SLS Loudspeakers
PRD Planar Ribbon Drivers — a breakthrough technology for contemporary loudspeaker industry

Introduction to planar ribbon drivers in view of contemporary audio reproduction

Planar ribbon transducers have been used in loudspeakers for several decades and several different designs are currently available in small quantities from a handful of manufacturers.

Over the last several years SLS Loudspeakers has embraced the idea of developing and perfecting this type of transducer and bringing the technology to its optimum potential. Significant research and many years of experience allowed SLS Loudspeakers to realize the vast possibilities which planar ribbon technology provides for the audio industry.

Some manufacturers refer to this type of transducer as planar dynamic, ribbon, isophase, leaf driver etc. due to the fact that in the majority of designs, sound is radiated by a flat and very thin diaphragm up to 30 microns (0.0012) thick. Almost all high quality planar ribbon drivers are relatively expensive in production, difficult to obtain in commercial quantities, and are considered as exotic or unconventional designs.
Better designs of this type are prized for unparalleled accuracy of reproduction, transparency, very low distortion and stunning resolution of subtle signal details and harmonic texture.

During the 80 s and early 90 s, planar ribbon drivers were used in only a few commercial, high performance loudspeakers. Dome tweeters ruled mainstream hi-fi audio. This fact could be partially explained by the high cost of a good planar driver at that time and the poor quality of CD audio in the 80 s. As it turned out, CD technology was far from perfect in its early years. First of all, technological limitations and other reasons led to establishing a sampling rate of A/D conversion at 44 kHz, which in turn, limited the recorded and reproduced audio spectrum to barely above 20 kHz. Specific distortion inherent to early CD audio, in a certain way, favored a fabric dome tweeter. A fabric dome tweeter, being critically damped with viscoelastic compound, is a very forgiving transducer. By gently rolling off high frequency output and smoothing temporal details of the signal, a dome tweeter had been partially concealing some of the deficiencies in early CD Audio, making it sound better . This, of course, came with a price of losing the very subtle details in the audio signal.

Despite all of this, audiophiles who owned high quality audio gear knew about real sound and have always admired the performance of high-resolution loudspeakers, which used planar diaphragm drivers, either dynamic or electrostatic (Quad ESL, Magnepan, Apogee, Martin Logan, Genesis, Infinity to name a few).

The end of the 90 s has opened a new era for audio reproduction with the rapid advancement of high resolution digital formats for audio recording, processing, storage and reproduction (Pacific Microsonics (PMI), High Definition Compatible digital (HDCD), Super Audio CD (SACD) and DVD-Audio). Professionals and ordinary consumers have the opportunity to experience quality sound beyond their expectations.

Most of electronic audio equipment available on the market today is capable of reproducing audio signals with vanishing distortion with up to 48 kHz bandwidth (derivative of 96 kHz sampling frequency and corresponding anti-aliasing filter) and in some cases even higher. The dynamic range of an audio signal available at the output of an amplifier today surpasses all possible limitations of the recording/playback chain in the past.

The quality of audio equipment currently available to consumers equals or even surpasses recording studio gear used ten or fifteen years ago. At the same time, the loudspeaker is the only item in the reproduction chain that remains highly unchanged. Fabric dome tweeters may have been the recipe for a good system in the 60 s and 70 s, when audio was dominated by inexpensive solid-state amplifiers, joined later by early CD audio, producing less than desirable results. While in the consumer loudspeaker industry, engineers are seeking solutions for better sound; professional loudspeaker manufacturers at large have acquired stiff tunnel vision over the years. They are stuck with 70 year old compromised technology and don t seem to recognize the need for change. Compression drivers loaded with horns may have been the only possible compromise between sound quality and high SPL output in the 30 s and 40 s, when amplifier power was low, and later, when it was expensive. Today, with all those limitations gone, the use of compression drivers, which excessively distort the original sound, is no longer desirable. Times have changed. Industry professionals and consumers alike are becoming more sophisticated in their expectations and are seeking better, more accurate loudspeakers, which provide sound reproduction with maximum resolution and clarity well above 20 kHz. Listeners, today, want to hear real music once again.

HDTV (high definition television) is another powerful media, which drives the quest for high-resolution quality audio as well. This revolutionary television format, which is providing fantastic quality HDTV images, accompanied by sophisticated multi-channel audio, is placing very high requirements on the quality of sound reproduction. It is a fact that standards and expectations of quality audio reproduction have been changed.

In the past, it was considered that the human ear could only perceive sound within the 20Hz — 20 kHz frequency range. These assumptions, made in the 20 s by audio pioneers Fletcher and Munson, were rarely questioned. Indeed if we visit an audiologist and have our hearing tested, we will most probably be told that we hear signals from 20 Hz to about 17 kHz. However it is a proven fact that the unique sound of many musical instruments is due to harmonics and overtones far beyond their perceived range. As was reported in S&VC magazine (On the Threshold of Discovery , September 2001,p.6), spectral analysis has shown that instruments and human speech have overtones well above 20 kHz, with some energy up to 40 kHz, and up to 100kHz for triangles and cymbals. Furthermore, research shows that humans respond to ultrasonic frequencies up to 60 kHz. Similar findings have been discussed in other numerous publications over the past several years. Today, we have taken a closer look at these facts since we have the capabilities to reproduce a full spectrum of music instruments and real life sounds. All this leads to a better understanding as to why transducers with extended high frequency response and superior resolution, (such as the planar ribbon driver) allow much more accurate reproduction of sound.

Construction of SLS planar ribbon drivers

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New materials have recently become available at considerably lower cost, opening an opportunity to develop and manufacture cost effective, state of the art, planar ribbon transducers. SLS loudspeakers has developed two basic planar ribbon models: the PRD500 and the PRD1000.
Fig1 (shown below) schematically depicts the construction of the central part of the SLS planar ribbon driver.
The driver has a stretched Kapton® (trademark of Dupont) diaphragm with a chemically etched aluminum conductor pattern that serves as a voice coil element. The film and the conductor each are typically 12-17 microns (0.0005 -0.0007) thick. The diaphragm is stretched on a very stiff and dimensionally stable fiberglass/copper layered frame, using a proprietary technique that enables a wrinkle free even tensioning. The diaphragm assembly is further precisely positioned between two tightly spaced rows (frontal and rear) of very large Neodymium magnets, which are bonded to low carbon steel plates. Each part of the magnet system is enclosed in a massive solid casing, made from cast aluminum.
The high-energy magnetic system creates a symmetrical magnetic field oriented in the plane of the diaphragm. When a signal current flows through the conductor, the whole diaphragm vibrates and radiates sound through the openings in the magnetic structure.

