



PCSC

Principles of Planar Technology & Surface Array Design



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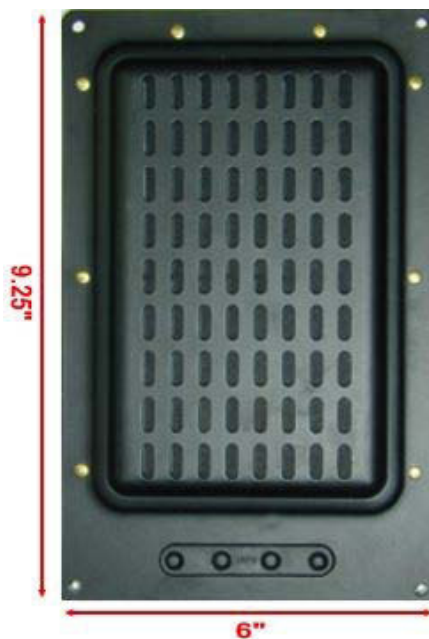
Introduction

The technical principles of planar magnetic speakers have been known since the 1920's. During the 1970's, a small number of companies developed various systems that were targeted primarily for the small niche market of high-end home stereo users. These early planar systems were known for their exceptional sonic performance and stereo imaging. However, this new "exotic technology" had significant flaws that limited their acceptance by the mainstream audio user.

While there were many attempts to create a planar speaker that could perform in the demanding professional audio world, it wasn't until 1998 that HPV Technologies began developing a planar transducer that would revolutionize the professional audio industry. Their R&D team created solutions to all of the inherent problems that had prohibited the use of planar speakers for the professional user and introduced the Planar Magnetic Transducer, branded as **MAD** (Magnetic Audio Devices).

The MAD drivers have been specifically engineered to take full advantage of the best qualities and capabilities of planar technology. In addition to HPV's stellar music speakers, the company continues to pioneer new applications of planar technology for long-throw mass notification systems, law enforcement and public safety communications, military field communications, maritime hailing and anti-piracy defense, and airport "bird-strike" abatement systems.

MAD1 Planar Magnetic Transducer -The universal building block of all MAD products



MAD-1 Front View



MAD-1 Side View

Using MAD transducers as a building block, HPV Technologies has introduced a brand new technology to the professional audio industry - **Flat Panel Surface MAD™**.

"This invention relates to a surface loudspeaker array using a plurality of full-range flat panel or planar magnetic transducers, which are mounted closely together on either a flat or a curved surface to produce the controlled sound dispersion in both the horizontal and vertical planes." (1)

(1) Quote from the patent application

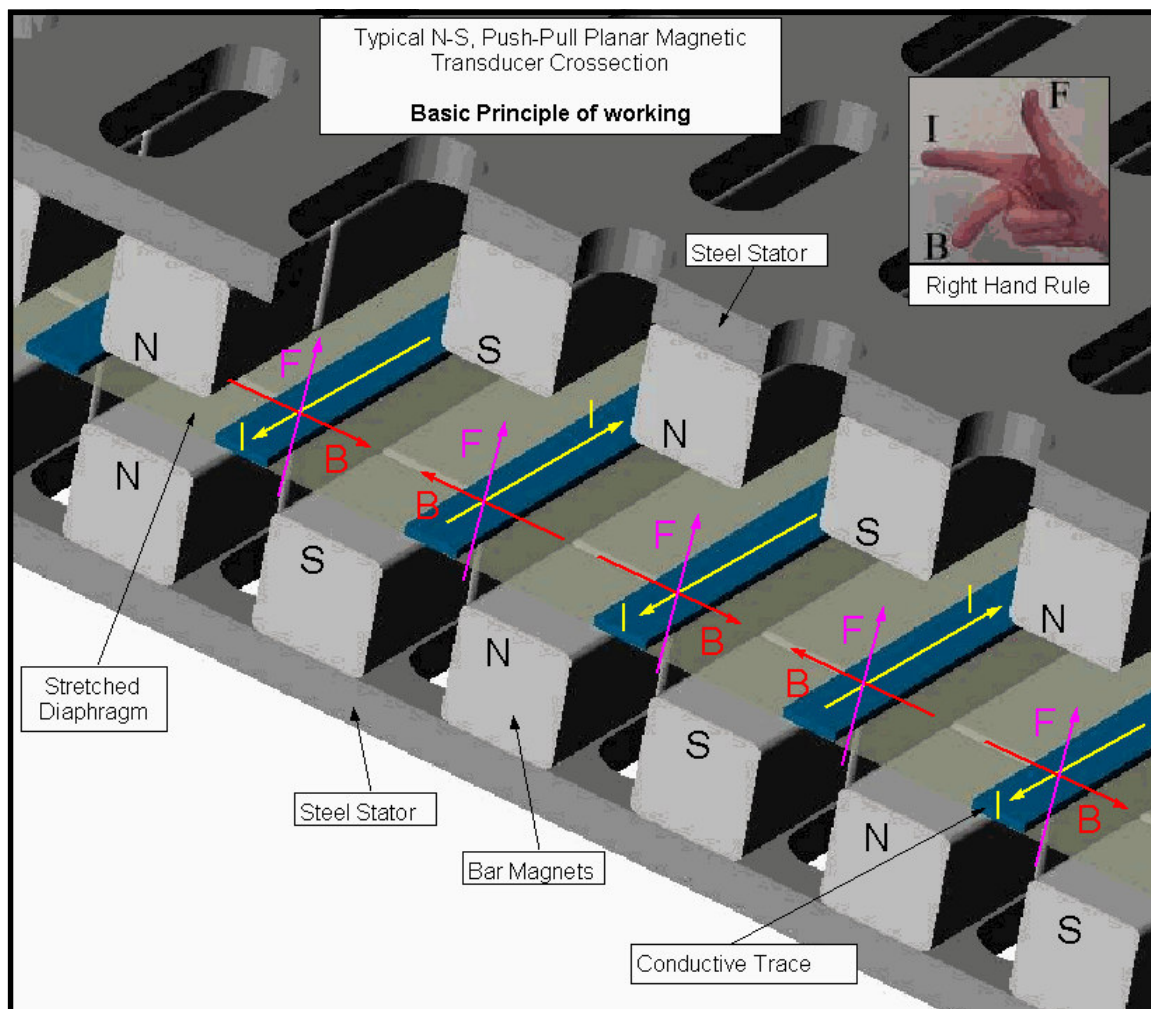
Flat Panel Surface Arrays can be configured in a variety of form factors tailored to specific performance requirements. For example, dispersion angles can range from nearly parallel-3 degree beams of sound (in both horizontal and vertical planes) to 360 degree coverage. Additionally desired SPL levels at specific distances can be created by simply adding more drivers to the array.

