Consumer Electronics Applications

CONEQ™

The world's first Acoustic Power Equalization Technology

- **Perfect Acoustic Power Equalization.**
- **Perfect Time/Phase Alignment.**

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CONEQ™

Acoustic Power Equalization Technology

For Consumer Electronics Applications

Winner of the "PAR Excellence Award" from ProAudio Review magazine at the 2007 AES Convention in New York

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The world we live in has flat acoustic power frequency characteristics. In other words, the acoustic characteristics of the nature are a set, flat reference. If we capture a sound with acoustically flat equipment, transfer it flat and reproduce it flat, our sound reproduction will be very close to original sound.

Current audio technologies allow us to capture the sound flat and store/transmit signal flat, giving us the possibility of managing adequate-quality sound for the original sound reproduction. Until now, speaker performance has prevented us from reproducing sounds flat.

To work as a perfect electro-acoustic transducer, a speaker must have a flat acoustic power frequency response and matched time/phase alignment. To correct the frequency response, equalization is performed. However, traditional one-point SPL on-axis measurement does not equalize the acoustic power frequency response. It is necessary to capture sound emitted from a speaker as a whole to equalize the acoustic power frequency response.

Real Sound Lab has developed the world's first Acoustic Power Equalization technology CONEQ™ (CONvolution EQualizer). CONEQ not only equalizes the acoustic power frequency response of the speaker, but also corrects time/phase alignment in the entire frequency band. As a result, the reproduced sound is extremely close to that of the source material, as if the original sound were relocated at the location of the speaker.

CONEQ delivers fully objective and reliable measurement results, regardless of operator or environment. It offers immense freedom to industrial and structural designers in terms of speaker layout and acoustic situations. It saves substantial development time.

CONEQ imbues a system with the highest fidelity and intelligibility while maintaining realism and naturalism in its sound. It eliminates "sweet-spots" and "dead-spots," effectively unifying the sound throughout the room.

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CONEQ™

1. Applications

High-end Audio, Home Audio, Home Theater, Car Audio, Personal/Portable Audio, Powered Speakers, MP3 Docking Station, Subwoofer, TV, Radio, Computer, Distributed Audio

2. Advantages

- Simplicity: Computerized automated measurements
- Speed: About 2 minutes to measure over 400 sample points and generate results
- Reliability: Fully objective measurements with repeatable results
- Flexibility: Provides industrial and structural design flexibility

3. Resolution

• Measurement Data Bands:	16384
• Measurement Data Sampling Rate:	48, 96KHz
• Equalizing Taps:	64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384, 32768 (Linear Scale)
• Supported Sampling Frequencies:	250, 500Hz, 1, 8, 16, 32, 44.1, 48, 88.2, 96KHz
• Expected Error Range (4096-Band):	± 1dB (40-24KHz)*/**

*Low and high-end errors depend on the speaker performance.
** Error range includes measurement error itself. Accurate measurement reduces the error in the result.

4. Sound Improvements

- Absolutely flat acoustic power frequency response
- Time/Phase aligned sound speaker response
- Reference grade sound
- Clarity and intelligibility
- Spatial image and depth
- Transients
- Elimination of sweet-spots
- Equalization and extension of deep bass

5. Target Curves

Applicable target curves to tailor sound (flat by default)

6. HA (Hearing Aid) Mode

Provides more comfortable sound to the hearing impaired people without the need for hearing aids

7. Solution

Digital (DSP, FPGA, ASIC)

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Acoustic Power

The Acoustic Power of a loudspeaker is the acoustic energy emitted from the speaker passing through a specific plane which covers speaker's entire frontal angle, in one second. More specifically, acoustic power is the product of particle velocity, which is perpendicular to the plane, and sound pressure. Acoustic power readings are obtained by calculation after measuring sound pressure frequency response at multiple points on a specific plane in front of a speaker.

