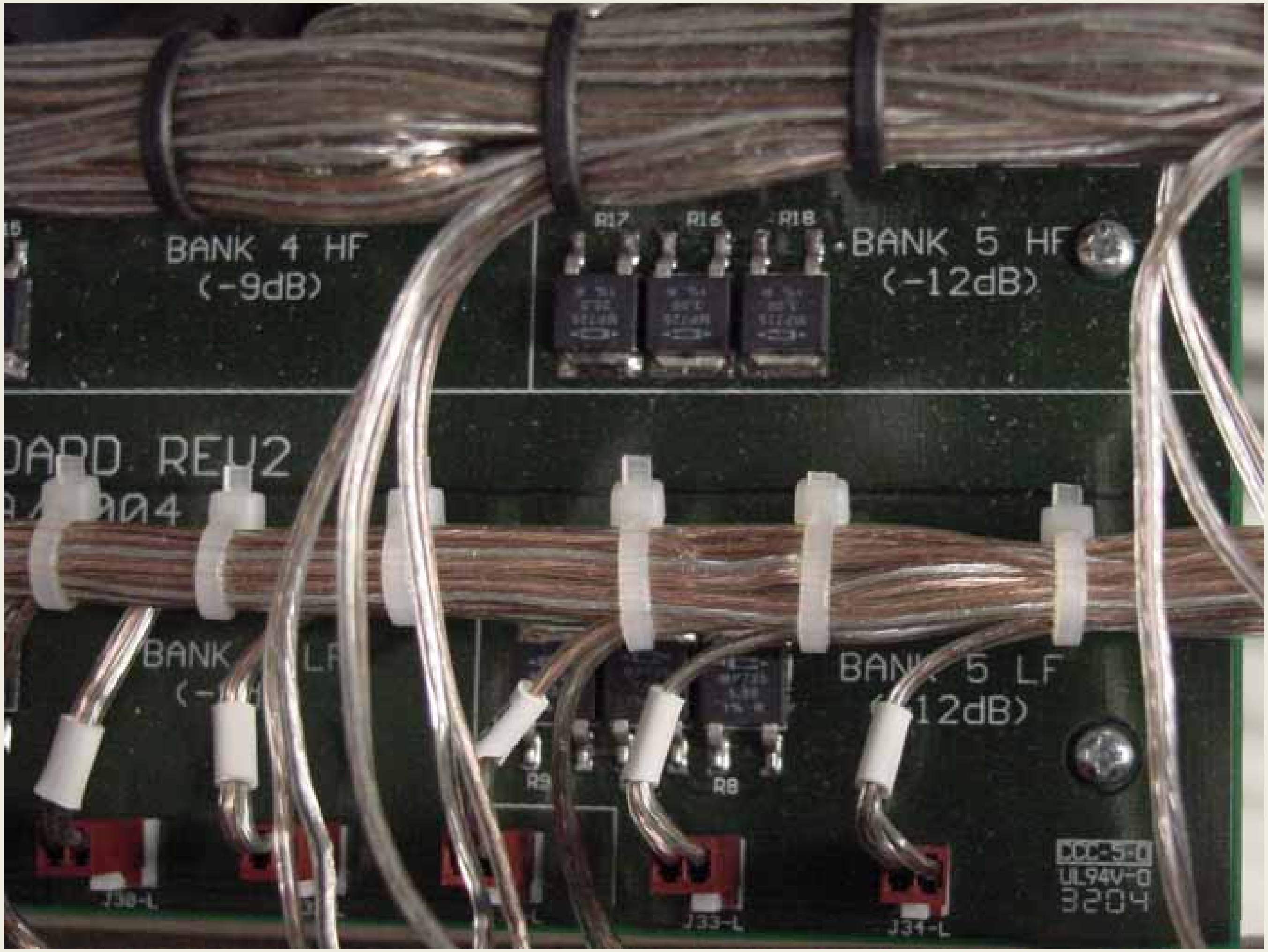


Keele's Third CBT Array Prototype of 2004
CBT30

Keele's Third CBT Array Prototype of 2004
CBT30



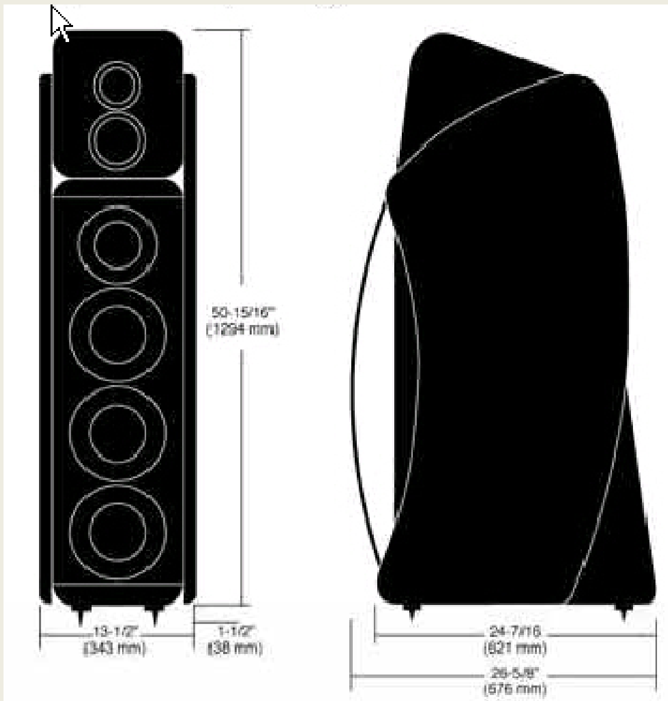
Keele's Third CBT Array Prototype of 2004
CBT30



CBT45 vs. Revel Salon (Measured Both with and Without Carpet)

Photos Revel Salon
(Measured Both with and Without Carpet)

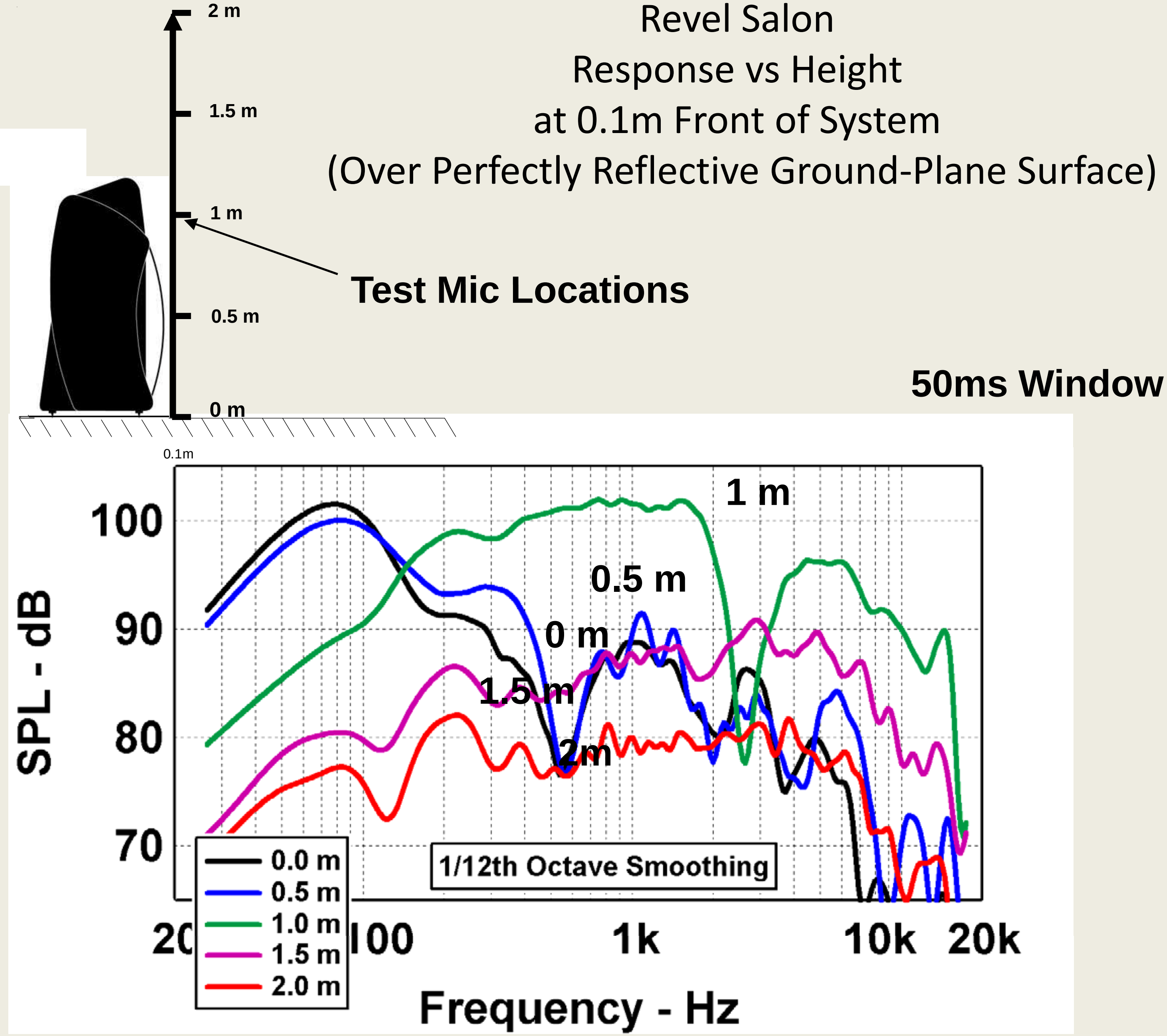
Revel Salon Description



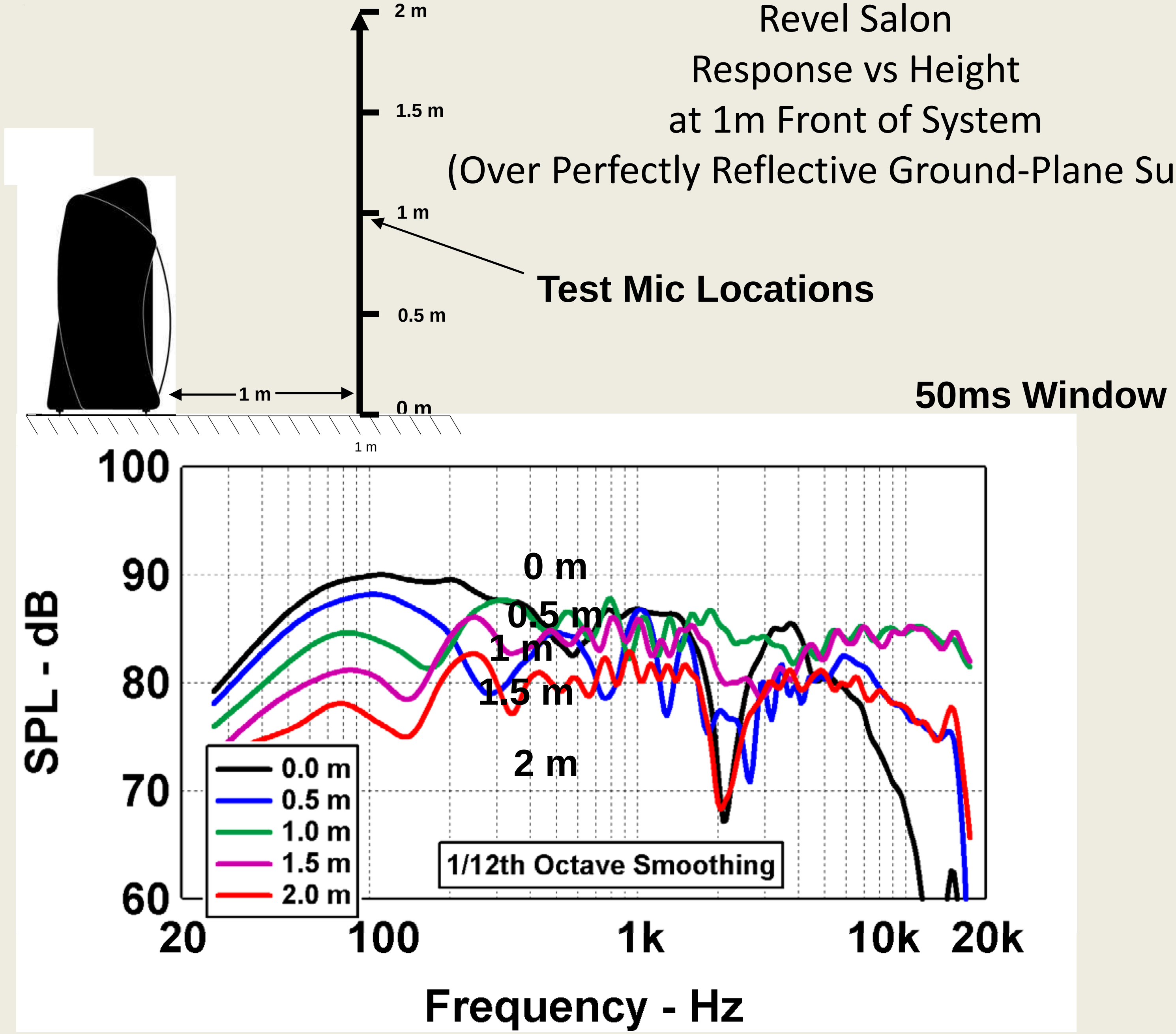
Salon Product Specifications

Sensitivity:	86 dB SPL, with 2.83 RMS @ 1 meter, 4 pi (anechoic).
Impedance:	6 ohms nominal, 3 ohms minimum
Filters (crossover):	4-way, 24 dB/octave (4th-order) acoustic response at 125 HZ, 450 and 2.2 kHz
In-room Frequency Response:	± 1 dB from 25 Hz to 12 kHz
In-room response relative to target response:	± 0.75 dB from 25 Hz to 20 kHz
First-reflections Response:	± 1 dB from 25 Hz to 17 kHz
Listening Window Response:	± 1.5 dB from 25 Hz to 18 kHz
Low Frequency Extension:	-10 dB @ 17 Hz, -6 dB @ 20 Hz (-3 dB @ 24 Hz)
Dimensions:	50 15/16" (1294 mm) H x 13 1/2" (342.9 mm) W x 26 9/16" (674.7 mm) D. Add 1 1/2" (38 mm) for spikes.
Shipping Weight:	approx. 240 lbs. (108.9 kg)

