Message - Impedance & Phase

I want to personally thank you for visiting us at one of the audio shows.

I enthusiastically invite you to visit us or one of our dealers to listen to our magnificent transmission line Adagio, Crescendo, or Maestro loudspeakers.

The Crescendo has received an enthusiastic Five-Star recommendation from Dick Olsher of The Absolute Sound (TAS). Over the past 10 years our loudspeakers have consistently garnered “Best Sound” and “Best Room” awards at every show we attend. There is a reason for that. I would like to share the inside story why that is and how Acoustic Zen’s loudspeakers differ from others.

Interestingly, loudspeakers are the most difficult component to properly design and manufacture in the audio reproduction chain. At the same time, loudspeakers are one of the easiest to bring to the market because it’s not always terribly expensive. Just drop a couple of high quality drivers into a box and you’re in the audio business! As long as you get sound out of them, it seems that people will buy them, even if they don’t sound like real music! That’s why there are so many loudspeakers manufacturers. The truth is, very few companies exist that make products that are properly designed and engineered to truly sound like music.

Great loudspeakers have to reproduce ten octaves of complex frequencies simultaneously. At the same time, they have to preserve the phase relationships of all these multiple fundamental tones and their harmonics. Loudspeakers also have to interface with the listening room to yield a proper musical tonal balance while producing an extremely wide dynamic range of sound without audible distortion. In reality, these are difficult goals to achieve. This is why, I believe, music lovers and audiophiles are continually changing their audio components, searching for that elusive “something” that will finally satisfy their ears and heart.

Let’s start with some basics. Why do different musical instruments have different sounds, even though they can play the same fundamental note? Different instruments use different methods for producing sound. For instance, the strings of a guitar or a violin, reeds in a clarinet or saxophone, or just columns of air like a flute, organ, or the human voice. Some produce sound when struck, like the head of a drum or the bars on a vibraphone or the strings that are struck by hammers in a piano. Ultimately, they all vibrate and cause the air around them to vibrate in sympathy to create sound.

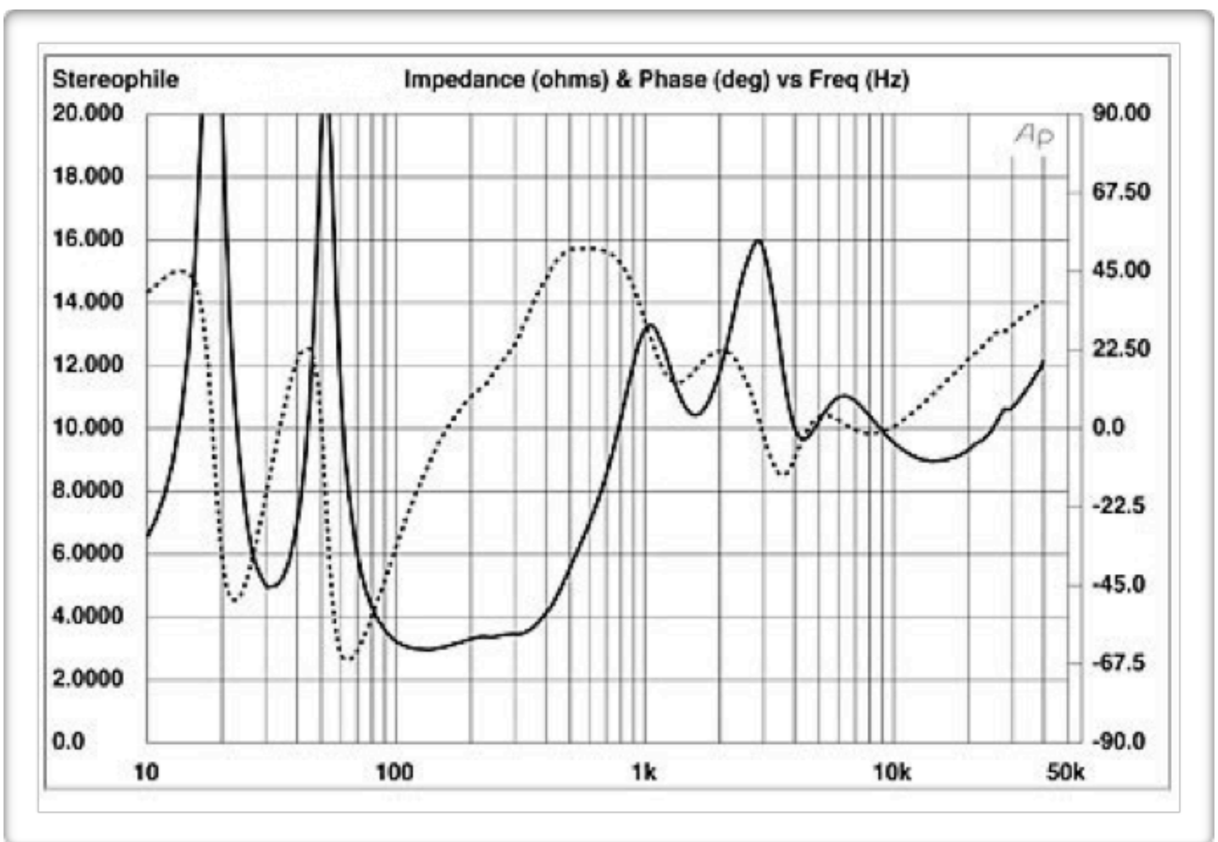
Different instruments have different size, material, and shape. Because of the different physical properties of the different musical instruments, each note played by those different instruments do not vibrate at only that single, fundamental frequency. They produce vibrations at many different frequencies, often called harmonics, partials, or overtones. The relative pitch and loudness of these overtones gives the note a characteristic sound we call the timbre of the instrument.

