Loudspeaker Accuracy

by John Dunlavy, FIREE, MAES, etc.

The Need For An Informed Approach

A lot of opinions circulate within the audiophile community regarding the subject of loudspeakers, the accuracy of their reproduction and the relative merits of their various designs.

But how much of the information conveyed by these opinions is sufficiently accurate and reliable to be worthy of our trust and confidence? Do those who proclaim the correctness of their views possess relevant technical credentials and credible experience? A few, certainly - but not all!

So, what can audiophiles believe with respect to the confused subject of "loudspeaker accuracy"? It all depends upon how "accuracy" is defined.

For example, if one considers accuracy to be a purely "subjective" property - a search for its meaning becomes lost in a sea of individual opinions and perceptions, where qualities such as "musical, sweet, rich, involving, pleasing, spacious, etc." are often used to describe and quantify the quality of reproduction. Accuracy then becomes a simple matter of the opinion of each listener", based upon their individual tastes. experience, hearing acuity, etc. This quickly leads to there being almost as many "varieties" of accuracy as there are individual listeners. It may also explain why so many different sounding loudspeakers, each claimed by their designer to be accurate", have proliferated faster than a crop of dandelions in springtime.

Likewise, loudspeaker measurements published by many manufacturers and magazines have led audiophiles to lose faith in what they have to reveal about "audible accuracy". But a technical assessment of such measurements often discloses many shortcomings. Among these are the limited kinds of measurements, the accuracy of the measurement equipment and microphone), the short distance over which the measurements were made, the "anechoic properties" of the measurement room and the competency of the technician/engineer making them. The old saying, "good measurements don't lie but measurers often do", is certainly true.

Poor quality, inaccurate and/or an incomplete set of measurements (often covering only a few of the many audible loudspeaker properties) may explain why most audiophiles have become sceptical about the value and reliability of measurements for determining the true accuracy of loudspeakers.

This begs an answer to the question: what is true accuracy? And, if there is a true accuracy", can it be identified by listening alone - without measurements? Or are measurements a valuable means for assessing the potential" of a loudspeaker to yield "audible accuracy"?

In searching for answers - what do good science/engineering, competent measurements, simple logic, and common-sense have to teach us about loudspeaker accuracy? And, can such knowledge help the average audiophile make a more informed decision when evaluating loudspeakers?

What Is Accuracy?

Let's begin by examining some of the popular viewpoints that have often polarized audiophiles during the past few decades. Hopefully, providing some well-grounded, relevant knowledge (combined with old fashioned logic) will help dispel many of the wrong views that have persisted for so long,

Many arguments about "accuracy" appear to be centered on whether any stereo pair of loudspeakers can ever reproduce complex music with sufficient accuracy to preclude a competent audiophile (with good hearing) from discerning any "meaningful" difference between the loudspeakers and the live musicians - during properly conducted, "real time", A/B evaluations within an acoustically-good listening environment. Many (if not most) audiophiles would probably vote NO! But the true answer is YES!

A further argument persists as to whether competently-made measurements are pertinent for assessing the potential audible accuracy of a given loudspeaker? And, how can audiophiles reliably interpret measured data and properly use it? Likewise, if a complete set of accurate accurate measurements are an important indicator of performance, why don't more audiophile magazines utilize them?

Having said all of this, just how should the accuracy of a loudspeaker be defined? Since "accuracy" and "truth" are related, an examination of the meaning of truth might be a good place to begin! In a university course known as criteriology, truth is frequently defined as: "the conformity of thought and thing".

Audible Accuracy?

Perhaps, the foregoing definition can be adapted to loudspeakers by referring to their accuracy as the "conformity of reproduced sound and the original live sound". Of course, it would seem proper to add the caveat: "as determined by a competent listener under properly controlled, "blind" listening conditions within a suitable listening environment".

So - what might such live Vs loudspeaker comparisons reveal? If an accurate recording of the musicians can be made within a suitable anechoic environment, such listening comparisons can often yield valuable information regarding the "subjectively perceived accuracy" of a loudspeaker. However, insuring the validity and repeatability of the data obtained can prove both frustrating and daunting for technically competent persons searching for a statistically significant result. Attempting to improve reliability by eliminating subtle cues, such as "standing-waves" within the room, that may alter the sound of the loudspeakers differently than the live musicians, can prove very difficult and time-consuming - but not impossible.

“Live Vs recorded sessions" conducted here at DAL, using either a pair of SC-IV/A or SC-V loudspeakers separated about 10 feet, with the musicians centered between them, have revealed that experienced audiophiles cannot consistently identify which they are listening to - with scores any better than random guessing. The live string-quartet was recorded in one of DAL's two, large anechoic chambers (24'L x 20'W x 16'H), using a matched-pair of instrumentation-quality, 1/2" omni-directional mics and a professional quality DAT recorder. Listening comparisons were conducted with the musicians and the loudspeakers located about 5 feet from a back wall - within a large room (more than about 8,000 square feet). The listening chair was located about 10 feet directly in front of the quartet and precisely equidistant from each loudspeaker. Every precaution was taken to ensure that all comparison sessions were rigidly controlled to preclude any factors being present that might skew or invalidate the results.

Needless to say, participants are almost always astounded that they cannot consistently distinguish between the live and reproduced sound. Similar "live Vs recorded" sessions have also been conducted using solo instruments, such as a guitar, piano, flute, voices, etc., with the same results.

Measurable Accuracy

Can a full set of competently-made measurements provide a reliable means for predicting the audible accuracy of a loudspeaker? Yes and no!

Although measurements can provide an accurate indicator of the potential for a given loudspeaker to provide audibly accurate reproduction of complex musical sounds, etc., they are not, taken alone, "proof positive"! This may certainly be true if: 1) an incomplete set of measurements exist: 2) the measurements are of doubtful accuracy; 3) the measurements are not properly interpreted by someone competent to do so.

A complete set of accurate measurements, to be meaningful, must include the following:

1. Impulse response
2. Step response
3. Amplitude Vs frequency (frequency response)
4. Phase response Vs frequency (may be inferred from the impulse and step responses)
5. Waterfall
6. Energy-time response
7. Impedance Vs frequency
8. Radiation patterns, in both vertical and horizontal planes, at several meaningful frequencies
9. Non-linear distortion (harmonic and I.M.)