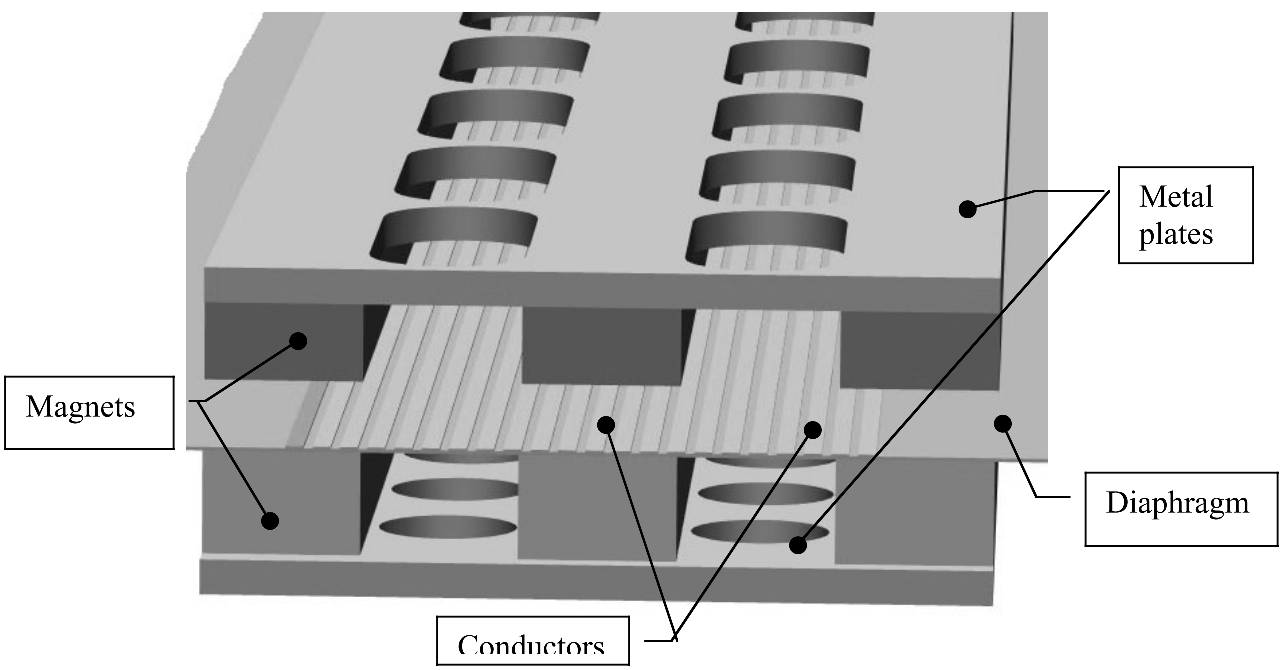


Fig1. Construction schematic of SLS planar ribbon driver motor structure

The design of a magnet system for a planar ribbon driver may vary depending on performance and cost considerations. Some of the earlier designs used low energy ceramic magnets, which did not allow for high sensitivity, making it impossible for a driver to deliver high output levels. Very recently high-energy grades of a rare earth magnet material, Neodymium (NdFeB), have become substantially cheaper and new magnet system designs became quite practical for manufacturing. SLS planar ribbon drivers magnetic systems are designed using FEA (finite element analysis) CAD software. They are cost effective and allow very high levels of useful magnetic flux. The PRD1000 and especially the PRD500 have extremely low levels of magnetic stray field insuring safe applications in close proximity to TV in home theater systems and other A/V installations.

Older or poorly designed models of planar drivers which still exist, often failed at high power levels for various reasons, but mostly due to the use of Mylar® (by Dupont) diaphragms. Mylar®, being readily available and inexpensive, has a quite low working temperature, not exceeding 120°-130°C, and thus could be easily destroyed at high power levels. A couple of newer driver models with higher power handling recently became available, use Kaladex® (by Dupont) PEN film (polyethylene naphthalate) as a diaphragm material. Kaladex® withstands up to 160°-170°C and is suitable for most audio applications. The new PRD line of planar ribbon drivers from SLS uses Kapton® as a diaphragm material. Kapton® (polyimide) is the most sophisticated and durable dielectric film material available. It withstands temperatures up to 400° C (750°F).

There are numerous proprietary design solutions implemented in the PRD500 and the PRD1000 drivers. SLS drivers use a special technique for improving heat transfer from the diaphragm, dramatically improving power handling. Solid aluminum construction and specifically arranged diaphragm mounting provide an acoustically inert structure, free of vibrations and resonances. SLS drivers have a unique progressive dampening technique that allows effective absorption of rear-radiated sound waves without them being reflected back and reradiated through the diaphragm.

A proprietary rear acoustic loading design allows different options of radiation patterns and arrangements. SLS drivers can be used with or without standard rear cups, thus enabling every possible spectrum of application from a dipole radiator, through resonance free anechoic rear enclosure with extended midrange response, to a monopole with precisely tuned rear cup for maximum SPL output. All above mentioned innovative features, and several others, play a dramatic role in overall driver performance.

During the development of the PRD line of drivers, many engineering options have been tried, many materials tested, and only the best, those that met strict specifications, reliability and consistency requirements where implemented. Therefore, the PRD500 and the PRD1000 possess an unsurpassed level of performance, delivering accurate, free from distortion, authentic sound in the most demanding audio applications.

The PRD500 and the PRD1000 represent breakthrough technology, aimed at contemporary audio reproduction. In comparison with one competition planar driver available in the professional market, SLS s PRD1000 is more than twice as light, is half as expensive, and has higher sensitivity and wider effective frequency range from 1 kHz up to 40 kHz. The unique manufacturing process, designed and set up at SLS Loudspeakers factory in Springfield, Missouri, allows for the manufacturing of precision grade transducers, with production SPL tolerances within ± 1.0 dB, over the reference frequency range.

Why PRD planar ribbon drivers have superior sound quality over any other existing tweeter technology.

In the process of comparing the PRD drivers with other high frequency transducer types, two models where chosen. One was a state of the art metal/ceramic composite dome tweeter from an established European manufacturer. Another unit was one of the best compression drivers on the market, which comprises a 4 titanium dome, edge wound CCAW wire voice coil, Neodymium magnet system and loaded on a short 40°x90° horn. The most significant distinguishing features of the drivers are outlined below.

