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Use of Ground-Plane Constant Beamwidth Transducer (CBT) Loudspeaker Line Arrays for Sound Reinforcement

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ABSTRACT

Ground-plane circular-arc CBT line arrays with wide horizontal coverage offer a very viable, high performance, simple, and thrifty alternative to the usual sound reinforcement setup where loudspeakers are elevated or hung overhead. Due to the broadband constant beamwidth/directivity/coverage characteristics and narrow vertical coverage of the CBT array, the ground-plane version offers a number of strong performance and operational advantages even when they are located on stage behind the performers. Among these are: even coverage, minimal front-back variation in sound level, flat-energy response, less energy directed upwards towards ceiling, improved intelligibility, less prone to feedback, and greater performer freedom to move around on stage. In addition, these arrays minimize the use of stage monitors, require minimal installation voicing and on-site equalization adjustments, and result in a much simpler system i.e. fewer speakers, fewer power amps, and fewer processing channels.

1 INTRODUCTION

1.1 General Comments

CBT or constant beamwidth transducer theory is based on un-classified military under-water transducer research done in the late 1970s and early 80s was applied to loudspeaker arrays by Keele in a series of nine AES technical papers between 2000 and 2015 [1-9]. CBT arrays provide wide-band extremely constant beamwidth and directivity behavior with virtually no side lobes.

One variation of CBT line array is the ground-plane CBT array [5]. It is essentially a free-standing CBT array which is split in half and then positioned close to a reflective surface. The resultant array configuration has a number of very strong advantages which are outlined in the introduction to [5].

Wide-angle broadband 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 non-CBT non-overhead arrangement consists of a pair of directional ground- or stage-mounted main systems located on either side of the stage coupled with stage monitors on the stage.

The pair of ground-mounted main systems are always located in front of the performers to minimise feedback problems and thus stage monitors are always required so that the performers can hear themselves adequately.

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 including:[1]

1. Exceptionally even coverage,
2. Flat energy response,
3. Less front-back variation in sound level (SPL vs. Distance),
4. Improved articulation and intelligibility at all listening locations,
5. No stage monitors,
6. No interference with audience sight lines,
7. Less prone to feedback problems and more performer freedom to move around on stage,
8. No voicing or on-site equalization adjustments required, and
9. A much simpler system.

Discounting potential feedback problems (which are minimized with the use of CBT speakers), the one major disadvantage of locating the "mains" speakers behind the performers and eliminating stage monitors is that the performers can no longer receive a custom monitor mix. The performers hear what everyone else hears! Of course, performers can still use in-ear monitors if a custom monitor mix is required.

1.2 Comments About an Existing Product

Superficially, the preceding sounds somewhat like the Bose L1 Cylindrical Radiator Portable Amplification Systems [10]. It is similar in concept, but very different in implementation.

The Bose columns are equally driven straight-line arrays and as a result are not constant directivity or beamwidth [6]. Their directivity continually increases with frequency. The CBT ground-plane arrays are broad-band constant directivity/beamwidth designs with vastly superior vertical coverage.

With the Bose L1s, the audience must be located in the vertical plane of the array for proper coverage, i.e. located between the bottom and top of the column. Above the top of the array the coverage completely falls apart. The CBT arrays in contrast, have wonderful coverage above the array.

In addition, the Bose L1's frequency response changes significantly with distance. The CBT array's response does not change with distance. Because the Bose L1's directivity increases with frequency, it will sound very dull in the reverberant field or behind an obstruction. This is in contrast to the CBT array's reverberant-field response, which is flat.

1.3 Sound Reinforcement Experiences

The following write-up is based on several experiences I had back in Oct. 2008 when I attended the 125th AES convention in San Francisco as a Harman International employee.

The first situation described is when I set up a pair of prototype ground-plane CBT arrays for stereo playback and vocal reinforcement for a Harman technical meeting in southern California.

The second was based on an experience I had at an outdoor band concert after I had participated in the "Bridge-to-Bridge" 12K run in San Francisco. At the end of the race they had a live band playing outside at the Presidio National Park where the band's "mains" speakers were just simply placed on the ground in front of the stage.