How Accurate Measurements Should Be Made

To be truly accurate and meaningful, measurements should be made within an anechoic chamber of suitable size having interior surfaces that are efficient absorbers of sound over at least the intended frequency range, e.g., from about 200 Hz to above 20 kHz for DAL's two chambers. The size and geometry of the room's interior should permit accurate measurements to be made at a distance of from 10 to 12 feet (normal listening distance for audiophile loudspeakers). This requirement implies a room with very stiff, "sound-proof" walls and interior dimensions that exceed a length of about 24 feet. a width of about 20 feet, and a height of about 16 feet. All interior surfaces of the chamber should be completely covered with wedges or pyramids (typically 18-24 inches thick) made of a reasonably high-density, open-cell, urethane foam. Properly chosen and installed, these sound absorbant wedges should significantly reduce the level of reflections (typically by more than about 30 dB) between the loudspeaker being measured and the microphone.

Such a chamber, properly implemented, should permit very accurate measurements (within about +/- 0.1 dB) to be made from about 200 Hz to 20 kHz, principally limited by the accuracy of the measurement equipment/system. If required, such a chamber can be calibrated to extend its measurement range down to about 50-60 Hz, by various (though time-consuming) means. Measurements below these frequencies can be made at near-field distances from bass or woofer drivers and cautiously "spliced" to the higher frequency data obtained anechoically, taking into account such factors as "directivity gain" introduced by more than one driver covering the same frequency range, etc.

Various test equipment and measurement systems are available for making a complete set of accurate loudspeaker measurements. Perhaps, the best-known and most accurate (overall) is the MLSSA system, invented and made by Doug Rife of DRA Labs in Sarasota, Fla. MLSSA runs on a computer (preferably a 586 or Pentium) and requires a calibrated, precision, instrumentation-type microphone, such as a B&K 4133 (or equivalent ACO Pacific, etc.), a quality power-amp with a rating of at least 100 watts (and an internal output impedance lower than about 0.1 Ohm).

Operated by a competent engineer or technician, properly trained and experienced in its use, MLSSA is capable of measuring virtually every meaningful loudspeaker performance parameter (including impedance) - with both speed and accuracy. However, present versions of MLSSA do not permit an easy, rapid and accurate measurement of "non-linear distortion" components, e.g., harmonic and I.M. distortions, a task best left to the use of a separate measurement set-up, e.g., an H.P-239-A (ultra low-distortion audio oscillator) and a HP-3580/A or B Spectrum Analyzer.

Combined with an HP-8904 Multi-Function Synthesizer, the HP-3580 can also be used as a very versatile system for "Time-Domain Spectrometry" measurements of frequency-response, etc. (It also permits moving a very narrow "time/distance window" in front of and across the exterior surface of a loudspeaker to evaluate "edge diffraction", enclosure vibration modes, etc.)

Another valuable measurement "set-up" consists of a Function-Generator (capable of producing impulses, tone-bursts, triangular and rectangular pulses of various lengths, etc.) and a high-quality, wide-band oscilloscope with excellent trigger capabilities. These permit a real-time evaluation of a loudspeaker's ability to accurately reproduce complex waveforms over a wide range of frequencies, essential for determining whether it can also accurately reproduce complex musical transients and waveforms with little or no waveform distortion.

What Measurements Have to Reveal About Audible Performance

Those who claim that measurements are virtually useless and provide little meaningful information about how "audibly accurate" a given loudspeaker can reproduce complex musical waveforms, usually possess little germane knowledge concerning measurements, how they are made, what they convey, and how to interpret them. (Frequently, such views are expressed by loudspeaker manufacturers who do not possess adequate measurement equipment and/or facilities, including a competent engineering staff?)

Contrary to the opinions of those who hold such false views, a full set of accurate measurements can provide both an excellent and reliable means for assessing the potential of a given loudspeaker to provide "audibly accurate reproduction". In other words, the true audible accuracy of any loudspeaker can never exceed that predicted by a full set of measurements, properly interpreted.

But a "hard-core" group of speaker designers still passionately proclaim that accuracy is a totally subjective property that can only be assessed and judged by each individual according to their unique tastes! The design methodology they pursue entails what is called "voicing" - designing a loudspeaker while listening to its reproduction of their favorite recorded music. However, this design approach is fraught with problems that do not require a "rocket scientist" to identify and condemn. It can, of course, lead to loudspeakers that appeal to individuals desiring a "sweet" or "full" or "pretty" or "polite" or "nice" or "..." sound!

But the odds of the "voicing" approach being able to yield a loudspeaker capable of truly accurate reproduction, verifiable by competent means (including comparisons with live music), is probably too small to compute.

Nevertheless, since "freedom of belief" is an important tenet in our society, we should respect the subjective viewpoint and design approach, even if we disagree with it. And, lest we forget, one of the key purposes and objectives of any audiophile system is to provide "subjective listening pleasure to the listener". Thus, even though a loudspeaker may measure and sound nearly perfect, if it does not meet the expectations of the listener, it has failed to fulfill its primary purpose.

Loudspeaker components possessing a high-tech appearance also seduce some audiophiles to believe they might also exhibit high-tech performance. Most often, however, appearance does not correlate very well with true performance. A prime example is the "high-tech" appearing metal dome tweeters, ceramic cone mids/woofers, etc. that seldom (if ever) exhibit high-tech performance. A look at their response to an impulse and a step in the time-domain reveals unacceptable levels of ringing, phase distortion, etc.

This is because domes and cones made of exotic metals store energy - for they lack the "internal-damping" and "loss properties" needed for achieving the best-possible impulse-response, etc. The design of very high quality domes and cones for "true audiophile and exacting recording" applications requires a unique combination of physics, engineering, chemistry and the acoustical properties of many materials - to say nothing of a significant measurement capability. Indeed, the loudspeakers which yield the best measured level of accuracy and the most audibly accurate reproduction do not use metal, ceramic and other exotic materials. But their use creates great advertising opportunities! Hmmm!

Interpreting A Set Of Measurements

Lets now focus on what a full set of accurate measurements can reveal about the potential ability of a loudspeaker to accurately reproduce a full range of music, along with its many complex transients, nuances and directional/instrument-size properties. (The comments below assume that the loudspeaker is measured, on the listening axis, within a good anechoic chamber at a distance of from 10 - 12 feet.)