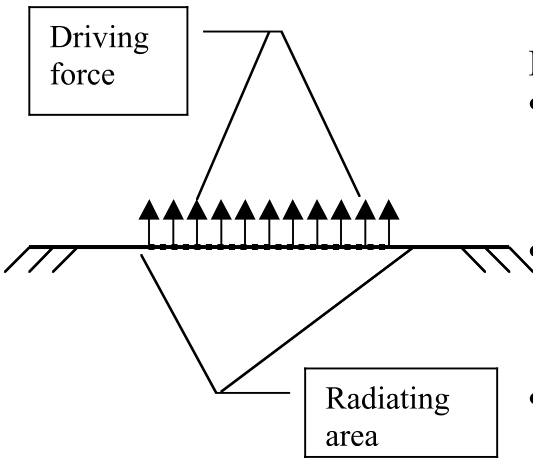


Fig. 2 Moving system of PRD driver

PRD planar ribbon driver (Fig. 2):

- **Driving force directly acts on the diaphragm** — purest minimalistic way of energy transfer- freedom from resonances, acoustical filtering, transmission delay and losses
- **Driving force is evenly distributed over the radiating surface** of the diaphragm — ideal condition for sound radiation, - no break-up resonances, no transmission delay, no wave cancellation
- **Mass of the diaphragm compares to the mass of associated air volume** vibrating along with the diaphragm thus creating ideal coupling conditions for sound energy transfer, effective and lossless dampening, accurate impulse response, and providing very high sensitivity and output extension up to 40 kHz
- **Purely resistive impedance** virtually free from inductive component — ideal and easy load for an amplifier and crossover network, no crossover resonance in a stop band, no phase shifts and excessive group delay, no high frequency losses
- **Flat radiating surface** — ideal shape for sound radiation, does not change with frequency — results : even and coherent wavefront, even dispersion, no wave cancellations, no signal delays, no obstructions or cavity resonances

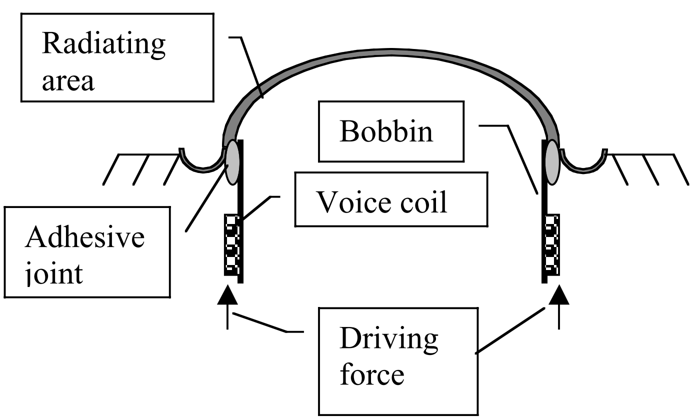


Fig. 3 Moving system of a dome

Dome tweeter (Fig. 3):

- **Driving force acts indirectly on the diaphragm**, energy is transmitted through voice coil stack, glue joint, bobbin and another glue joint — generates distortion due to resonances, mechanical filtering, transmission delay and losses
- **Driving force is distributed along the circular joint** of the voice coil and the dome - break-up resonances, transmission delay, wave cancellation
- **Mass of the moving system is 50 —100 times higher than the mass of the PRD diaphragm** — poor impulse response, limited sensitivity and limited high frequency extension

- **Complex impedance with large inductive component** and clearly pronounced resonances —complex load for an amplifier and crossover network, exhibits transfer function resonance in a stop band, imposes phase shifts and excessive group delay, increases high frequency losses

- **Curved radiating surface with frequency dependant vibrating pattern**— results in uneven and incoherent wavefront, uneven dispersion, wave cancellation, signal delays, obstructions or cavity resonance (in case of inverted dome).

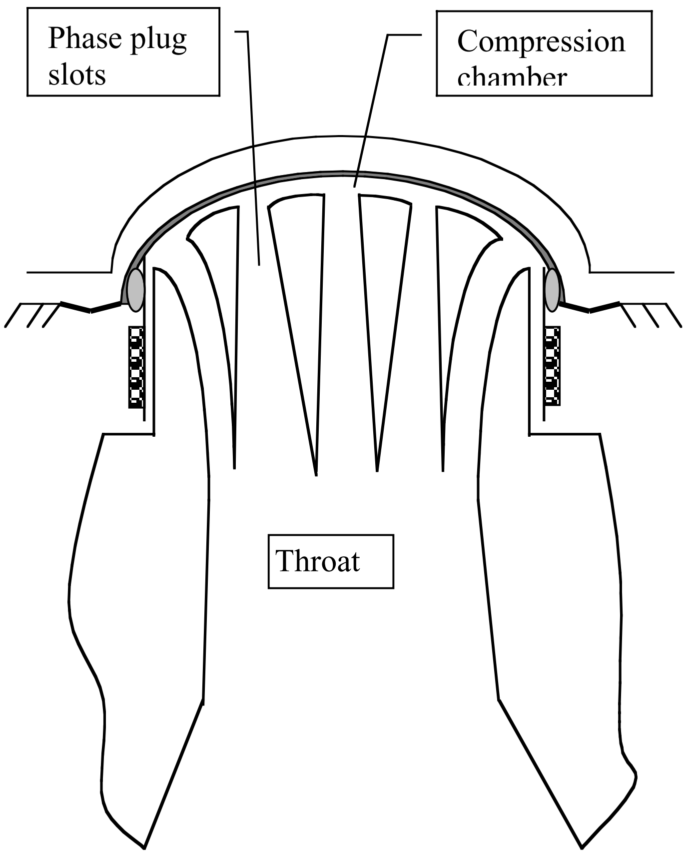


Fig. 4 Central part of a compression driver

Compression driver (Fig.4)

All the dome tweeter problems are inherent for a compression driver as well. Additionally, a compression driver s performance is severely degraded due to the following factors:

- **Large metal diaphragm generates uncontrolled break-up modes** starting form relatively low frequencies covering upper half of effective range
- **Very limited high frequency extension (maximum 16kHz)** due to large mass of the moving system, break-up resonance, transmission losses in the throat
- **Severe non-linear distortion at high SPL** due to air compression, turbulence and non-linear propagation in the compression chamber and the throat (harshness) leading to listening fatigue
- **Very audible sound coloration** due to wavefront and spectral balance distortion

From this comprehensive graphical demonstration, it is clear that the planar ribbon driver is a far more accurate transducer in comparison with the dome tweeter or compression driver. The PRD driver radiates sound directly, without obstructions or resonances, and with minimum distortion. A dome tweeter has many more distortion mechanisms. A compression driver has even more severe sources of distortion, especially at high SPL output.

Comparative test results

In order to find objective grounds, which correlate with listening experience and technically explain the superior performance of the PRD drivers, a number of measurements/tests were performed. These tests also provide evidence of the technical considerations demonstrated in the previous paragraph. Below there are graphs illustrating these results.