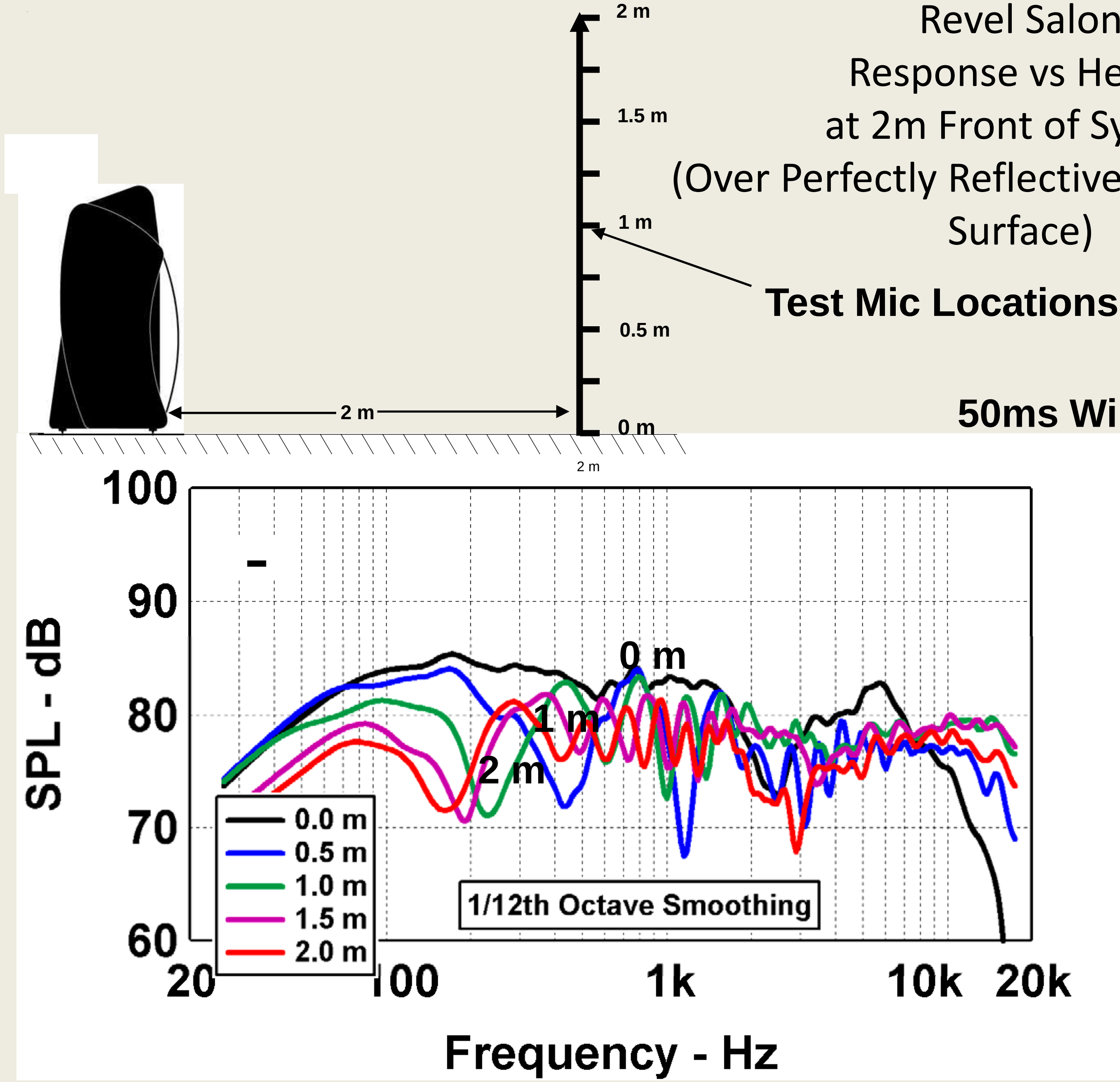
Revel Salon
Response vs Height
at 0.1m Front of System
(Over Perfectly Reflective Ground-Plane Surface)



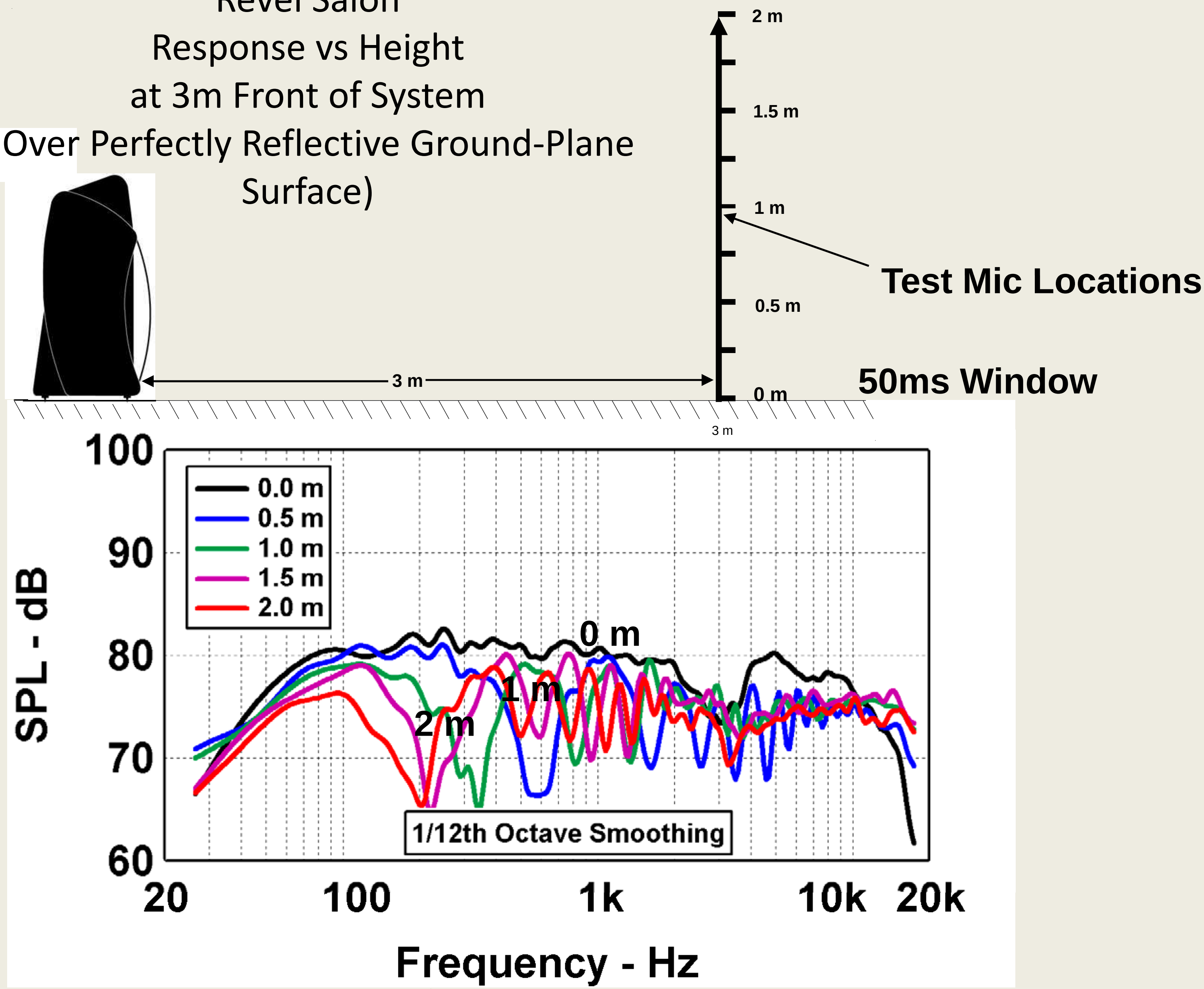
Revel Salon
Response vs Height
at 1m Front of System
(Over Perfectly Reflective Ground-Plane Surface)



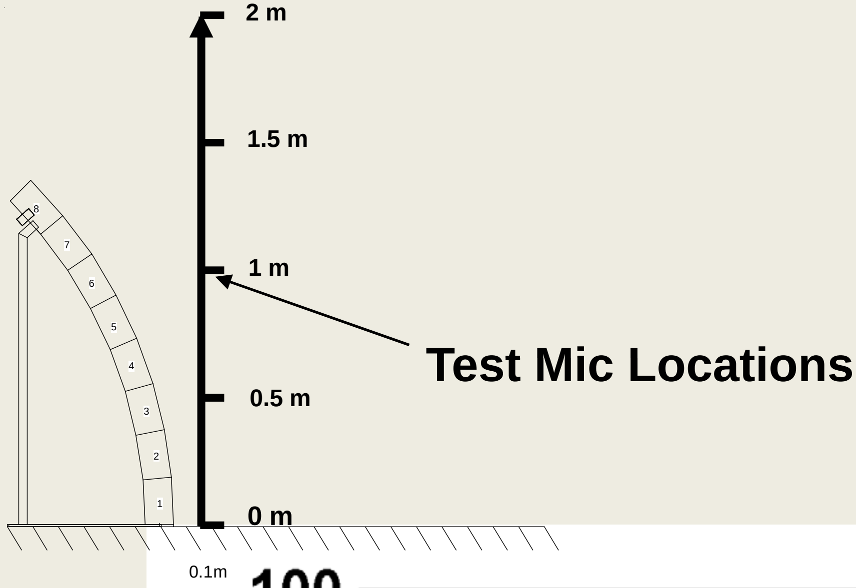
Revel Salon
Response vs Height
at 2m Front of System
(Over Perfectly Reflective Ground-Plane Surface)



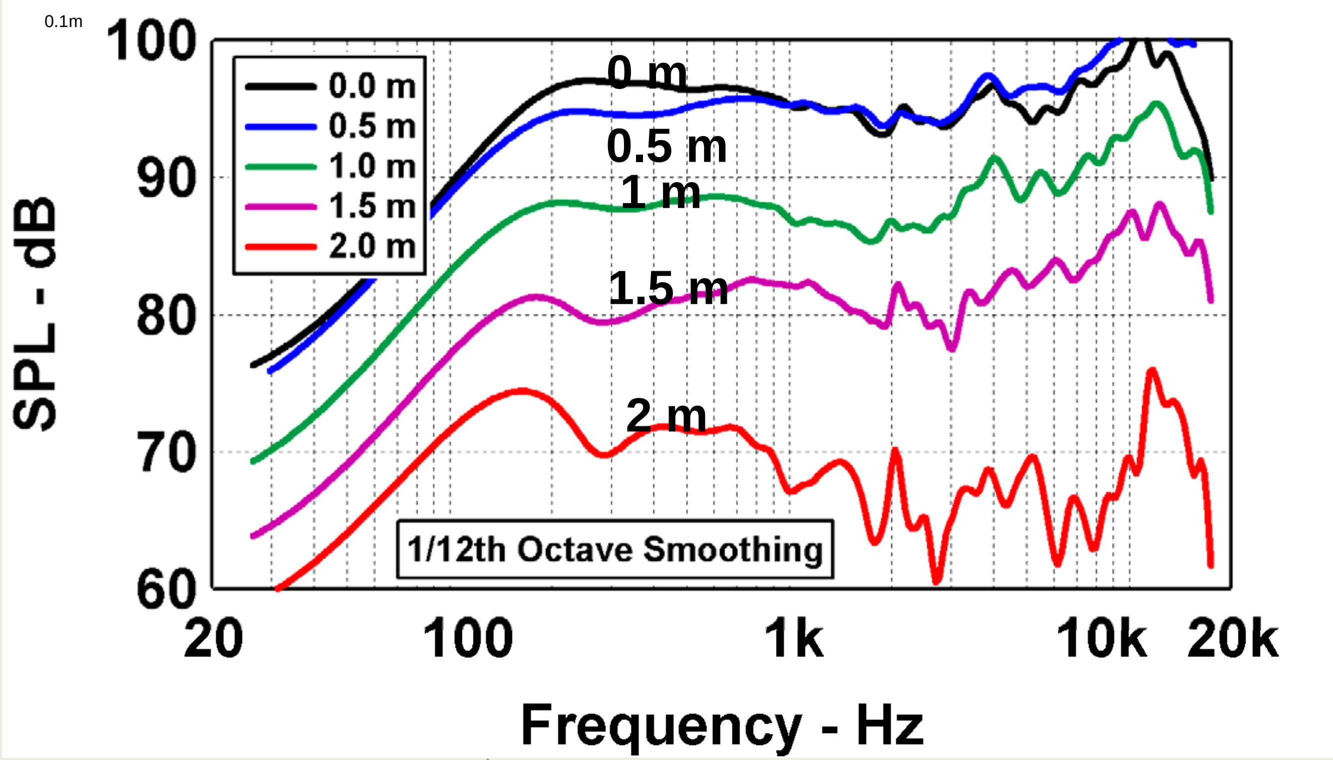
Revel Salon
Response vs Height
at 3m Front of System
(Over Perfectly Reflective Ground-Plane Surface)



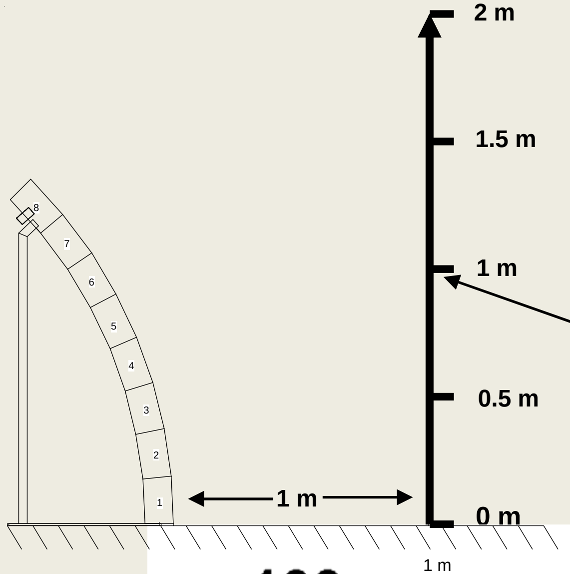
CBT45
Response vs Height
at 0.1m in Front of Array
(Over Perfectly Reflective
Ground-Plane Surface)