Every sound has a source. The sound emitted from the sound source travels in all directions through air, similar to ripples on the surface of water after dropping a stone. Just as the ripples carry kinetic energy, the sound waves carry acoustic energy. The acoustic energy at a moment is acoustic power. The sound we hear in the natural world is the sum of the acoustic energy arriving from all directions, converted to sound pressure at ears.

It is easier to understand acoustic power if the acoustic terms and formulas are explained in electric equivalents as below. (The units for the acoustic terms are not assigned here to maintain simplicity.)

<TERMS>

Acoustical	**Electrical Equivalent**
Sound Pressure	Voltage (V)
Particle Velocity	Current (A)
Acoustic Power	Electric Power (W)

<FORMULAS>

Acoustical: Sound Pressure X Particle Velocity = Acoustic Power
Electrical: Voltage (V) X Current (A) = Electric Power (W)

Acoustical: Acoustic Power X Time = Acoustic Energy
Electrical: Electric Power (W) X Time (H) = Electric Energy (WH)

The Necessity of Using Acoustic Power

When we hear the sound from the speakers, we are hearing the acoustic energy arriving to our ears (converted to the sound pressure) from the multiple directions as both on-axis and off-axis sound. Traditional equalization is based on one-point SPL on-axis measurement and does not correspond to the sound we actually hear at the different locations in the room. Therefore, we should equalize the acoustic power instead of the one-point SPL on axis.

Abstract

CONEQ™ (CONvolution EQualizer) is the world's first Acoustic Power Equalizing technology developed by Real Sound Lab. CONEQ Workshop software, sound analysis tool, and its hardware solution, APEQ (Acoustic Power Equalizer), are used at recording and broadcast studios, film studios, theaters and concert halls where the sound quality is critical and consistency is required. CONEQ is also used to calibrate microphones, including microphone amplifiers.

This document will discuss how CONEQ can be used for consumer TV, radio, home audio, high-end audio, home theater and automotive applications.

Traditionally, a speaker's frequency response is equalized only at one point on-axis (typically 1 meter from the high frequency driver), while the off-axis sound has been ignored. The equalized sound will never be heard unless a listener sits exactly at the measurement point. In reality we hear off-axis sound as direct sound, while the rest of the off-axis sound reaches our ears as indirect sound after reflecting off the walls, floor, ceiling and furniture. Indirect sound makes up a nearly half of the sound we hear in a room with fair acoustics. Therefore, *the equalization of off-axis sound is more important than one-point on-axis sound*. CONEQ measures a speaker's frequency response at over 400 sample points spanning the entire radiation of angles, thereby equalizing the whole acoustic power emitted from the speaker.

CONEQ equalizes the acoustic power of a speaker by using a reverse filter, which is synthesized from an acoustic power measurement. CONEQ's measurement process is fully automated and easy to perform using single microphone connected to a laptop computer with CONEQ Workshop software. The accumulated measurement data of over 400 points in 16384 frequency bands is analyzed and calculated to generate coefficients, which are later used to build an equalization curve. Realization is based on FIR (Finite Impulse Response) filter which typically resides in a DSP, FPGA or ASIC. The number of taps of the FIR filter, which translates to the number of frequency bands of equalizer, is selected from 128, 256, 512, 1024, 2048 and 4096 depending on the application. (A maximum resolution of 65,536 bands is available for scientific applications.) CONEQ delivers fully objective and reliable measurement results, regardless operators and environment.

Compared to the "room acoustic compensation method," which measures the audio signal at only a single listening point, CONEQ provides more natural and realistic sound. CONEQ imbues a system with the highest fidelity and intelligibility while maintaining realism and naturalism in its sound. It eliminates "sweet spots and dead spots," effectively unifying the sound throughout the room.