Fig. 5 depicts the PRD1000 driver SPL curve measured at 1m/1W. The optional horn was not attached. As shown, the PRD1000 with 103 dB/1m/1W sensitivity has output extending up to 40 kHz. Being able to reproduce signals above 20 kHz, the PRD drivers not only accurately reproduces a spectral balance of a recording, but also reconstructs minute details of the temporal signal structure.

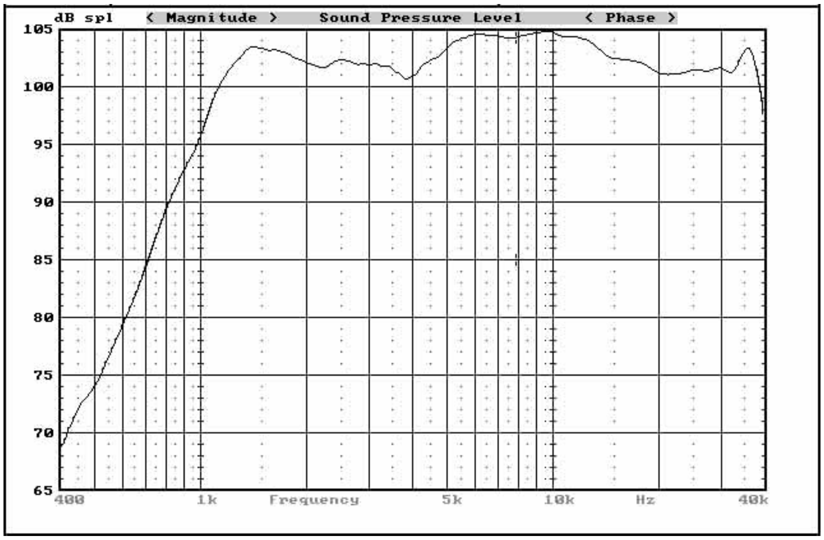


Fig.5 PRD1000 SPL response

It is a fact, that a frequency response, while carrying very informative data, does not fully describe the nuances and differences in performance. One of the most comprehensive measurement data showing spectral behavior of a transducer in time is a cumulative decay spectrum (CDS) or a waterfall, which is derived from a driver s impulse response. As practice shows, CDS correlates very well with subjective perception of sound quality. Fig6. shows the impulse response of the PRD500 driver.

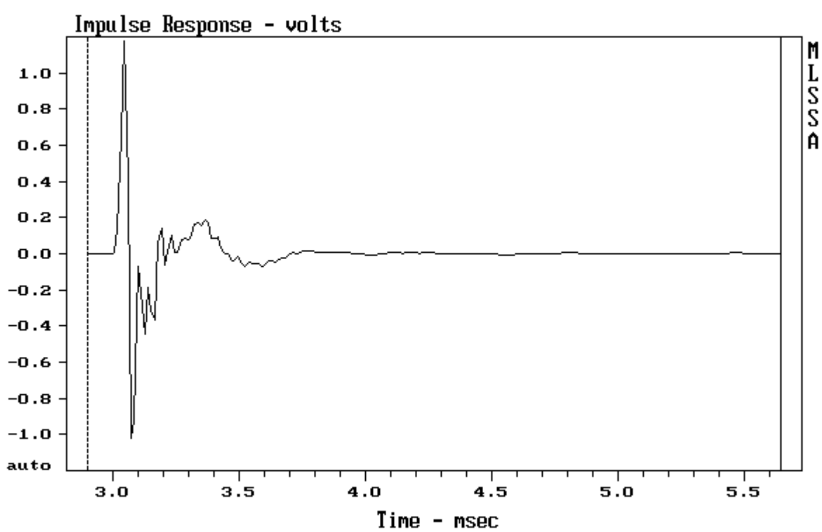


Fig.6 PRD500 impulse response

Fig. 7 shows the impulse response of high performance metal/ceramic composite dome tweeter from a respectable European manufacturer.

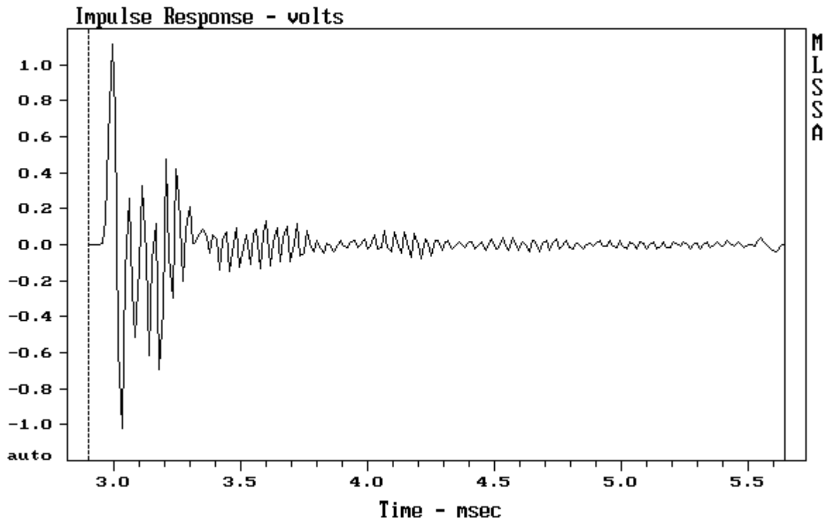


Fig.7 Metal/ceramic composite dome tweeter impulse response

As we see, the PRD500 impulse response is clean and exhibits very little delayed energy, thus showing excellent signal resolution. Contrary to the PRD500, the dome tweeter shows a lot of fluctuating energy (3.1-3.4 msec) immediately after the initial reaction. Moreover, severe structural resonances result in substantial delay and slow release of stored energy long after the end of input signal (3.4 — 5.5 msec).

CDS provides a more complete picture of the situation mentioned above. Fig. 8 shows the CDS of the PRD500, and Fig.9 shows the CDS of the dome tweeter, measured and calculated identically.