1. Amplitude Vs Frequency (frequency response)

The modulus of amplitude Vs frequency often referred to as "frequency response" should fluctuate less than about +/- 1 dB for a loudspeaker to be considered truly accurate. Despite the claims of many manufacturers that their loudspeakers meet a +/-2 dB spec. limits, very few (even expensive models) are better than about +/- 4-5 dB

Frequency response, accurately measured at an "on-axis" distance of from 10-12 feet, reveals the spectral balance of a loudspeaker. Listening (within a room possessing good acoustics) to a superb, high-definition recording of complex orchestral music, a well-trained listener with excellent hearing can often detect a flaw in spectral balance amounting to a peak of as little as about 2 dB, covering a 1/3 rd octave, if the loudspeaker is exceptionally flat (perhaps +/- 1 dB) over the remainder of the audible range, The case appears to be quite different, however, with respect to narrow "drop-outs" in an otherwise flat frequency response, with nulls of -3 dB to -5 dB usually being difficult to detect if they are limited to less than about 1/10 th to 1/4 th of an octave. This is especially true when listening to loudspeakers within a room having medium-to-large dimensions, where reflected sounds combine with the direct-path sound to create a spectrum of closely-spaced peaks and nulls. Such a spectrum is often interpreted by our hearing process as a "spacious sound", attributable to listening within a large room.

2. Impulse response

In may be difficult for non-technical readers to appreciate that a simple impulse (often referred to as a "cosine pulse") contains all frequencies from near D.C. to a high frequency based upon the rise-time of the pulse.

By mathematically performing a Fourier analysis of an impulse, using FFT software and a computer, one can obtain all other measurable parameters listed above, except for Impedance Vs frequency, Radiation patterns, and Non-linear distortion (harmonic and I.M.). Thus, measurement equipment based upon using FFT begin with one or more pulses. (MLSSA employs several thousand in a pre-programmed quasi-random sequence.)

Viewed directly, an accurate loudspeaker should be able to reproduce an impulse that rises rapidly to its maximum peak level, drops through zero to a negative peak level that should not exceed about 0.1 that of the positive peak. Further ringing should be at a level typically lower than -20 dB and should only persist for a time less than about 300 micro seconds. (See Figure 2 for examples of the measured "impulse response" of typical loudspeakers.)

An excellent impulse-response, with a steep rising "pulse", followed by little or no "ringing", permits critical listeners to discern realistic resolution of short-duration, complex musical transients. A poor impulse response can convert a sharp "tic" sound to one resembling a dull toc" sound.

3. Step response

The step response of a loudspeaker depicts its ability to accurately reproduce a long rectangular pulse with minimum slope, etc. Mathematically, it is the integral of the impulse response. The step response of a near perfect loudspeaker should resemble the first half of a "square-wave passed through a network with a bandwidth equal to the loudspeaker's frequency response. This would appear as a rapidly rising amplitude followed by a smooth, slow decay in amplitude over several milliseconds, eventually approaching a level of zero. The rate of decay should be approximately "exponential" with time, yielding a curve with a small "droop" - not a "triangular shape", as some sources have stated. (See Figure 3 for examples of the measured "step response" of typical loudspeakers.)

For those who know how to interpret its shape, a step-response can reveal a lot of valuable information about a loudspeaker's amplitude and phase properties in both the frequency and time domains, including blurring of complex transients, smearing of tone-bursts, rise-time, etc.

4. Phase response Vs frequency (may be inferred from the impulse and step responses)

A loudspeaker that exhibits excellent impulse and step-responses, must theoretically also exhibit a flat curve of phase Vs frequency. This is because a phase shift exceeding 180 degrees within the loudspeaker's primary frequency range will result in a step response that overshoots to negative values at a time (measured from the start-up of the pulse or step) that is related to the inverse of the frequency or frequencies at which a phase reversal occurs.

The audibility of non-minimum phase performance has been debated over the years by many recognized experts in the field of audio. The majority appear to hold the opinion that departures from a "flat-phase" condition is probably not audible when listening to most recordings - especially those made using multi-miking techniques. However, the final decision of the jury" has yet to be rendered with respect to what "phase aberrations can be heard under different listening conditions with high-quality source material. Since good engineering and physics provide ample instructions for designing and manufacturing loudspeakers with excellent phase response, why not achieve it - and quit grumbling?

5. Waterfall

The waterfall response of a loudspeaker, often referred to as the "cumulative spectral decay", provides an excellent graphic view of how well the amplitude Vs frequency components decay with time. This, of course, assumes that the technician or engineer making the measurement chooses the optimum time-window, risetime, bandwidth and other relevant program parameters when using a system such as MLSSA.

A truly accurate loudspeaker, e.g., one possessing excellent time frequency domain properties, should exhibit a single "first curve" of frequency response (at the top of the graph), followed by a "second" curve (in the time-domain) at a level approximately 10 dB below that of the maximum response (first curve) above about 300-500 Hz. Subsequent curves, delayed in time, reveal how smooth the frequency response remains during the "roll-off phase". (See Figure 4 for examples of the measured "waterfall response" of three typical loudspeakers.)

A loudspeaker which exhibits a rapid, wideband, "spectral decay". as evident from its waterfall plot, may be assumed to possess the ability to accurately and realistically reproduce sharp, complex musical transients with life-like qualities.

6. Energy-time response

The "energy-time" plot of a loudspeaker is essentially a logarithmic plot of amplitude Vs time (wide-band) that reveals how rapidly and smoothly the full frequency spectrum decays in the time domain. A loudspeaker with an excellent energy-time response decays 20 dB or more within about the first 10-30 microseconds. Because it is a logarithmic plot (typically displaying an amplitude range exceeding 20 dB), it often reveals low-level signal decay problems that might be missed when looking at an impulse-response plot with a "linear amplitude" vertical scale that reveals little detail at levels below about - 10 dB.

7. Impedance Vs frequency

Plots of impedance Vs frequency, and especially those which also plot the reactive components (capacitance and inductance) are valuable in determining how "benign" a "load" the loudspeaker presents to the output circuit of the power amplifier.

This especially holds true with respect to power-amps using vacuum tubes in their output stage, which frequently exhibit output impedances exceeding a few ohms. For example, a tube-type power-amp with an output impedance of 3 Ohms will exhibit a "systems loss" of 6 dB at a frequency where a loudspeaker's impedance drops to 3 Ohms, causing a rather undesirable dip in the overall amplitude response of the system. (See Figure 5 for examples of the measured "impedance" of typical loudspeakers.)