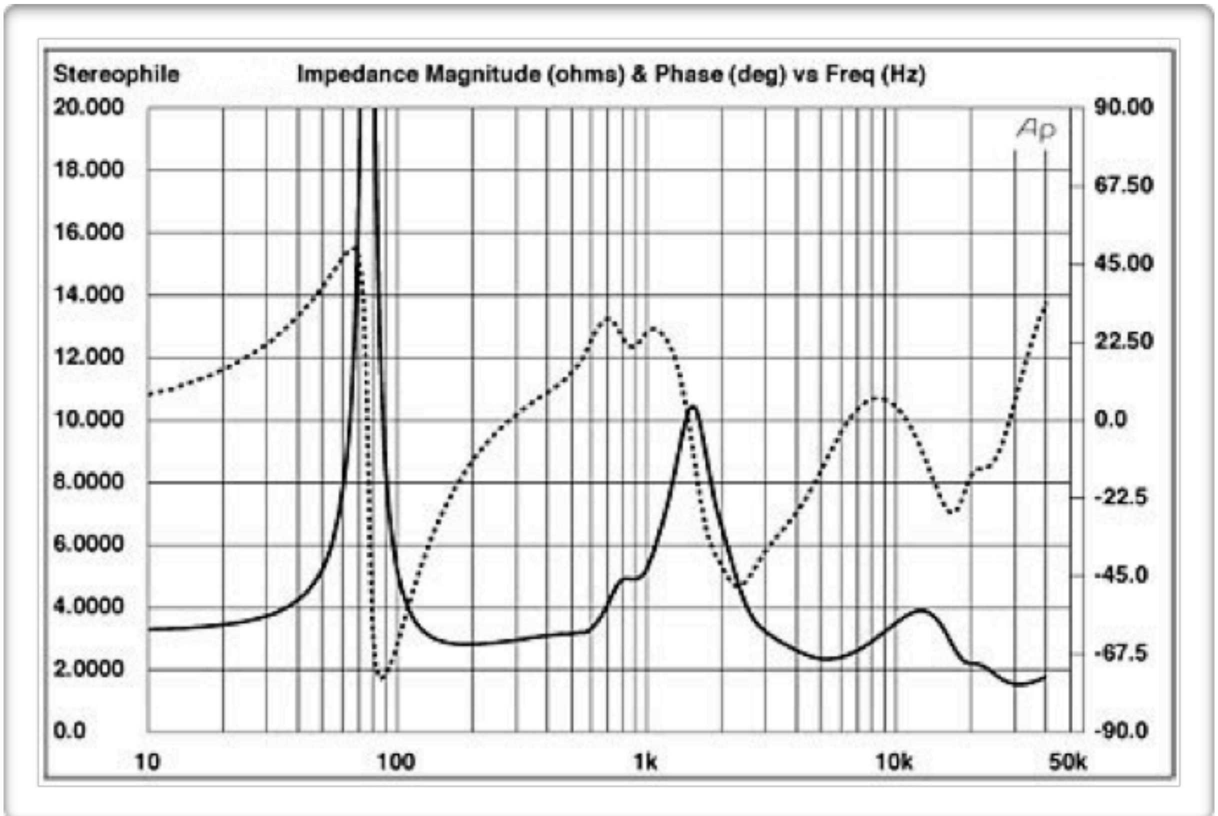
I recommend that you view this YouTube video: https://www.youtube.com/watch?v=VRAXK4QKJ1Q. Note how fundamental and harmonic frequencies and various pitch structures are very complex in their waveforms for the same note when played by different instruments.