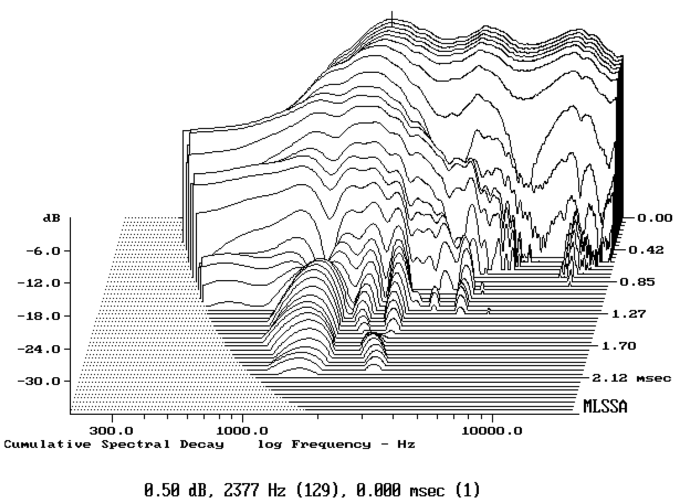


Fig.8 PRD500 cumulative decay spectrum

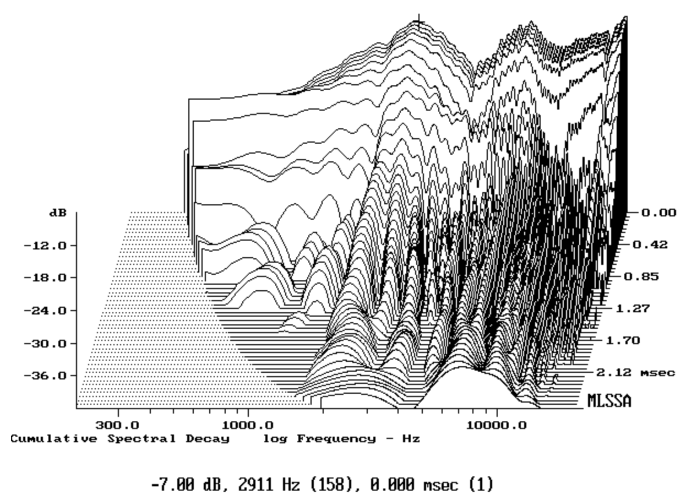


Fig.9 Metal/ceramic composite dome tweeter cumulative decay spectrum

Basic specifications of the dome tweeter are as follows: 93 dB/1W/1m, 2 kHz-22 kHz frequency range, 20W RMS power handling. Basic PRD500 parameters are as follows: 101

dB/1W/1m, 1.8kHz- 40kHz frequency range, 50 W RMS power handling, 8ohm nominal resistive impedance.
While the frequency response of the PRD500 is more extended and smoother than that of the dome tweeter (not shown), it is not the main difference, which affects the performance. Looking at both waterfall graphs, one can see the striking difference in the amount of delayed energy from the drivers. While the PRD500 CDS is very clean, the dome tweeter has many delayed resonances extending beyond 2.5msec across most of its frequency range. This is a clear indication that the dome tweeter will not resolve the signal as well as the PRD500. Subjectively it manifests as audible colorations, lack of transparency and masking of low-level subtle details in timbral characteristics of voices and instruments.

Another revealing set of measurements represents a comparison of the larger PRD1000 driver and the state of the art 2 compression driver. The PRD1000 basic parameters are as follows: 103 dB/1W/1m without horn, 1kHz-40 kHz effective frequency range, 70W RMS power handling, 8 ohm nominal resistive impedance. First of all, let us look at the impedance curves at Fig. 10. While the PRD1000 impedance is mostly resistive (lower curve), compression driver exhibits enormous impedance fluctuations (upper curve) due to structural and acoustical resonances and reflections throughout its whole system.

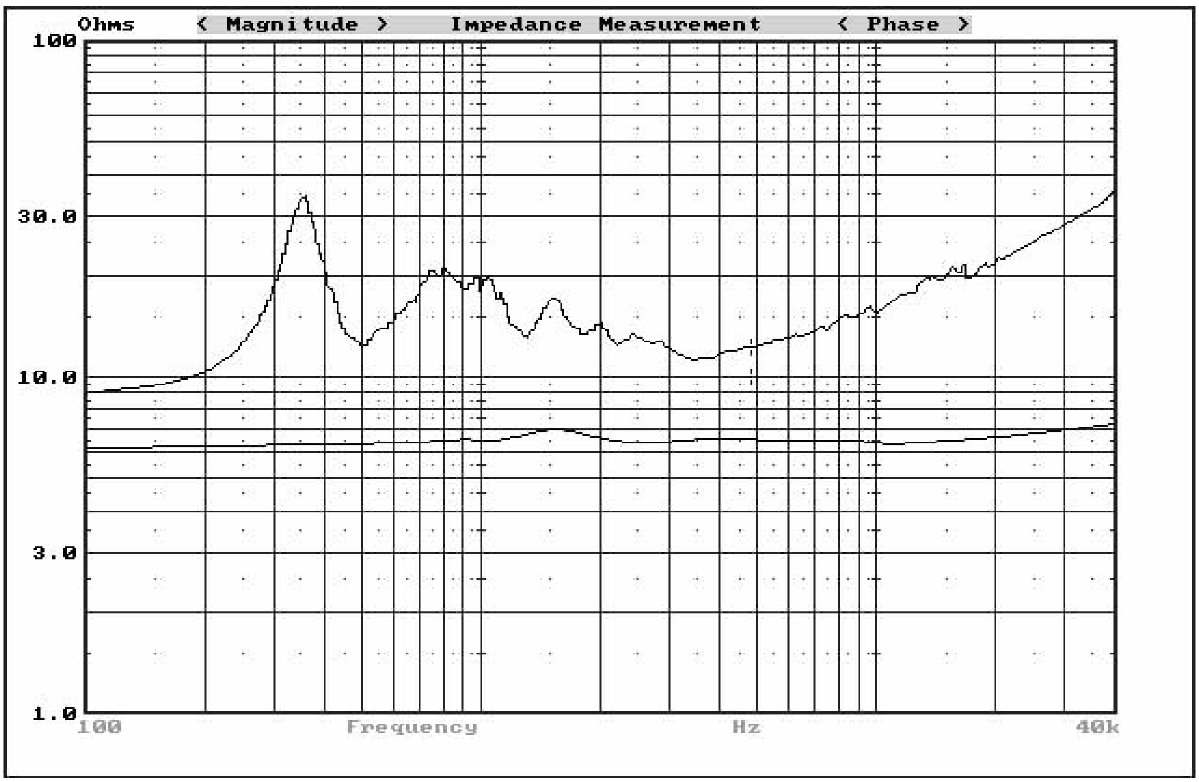


Fig.10 PRD1000 and 2 compression driver impedance comparison

The next set of graphs depicts the impulse response of each driver (see Fig. 11,12). These results very much resemble the situation with the PRD500 and the dome tweeter sample. As expected the compression driver exhibits significant impulse distortion, while the PRD1000 has very clean response. The picture of performance differences becomes even more understandable after examination of the drivers CDS (Fig.13, 14).