Unlike conventional equalizers, CONEQ is also suitable for subwoofer equalization. Conventional equalizers are not capable of this because of the difficulty of low frequency measurement itself and their inadequate frequency resolution. CONEQ provides resolution accuracy of about 5Hz when 4096-band is used. CONEQ also provides lower sampling frequencies to separately treat the subwoofer range.

CONEQ offers extreme flexibility to industrial and structural designers in terms of speaker layout and acoustic situations. Plus, it saves an invaluable amount of development time.

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How to Use CONEQ™

CONEQ™ application begins with measurement of acoustic power. This measurement process requires a PC with CONEQ Workshop software, a measurement microphone and microphone amplifier (audio I/O).

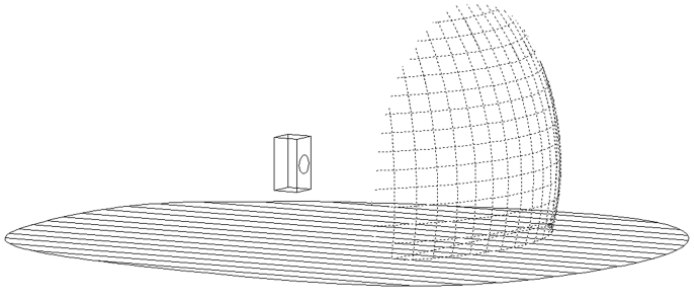

Fig. 1 Measurement Plane

CONEQ Workshop supports a wide-range test signal (0Hz-24KHz and 0Hz-48KHz for 48KHz and 96KHz sampling respectively). While playing the test signal through the individual speaker (or group of speakers), it measures the reproduced sound. One does this by moving the handheld microphone slowly in the proximity of the speaker (0.5-1.5 meters, depending on the size of the speaker and the room). Cover the entire frontal area, first from side to side and then from top to bottom for a consistent grid pattern. If there is a floor or a wall in the proximity, move the microphone close to it. Fig. 1 illustrates the desired grid of sample points. A measurement of over 400 points is completed in about two minutes.

Based on this measurement result, CONEQ Workshop will calculate the acoustic power of the speaker (Fig. 2). The resolution of the measurement is 16384 bands (1.465Hz step) and the calculation result is reduced to 4096 bands (5.86Hz step).

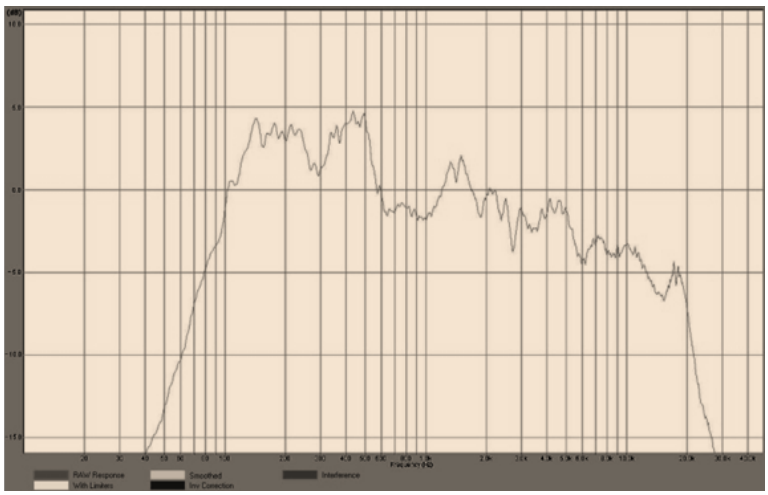

Fig. 2 Raw Acoustic Power Data

Fig. 3 represents the reversed curve (after application of correction limits and light smoothing) to Fig. 2's data. Fig 3's curve, built into a filter, effectively flattens the speaker's acoustic power response. To realize such a filter, an FIR (Finite Impulse Response) filter is used. An FIR filter is composed mathematically and the coefficients are loaded onto a physical filter in a DSP or FPGA for real-time calculation.