The unique aspect of MAD Surface Array technology is that all of the various systems are created using just one transducer model, the **MAD-1** driver which can deliver maximum clarity and intelligibility from the near field to distances beyond a mile.

The MAD Planar Magnetic Transducer

The MAD planar speaker is **fundamentally different** from conventional cone speakers or compression drivers as the entire radiating area is directly and uniformly driven by the strong magnetic field. MAD Planar Magnetic Transducers are specifically designed to work in a tough professional audio environment. Its size, resonant frequency, efficiency, power handling, impedance, distortion, are the parameters all tied together into a design that greatly outperforms similar existing products.

MAD Transducer is typical North-South, **push-pull design**. It has two identical stators which carry the magnets. Stators are made from stamped and formed steel with extreme rigidity. Very strong Neodymium bar magnets are glued to the inside surface of the stators in a north-south arrangement as shown on the cross section of the transducer below.



Cross section of MAD Transducer

How The MAD Planar Transducer Works

Magnets are arranged in a such a way that North and South poles alternate. Magnetic field lines exit north poles and enter south poles. Steel Stators close the magnetic circuits. Useful magnetic field lies in plane with the diaphragm, hence the name - Planar Magnetic.

The stators serve several purposes that include securing the magnets in the proper orientation, closing the magnetic circuits between the magnets, and providing a perfectly flat surface on which to bond the stretched diaphragm. On one of the stators (called the **active stator**) a very thin diaphragm with a printed conductive coil is stretched and bonded. These conductive traces are centered between magnets in a predefined pattern.

When the amplified signal is brought to the transducer terminals, it creates an alternating current that flows through the conductive traces. The current interacts with the magnetic field and creates the force that moves the traces to one side. Traces are arranged on the diaphragm surface in such a way that force moves them all to one side. When the current changes direction, force moves all traces to the opposite side.

Since the traces are strongly bonded to the diaphragm surface, the whole diaphragm moves back and forth as a piston. Even though the diaphragm is flexible, it exhibits **piston movement** because conductive traces cover more than 80% of its surface. When the diaphragm moves back and forth according to the signal change, it creates a sound wave that passes through the holes punched in the stators face.

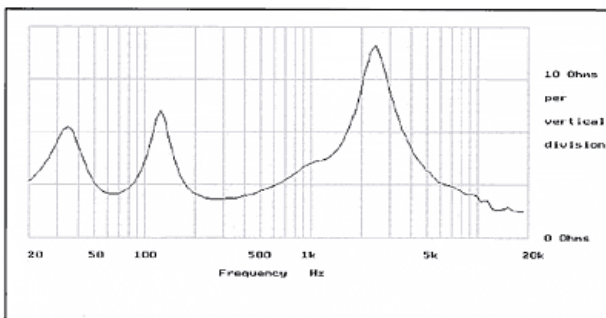
The MAD transducer is **dipole**. It creates the sound on both sides of the diaphragm with equal intensity, but opposite polarity. Front and rear sound waves meet at the sides of the transducer and cancel. This creates a typical dipole, figure-of-eight dispersion pattern. Sound on the side, top, and bottom is almost completely canceled.

This dipole characteristic is very useful in applications where sound is not desirable at the sides of the speakers. Additionally, if a dipole transducer is mounted in a closed cabinet it **becomes monopole** and radiates energy only out the front. In the low frequency range, a monopole is omni-directional (radiating sound all around the speaker with equal intensity) and may produce too much acoustic energy at the sides and rear of the speaker. If the rear of the speaker cabinet is an open enclosure and the rear waves are absorbed, the transducer **becomes cardioid**. A cardioid dispersion pattern keeps sound cancellation on the sides while simultaneously reducing the energy that would radiate out the back of the transducer.

MAD's Planar Impedance Characteristics

Conventional drivers have variable impedance curves across the whole frequency range. Due to high moving mass, suspension system, and high coil inductance, the impedance of cone speakers or compression drivers varies dramatically. In the picture below, is a typical impedance curve of a two-way speaker system in a vented cabinet with a woofer and compression driver.

The first two peaks are the woofer and port resonances in the cabinet. The third peak is created by the crossover components.