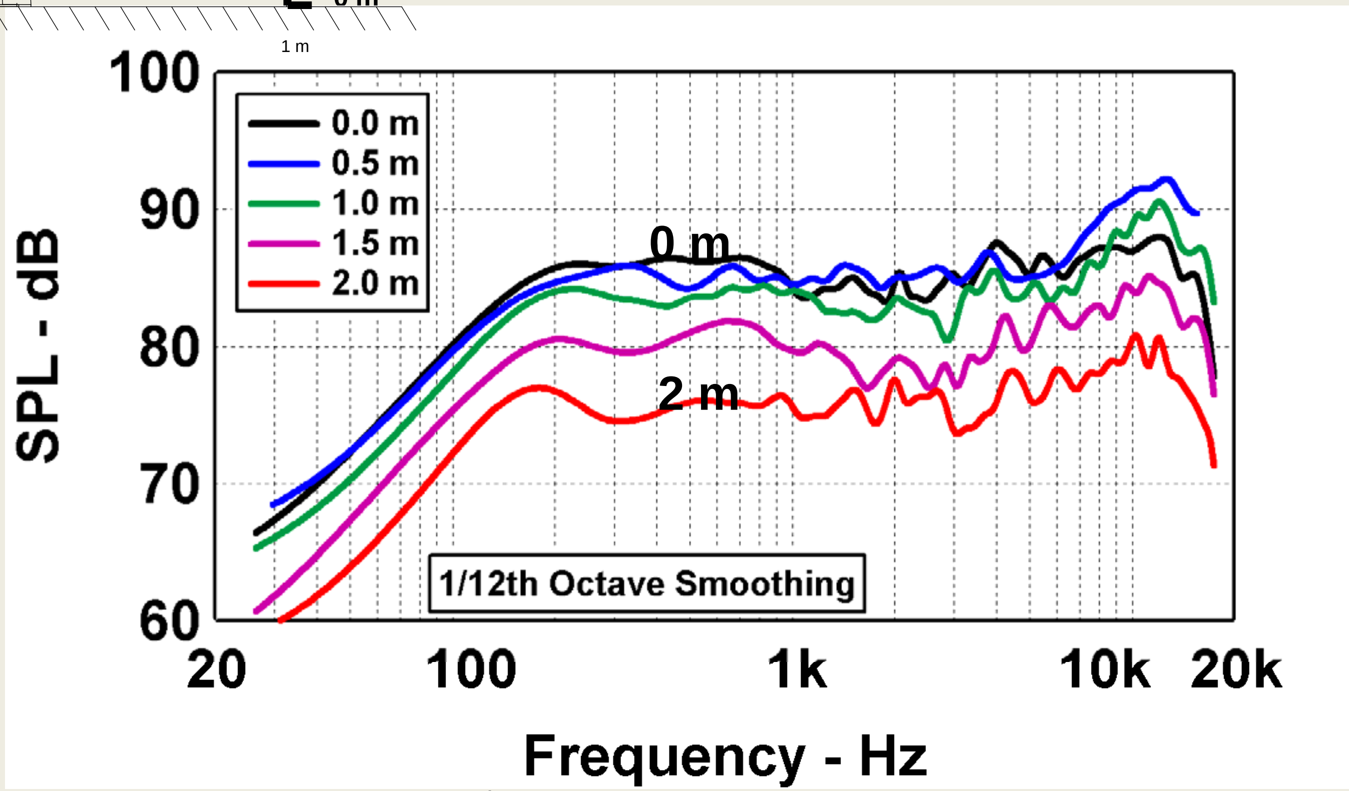
25ms Window



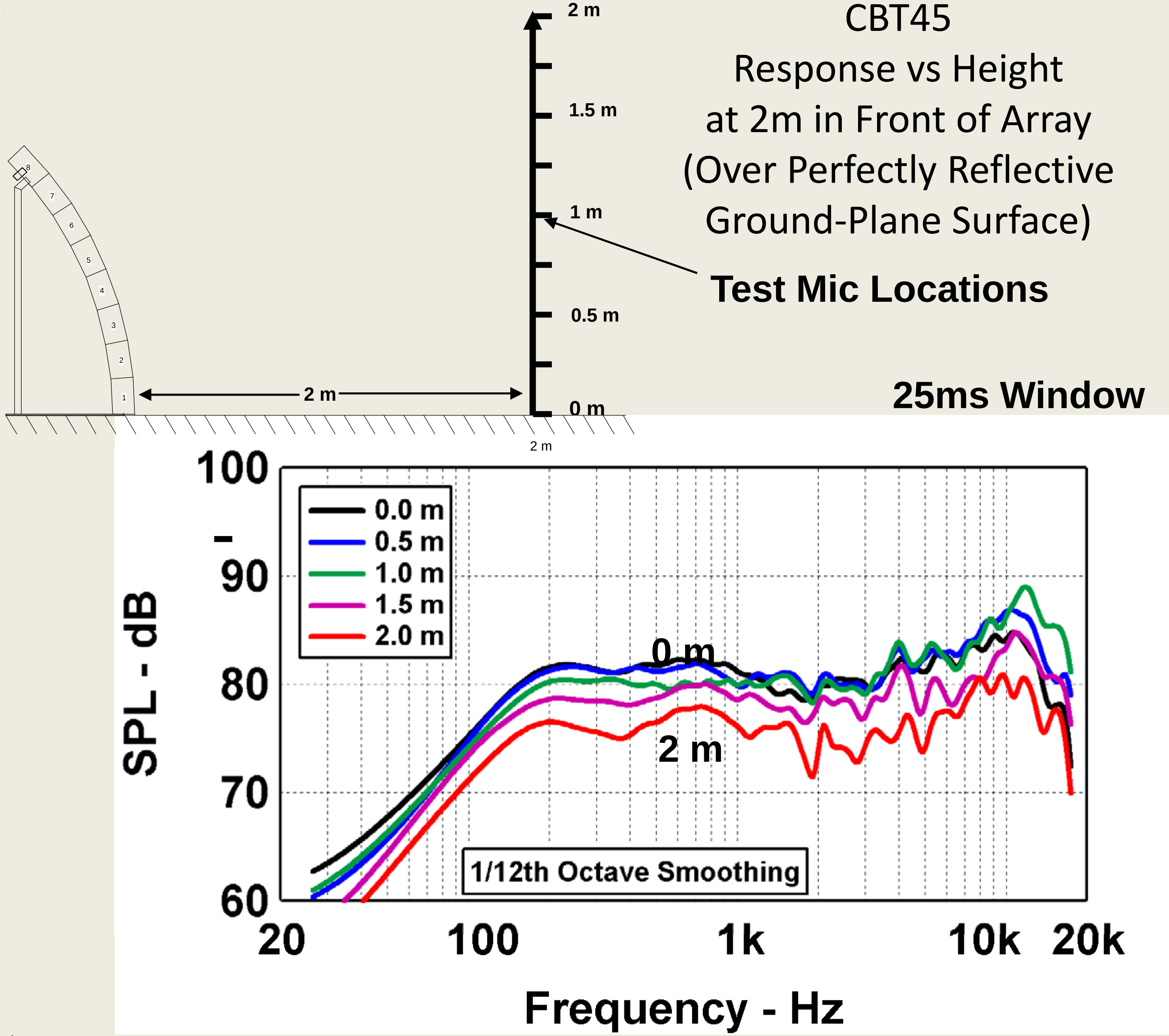
CBT45
Response vs Height
at 1m in Front of Array
(Over Perfectly Reflective
Ground-Plane Surface)



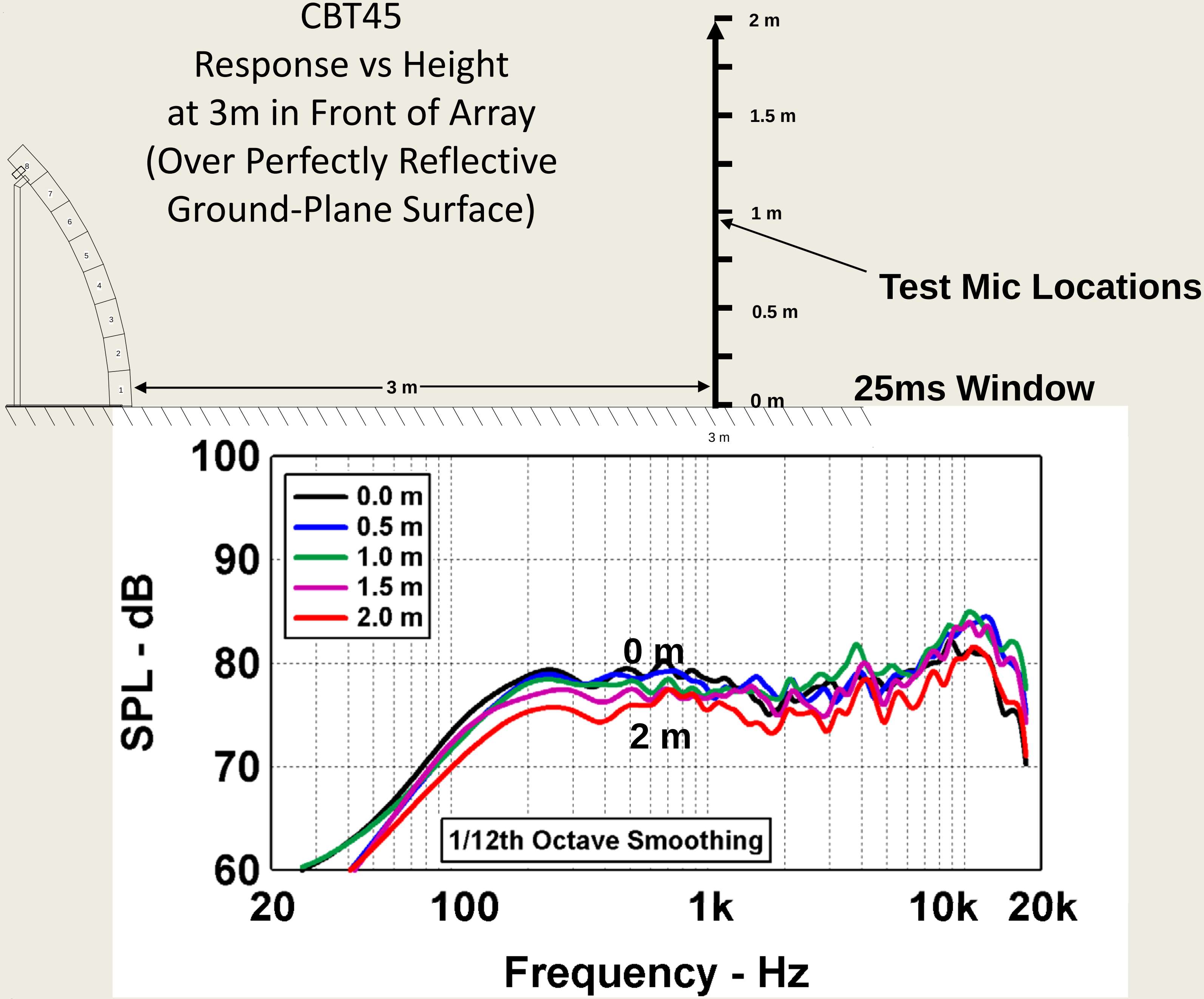
25ms Window



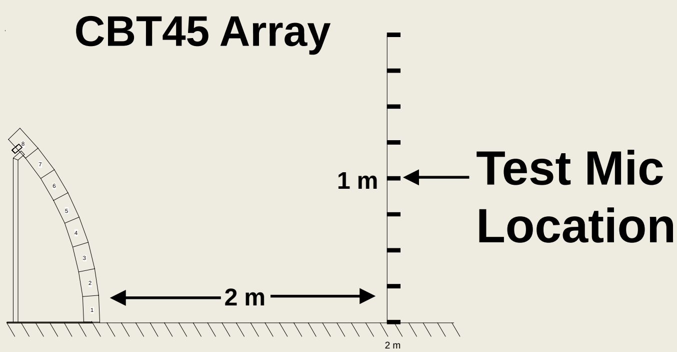
CBT45
Response vs Height
at 2m in Front of Array
(Over Perfectly Reflective
Ground-Plane Surface)

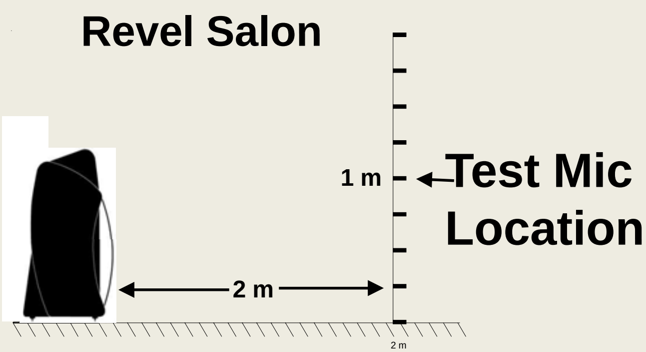


CBT45
Response vs Height
at 3m in Front of Array
(Over Perfectly Reflective
Ground-Plane Surface)

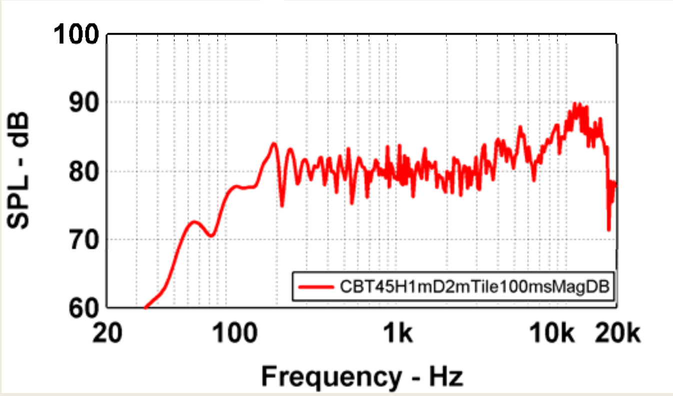


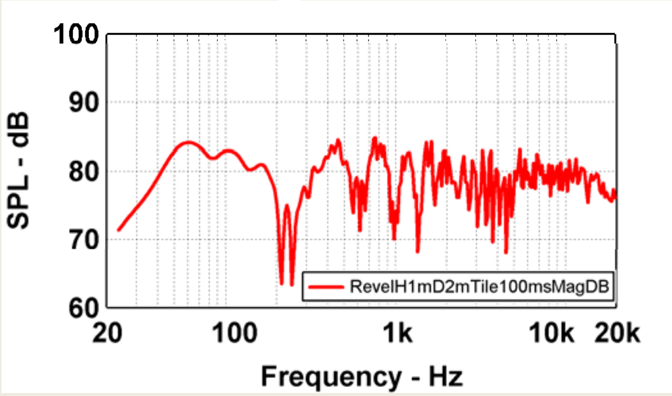
Revel Salon vs CBT45, 2m On Axis, 1m High
(Over Perfectly Reflective Ground-Plane Surface)