A well-designed, accurate loudspeaker should exhibit a minimum impedance of about 3 Ohms, a maximum impedance of about 10 Ohms and a maximum reactive component, expressed in degrees relative to the resistive component, of about +/- 45 degrees.

8. Radiation patterns

Although many different opinions exist with respect to the ideal radiation patterns that an accurate loudspeaker should exhibit, some logic should apply (coupled with meaningful listening comparisons with live music). The radiation patterns of a loudspeaker Vs frequency, in both horizontal and vertical planes, determine how accurately it radiates its maximum radiation level in the direction of the listener and how smoothly it distributes its sound energy in the direction of reflective surfaces within the listening room, including the floor and ceiling.

A properly designed, vertically symmetrical array (VSA) of drivers (Bass-mid-twit-mid-bass) arranged along a common vertical axis, usually provides the best and smoothest coupling of radiated sound into a typical room. This is especially true of sound energy reflected from the floor at the mid-point between the loudspeaker and the listener, which often dominates in amplitude over the direct sound for most non-VSA designs. Thus, a VSA design probably possesses the highest probability of yielding the best overall imaging within most rooms.

Likewise, loudspeakers with "horizontal" radiation patterns that possess left-right symmetry tend to provide the most accurate and stable stereo soundstage, with the least blurring and drifting (in direction) of a given sound. Of course, to obtain the most accurate stereo sound stage and imaging, it is important that loudspeakers with symmetrical radiation patterns be located symmetrically be located symmetrically within the listening room, with respect to walls and other room boundaries (especially the side walls adjacent to each of the loudspeakers). Figures 6 and 7 provide examples of loudspeakers possessing good and poor radiation patterns in both vertical and horizontal planes.

Not shown in Fig. 7 is the radiation pattern of a loudspeaker designed with drivers stacked vertically along a common vertical axis, but not equidistant from both vertical edges of the enclosure. Such a loudspeaker almost always exhibits horizontal radiation patterns that are asymmetrical with respect to the intended listening axis, with the potential of creating skewed or blurred stereo imaging because of asymmetrical reflections from side walls, etc. (An asymmetrical positioning of drivers relative to the vertical edges of an enclosure is often used to reduce peaks and nulls in the on-axis frequency response caused by "edge diffraction".) The proper means of effectively eliminating or mitigating edge diffraction is to apply appropriate amounts of efficient acoustical absorbing material between the drivers and the edges of the enclosure.[1]

[1] U.S. Patent # 4,167,985, issued on Sept. 18. 1979 to John Dunlavy.

9. Non-linear distortion (harmonic and I.M.)

Non-linear distortion products (harmonic and I.M.) are more audible at some frequencies than others. Generally, low-order (2nd and 3rd) harmonic distortion products are inaudible to most listeners when they do not exceed levels of about 1 - 5 % at frequencies below about 100 Hz. At higher frequencies, levels as low as about 0.3 % become detectable by some listeners

Since I.M. distortion does not usually appear in nature, is usually more audible at lower SPL levels than harmonic distortion.

Last Comments

Audiophiles possessing relevant technical competency often possess an advantage with respect to using competently made measurements as a useful guide for determining whether a loudspeaker possesses the potential to faithfully and precisely emulate the original live music, given a high-quality audio system, an accurate recording and, of course, a good listening environment.

However, the qualities of even the most accurate loudspeakers are often compromised by a listening room with poor acoustical properties, e.g., small size (relative to the size of the loudspeaker), poor ratios of length-to-width-to-height or less than optimal "acoustical damping". Also, incorrect loudspeaker placement within even the best room can produce unsatisfactory reproduction. Given such problems, it is questionable whether the attributes of a truly accurate loudspeaker can be audibly distinguished from a loudspeaker of poor design.

Fortunately, evidence exists to support the belief that most experienced audiophiles with good hearing can discern between the direct sound radiated by a loudspeaker and the reflected sound from room boundaries, if the reflected sounds arrive "beyond the fusion time of the listener's ears". This is typically about 5-10 milliseconds (equivalent to a delayed path of from about 5.6 to 11.2 feet, or longer.) But this generalization usually does not apply at lower mid-range and bass frequencies, where a wavelength may be equal to or greater than the differential distance between direct and reflected paths.

This brief paper would not be complete without commenting on the use of subjective listening criteria for evaluating loudspeakers. However, it does not seem important to dwell on the subject at any length because such criteria are, by their very nature, relative to each individual's perception of accuracy and the attributes that define it. Thus, "beauty lies in the ears of the beholder" with respect to the subjective perceptions held by each different listener - making it exceedingly difficult (if not impossible) to interpret the comments of any given person with respect to their individual perceptions of how accurate" a particular loudspeaker may sound. A few examples of subjective criteria that some listeners incorrectly relate to "accuracy" are

1. *Rich or full* sound

2. *Presence*

3. *Boom-box* bass

4. *A wide "sound-stage"*

Reflecting upon this list, one must eventually conclude that such "subjective accuracy" involves numerous possible combinations of the above . none of which necessarily relate to the sound of the original live music, etc. Of course, not every listener may want accurate reproduction, preferring instead what amounts to an artificial "enhancement" of the original sound - examples of which are:

1. *Rich or full* sound - often achieved by elevating the amplitude response a few dB within the spectrum from about 150 - 400 Hertz. (While some listeners may find a "rich and full sound" subjectively pleasing, others may find such sound quality lacking in spectral balance and definition of transients.)

2. *Presence*. adding a few dB within the spectrum normally occupied by most male and female voices (typically from about 500 - 3 kHz) yields the effect of voices appearing to emanate from a location somewhat forward of most musical instruments, creating a false presence effect.

3. *Boom-box* bass - Easily obtained by using a "ported" enclosure with a "broad peak" in the bass region, centered near the peak frequency of most "kick-drums". (Often preferred by listeners who mostly listen to rock music or who desire an elevated response in the bass region.)

4. *A wide "sound-stage" heard over a "wide listening area"?* - Creating the illusion of a wide (but false) sound-stage, perceived over a wide listening area, can be achieved by several means, all of which yield inaccurate and/or "blurred" imaging with respect to the width and direction of individual instruments, voices, etc.