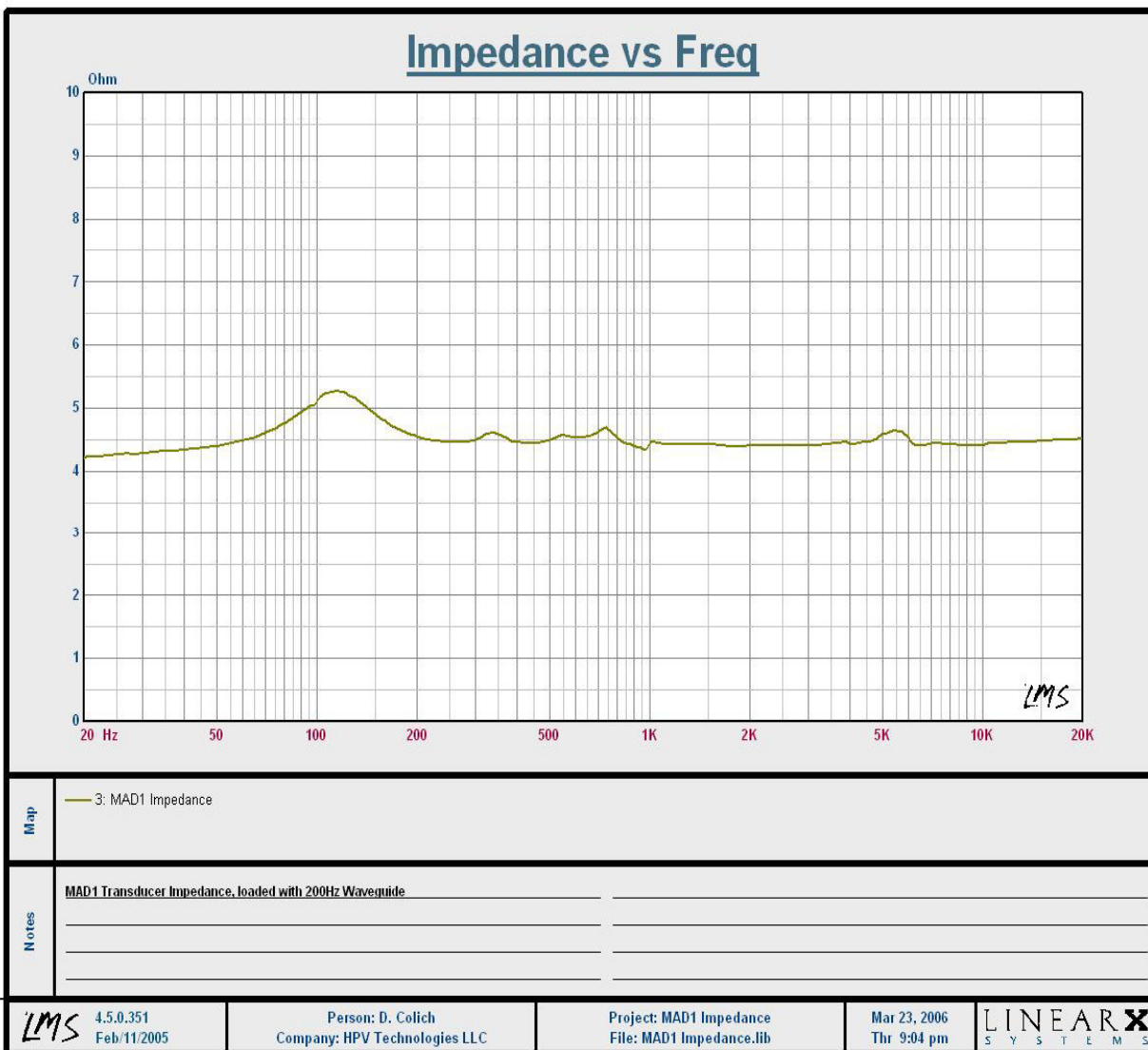


Typical Impedance curve of two-way speaker

Variable impedance curve present a difficult load to the amplifier and may cause sound degradation. The crossover point between woofer and compression driver is in the middle of critical vocal range which frequently muddles the sound and diminishes vocal intelligibility.

MAD-1's Transducer Impedance

The MAD transducers have a very flat impedance response throughout the frequency range, as illustrated on the following graph. This smooth and consistent impedance load will have a **direct impact** on an amplifier's ability to generate uniform power output while minimizing low distortion and maximizing overall sonic performance.

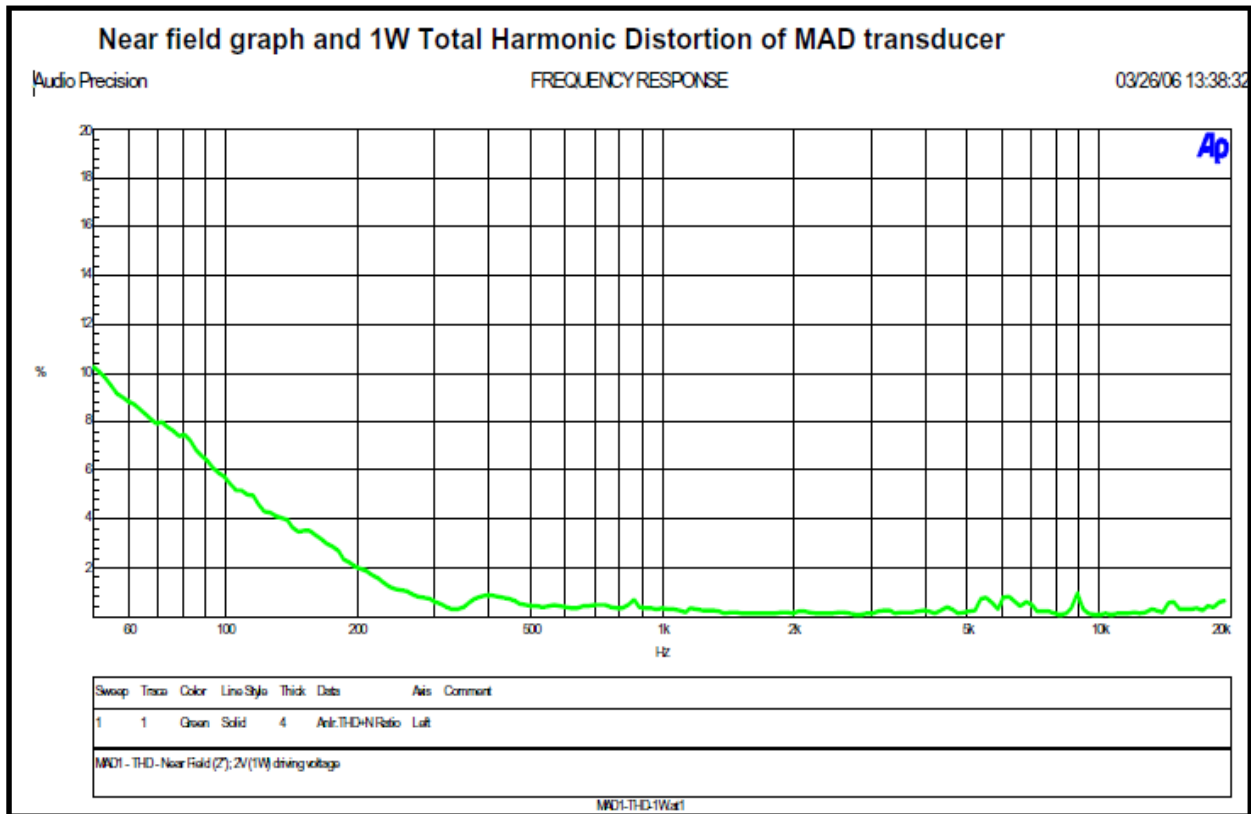


Uniform driving force + uniform diaphragm stretching = low distortion & high performance!

MAD transducers incorporate a very strong magnetic structure to achieve high sensitivity, very low distortion, and exceptional sound quality. Two pounds of the strongest commercially available Neodymium magnets are used in each transducer.