The band sound reinforcement situation prompted me to think about the potential advantages of using ground plane CBT array loudspeakers set on the stage behind the performers (sans stage monitors) rather than using ground-placed big-box PA speakers. The band here had no overhear trusses or rigging setup to handle overhead mounting of the "mains" speakers.

[1] Note: Additional details on each of these bullet points are in the conclusion Section 6.

2 STEREO PLAYBACK

2.1 Introduction

I set up a pair of prototype CBT ground-plane line arrays[2] for a stereo playback demo in the car lab at the Harman Campus in Northridge California.

Coincidentally, this space was also going to be used for a Harman technical meeting just before the AES convention in San Francesco. Because the CBT30 array speakers were already setup for stereo playback we decided to use them as well for the meeting's vocal reinforcement of a talker using a lapel microphone.

We thought this would be a great opportunity to demonstrate the excellent coverage offered by a ground-plane CBT array and would be a good match to the narrow low-ceilinged 8.5 ft high room with a long 50-ft throw. The floor was covered with 12"x12" polished tiles, which provided a highly reflective visual and acoustic surface to properly base the ground-plane arrays. The ceiling was acoustical tile. No absorption or diffusive objects were on the walls in this room. A quite challenging space!

Once the CBT arrays were set up, an interesting listening experiment was to simply walk towards one of the systems with them playing loudly at normal listening distances. They do not get louder as you walk towards them even though at the end you are standing directly in front of the system (6] Section 2.7.6 Fig. 35)!

2.2 Setup

The arrays were powered by a bi-amped pair of Crown amplifiers driving a dbx DriveRack 260 loudspeaker processor providing crossover and equalization. A CD player provided the music.

[2] This system was a prototype high-end 1.9 m (75") tall 30º-arc two-way CBT ground-plane array composed of 34 each 53 mm mid-woofers and 90 each 18 mm inverted-dome tweeters, called the CBT30. The system's vertical beamwidth was a narrow 22.5°.

The CBT30 arrays were crossed over at 1 kHz and were equalized flat to 20 kHz. The equalization and crossover were designed based on anechoic curves only; no voicing was accomplished or needed. The arrays were set up along the narrow end of the room spaced about 10 ft apart and fairly close to the rear wall as shown in Fig. 1.

Fig. 1. A pair of prototype CBT30 ground-plane CBT arrays set up in the car lab at Harman's Northridge California campus for stereo listening (note flanking subs). The room is approximately 20 ft wide, 55 ft long, with an 8.5 ft ceiling.

2.3 Results

On stereo playback, the arrays performed admirably. The coverage was extremely uniform right-left, up-down, and near-far. Ground-plane CBT arrays are specifically designed to eliminate ground-bounce reflections and thus sounded very well balanced at standing, sitting, and even when listened to with your ear close to the floor.

Although the room was quite reverberant, the broadband constant-coverage characteristic of the arrays allowed them to still sound very natural. The broadband constant-energy characteristic of the CBT arrays meant that the sound was well balanced and natural even around the corner at the rear of the room in an alcove out of the direct sound path.

Loudness was still adequate even at the rear of the room 50 ft away.

The array's sounded very good when listened to in the extreme nearfield with your ear only inches away from the array. This was true no matter where you listened to the array: near the floor, near the center of the array, or near the top of the array!

3 VOCAL SOUND REINFORCEMENT

3.1 Introduction

For vocal sound reinforcement, a lapel microphone and mixer was added to the previous stereo playback setup. Fig. 2 shows this situation with the person speaking located directly in front of the left CBT array.

The talker was free to walk around anywhere in front of or to the sides of the arrays. The system was turned up to just slightly below the howl-back level with the talker about two feet in front of the left array. Thus set, the system was quite impervious to howl back no matter where the talker spoke from.