Claims by manufacturers that their loudspeakers can provide a truly accurate sound-stage and precise imaging for a person seated anywhere within the listening room are simply false. This is because the ability to accurately discern the direction of a given instrument or voice when listening to a two-loudspeaker stereo system is governed mainly by three factors: 1) the accuracy and pair-matching of the loudspeakers, 2) the symmetry of the room with respect to the location of the loudspeakers and the listener, and 3) precisely equal path distances between the listener and each loudspeaker. (These three factors are governed by the inviolable laws of physics and by the well-known properties of our hearing process.)

Loudspeakers which provide the illusion of a wide soundstage, regardless of the listening location, do so by sacrificing the pin-point imaging and precise sound-stage available from truly accurate loudspeakers correctly located within the listening room. The result is always a blurred or distorted stereo soundstage, with discrete sound sources losing their normal direction, location and/or width as a listener moves from one location to another with the listening room. *Anyone or any company claiming to have developed a pair of stereo loudspeakers capable of achieving truly accurate stereo imaging anywhere within a listening room should submit their proof - to be nominated for a Nobel Prize in physics.* (With three discrete front channels, e.g. left-center-right, the possibility exists! With two channels, the answer is NO - NO - NO!)

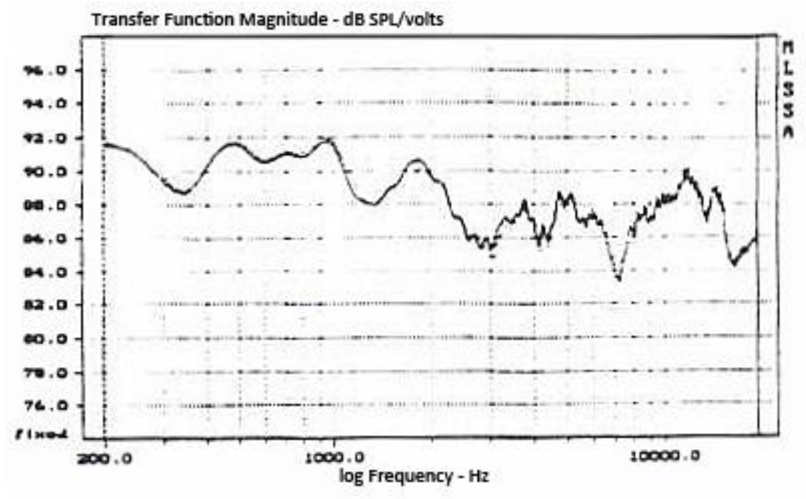
While it may seem an easy and simple task, the design and manufacture of a loudspeaker capable of recreating the original "live" sound or music with a level of realism that precludes a competent listener from discerning the live sound from the reproduced sound, in real-time within a good listening environment, is an extremely complex task. It requires a competent and experienced engineering staff (possessing proper academic/professional credentials) with a laboratory facility having the latest and most accurate measurement equipment, etc. - including a large anechoic chamber.

<u>**CAVEAT EMPTOR**</u>

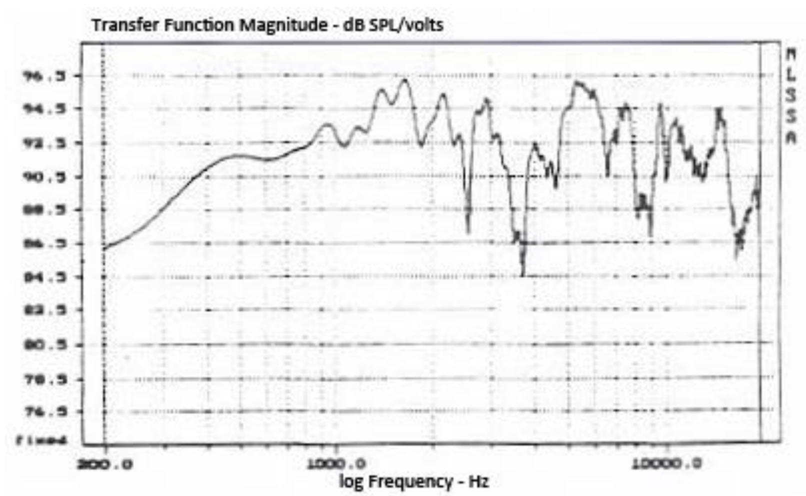
FIGURE 1

<u>Examples of the Frequency Response of Different Loudspeakers</u>

A highly-rated, medium-priced", conventional, ported-box loudspeaker



A highly-rated, "medium-priced", planar membrane loudspeaker



A "medium-priced", minimum-phase, closed-box loudspeaker (A standard DAL model)

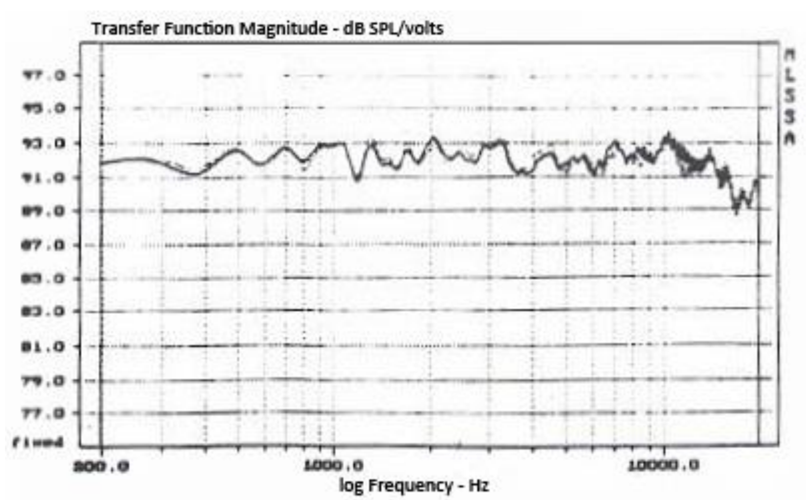
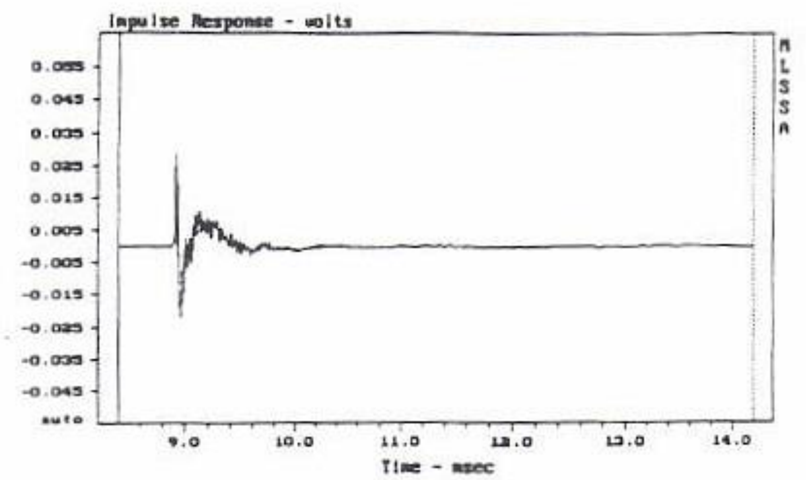