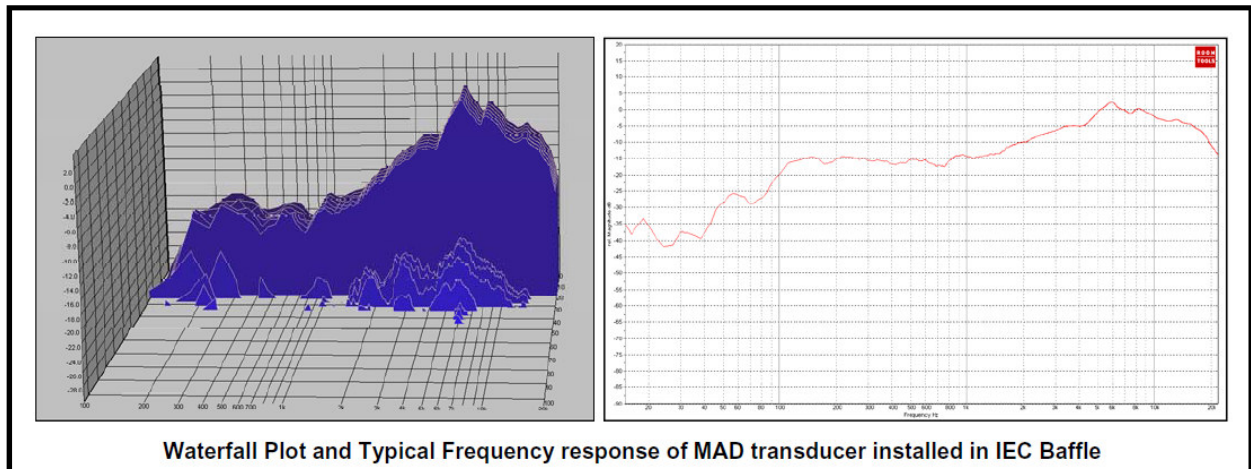
Magnetic field density is very linear between rows of magnets as well as along the depth of the magnetic gap. This creates linear forces that move the diaphragm back and forth **with minimum distortion**. With the diaphragm properly tensioned and stretched on a perfectly flat surface of the Active Stator, this together with very the uniform driving forces evenly distributed across the surface of the diaphragm, provides excellent sound quality with extremely low distortion. With one watt of power, a MAD transducer typically has only 0.1-0.2% distortion within most of its operating frequency range.

One other way of illustrating a transducer's performance is by showing the percentage of Total Harmonic Distortion (THD) plus noise plotted versus Frequency. This graph illustrates the MAD1 transducer's near field THD plus noise response @ 1W input power.



MAD-1 Frequency Response

A smooth Frequency Response is important...but it's just a part of the evaluation process when selecting a speaker system. The whole picture is much bigger and one needs to understand other important parameters such as the speaker phase response, impedance, transient response, and manufacturing consistency.



The left graph above shows a “Waterfall” plot (illustrating a frequency response verses time) of the MAD transducer and what happens with the output of the speaker after the signal stops. Note that the driver's sound stops almost totally without any long-term “ringing” that continues after the source has been terminated.

MAD Frequency Response-continued

On the preceding response graph, note that the **frequency response is very smooth**. The MAD-1 driver has high directivity in the upper frequency range and produces a naturally rising frequency output. This response can be modified as needed with Digital Signal Processing in a concert events. However for long throw applications where air absorption can attenuated high frequency content, this rising response will help to maintain very clear, natural, and highly articulate vocal intelligibility.

MAD Transient Performance

MAD transducers have **extremely fast transient response**. This is a result of the very strong and linear electromagnetic force and a very lightweight diaphragm. In fact, the mass of the diaphragm is so light that it is comparable to the mass of the air it moves.

With the strong magnetic forces and low mass, the diaphragm is able to achieve **very high acceleration**, i.e. it can start and stop almost momentarily if the signal is applied or stopped. Musical content typically has very sharp and fast peaks, that require extremely fast diaphragms to accurately reproduce these impulses. MAD speakers reproduce these signal with exceptional accuracy while retaining the musical detail. By comparison, the drivers in conventional speakers have much higher mass that results in slower transient response. This produces sound which has rounded off and distorted these sharp peaks thus diminishing the musical fidelity.

When listening to MAD speakers one can hear every single, small detail in the sound perfectly, regardless of loudness. With conventional speakers, low level signals are very difficult to understand and typically one needs to turn the volume up to be able to understand clearly what is reproduced. Flat frequency response is not as important as smooth and consistent response. MAD drivers have very smooth, but not flat frequency response. Rising response is very easy to correct, if required.

MAD Efficiency

MAD transducers have very strong magnetic motor structure and a very lightweight diaphragm, which creates a transducer with high efficiency. High efficiency enables very high sound pressure reproduction with a small amount of amplifier power. Less power means less thermal stress on the driver and a more reliable system.

For example, in MAD's WG200 mass notification speaker system a single MAD-1 transducer is properly loaded with a 200Hz waveguide resulting in a very high efficiency of 103 dB/1W/1m across the whole frequency range. This is comparable to average compression drivers sensitivity. With the high power handling and extraordinary peak power capabilities of 1000W (at 100 ms transient duration), the WG200 cabinet can produce 133 dB peak output at 1meter. An array of WG200 cabinets in a Line Array configuration could produce approximately 75 dB-SPL at 800 meters. This system would create perfect intelligibility for very effective for very long throw, full-range mass notification systems.