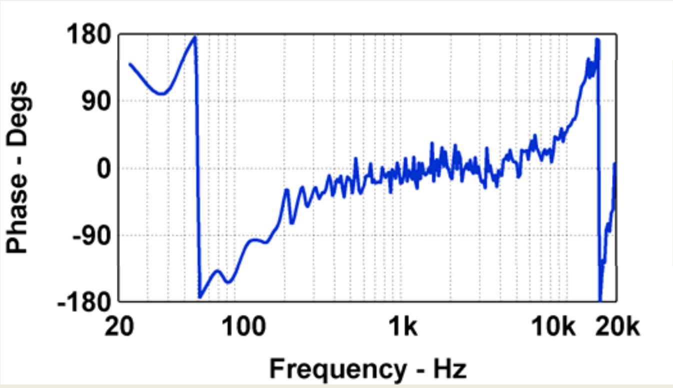


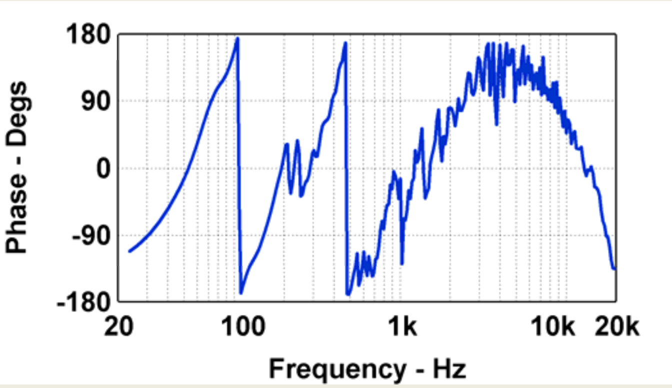


100ms Time Window

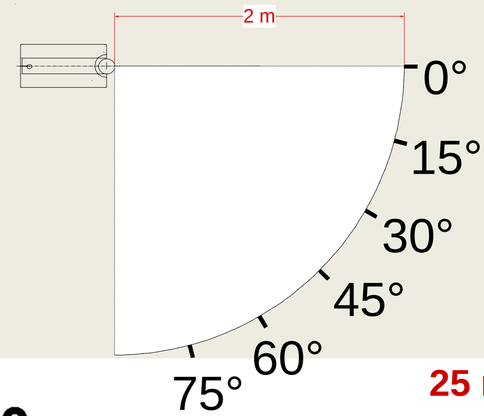


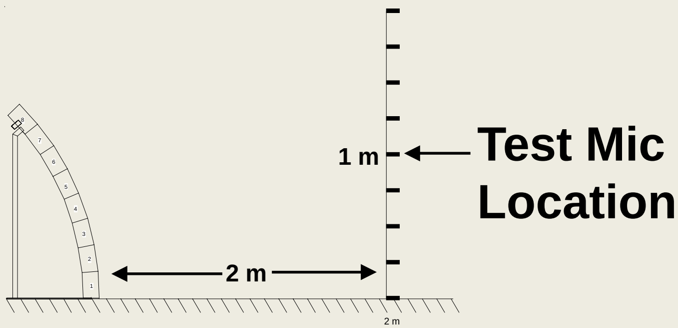


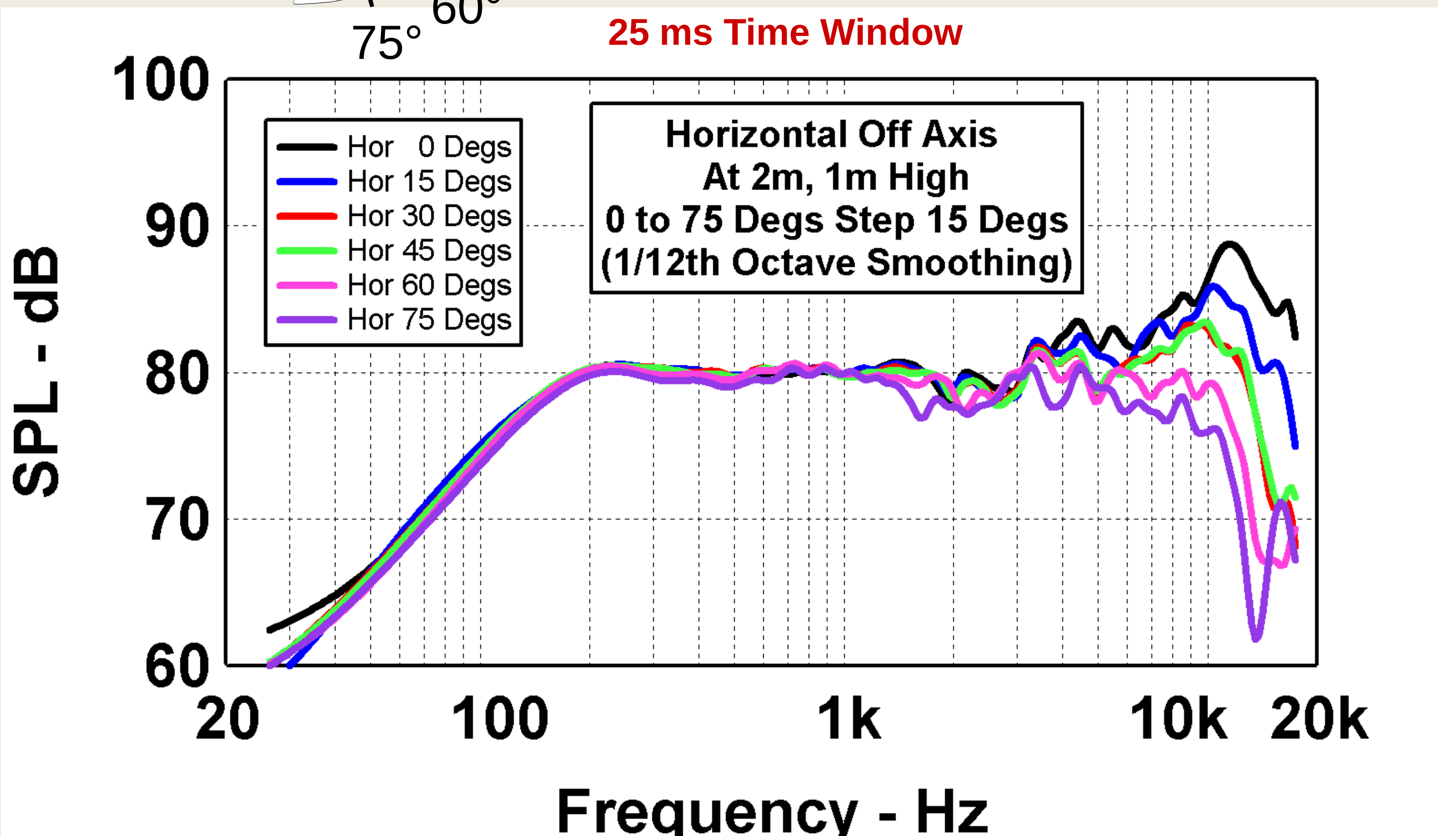




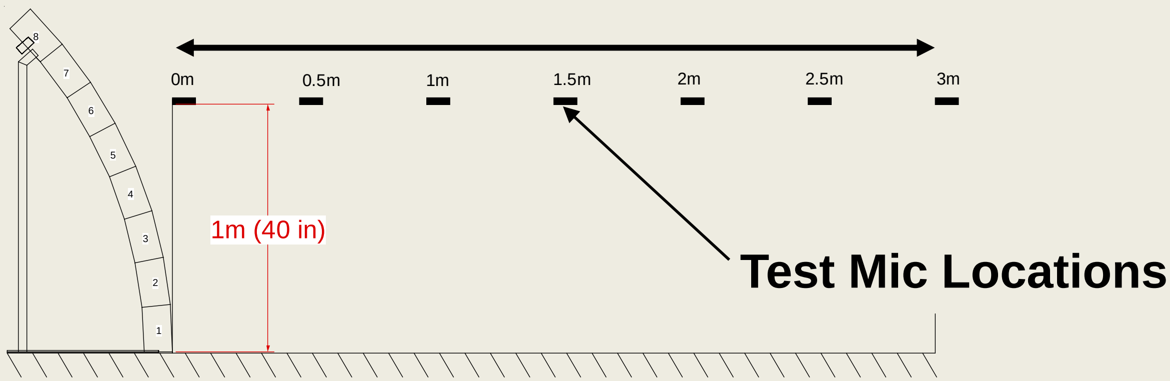
CBT45 Horizontal Off-Axis Frequency Response

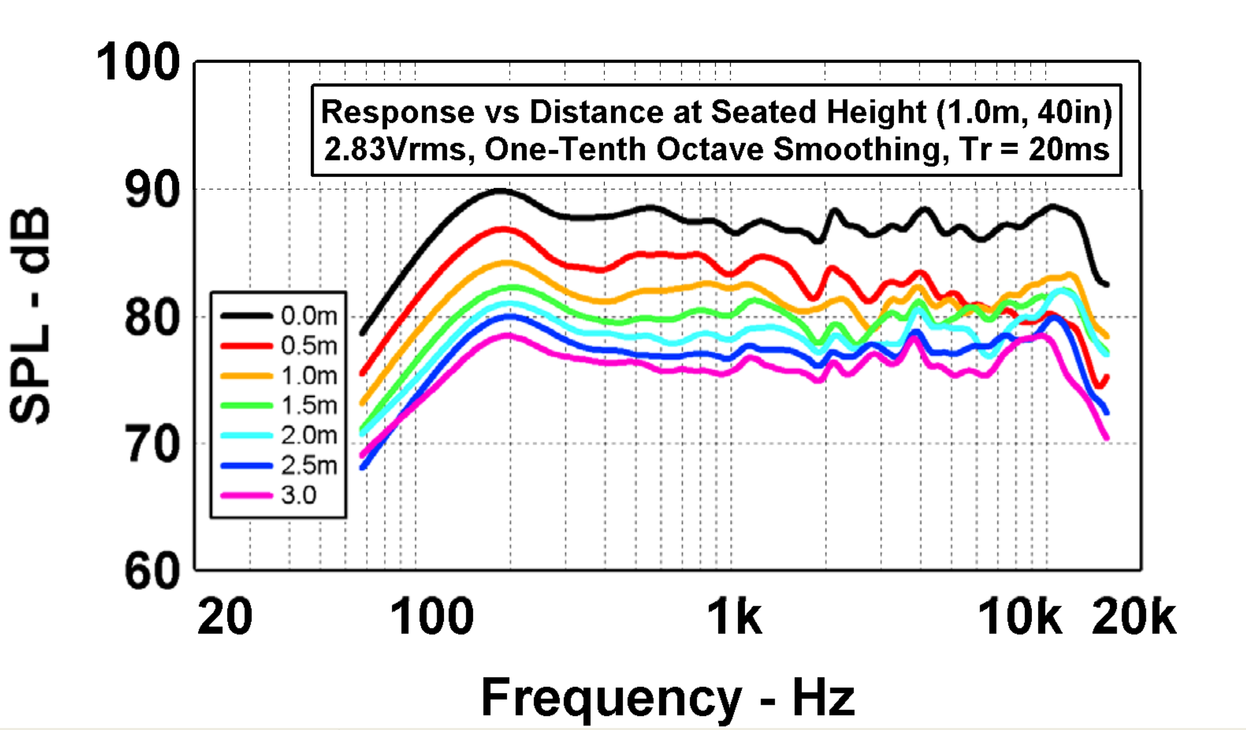




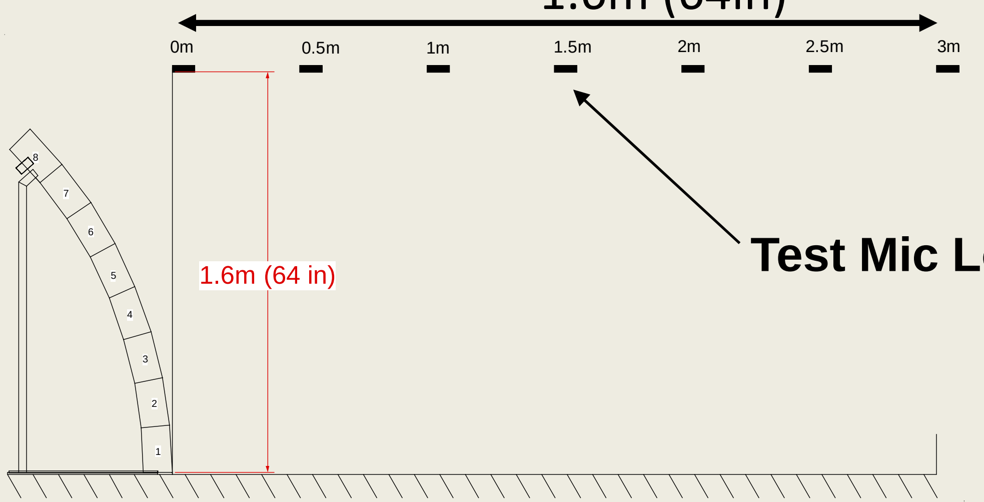


Response vs Distance at Seated Height
1m (40 in)

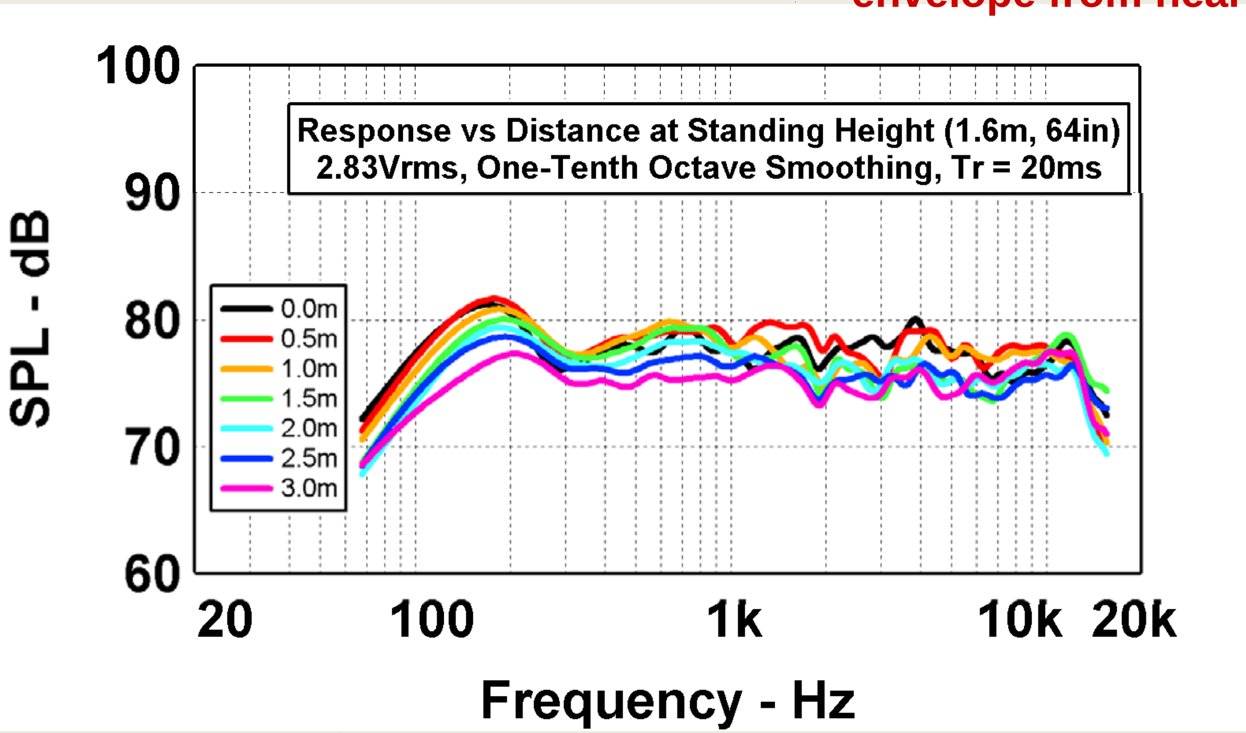




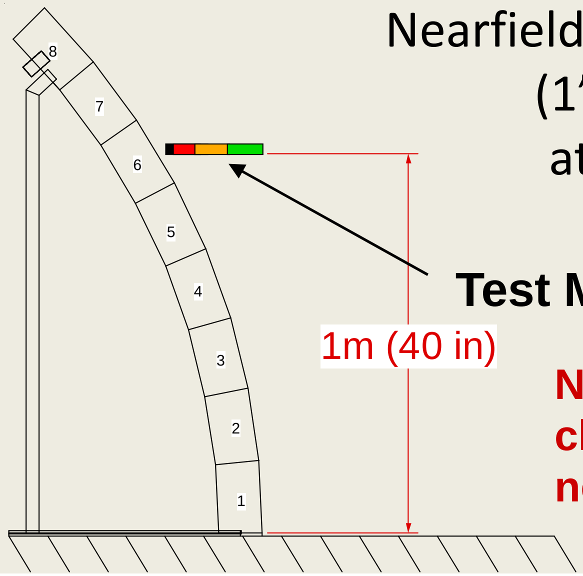
Response vs Distance at Standing Height



Fits a 4 to 5 dB response envelope from near to far!