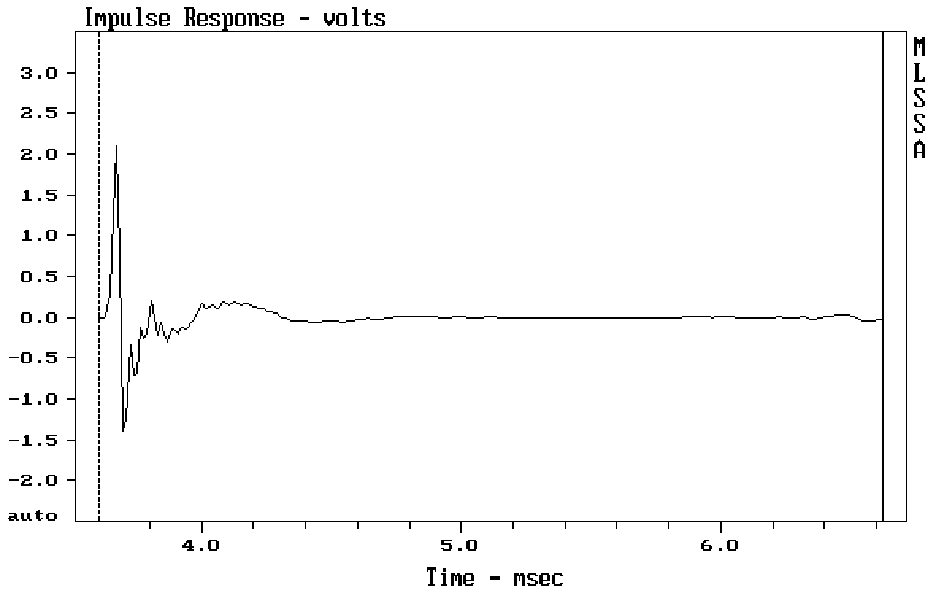


Fig.11 PRD1000 impulse response

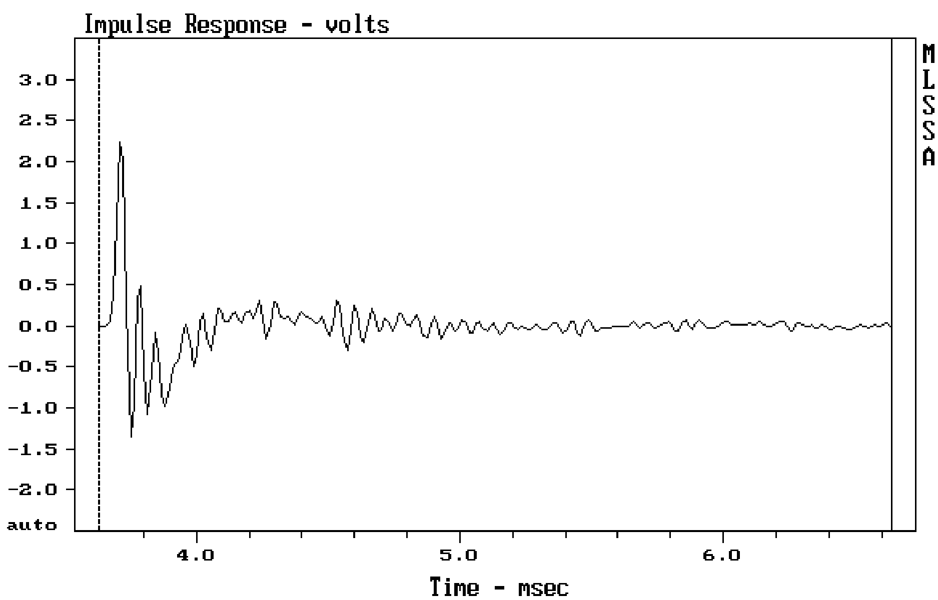
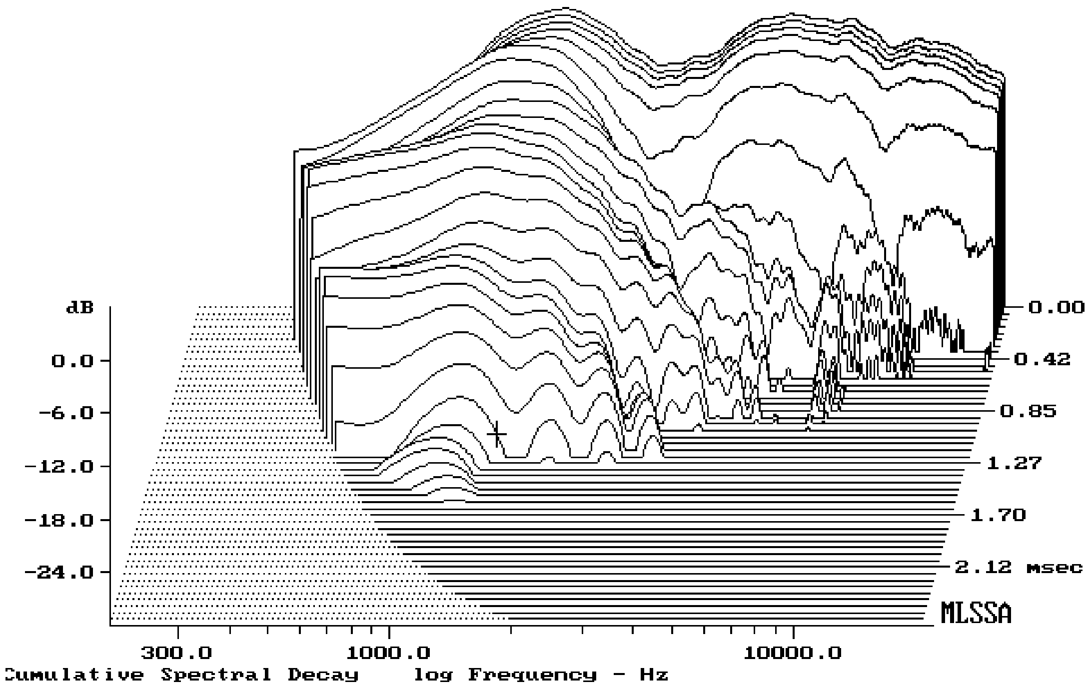
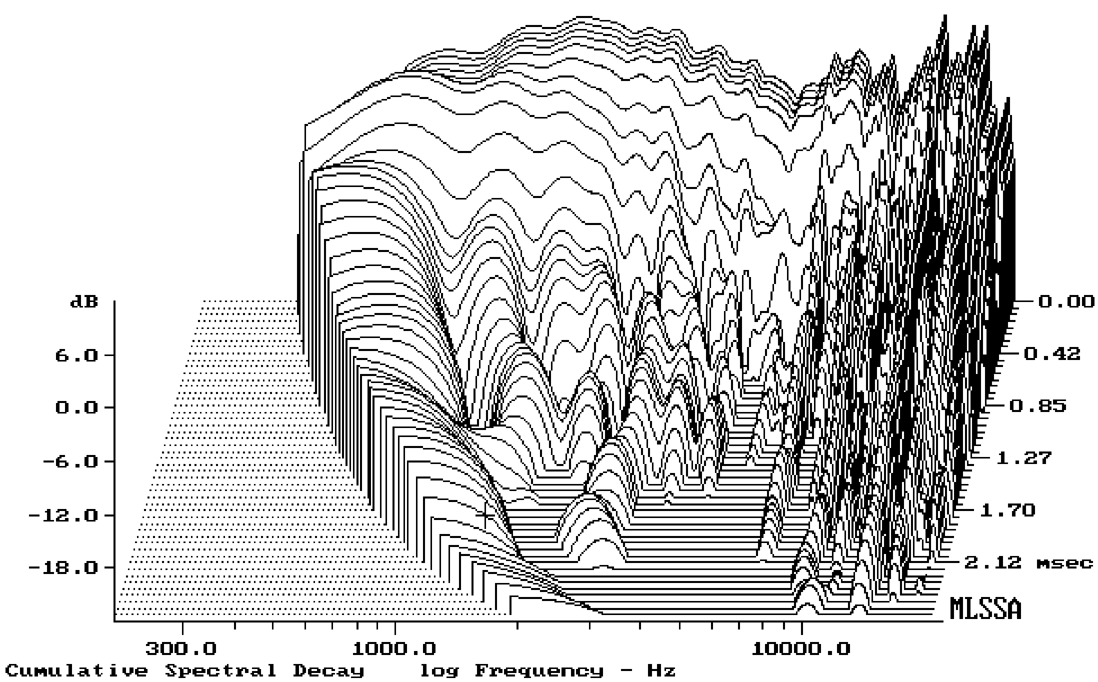