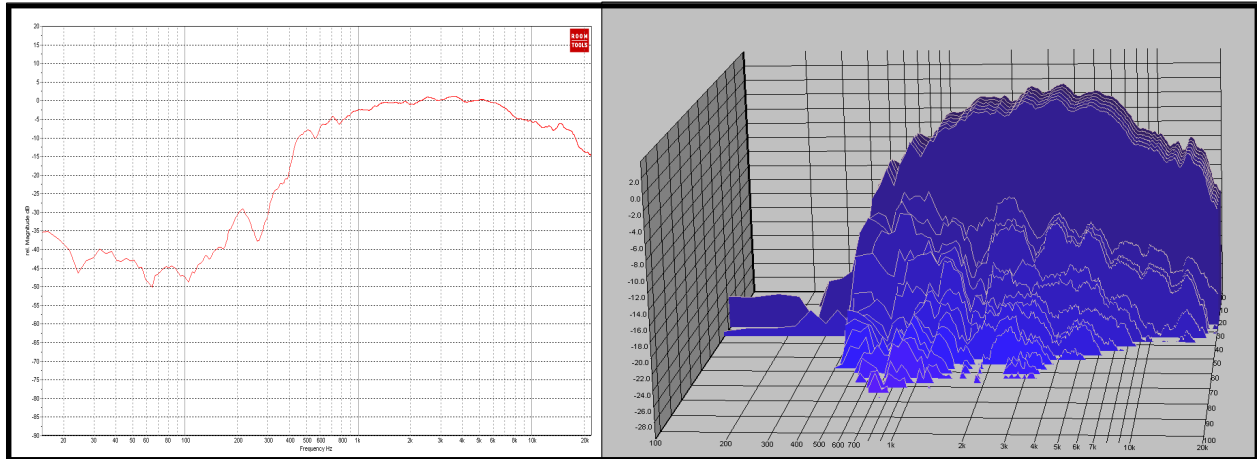
MAD Quality Control

Manufacturing consistency of MAD drivers is extremely high. Measured frequency response during the regular Quality Control testing shows a very narrow spread of curves variations and are typically within 1 dB (+/- 0.5 dB). This is quite impressive compared to conventional drivers where consistency of frequency response from driver to driver can often vary from 2-6 dB. MAD's manufacturing standards confirm that every performance parameter is tested and verified before assembly. Users are assured that every MAD system will provide a perfect solution their critical applications regardless of the size or shape of the array.

In another example, MAD LT-PMS-54-WG500 (see image on the front page) surface array has measured efficiency of 100 dB at 10m (33 ft). Utilizing full power of 13500W from built in amplifiers this speaker can produce an incredible full range SPL of 141 dB. Story doesn't stop here for this speaker system. LT-PMS54-WG500 is a Surface Array and projects sound to long distance with minimal loss of SPL and clarity. During one official MAD demonstration, measured output was 112dB @300m with only 1000 W applied. With full power output SPL would have been way above 120 dB!!

For comparative analysis, a high-end compression driver was measured. It has very nice frequency response. If you look at the left frequency response graph, you may conclude that this is an excellent driver.

The real 3-dimensional response is totally different. The waterfall plot shows a lot of ringing that continues after the signal has been stopped. This ringing creates colored and distorted sound (the typical honky sound of some horns with compression drivers). Listening to complex and fast musical sounds through this kind of speaker is not very pleasant as it will produce ear fatigue at moderate to high listening volumes. The ringing also diminished voice clarity and intelligibility.



Frequency Response and Waterfall plot of high-end compression driver

Cone drivers employ complex construction with many parts and glue joints. The unavoidable shortcomings of this construction are **high mass** in the cone/voice coil assembly (which creates high system inertia, i.e., poor moving mass acceleration), **inadequate cone stiffness**, relatively **high distortion**, and a tendency within the assembly to change or alter designed parameters over time...which gradually decreases the overall performance.

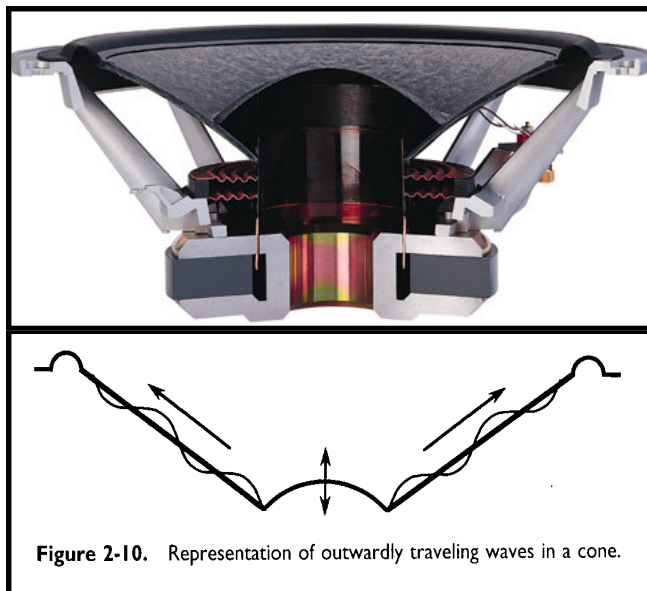


Figure 2-10. Representation of outwardly traveling waves in a cone.

Cross section of high quality cone driver

A cone speaker uses a voice coil to drive only the small center ring of the speaker, which in turn must push and pull the much larger area of entire cone. This inherent design factor causes what is referred to as "cone breakup"...which can dramatically change or color the sound.

Beside the cone break up modes, other parts of the cone driver (i.e., the surround, spider, & tensile leads) can go into a resonance and create very irregular frequency and phase response with a lot of added distortion. Due to cone break-up modes, these drivers can not be used as full range speakers and are usually limited as low frequency drivers

Reliability and life expectancy

MAD transducers have only **one moving part**. Once the diaphragm is properly stretched and glued in place, performance remains stable for years of operation without degradation. If the amplifier power is kept within the factory recommended safe operation range, life expectancy can be very long, in excess of 10 years.

There are planar magnetic speakers still in operation (Magneplanars from Magnepan) that were produced over 30 years ago. With proper care to avoid mechanical damage and keeping power under control, planar magnetic speakers have almost an **unlimited life**. Of course, the assumption is that the materials (magnets, metal parts, ...) don't degrade over time.

MAD transducers use Polymer diaphragm substrate with aluminum conductors. This material is very strong and stable. Initial tension in normal operation doesn't change. It is thermally very stable. Designed upper operation temperature of all MAD transducers is 120 deg C **without performance change**.

Overdriving the diaphragm can not damage it, even if it slaps hard against the magnetic structure. The Stators are powder coated while the Neodymium magnets are plated with high quality coating. All of this can provide reliable long term operation even in the worst environmental conditions. MAD speakers can work reliably in **any environmental conditions**, including extreme cold, extreme heat, snow, rain, or dust.

By comparison, conventional drivers have very complex construction with lots of parts and glue joints that are susceptible to environmental and mechanical changes during long term operation. Typical problems to the "moving system" components involve the following issues.