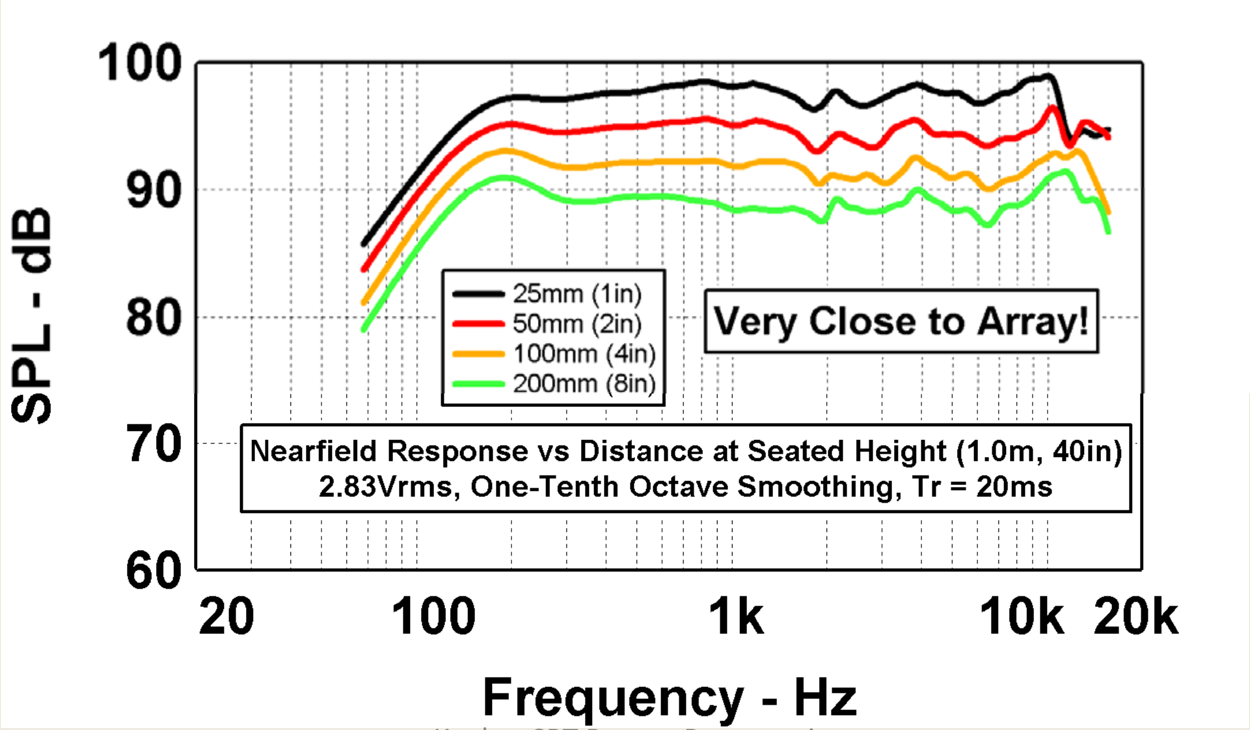


Nearfield Response vs Distance
(1", 2", 4" and 8")
at Seated Height
1m (40 in)



Test Mic Locations

Note uniformity of very-close response! Is a perfect near-field monitor!



Implementation Using Systems

ProSoundWeb
News & Information for the Audio Professional

Real World Gear: The Latest Mini Line Arrays


Void Acoustics Arcline 6


TOA Electronics HX-5


Tecnare MiniArray


Proel Group AXIOM AX2265P


Outline Mini-COMPASS


Meyer Sound M1D


Martin Audio OmniLine


Ljud Design Scandinavia LDS CL-100


L-Acoustics KIVA

Implementation Using Systems

ProSoundWeb
News & Information for the Audio Professional

Real World Gear: The Latest Mini Line Arrays


EM Acoustics HALO


Duran Audio AXYS Target U16


EAW NTL 720 (“B.L.A.M.”)


D.A.S. Audio Variant 25A


d&b audiotechnik T10


Coda Audio LA5A


Biema LAVA System

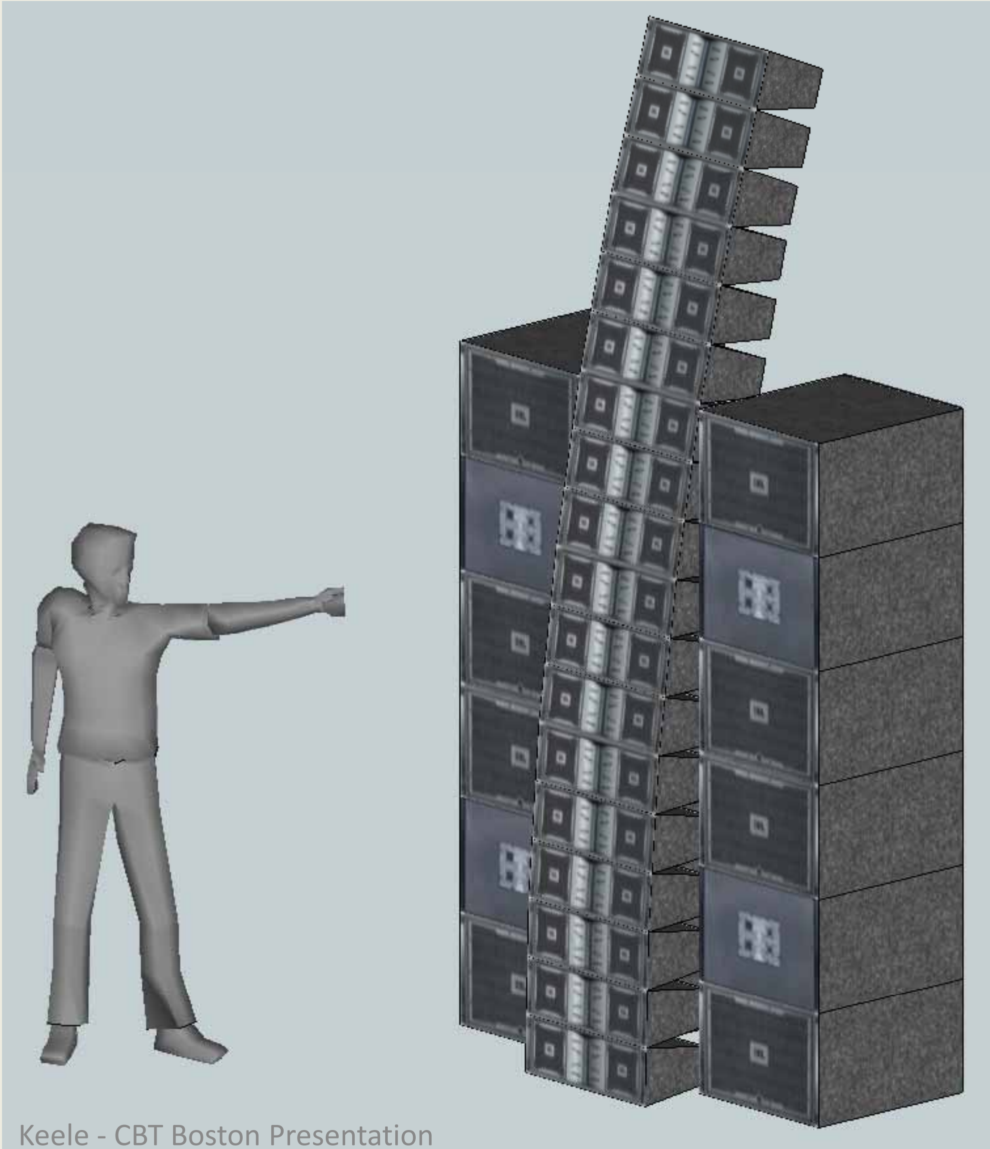

Alcons Audio LR7

Implementation Using Systems

A Killer CBT Ground-Plane System I designed Using 18 Each JBL VT4886 & 12 Each VT4883 Systems Drawing Using SketchUp. An 18° circular arc with an above-ground vertical beamwidth of 13.5°.

This system should be an absolute killer!!! 36 ea compression drivers, 72 ea 2.5” mids, 36 ea 6.5” LFs, and 24 ea 12” subs. 13,500 Watts HF, 19,200 Watts LF, 1,446 Lbs!!!!!

But wait there’s more………………………..., double all these numbers for ground plane operation: 72 ea compression drivers, 144 ea 2.5” mids, 72 ea 6.5” LFs, and 48 ea 12” subs!!

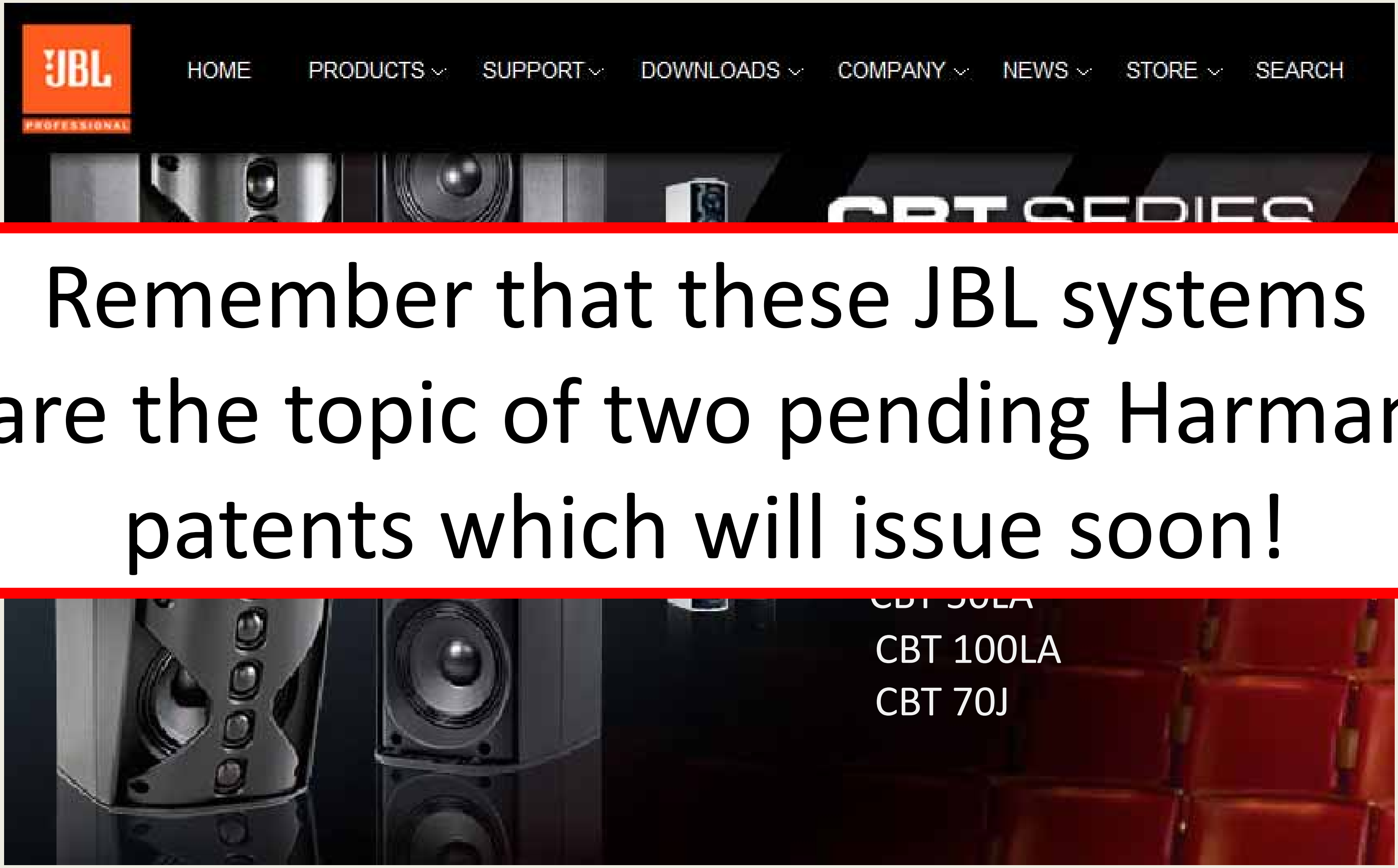


Application of CBT arrays in Sound Reinforcement:

New CBT Systems:

CBT 50LA
CBT 100LA
CBT 70J

Application of CBT arrays in Sound Reinforcement:



Remember that these JBL systems are the topic of two pending Harman patents which will issue soon!