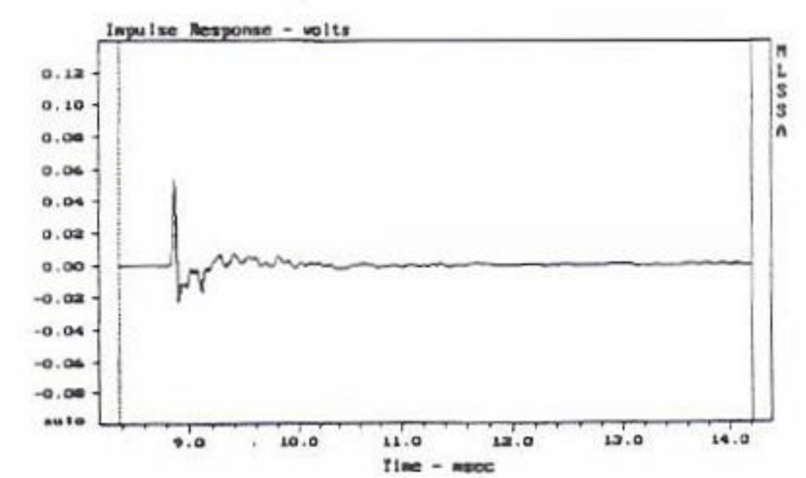
FIGURE 2

<u>Examples of the Impulse Response of Different Loudspeakers</u>

A highly-rated, medium-priced", conventional, ported-box loudspeaker



A highly-rated, "medium-priced", planar membrane loudspeaker



A "medium-priced", minimum-phase, closed-box loudspeaker (A standard DAL model)

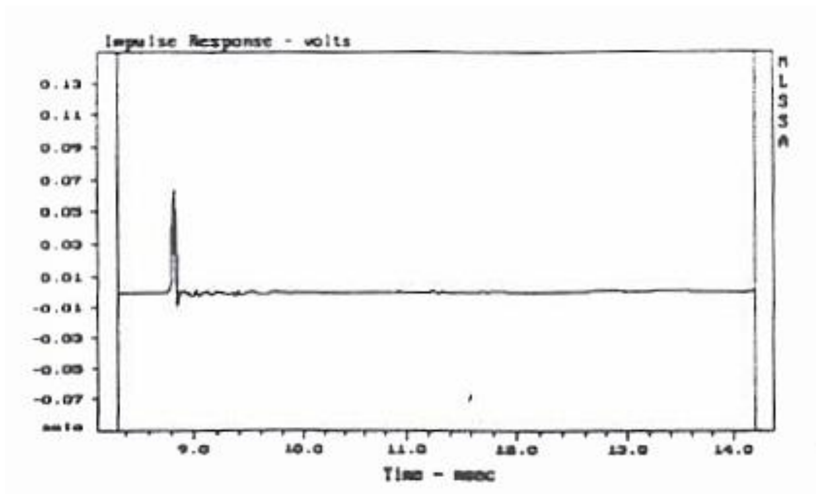
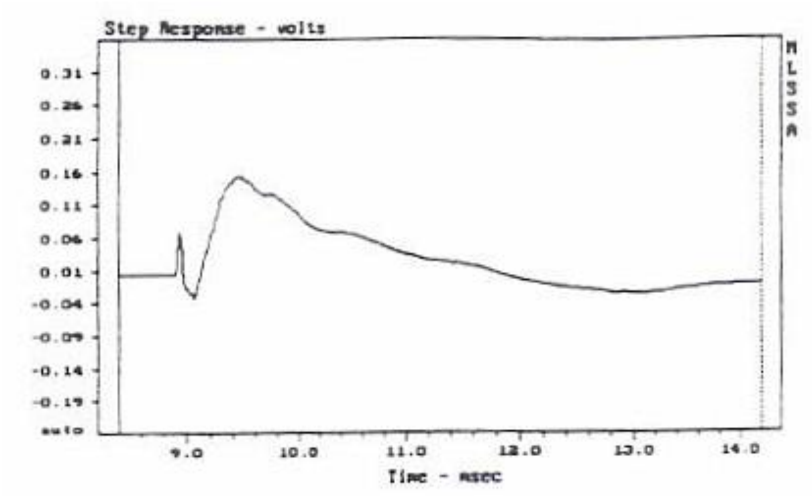


FIGURE 3

Examples of the Step Response of Different Loudspeakers

A highly-rated, medium-priced", conventional, ported-box loudspeaker



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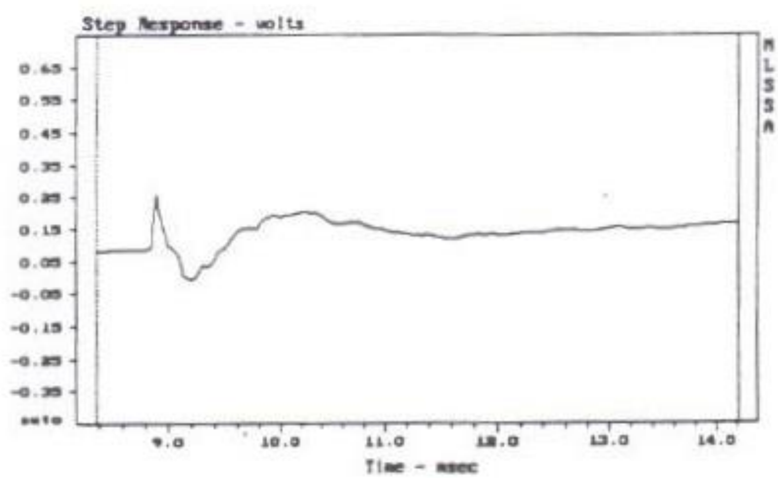