1. The **suspension gets looser** and provides less and less centering support of the voice coil. Frequency response and distortion constantly slip away from the originally designed parameters. This can explain why some PA systems sound so terrible.
2. Due to **thermal expansion**, the coil can easily get skewed or deformed and can rub against parts within the very narrow magnetic gap. This can create audible mechanical noise or even complete coil failure.
3. **Overdriving the coil** beyond excursion limits can cause the coil to get pushed into the back plate of the magnetic structure causing coil deformation or failure.
4. If any of the **glue joints fail** (voice coil to coil former, former to spider, former to cone, cone to surround), the driver components become unstable and performance will suffer badly. Life expectancy of conventional drivers is 3-5 years.

Full frequency range operation

MAD drivers and systems are designed for full-range operation and in most applications no crossovers are required. This is true for the A-8/A-9 concert systems, the WG-200 and WG-500, the M-3 and M-4, and the LT-PMS systems. A full-range driver is very desirable for many of the reasons previously cited and currently MAD's Planar Magnetic Technology is the only system to provide this capability.

For special performance and form factor circumstances, HPV has developed 2 and 3 way systems that require crossovers as in the MTM-1 and MTW systems. These systems however all utilize planar transducers for reproduction in the 190 Hz. to 18,000 kHz range. This insures that this entire bandpass is driven by same planar components without any change to the speaker's tonal quality or degradation to the sonic performance.

Conventional drivers can not reproduce a full-range signal because of their electro-mechanical limitations and therefore they are confined for use in limited frequency bands. For full-range application designers are forced to use different kind of drivers—woofer for low frequencies, cone or compression drivers for midrange, and dome or high frequency compression drivers for high frequencies. These devices all have different sonic and mechanical characteristics which when combined together, create anomalies in phase response, transient response, and off axis response which ultimately colors the sound and diminishes the vocal intelligibility.

Sound Radiation Characteristics

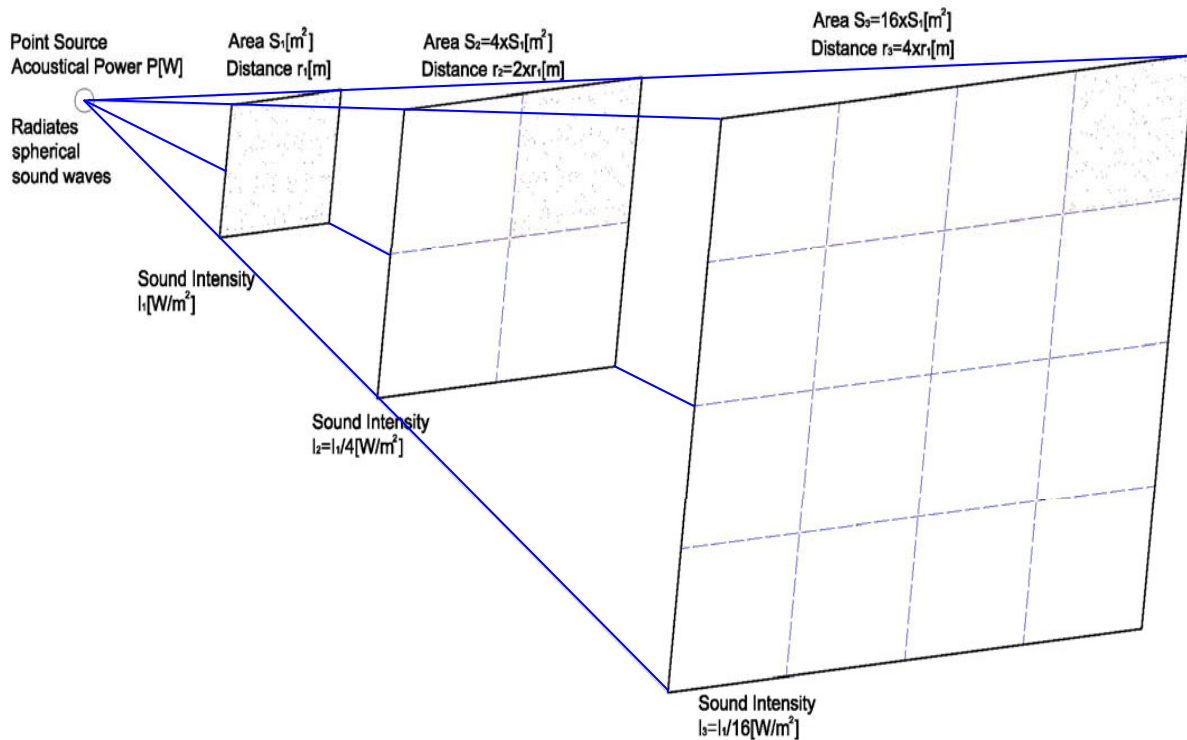
There are three types of ideal sound sources:

- Point Source - most common
- Line Source - Recently common in Professional Sound reinforcement Applications
- Plane Source - MAD Surface Array Technology - new, unique technology on the market

Point Source:

A Point Source radiates sound as spherical waves. The performance of a Point Source can be imagined as a small **pulsating sphere** that expands sound out in all directions. For example, a bass speaker operating in a close cabinet at frequencies below 200-300 Hz, radiate sound as a Point Source.

This spherical radiation can be illustrated in a simplified way that shows how the area of the expanding sphere enlarges as distance from the source increases.



In the above illustration, the energy radiated from the Point Source is evenly distributed over the surface of an expanding sphere. The surface area of the sphere is inversely proportional to the distance (i.e. the radius of the sphere) squared. If we double the distance, the surface of the sphere will be **four times larger**. This is the famous **Inverse Square Law**.

Sound intensity is directly proportional to the covered surface. Converting sound intensity into sound pressure level (i.e. dB-SPL), the dB-SPL from an ideal point source radiator will diminish at the rate of 6 dB per doubling of distance.