Application of CBT arrays in Sound Reinforcement:

- (Aug. 28, 2008) I received e-mail and photos from **Marshall Kay** concerning large 12 ft tall CBT arrays that they constructed and installed in a large church in North Carolina.
- Kay is founder and president of loudspeaker manufacturer Audio Artistry. Siegfried Linkwitz works for them and is responsible for their current speaker line. Here is their “Beethoven” system ----- → →

CBT Arrays Installed in Marshall Kay's large 1200 seat North Carolina Church in a LCR configuration

(56 Four inch midrange drivers and 22 Ribbon Drivers)

CBT Array Installed in North Carolina Church Cont.:

CBT Array Installed in North Carolina Church Cont.:

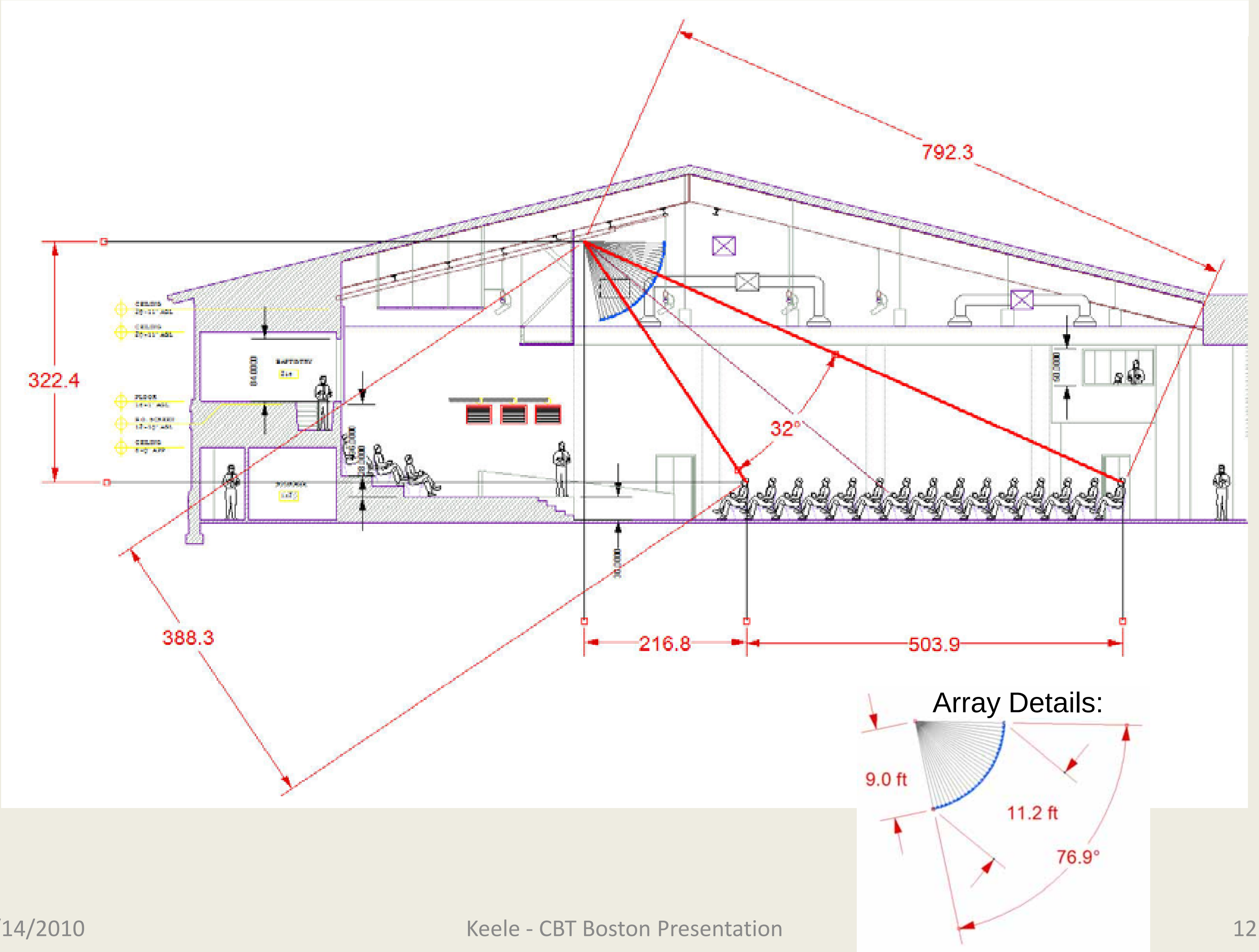
CBT Array Installed in North Carolina Church Cont.:

Three Half-Height Stage Monitors

Three Half-Height Stage Monitors

Three Half-Height Stage Monitors

Side View of Church



CBT Array Installed in North Carolina Church Cont.: Comments from Kay's E-mail:

- Kay comment: "Coverage is quite uniform over most of the seating area and we have had overwhelming positive responses about the sound quality. I am amazed at how quickly the level drops as you pass by the -6dB point and this required us to carefully tweak the aiming of the arrays to keep from missing seats in the front of the church."

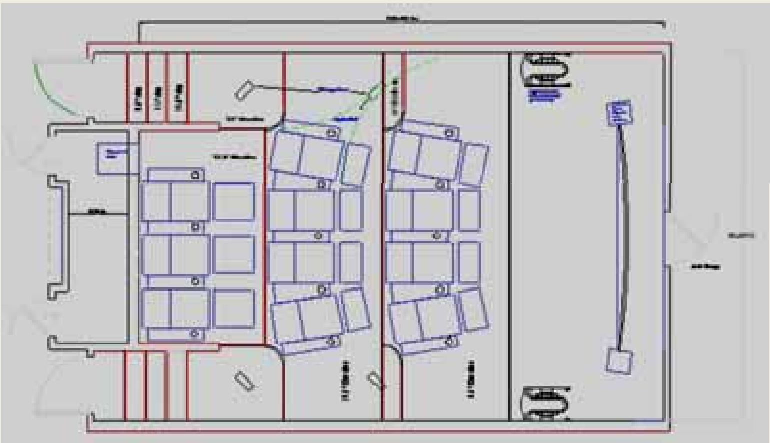
Comments Concerning Listening Outside the Room

- Keele comments: "I was quite interested in your phone comment that when you step out the door of the church and hear the PA bleed through, the sound is well balanced and natural sounding and not like the typical sound system that sounds very muffled, bass heavy, and unintelligible. I attribute this completely to the constant directivity/beamwidth characteristics of the CBT array that energize the room with a flat sound power spectrum. It's this characteristic of the CBT arrays that allows them to sound good even when listening behind a physical barrier that blocks the direct sound (see comment 3 in the next-to-the-last e-mail in this chain).

- Kay comments: "Having worked with Siegfried Linkwitz on dipoles, the out of the room test is one I always check and I was happy to find that the balance was amazingly good. I think this approach to directivity control, that Don has describe so well in his papers, will help a lot of problematic acoustic situations. Hopefully, we will see it become available in a commercial offering available to all."

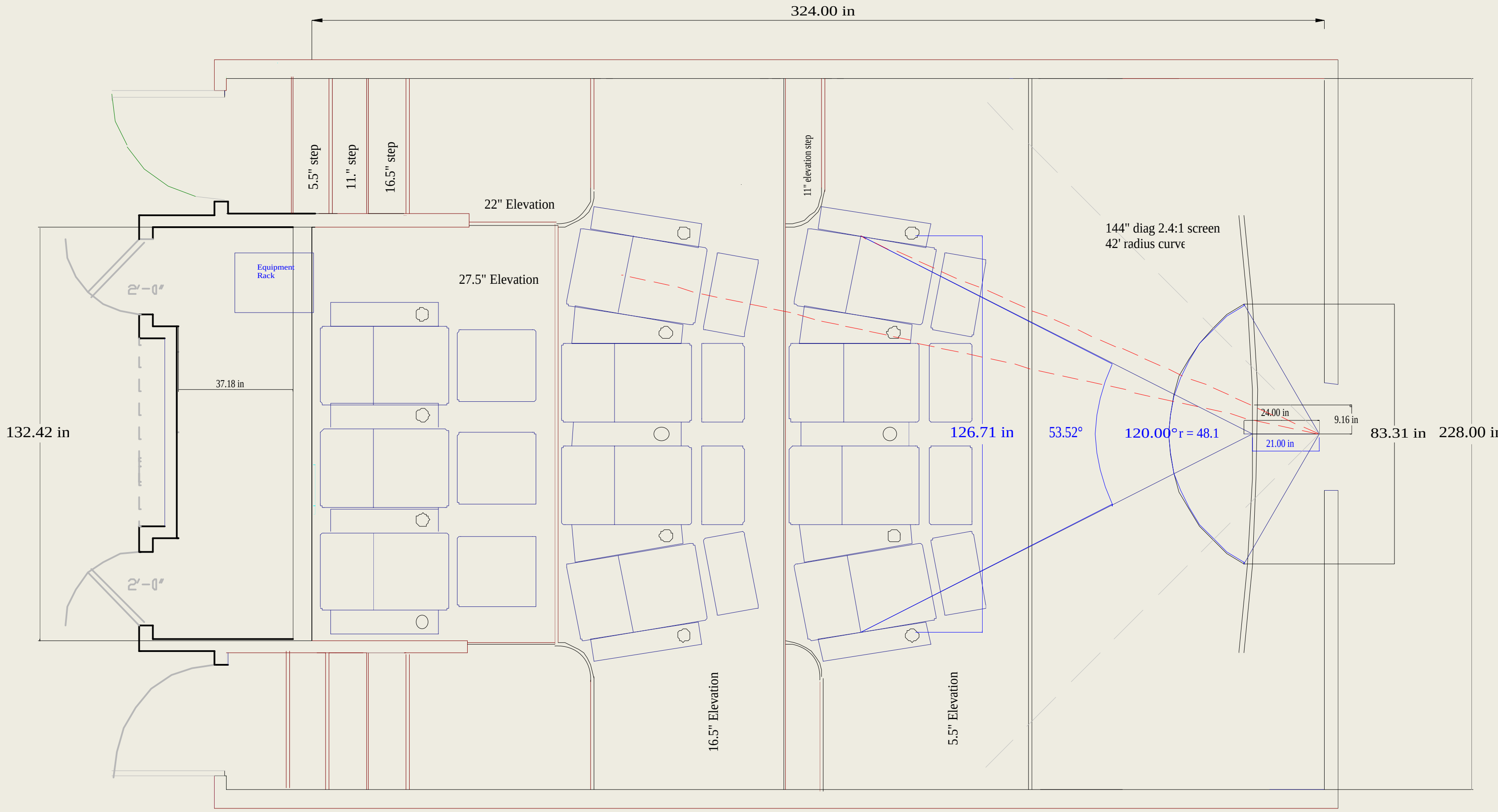
Recent Addition by Monte Kay to his Home Theater!

(Brother of Marshall Kay, http://www.mfk-projects.com/)



Monte Kay's CBT Center Channel

(120° Circular-Arc CBT Array, 7 ft Wide)



Monte Kay’s CBT Center Channel

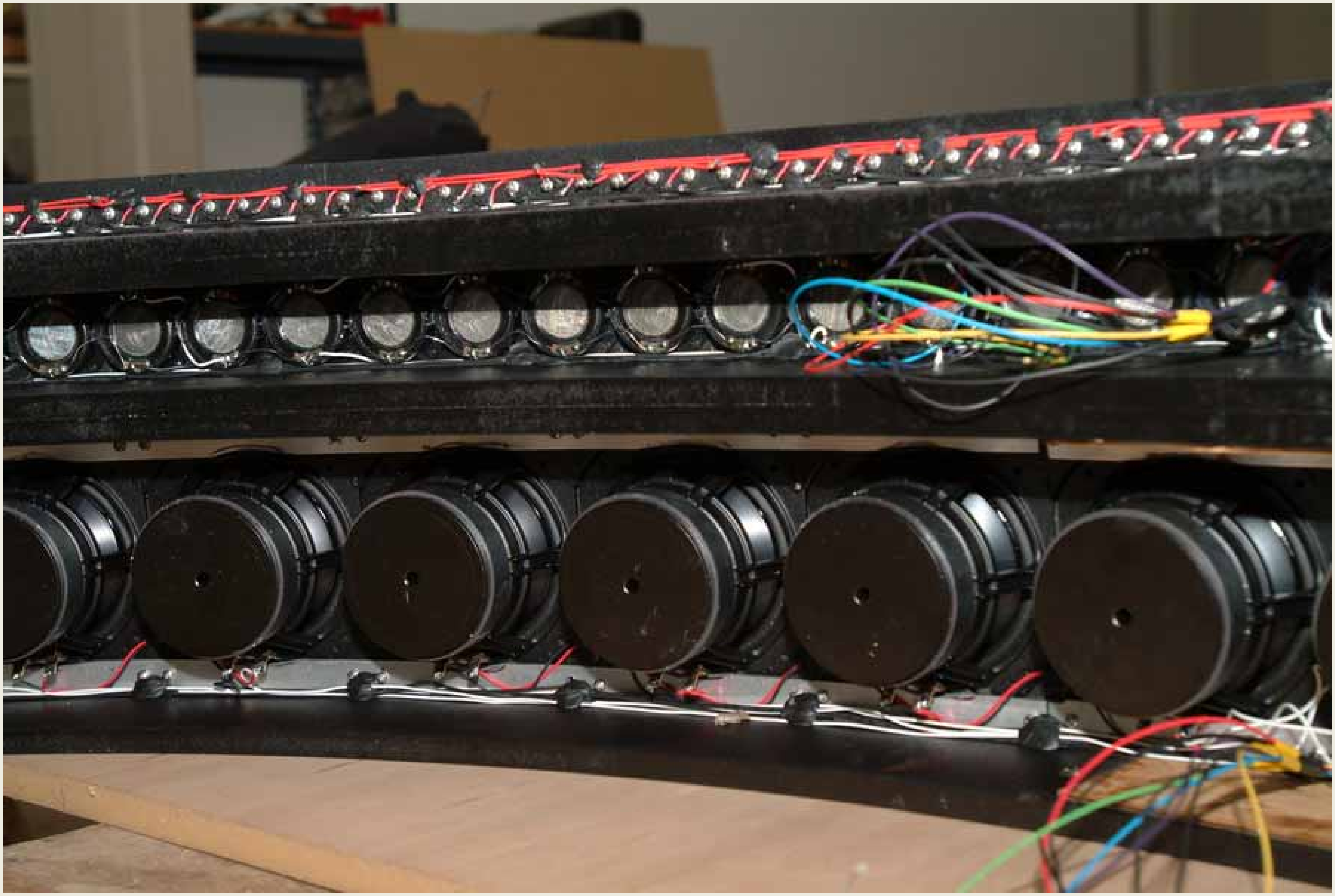
Uses 132 each
Tang Band tweeters
(0.77” Dia. Small!!):