Fig. 12 2 compression driver impulse response



-27.37 dB, 1400 Hz (76), 1.219 msec (24)

Fig. 13 PRD1000 CDS



-18.65 dB, 1511 Hz (82), 2.120 msec (41)

Fig.14 2 compression driver CDS

The PRD1000 has a clean and fast decay, largely subsiding in 1 msec. The compression driver shows a substantial number of delayed resonances and stored energy spread over its frequency range that does not decay below — 30 dB (relative to the reference output level) until 2.5msec. It is worth mentioning that the compression driver has very large contamination above 7 kHz. This may be explained by the fact that starting from 7kHz, the large 4 diaphragm experiences a series of break-up resonances which can be seen as a number of pronounced ridges spread from 7kHz and up. Considering that the dynamic range of the decay on these graphs is only 30 dB, we can get an understanding of how this delayed energy would affect sound quality. 30 dB is far from the real dynamic range that one can experience with live instruments such as piano, percussion, triangles, cymbals etc. If a recording is not heavily compressed, the compression driver will smear and mask the low-level signal information in very fast and dynamic musical passages. It will not resolve the signal enough so that a listener can experience the original sound.

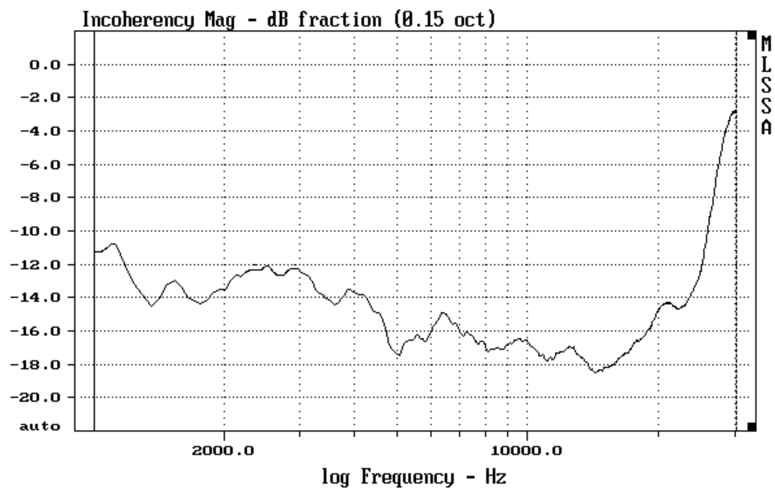
The presence of high level delayed resonances at higher frequencies may explain why compression drivers have such severe colorations, harshness and cannot accurately reproduce the sound of many instruments with high densities of overtones.

The delayed energy, which can be seen in 1-4 kHz range, may contribute to the phenomenon of honky and reverberant sound from compression drivers with smeared midrange detail, easily heard on vocals and some woodwind instruments. However, this does not seem to be the only reason. The other is definitely a waveform distortion, taking place in the throat and the compression chamber.

One of the most interesting subjects directly related to sound quality, which always attracts attention, is non-linear distortion. There have been many research works done explaining the issue of non-linear distortion, its audibility and its correlation with subjective perception of sound quality. It is quite a contradictory subject. One fact is clear. Simple harmonic distortion cannot adequately express the quality of audio performance. Real life examples do not support the notion of 2^{nd} and 3rd harmonics and THD as a reliable reflection of non-linearity in loudspeakers.

More and more research indicates that only complex test signals, such as multitone or multifrequency noise bands, can reveal the real picture. The idea that lies behind these kinds of tests is to separate the linear part from the output signal and extract all non-linear products or spectral contamination. This non-linear distortion is produced when the DUT (device under test) is subjected to a complex test signal that closely resembles a real musical signal. It is considered that harmonic distortion tests, or two-tone intermodulation measurements, cannot reliably tell us about the sound quality of a device. When a more complex signal is fed into the non-linear device (driver or loudspeaker), the output signal becomes contaminated with endless combinations of higher order intermodulation distortion that cannot be readily detected using common technique. It is believed that these high order complex intermodulation products are much more fierce and detrimental to the original signal than any of the commonly measured harmonic distortion.

In order to compare the non-linear behaviour of the PRD1000 and the compression driver, incoherency distortion measurements were performed, using MLSSA analyzer. Incoherency measures the fraction of the output signal that is not linearly related (coherent) to the input signal. The incoherency distortion measurements where performed in near field test, thus largely rejecting parasitic noise and reverberation from the test environment. The near field incoherency measures primarily driver intermodulation distortion, as a reaction to complex pseudorandom MLS input signal. Fig 15,16 shows the incoherency distortion of the PRD1000 and the compression driver respectively.



The test was preformed at moderate SPL (110dB/1m) due to the test microphone max SPL limit (the mic was placed in the near field).