The howl back volume setting did not seem to depend much on the talker's position, i.e. it could be set with the talker in front of an array or off to one side. Note that with the speakers behind the talker, there was no need for floor monitors, i.e. the talker hears exactly what the audience hears only somewhat louder! In contrast to a typical point-source speaker, the level of a CBT array does not get inordinately loud even when you get close to the array.

3.2 Setup

A small external mixer and limiter provided the amplification and processing for the wireless lapel mic. These were added to the setup described in the previous section (Section 2.2).

A table was setup in front of the CBT arrays to provide a work surface for the person speaking. The talker used the lapel mic for vocal reinforcement. Note that at all times the person speaking was directly in front of one or the other CBT array. Fig. 2 shows the setup.

As noted in the introduction (Section 3.1) this creates a potentially strong howl-back problem for a conventional loudspeaker but not for a well-designed CBT array because of its extremely even coverage at all locations in front of the array; right-left, up-down, and near-far.

Fig. 2. A pair of CBT30 arrays set up in the car lab for vocal reinforcement at the Harman Tech meeting (the subs were turned off for this application).

3.3 Results

The narrow 22.5º above-ground vertical coverage of the prototype CBT30 arrays punched right back to the rear of the long 55 foot room. The level in front of the room was very good but not objectionably loud. The level in the rear was adequate but could have been louder.

However, the intelligibility was excellent in all parts of the room including locations in the rear of the room around the corner in an alcove out of the direct sound path. No complaints were voiced from people in the rear of the room. The system sounded very natural at all locations in the room. The reinforced voice sounded essentially the same as the un-reinforced voice, only louder. It was hard to tell when the system was on because of the naturalness of the reinforced sound.

4 LIVE BAND SOUND REINFORCEMENT

4.1 Introduction

On Sunday morning Oct. 5, 2008, I ran the "Bridge-to-Bridge" 12K (7.5 miles) run in San Francisco. It started at the Ferry Building near the Bay Bridge, ran through the Fisherman's Wharf area, turned around under the Golden Gate Bridge, and ended at the parade grounds in Presidio National Park. There were over 5,000 runners! At the end of the race, they had a live band playing outside at the Presidio Park.

4.2 Setup

The band's PA consisted of a set of un-branded ground stacks on each side of the stage covering the audience area along with four stage monitors on stage.

Each ground stack consisted of two double-18" sub boxes along with three splayed high-end boxes that appeared to be two-way 15" woofer plus HF horn systems. Coincidentally, they were using a fairly-large Soundcraft mixing console for control. The band's stage and speaker setup are shown in Fig. 3.

Fig. 3. Band Sound Reinforcement at Presidio Park, San Francisco, CA for "Bridge to Bridge" 12K Run, Sunday Oct. 5th, 2008.

4.3 Results

The system was loud and clean but suffered from major coverage problems particularly at the extreme sides at the front of the stage out of the range of the HF horns. Coverage in the front of the audience area directly in front of the systems was adequate although overly loud and suffered from significant tonal changes when walking across the front of the systems due to comb filtering effects.

Coverage behind and to the sides of the ground stacks was very marginal and uneven, hence the use of the stage monitors. The front-rear level change in the seated audience area was quite significant. It was uncomfortably loud in the front and just adequate in the rear.

5 SIMULATIONS: SPL VS. DISTANCE

5.1 Introduction

SPL vs. Distance simulations were accomplished for a modelled 3 m (10 ft) tall 20° arc ground-plane CBT array. This array has a narrow above-ground vertical beamwidth of 15°.

This ground-plane CBT array would be an appropriate design for the band mentioned in Section 4. It could be setup on stage behind the band members and they would not need stage monitors.

The SPL vs. Distance was calculated for both the CBT array and a reference point source. Two simulations are presented here where the SPL levels of both systems are matched at a location up front very close to the systems and a location far from the systems at the rear of the audience area.

5.2 Simulation Results

The simulation results are shown in Figs.4 and 5.

Fig. 4 shows the SPL vs. Distance for the situation where the loudness of the CBT array and the point source were matched at a point very close to the speakers at 0.3 m (1 ft).