A "medium-priced", minimum-phase, closed-box loudspeaker (A standard DAL model)

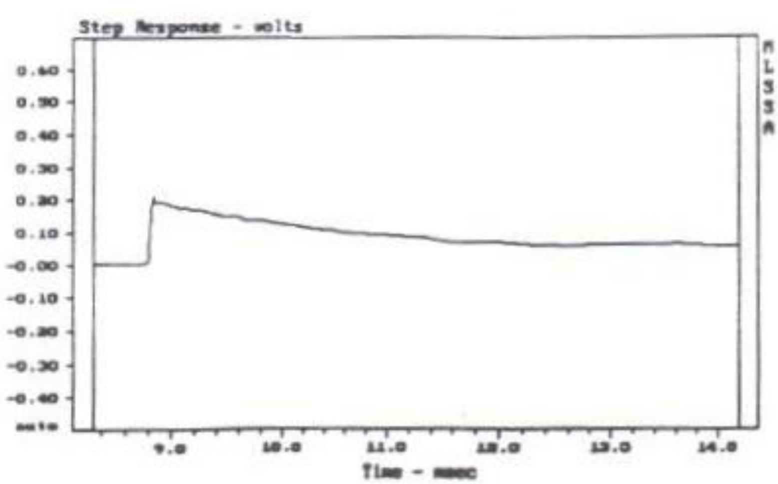
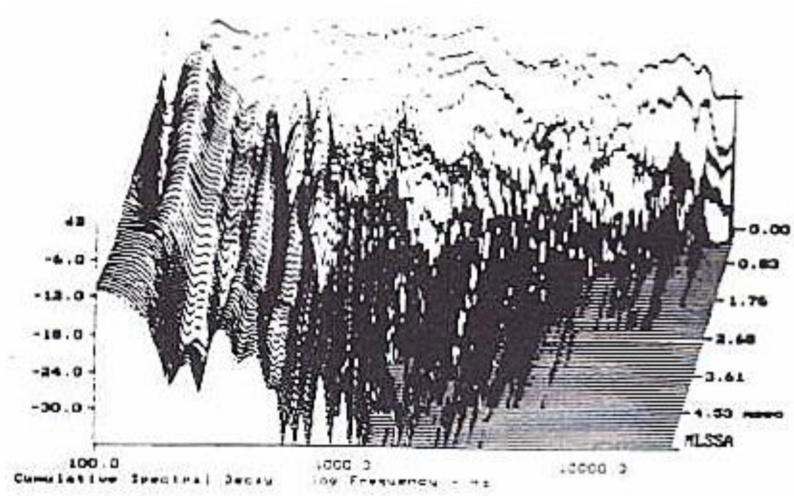


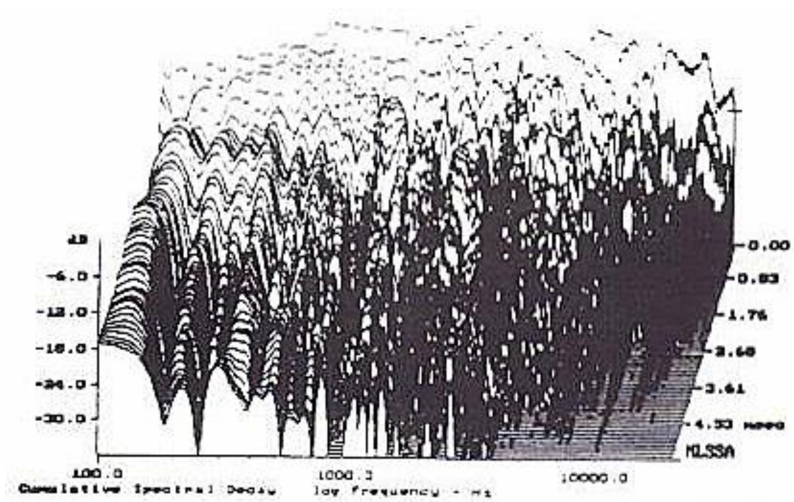
FIGURE 4

Examples of the Waterfall Response of Different Loudspeakers

A highly-rated, medium-priced", conventional, ported-box loudspeaker



A highly-rated, "medium-priced", planar membrane loudspeaker



A "medium-priced", minimum-phase, closed-box loudspeaker (A standard DAL model)

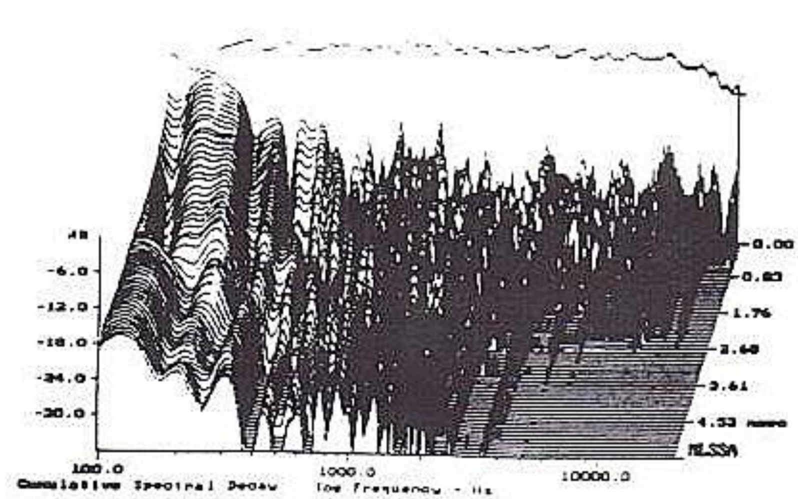
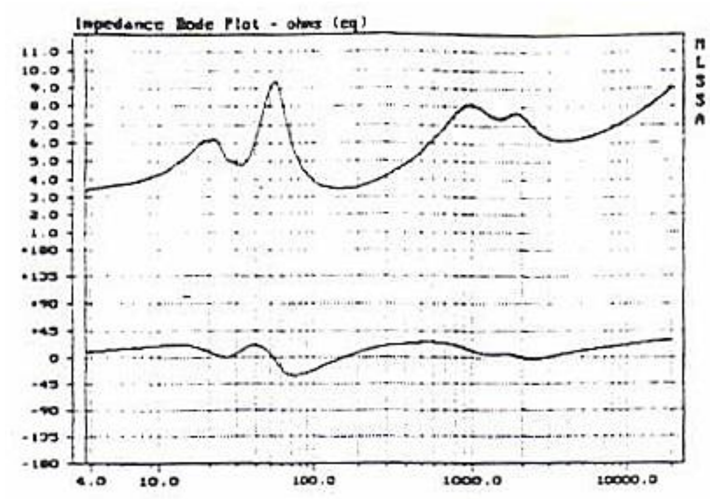