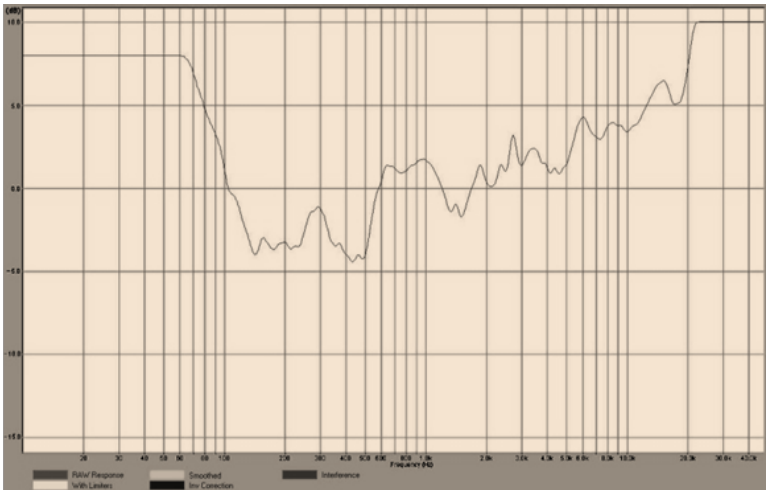

Fig. 3 Smoothed and Inverted Data

The result is an absolutely flat acoustic power response (Fig. 4). Equalization error can be kept within ±0.5dB across the entire bandwidth. This error includes the measurement errors recorded in the Raw Acoustic Power (Fig. 1). Correction error may increase in the low end if the speaker has poor low frequency response. In this case, the speaker has a good response down to 70Hz. High-frequency performance likewise depends on the high frequency response of the speaker.

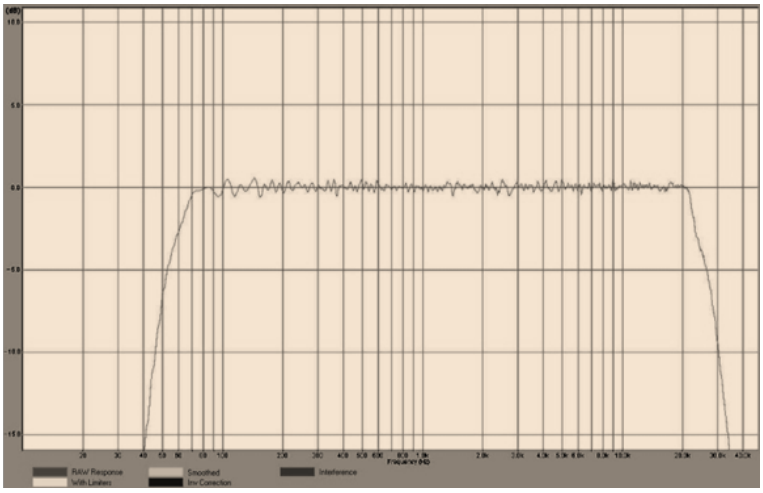

Fig. 4 CONEQ Equalized Acoustic Power Response

Real Sound Lab offers a CONEQ hardware, called “APEQ-2Pro” (pictured below), containing a powerful FPGA for professional use. The APEQ-2Pro performs two channels of 4096-band FIR filtering. After obtaining reverse equalization curves using CONEQ Workshop, consumer electronics engineers can use the APEQ-2Pro as a tool to test their results.

APEQ-2Pro

The actual consumer electronics products can have either FPGA, DSP or ASIC on board to realize CONEQ’s process. The band resolution can be selected from 128, 256, 512, 1024, 2048 and 4096 bands, depending on the application. For example, 256 or 512-band for TVs, 4096-band for high-end audio, 128 or 256-band for portable personal audio.

With precision capabilities up to 65,536 bands, CONEQ Workshop makes a powerful acoustic measurement tool for R&D and academic use.