Line Source:

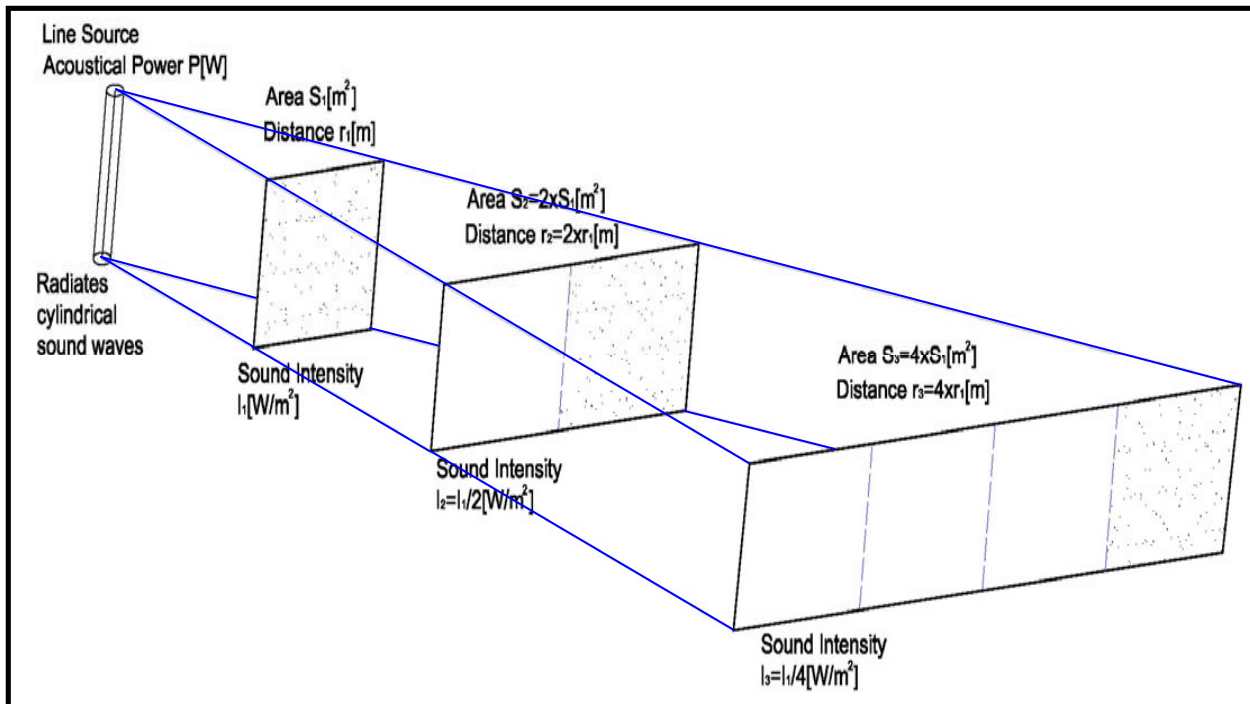
A *Line Source* can be imagined as an infinitely long, small diameter pulsating cylinder that radiates sounds out from the source in a cylindrical pattern. A practical example for the line source would be traffic noise radiated from a busy highway.

With a perfected designed Line Source, the cylindrically radiating energy from the Line Source is evenly distributed over the entire surface of the expanding cylinder.

The surface area of the cylinder is directly proportional to the distance (radius) of the cylinder. If we double the distance, the surface of the cylinder will be **twice** the size. Since the sound intensity is directly proportional to the covered surface, the SPL from an ideal Line Source radiator will fall at the rate of 3 dB per doubling of distance.

The directional control of a Line Source is directly related to the physical size of the source relative to the wavelength of the signal being reproduced. This means that a speaker (or an array of speakers) can only control the dispersion angle of a particular frequency if the speaker has a dimension that is **equal to or greater** than the wavelength that is being reproduced. If the Lines Source has limited size, it will behave as a Line Source within a limited frequency range and for a limited throw distance.

A simplified graphical representation for Line Source can be used to explain the Line Source Radiation Properties. The following diagram illustrates this cylindrical radiation showing how the area of the expanding cylinder enlarges as distance from the source increases.

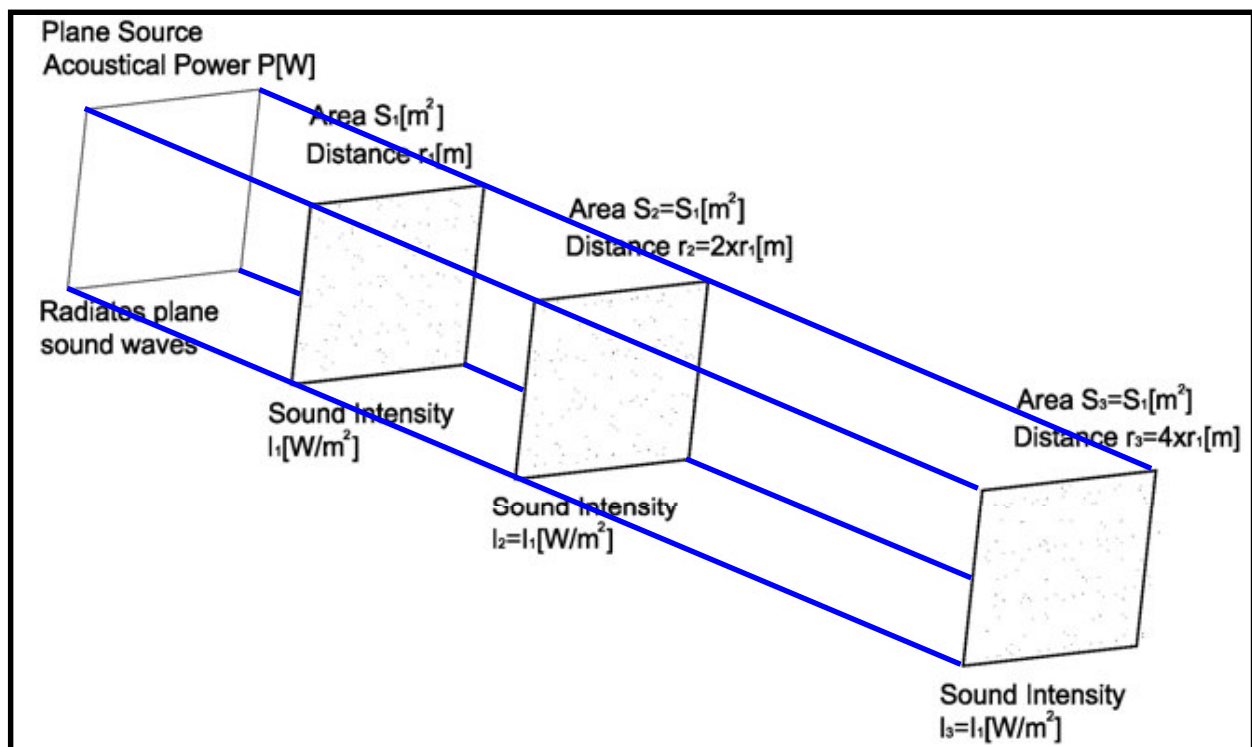


Plane Source

A Plane Source can be imagined as infinitely large two dimensional, flat surface sound radiator. Real life example for a plane source would be traffic noise generated in the middle of the long tunnel that propagates towards the tunnel exits.