FIGURE 5

Examples of the Impedance Vs Frequency of Different Loudspeakers

A highly-rated, medium-priced", conventional, ported-box loudspeaker



A highly-rated, "medium-priced", planar membrane loudspeaker

A "medium-priced", minimum-phase, closed-box loudspeaker (A standard DAL model)

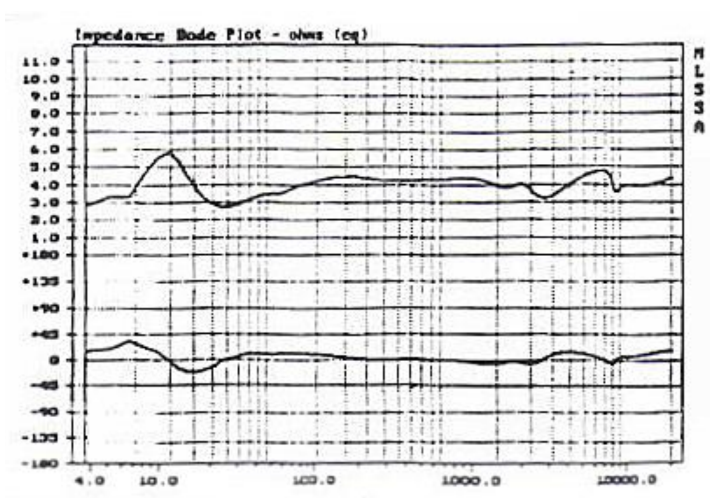
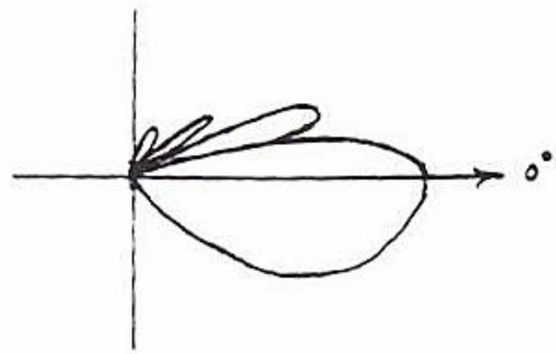


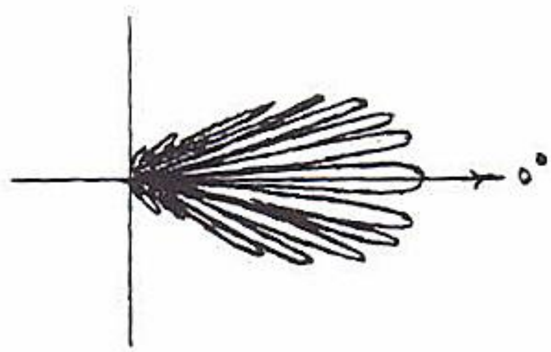
FIGURE 6

Examples of Typical Vertical-Plane Patterns of Different Loudspeakers

A highly-rated, medium-priced", conventional, ported-box loudspeaker at about 3 KHz



A highly-rated, "medium-priced", planar membrane loudspeaker at about 3 KHz



A "medium-priced", minimum-phase, closed-box loudspeaker (A standard DAL model) at about 3 KHz

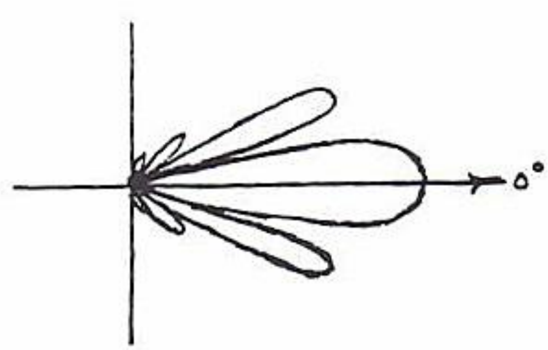
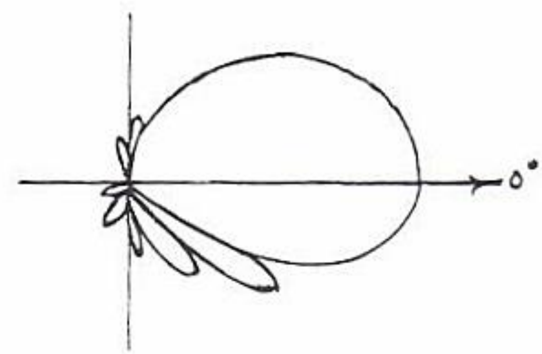


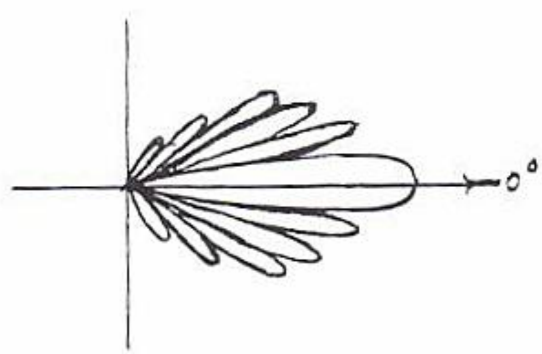
FIGURE 7

Examples of Typical Horizontal-Plane Patterns of Different Loudspeakers

A highly-rated, medium-priced", conventional, ported-box loudspeaker at about 3 KHz



A highly-rated, "medium-priced", planar membrane loudspeaker at about 3 KHz



A "medium-priced", minimum-phase, closed-box loudspeaker (A standard DAL model) at about 3 KHz