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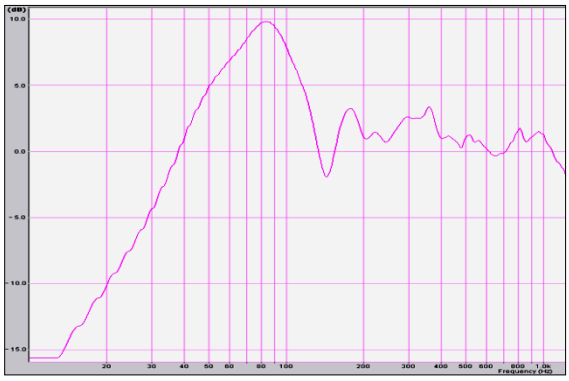
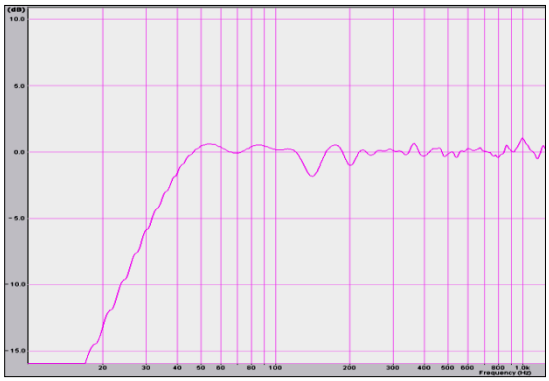
Other Applications and Advantages

Subwoofer Equalization

CONEQ™ is also suitable for equalization of subwoofer-range frequencies. Traditional methods provided unreliable data from unstable readings at these low frequencies and imprecise adjustment capacities at very limited resolutions. CONEQ, by contrast, enables highly accurate low frequency measurement and equalization. Its frequency resolution is about 6Hz for a 4096-band measurement, with a 17 bands of adjustment available below 100Hz.

The figure on the left illustrates a subwoofer response with room acoustic influence showing a large boost centered at 80Hz. The other image shows how CONEQ equalizes the bump to exactly the same level (0dB) as the higher frequencies.

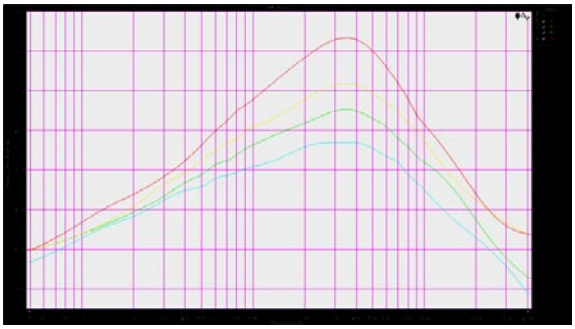


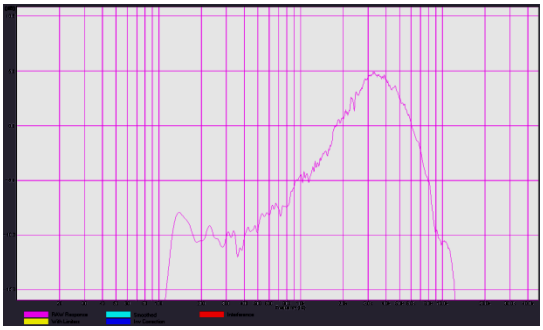


CONEQ HA (Hearing Aid) Mode

CONEQ makes use of target curves for unique applications, one of which is HA (Hearing Aid) mode. The elderly and otherwise hearing-impaired have very low sensitivity at higher frequencies. Some data show that their hearing ability drops -30 or even -50dB at the 4-5KHz range relative to lower frequencies. CONEQ can use a target curve to provide exact compensation to a hearing-impaired listener, providing an audio experience beyond the quality of hearing aids. It can also reduce volume level for improved clarity and intelligibility so the elderly and hearing-impaired can enjoy clear sound without hearing aids.