Fig. 5 shows the SPL vs. Distance for the situation where the loudness of the CBT array and the point source were matched at a point far from the speakers at 30 m (100 ft).

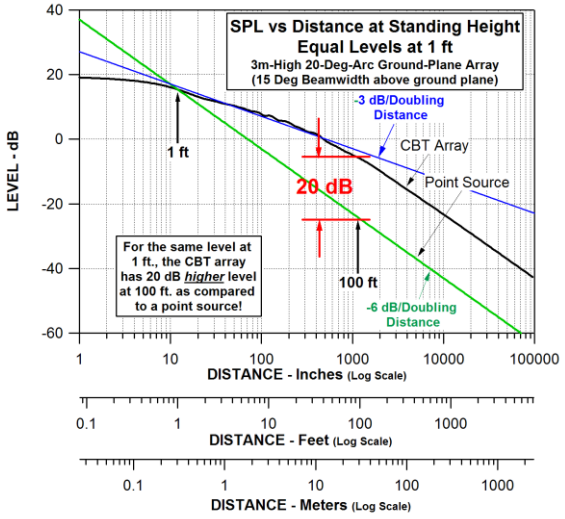

Fig. 4. SPL vs. Distance for Equal Levels at 1 ft in Front of Speakers

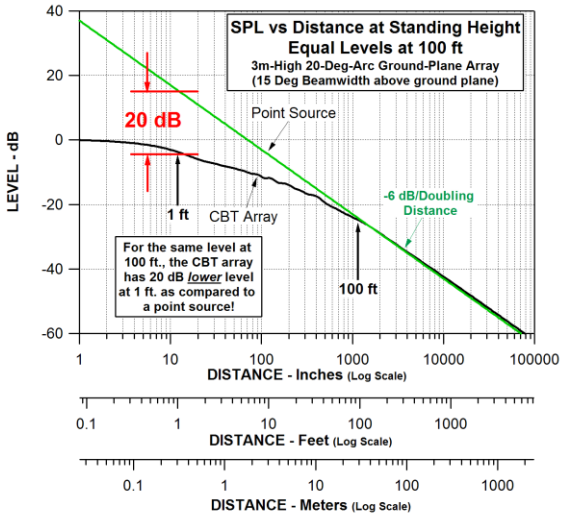

Fig. 5. SPL vs. Distance for Equal Levels at 100 ft in Front of Speakers.

5.3 Observations

The SPL vs. Distance of the point source rolls off at 6 dB per doubling of distance for all distances. However, the CBT array rolls at only half this rate at about 3 dB per doubling of distance over a significant range of from 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 [6].

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 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's SPL vs. Distance are clearly illustrated in Figs. 4 and 5. Fig. 4 shows 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, Fig. 5 shows that for the same loudness in the rear of the audience area, the CBT array can be significantly less loud up front, again sometimes as much as 20 dB!

6 CONCLUSIONS

Use of ground-plane loudspeaker arrays can greatly help in a number of sound reinforcement situations.

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 outlined in the following:

6.1 Exceptionally Even Coverage:

The inherent broadband constant beamwidth and 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.

6.2 Flat Energy Response:

The system's broadband 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.

6.3 Less Front-Bac*k* 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.

6.4 Improved Articulation and Intelligibility at all Listening Locations:

This is a direct result of the constant beamwidth and directivity characteristics and the absence of polar lobes of a CBT array. Potentially destructive sidewall reflections are minimized because the room's side walls are illuminated with flat sound energy.

6.5 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.

6.6 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!

6.7 Less Prone to Feedback Problems and More Performer Freedom to Move Around on 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.

6.8 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.

6.9 A Much Simpler System:

1. Fewer speakers,
2. Fewer power amplifiers,
3. Fewer processing channels, and
4. Minimal on-site voicing, equalization, and adjustment required.

Point 4 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!

References

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[10] Link to Bose L1 compact system: https://www.bose.com/en_us/products/speakers/portable_pa_speakers/l1-compact-system.html