When we listen to music, imagine how complex the total sound wave must be! I discuss instruments and music because all of the frequency, pitch, phase, time, and amplitude of music relate to how we must reproduce such complex sound waves from loudspeakers, and why so many loudspeakers sound so different from each other.

In an audio system, the loudspeaker is a reactive load. This means that loudspeaker presents a reactive load to the amplifier. Being reactive means the loudspeaker has resistance, capacitance, and inductance. The combination of these factors creates the loudspeaker's impedance. When you're listening to music, the output from your amplifier is a recreation of the input signal that drives the loudspeaker's voice coils with current.

Because a loudspeaker's impedance is reactive, the current flowing to it from your amplifier will lag or lead the signal voltage by what is known as a phase angle. Refer to the below impedance and phase curves of two very expensive loudspeakers that were reviewed by Stereophile:





The black line is the varying impedance of the loudspeaker at different frequencies and the dotted line is the phase curve.

From these two examples, the speaker's impedance varies from 3 Ohms to 15 Ohms as well as creating a phase swing of +45^0 to -45^0. This is fairly realistic for most high-end loudspeakers, but some speakers will even exceed this! How do those variances in impedance and phase angle ultimately affect the quality of the sound the loudspeakers produces? A lot!

In an audio system, the amplifier "sees" the load presented to it by the loudspeaker. Ohm's law states that voltage (V) is equal to current (I) multiplied by the resistance (R) in the circuit, so V= I x R.

Simply, the voltage at the amplifier output is affected by the resistance of the load to create the varying current required by a musical signal that drives the voice coil of the loudspeaker. In reality, it's a little more complicated because the load of a loudspeaker is reactive, not purely resistive as Ohm's law assumes.

With a reactive load with inductive and capacitive properties, the Power equation formula is: $\mathbf{P_{avg} = V_{rms}\ x.\ I_{rms} \cos \varphi}$

> **P** is power output of the amplifier
> $\mathbf{I_{rms}}$ is current expressed as Root Mean Squared (RMS)
> **cos φ** is the "power factor" of the circuit

The voltage and current in the circuit are affected by a reactive load where **φ** is the phase angle the reactive load creates, and the power factor is a function of the cosine (**cos**) of that phase angle. That reactive load becomes a part of the amplifier's "power factor" calculation.

The reactive load will cause the signal to vary from its original state in relation to the impedance and phase angle characteristics of the loudspeaker (inductive positive swings or capacitive negative swings). Distortion is now introduced.

Some of the amplifier's output is wasted as excess current that gets dissipated as heat in the voice coils and causes the amplifier to work harder and become less stable.

Changing the phase angle in the equation will effect everything else. **Note:** **cos** 0 degree= 1, **cos** 45 degree= 0.707, **cos** 90 degree= 0

The amplifier's output power will vary with changing phase angles and impedances that are caused by a reactive load. The worst case is that the amplifier sees either pure inductance (phase angle +90 degrees) or pure capacitance (phase angle – 90 degrees). Under those conditions, the voltage and current output from the amplifier are 90 degrees out of phase; the cosine of 90 degrees is zero which means no power is delivered to the speaker when it's needed. Fortunately, this doesn't normally happen because there is always a level of pure resistance in the impedance that counteracts some of the phase shift. However, because highly complex frequency sound waves change very fast (maybe 100 Hz at this moment and changing to 2 kHz within a µsecond) and the amplifier output power varies with different frequencies. The shifting phase angle will alter the original fundamental and harmonic frequency's amplitude and distort it to another overtone or timbre.