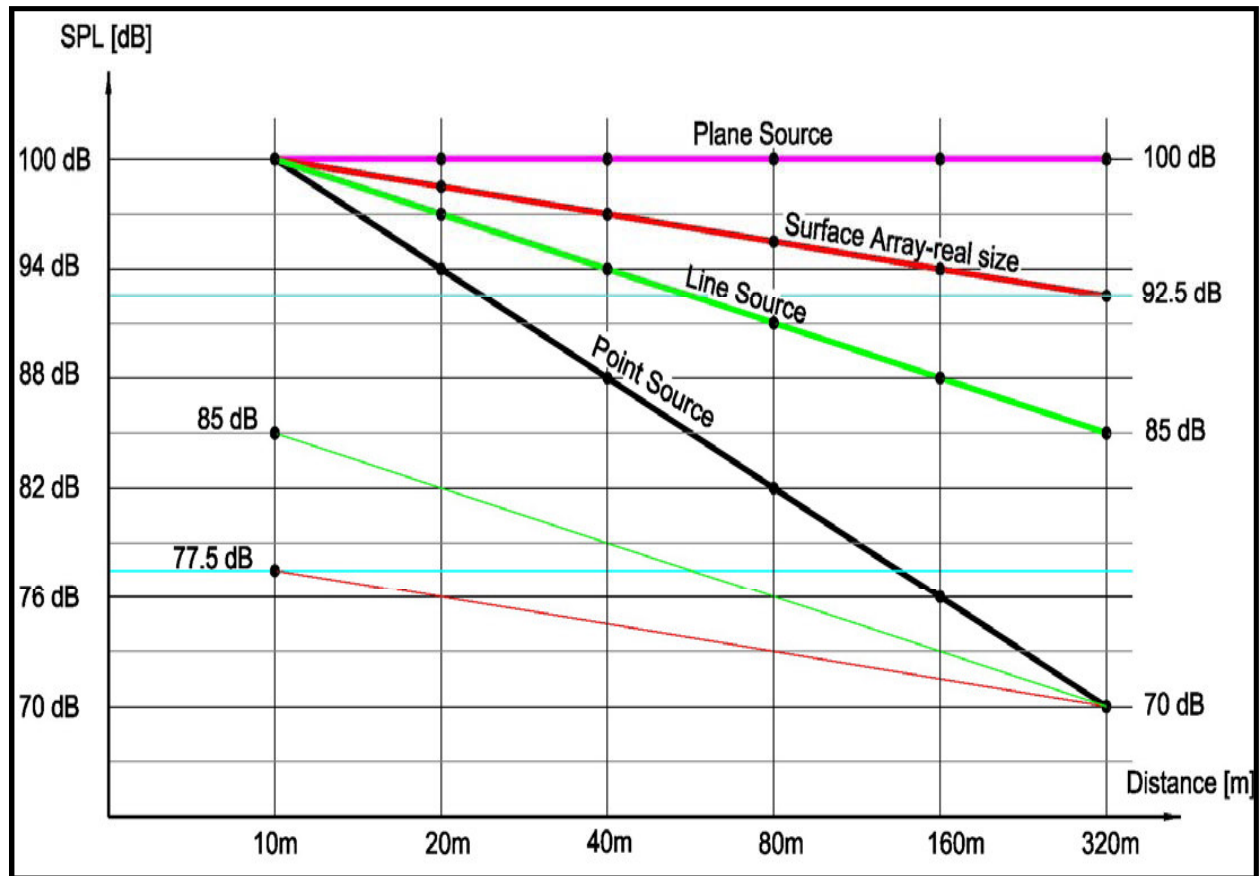
As the sound waves propagate from the plane sound source, they do not expand but continue to pass through the same area as the source itself. Therefore, the energy density at any point in space is equal to the energy density at the sound source plane itself. The sound pressure level is constant everywhere in the vicinity of a plane sound source. SPL is independent of the distance from the plane assuming that there is no loss in acoustic energy due to environmental conditions.

MAD™ Surface Arrays represent the closest approximation to the plane sound source. A Plane sound source is the ideal for very long distance sound projection.



Comparative analysis between different types of sound sources

The graph below shows how SPL drops off versus distance for three types of ideal sound sources - Point Source, Line Source and Plane Source. MAD Surface array was included to show where it belongs compared to the other ideal sound sources. This is a simplified example for easy understanding of the differences between the different types of sound sources.



If we assume that the starting SPL at 10 meters is 100 dB, the final SPL at 320 meters will be quite different for these 4 sound sources. In reviewing this graph, we can determine the following.

1. The **Point Source** SPL drops 6 dB per doubling the distance. At 320 meters, the point source will produce SPL of 70 db.
2. The **Line Source** SPL drops 3 dB per doubling the distance. At 320 meters, the line source will produce a much higher SPL of 85 dB. This is 15 dB higher output than from the point source.
3. The **Plane Source** SPL is independent from the distance and will produce the same SPL as at the 10 meters and 320 meters; i.e. 100 dB. This is 30 dB higher SPL than from the point source.
4. **MAD Surface Array** lies between Line Source output and Ideal Plane Source. On average Surface Arrays will lose 1.5 dB per doubling of distance. Therefore at 320 meters it will produce 92.5 dB-SPL.
5. If we assume that the output of 70 dB at 320 meters is adequate and project the Line Source and Surface Array curves back to 10 meters, it shows that the Line Source needs to produce 85 dB at 10 meters. A Surface Array needs to produce only 77.5 dB at 10 meters. And of course, an ideal Plane Source would only need to produce 70 dB at 10 meters.
6. This shows that when comparing the output of a **Point Source** device with the same SPL at 320 meters, a **Line Source** will require ~32 times less power, the **surface array** will need ~178 times less power while the ideal **Plane Source** will need 1000 times less power.
7. For a Line Source to reach the same SPL at 320 meters as Surface Array it would require ~6 times more power. Even though real life is different, this simplified example shows that the Surface array has huge advantages compared to other sound sources for very long throw applications.