PARTS EXPRESS
YOUR ELECTRONICS CONNECTION

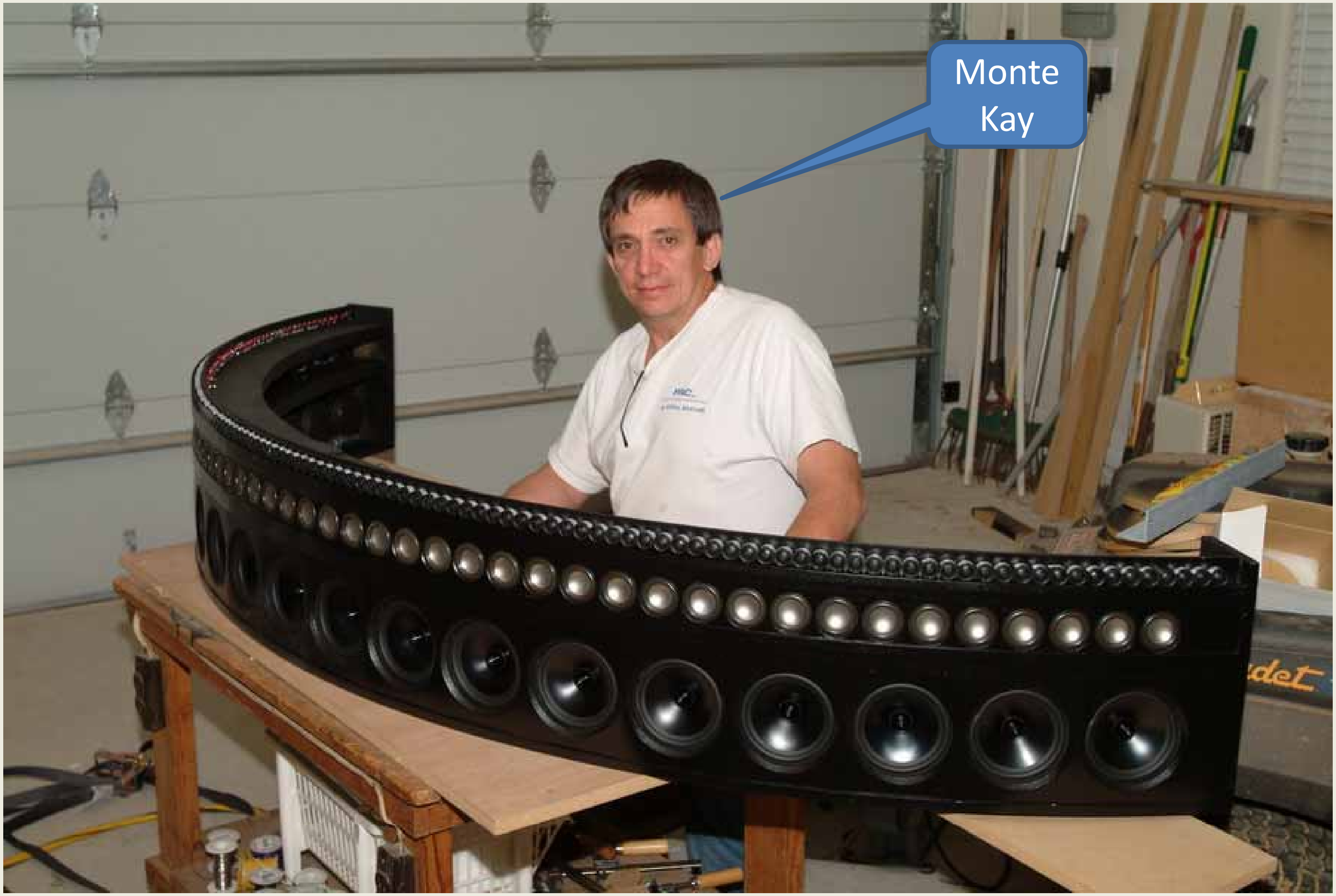
Monte Kay's CBT Center Channel

Monte Kay's CBT Center Channel

Monte Kay's CBT Center Channel



Monte Kay's CBT Center Channel



Monte Kay's CBT Center Channel

Use of Ground-Plane CBT Line Arrays for Sound Reinforcement

Band Sound Reinforcement at Presidio Park, San Francisco, CA for "Bridge to Bridge" 12K Run, Sunday Oct. 5th, 2008

Use of Ground-Plane CBT Line Arrays for Sound Reinforcement: Cont.

- **Wide-angle broad-band ground-plane CBT line arrays offer a very viable, high performance, simple, and thrifty alternative to the usual reinforcement setup, particularly when the main speakers can't be hung overhead. The usual arrangement consists of a pair of directional ground-mounted main systems located on either side of the stage coupled with stage monitors on the stage as outlined in the previous description.**

- **A single or double set of ground-plane CBT arrays located on stage behind the performers can substitute for both mains and stage monitors. Thus located, the CBT array offers a number of very strong advantages:**

1. **Exceptionally Even Coverage:**

   The inherent broad-band constant bandwidth/directivity design of the CBT arrays provides extremely even coverage at all locations: right-left, up-down, and near-far. This includes points on and near the floor, points above the array, and points in the extreme nearfield only inches from the front surface of the array. Because the array is specifically designed to operate over a reflective ground plane, it does not suffer from destructive floor reflections that cause comb filtering effects.

2. **Flat Energy Response:**

   The system's broad-band constant directivity means that its radiated power is unvarying with frequency.

   With constant radiated power the system sounds equally well balanced in the direct field or in the reverberant field, and even behind obstructions that block the direct sound.

3. **Less Front-Back Variation in Sound Level:**

   The CBT array's sound level falls only 3 dB for each doubling of distance for a significant distance in front of the array. This means that a CBT array can supply much higher levels in the back of venue for the same levels in front as compared to a typical sound reinforcement two-way woofer-horn speaker system. This also means that if a CBT array is set up to supply the same levels in the rear of the audience as a typical reinforcement speaker, the levels in the front of the audience area and on stage will be significantly lower. (See the following graphs.)

Use of Ground-Plane CBT Line Arrays for Sound Reinforcement: Cont.

4. **Improved Articulation and Intelligibility at all Listening Points:**
   This is a direct result of the constant beamwidth/directivity and the absence of polar lobes of the CBT array. Destructive side wall reflections are minimized because the room's side walls are illuminated with flat sound energy.

5. **No Stage Monitors:**
   With the CBT arrays mounted behind the performers, the performers hear the same sound that the audience hears. Practically, this works only because a CBT line array's sound level on stage is much lower than typical sound reinforcement speakers for the same level in the audience area.

6. **No Interference with Audience Sight Lines:**
   This is a direct result of the capability of CBT arrays to operate behind the performers. Large and bulky systems mounted to the right and left of stage front are not required!

7. **Less Prone to Feedback Problems and More Performer Freedom to Move Around on the Stage:**
   This is a another direct result of the constant beamwidth/directivity and the absence of frequency-dependent polar lobes of the CBT array. With these characteristics, the feedback threshold is essentially independent of position which means that once the howl-back level is set at a particular location, the system will not be prone to go into feedback at other locations.

Use of Ground-Plane CBT Line Arrays for Sound Reinforcement : Cont.

8. **No Voicing or On-Site Equalization Adjustments Required:**

   Voicing and equalization is only a requirement for speaker systems that are not constant directivity and beamwidth and that may exhibit frequency-dependent lobes. The CBT crossover and equalization is set at design time and requires essentially no adjustments in the field. The only choices that must be made in the field are the CBT's coverage angle (directly dependent on the CBT's arc angle: Beamwidth = 0.75 x ArcAngle) and its aiming.

9. **A Much Simpler System:**

   a. Fewer speakers

   b. Fewer power amps

   c. Fewer processing channels

   d. Minimal on-site voicing, equalization, and adjustment.

   This is a direct result of the elimination of the stage monitors and the simpler curved-arc CBT design that requires no DSP processing. The constant directivity/beamwidth nature of the CBT array minimizes the need for on-sight EQ and adjustment. Set it up and forget it!

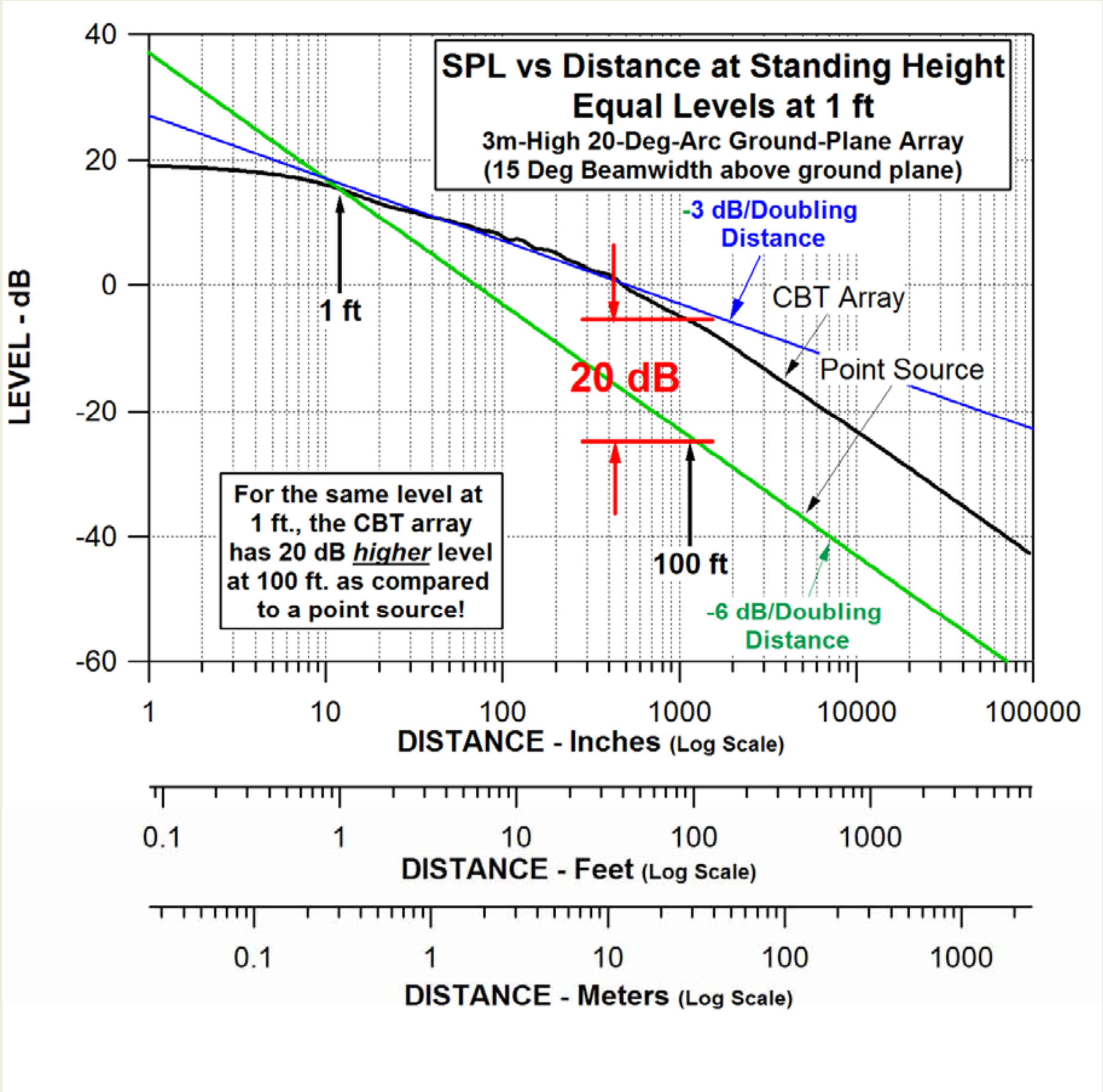
SPL vs. Distance

- The following two graphs show the simulated sound pressure level versus distance comparing a point source to a 3m-high 20-deg-arc ground-plane CBT line array providing a 15 deg above-ground beamwidth. This CBT array would be an appropriate design for the previously mentioned band application The point source rolls of at 6 dB per doubling of distance for all distances. However, the CBT array rolls at only half this rate at 3 dB per doubling of distance over a significant range of about 1 ft to 100 ft in front of the array. However, at distances beyond 100 ft, this CBT line array also rolls of at 6 dB per doubling of distance. In contrast to an equally-driven straight-line array, the distance rolloff of a CBT line array is essentially independent of frequency.

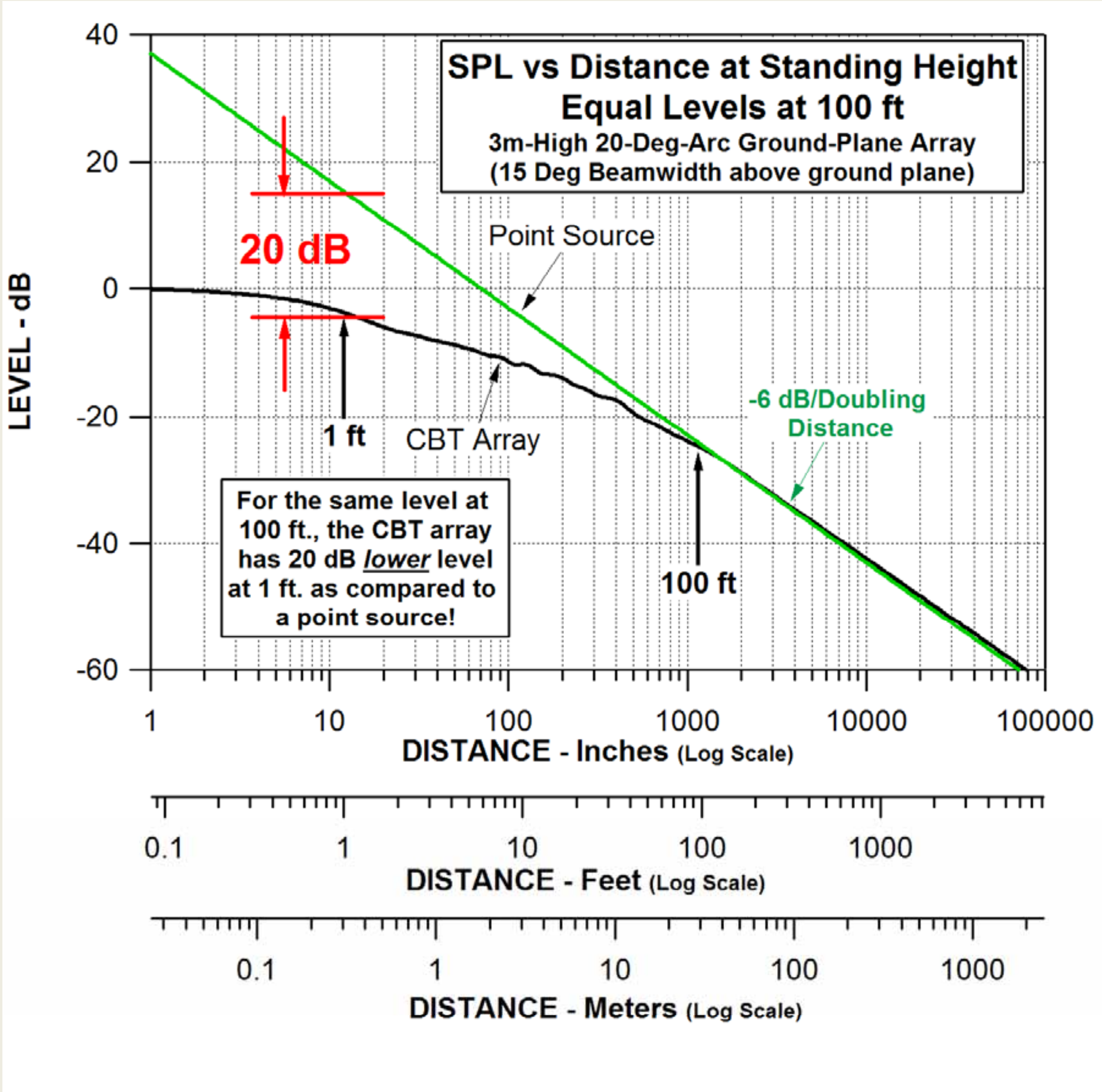
- The gradual 3 dB per doubling of distance rolloff of the CBT array is a great advantage in many sound reinforcement situations. It means that the CBT array's roll off with distance is much less rapid than the roll off of a typical two-way reinforcement system composed of a 15" woofer with HF horn. When the typical two-way system is turned up loud enough to provide adequate level to the rear of the audience area, it is *very loud* at listening points near the front of the audience area and particularly loud directly in front of the speaker. The CBT array does not suffer from these problems.