Another way to explain the effect of phase angles in a loudspeaker is with the example of loudspeaker polarity. For example, the left and right loudspeakers are "180 degrees out of phase" when the connections to the +/- terminals on one loudspeaker are reversed relative to the other loudspeaker. This will cause the sound pressure that your loudspeakers create to be out of phase and cancel each other, resulting in little or no sound. All of the sound stage will collapse and the overall amplitude will be lowered. (If you face loudspeakers directly at each other that are out of phase, they will cancel even more, almost to the point where you cannot hear them at all!) Try it yourself at home as this is an easy way you can experiment with these principles. Vocals will shift out of center stage and both pitch (the fundamental frequency) and overtone (the harmonics) of the original sound will be totally altered or canceled. This is what happens when the signal is out of phase 180 degrees.

What happens to the sound if the loudspeakers are 90^0 out of phase?

Scenario:

- The right channel has a 1 kHz sound wave with an inductive phase of $+45^0$
- The left channel has a sound wave at 2 kHz with a capacitive phase of -45^0 in the same time domain (see the first graph above).

Result:

- The two frequencies are 90^0 out of phase
- One loudspeaker creating compression
- One loudspeaker creating rarefaction (cancellation)
- There will be a very noticeable increase or drop in amplitude compared with the original sound wave. The combined waveform will not reproduce the original musical overtones or timbre accurately. Specifically, incorrect phase leads to lateral image shifts, and alters the original timbre of the instrument in the signal.
- The greater the impedance and phase angle shifts, the greater the effect on the amplifier's output, power factor, and the overall system's ability to correctly reproduce the musical waveform.
- The recorded music that we listen to is highly complex. Thousands of frequencies and amplitudes are continuously changing in microseconds. Phase inaccuracies will cause the original frequency amplitude to shift and intermodulation distortion.

Remember the graphics in the You Tube video? Look at the spectrum of different instrument's fundamental and harmonics samples. When the phase angle swings up and down, it will color the original sound timbre or overtones. Its similar to a synthesizer where you can actually adjust the different fundamental and harmonic frequency's amplitude as well as their phase that emulate instrumental or vocal waveforms. This is why all the brands of loudspeaker sound so different even though most of them have similar +/- 3 dB Sound Pressure Level (SPL) specifications. Also, most of them have such wildly varying impedances and phase curves that it damages the accuracy of their actual output.

I encourage you to check the past 30 years or so of speaker measurements in *Stereophile* (or any other publication that does speaker performance measurements) and look at the impedance and phase measurements. Almost none have flat and smooth traces. Some have electrical phase swings as much as +/- 45^0. All have some level of variance. This is one of the major factors that make all loudspeakers sound very different and unfaithful to the original signal.

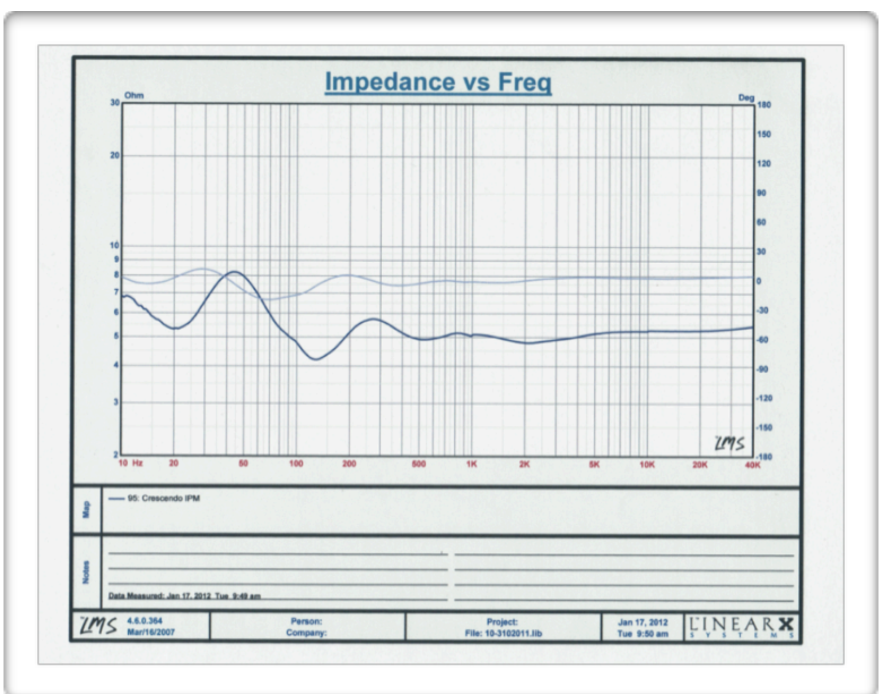
Human ears are remarkably sensitive to vibrations in the air, especially in the 200 Hz to 4 kHz range. This is where most fundamentals and primary harmonics created by most instruments and the human voice occur. When we listen to an instrument played live, we hear it in what we call absolute phase or absolute polarity; there is zero degrees of phase shift in the sound you hear. Recorded sound by its very nature cannot perfectly reproduce that live sound. Fortunately, good recording engineers do everything possible to recreate the music as faithfully as possible. They strive to capture the fundamental and harmonic content of music in a way that. As a result, when played back through a quality audio system, the recording will recreate that musical event as faithfully as possible.