Fig.15 PRD1000 incoherency distortion

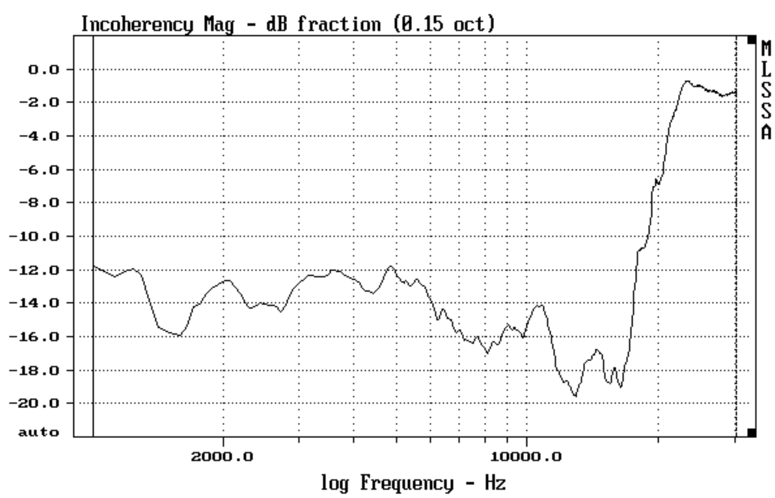


Fig.16 Compression driver incoherency distortion

As we can see, in the range of 1 — 3 kHz, the distortion of both drivers are comparable. Above 3 kHz, the PRD1000 has less distortion.
The last and the most remarkable result was

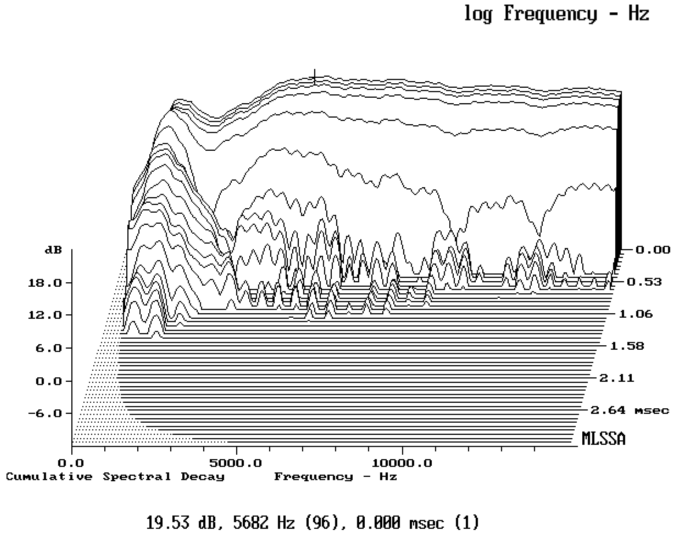


Fig.17 PRD1000 incoherency distortion CDS

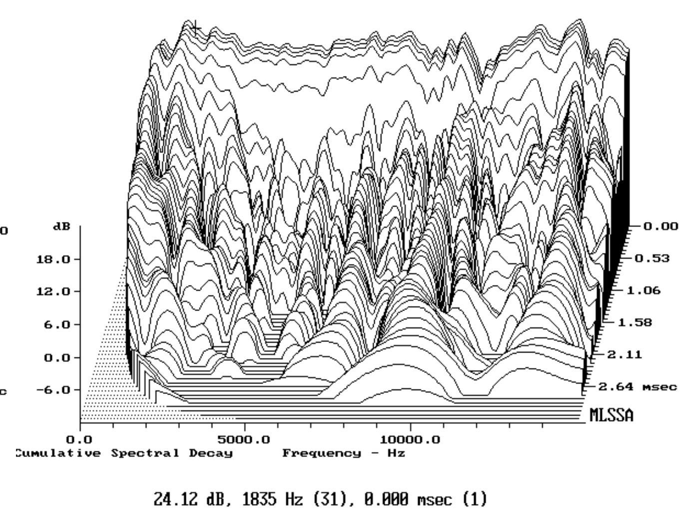


Fig.18 Incoherency distortion CDS of compression driver

Achieved by performing CDS (waterfall) calculations of incoherency distortion.
As expected, the dynamic changes give us much more information than static frequency response of distortion. It is worth noticing that these remarkable calculations have become possible due to unique capabilities of such powerful test instrument as MLSSA analyzer. Figures 17 & 18 depict the incoherency CDS of the PRD1000 and the compression driver, respectively. The conclusions are clear. Our ear integrates all signals that fall in the first several milliseconds of time span. Thus we perceive the whole energy that exists during this time as one signal. Looking at the PRD1000 incoherency, it is understandable why the PRD1000 has such a transparent and free of smear, strain and grunge performance.
Unlike the PRD1000, the compression driver has enormous amount of delayed distortion energy generated over the entire frequency range. The distortion is especially significant above 6-7kHz point due to severe break-up modes, reflections and non-linearity in the throat and in the compression chamber.

Conclusion

From the electro-acoustical and mechanical points of view, it is proven that the PRD planar ribbon drivers represent innovative technology in sound reproduction. Furthermore, by performing a series of accurate, objective tests, it is shown that the mentioned design concept is far superior to any existing technology, aimed at mid and high frequency reproduction. The concept of a planar transducer is not new. However, the PRD driver has numerous proprietary design solutions, which result in performance levels and parameters previously unheard of.

The PRD500 and the PRD1000 can be used in virtually every application in high performance consumer and professional audio. Besides the direct radiating standard option, the drivers could be used with a number of wave guides and horns, developed for the purposes of controlling dispersion and increasing the maximum output levels. It is important to stress, that the cast aluminum horns, designed for the PRD drivers, do not use compression mechanism or phase plugs. They do not have extended throat interfaces or significant discontinuities, as is the case with compression drivers. Therefore, the PRD horns do not limit high frequency extension and they do not have the distortion associated with regular horns.

The PRD drivers have vertically elongated, rectangular, flat diaphragms. They are ideal devices for use in line source systems, for creation of truly coherent, continuous line source sound. Line arrays are becoming very popular, due to their effectiveness and unique characteristics. However, the major unresolved problem in line source systems is proper acoustical coupling. This problem cannot be fully resolved with conventional compression driver technology despite all the elaborate marketing and engineering efforts from many major pro manufacturers. These engineering efforts disregard the fact that it is time to give up the 70-year-old, mostly unchanged technology, and move on, at least in cases where quality sound reproduction is desired. Instead, several line array manufacturers are still trying to squeeze a spherical wave into a cylindrical one, with very questionable results, further degrading the sound performance of initially compromised compression driver technology.

The use of the PRD drivers in line array systems can truly reveal the potential of these unique transducers.