- The advantages of the gradual 3 dB roll off of the CBT array are illustrated in the following two graphs. The first graph illustrates that for equal sound levels up front, the CBT array can provide much higher levels in the rear of the audience, sometimes as much as 20 dB! Alternately, the second graph shows that for the same loudness in the rear of the audience area, the CBT array can be significantly less loud up front, sometimes as much as 20 dB.

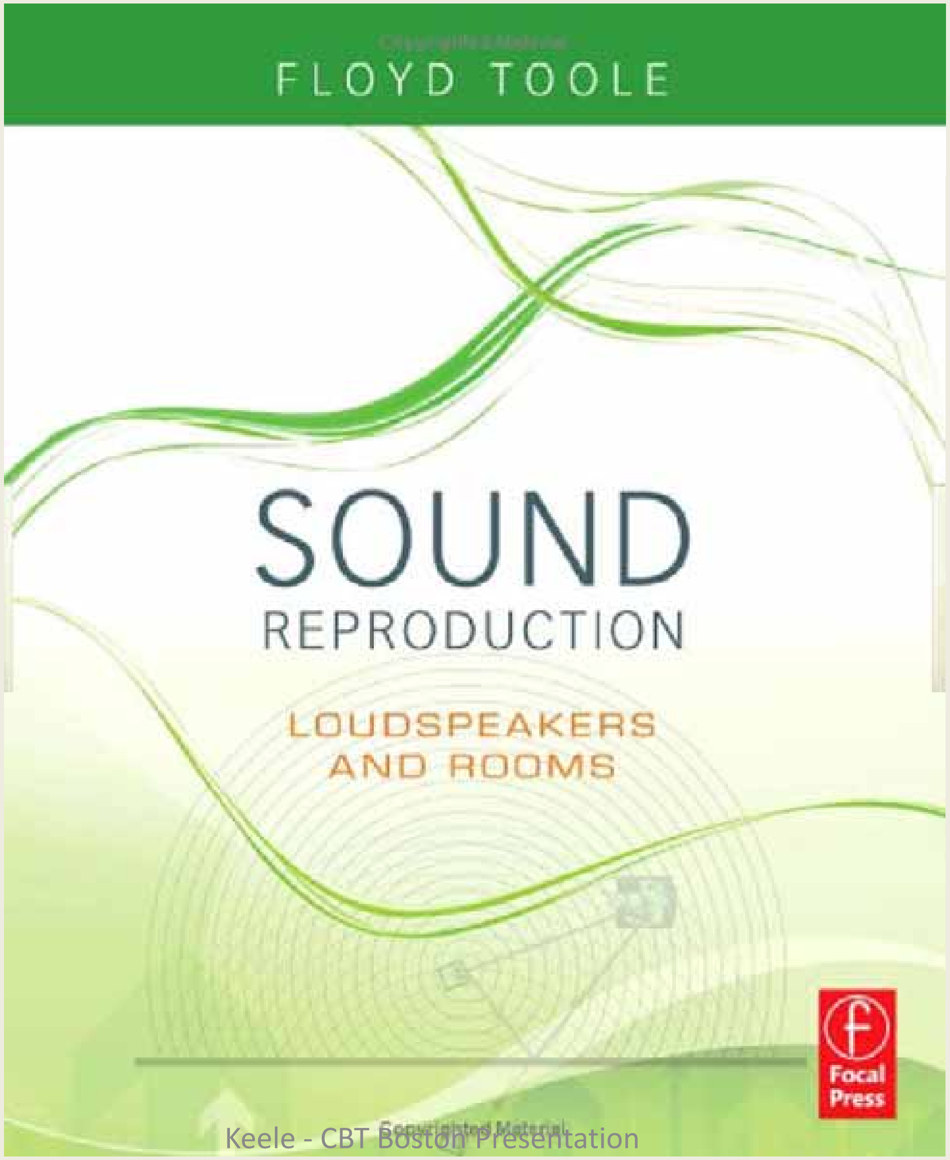
SPL vs. Distance



SPL vs. Distance



An Excellent Book!



Sound-Fields generated above a ground plane by several sources.

(Page Images Courtesy Focal Press)

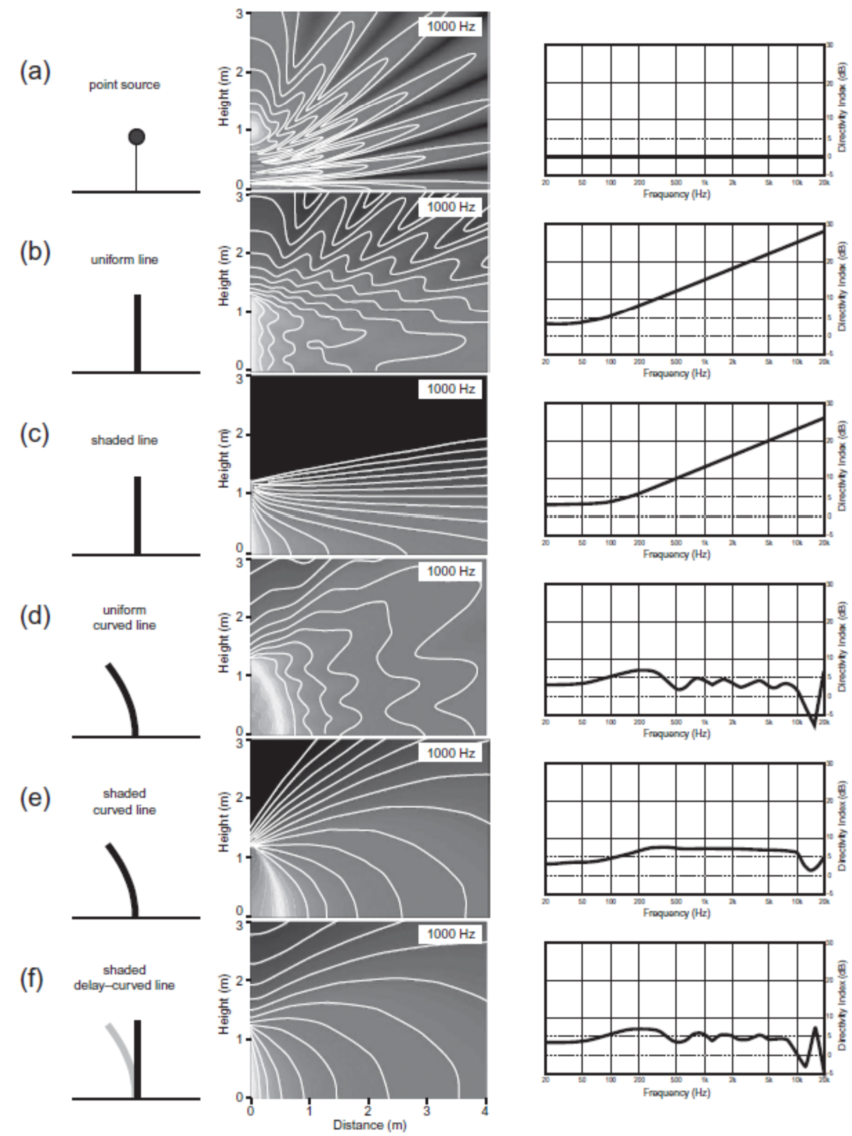


FIGURE 18.3 *Illustrations of the near-sound fields generated above a ground plane by several sound sources. The shading gets darker as sound levels drop; adjacent contour lines represent sound levels that differ by 3 dB. The original paper displays results for several frequencies; all of those shown are for 1 kHz. The words and graphics on the left explain the sources. On the right are far-field directivity indexes. Data from Keele and Button (2005).*

The Perfect Surround Speaker?

(Page Images Courtesy Focal Press)

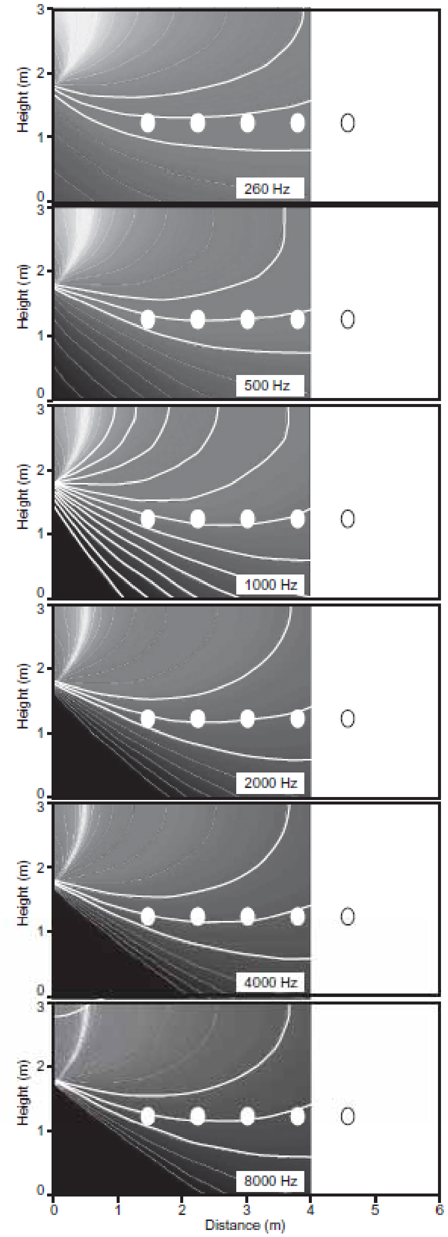
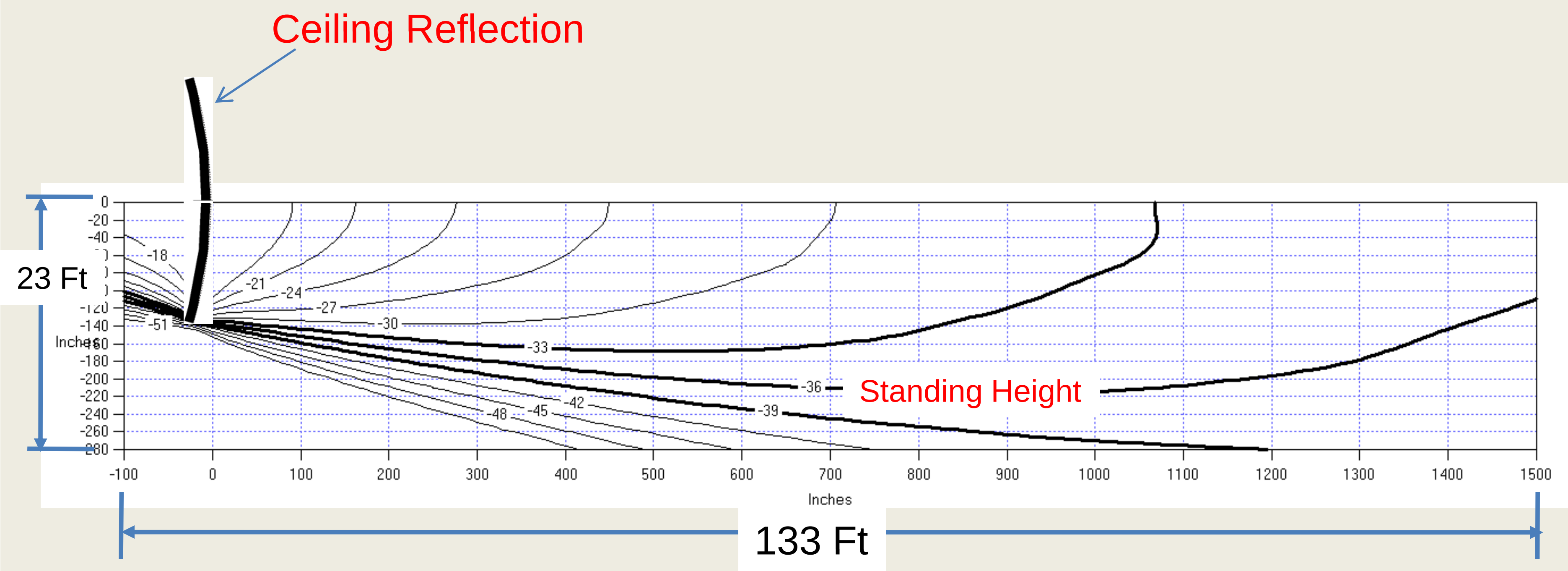


FIGURE 18.21
Data from Keele and Button (2005) showing a constant beamwidth transducer (CBT) inverted to simulate a surround loudspeaker, showing sound levels as they might be at several listening locations. This simplistic illustration ignores the fact that in reality there is a wall behind the loudspeaker, which was not part of the Keele and Button simulations. A real loudspeaker for this application would need to be modified to accommodate this constraint. The white lines are contours of equal sound level and adjacent lines differ by 3 dB.

CBT Ground-Plane Array Upside Down on the Ceiling

(16° Circular-Arc Array, 12° Beamwidth, 11.5 ft high)



Enough Already!
The End