Are you are looking for true, life-like sound from your audio system, and want to get the event recreated as faithfully as possible? It is critically important that your loudspeakers have smooth and flat SPL, impedance curves, and phase curves. Otherwise, the loudspeakers will cause distortion of the musical waveform!

I'm not going to talk about the importance of how to properly design a crossover or how to choose drivers or cabinet design in this document. Instead, I wanted to emphasize how impedance and phase problems cause all kinds of distortions. To learn more about the technology we put into our loudspeakers, please see the white paper Should the Acoustic Zen Crescendo *MKII* be your last speaker? Please take note of the impedance and phase measurements!

To properly evaluate the fidelity of loudspeakers, it is key to listen to the spirit and essence of music with the most life-like source possible. This is possible with recordings of unamplified acoustic instruments.

Please have a look at the Acoustic Zen Crescendo (or Adagio or Maestro) speaker measurements for impedance (blue color) and Phase (light blue color). Amazingly, they are almost flat at 0 degrees. It is our belief that Acoustic Zen has solved the engineering problems associated with reproducing this wide spectrum of musical information in the most life-like manner via loudspeakers.



Acoustic Zen transmission line based loudspeakers do not bloat the bass or suffer from the one-note bass associated with ported enclosure designs. The bass is fast and accurate.

The tweeters, midrange drivers and woofers are time and phase aligned with each other to present a coherent point source that produces real-world, life-like images. Our loudspeakers are voiced to sound like a live acoustic concert. They don't transform it into an in-your-face and over-processed musical event created by some wizardry in a recording studio. On natural acoustic recordings, the timbre and harmonics of vocals, pianos, stringed instruments, guitar, brass, woodwinds, percussion, and countless other instruments all sound like the real thing—not flashy, just natural. That's because our speakers are so neutral and have such low distortion along with wide dispersion, that they faithfully recreate the musical waveform better than competing brands that are sometimes two or three times the price! This greatly reduces listening fatigue and increases listener smiles! Our speakers present a benign load to power amplifiers so that both tube and solid-state amplifiers sound their best.

Years ago when I manufactured high-end audio amplifiers and cables, I owned some of the best loudspeakers available at that time. Surprisingly, all of them sounded different. Many were great at reproducing parts of the audio spectrum. However, they still missed the soul and spirit of the music compared with any of the live concerts I attended. I knew there was an important mystery I needed to unravel. This is why I decided to design and build my own loudspeakers that would actually perform as I heard with live music.

It was very difficult to solve the myriad number of engineering problems inherent in creating a neutral and musical transducer. It took over 15 years of research and experimentation to achieve a loudspeaker that does justice to the ideal of recreating a live musical event.

The Crescendo, in particular, is the result of those many years of development. It meets all of my design criteria:

- Natural, musical sound
- Very flat and smooth frequency response
- Exceptional phase accuracy
- An almost purely resistive load to the amplifier.

The near perfect frequency response and life-like sound of the speaker would be lost if it presented a reactive load (non-zero phase angle) to the amplifier. This would add its own colorations to the reproduced sound.

We believe that there is no competitor that can match the engineering achievement of our loudspeakers as being natural sounding and independent of the amplifier driving them.

If you want to listen to life-like sound with the true spirit of music that touches your heart, then I encourage you to listen to our loudspeakers with your favorite recordings. Life's too short to listen to loudspeakers that are less than what's possible!

If you've changed your audio system components and you're still not satisfied, please experience a pair of Adagio, Crescendo or Maestro loudspeakers from Acoustic Zen. You will smile and say Finally…Music!

Please visit your local Acoustic Zen dealer, visit our website at , or give us a call at 858-487-1988 and let us help you discover how to experience our motto…

"Music… No Compromise".

Robert Lee