The left figure below illustrates the target curves of HA mode. The right figure represents the speaker response after CONEQ equalization in HA mode. The tremendous high-frequency boost sounds just right to the hearing impaired.





Note: The actual target curves used in the CONEQ HA Mode are different from the above examples.

Time/Phase Alignment Correction

Filters, amplifiers, crossovers, loud speakers and the location (layout) of speaker components all contribute to time/phase alignment errors in the audio signal chain, which tend to smear the sound and degrade the transient response.

CONEQ solves this problem automatically. CONEQ-corrected speakers are perfectly time/phase aligned.

Speaker Array

Speaker arrays, consisting of multiple smaller speakers in a line, are often used to increase the acoustic outputs and bass response within a limited layout. However, such arrays create complex directionality patterns from multiple deflections and mutual couplings between the speaker units. Moreover, the pattern changes uncertainly and rapidly across the whole frequency range. This obviously degrades sound quality by smearing the sound image. Equalizing such complex patterns with conventional equalization techniques is not possible because of their inability to measure wide angle frontal patterns and correct them at every small increment of frequency.

CONEQ solves this problem quite easily. Any shape of array is accepted: vertical, horizontal, slanted, or any combination thereof. CONEQ analyzes the sound of wide frontal angle at every 1.5Hz, and equalizes the total acoustic energy emitted from the speaker array. CONEQ makes speaker arrays perform as one ideal speaker, with high resolution and a clear sound image.

Flexibility in Industrial Design

CONEQ completely resolves sound problems caused by acoustically incorrect industrial or structural design.

In today's flat-panel TVs and radios, sound performance is often compromised for the sake of industrial design, which often forces the mechanical design of a cabinet to be acoustically inadequate or incorrect. Audio engineers have tried for years to compensate for such problems with factory-set equalizers and/or custom filters, yet these solutions never successfully cleared the problems.

The drastically shortened development time and objective sound solution provided by CONEQ is an invaluable contribution for the audio engineer.

The design flexibility CONEQ provides is also passed on to the industrial designer, who is now free to pursue his design with fewer worries about the acoustic compromises of his design.

Car Audio

A car is an odd acoustic environment: abnormal room shape, irregular speaker layout and listening positions, reflective surface materials and extremely small room volume. Woofers, mid-range drivers and tweeters are often in offset positions. This leads to a strange frequency response and time/phase alignment errors which cannot be corrected by conventional equalizers or filters. Car audio is thus a suitable application for CONEQ.

CONEQ measures the "Acoustic Power Volume Density Frequency Response" of the given listening space excited by the speaker system. It equalizes the power density of the volume while simultaneously correcting the time/phase alignment. The resulting reproduced sound is very close to the original source material regardless the seating position.

CONEQ can also be used with 3D and surround processes.

(Ref: Car Audio Tech Note)

PD Curve

The CONEQ concept is based on flat acoustic power frequency response. CONEQ-equalized sound is the reproduction of the exact sound contained in the source material. At the recording studio, it is important to use acoustic power-equalized speakers to objectively check the recorded sound.

However, such speakers for consumer use tend to exhibit sharper or peaky sound depending on the room acoustics and source materials. It is recommended to apply the target curves named "PD Curve" developed by Real Sound Lab.

The PD curve compensates for the mid-high frequency boost caused by the plane/diffuse sound field of the room. It is applied as a target curve after obtaining a flat acoustic power frequency response of the system using CONEQ. It provides a smoother sound while maintaining the clarity and intelligibility.

The PD curve is effective in high-end audio where listening positions are relatively far from the speakers and receive more plane/diffuse sound, and car audio where diffuse sound is prevalent.

(Ref: PD Curve Tech Note)

Compatibility

CONEQ simply improves speaker performance. It is compatible with any other sound processes, such as 3D sound, virtual surround, bass enhancers, compressors and auto-volume.

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