PanPhonics Panels in Active Control of Sound

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Introduction

PanPhonics Panels have numerous applications in a wide range of fields. In the active control of sound, PanPhonics Panels offer advantages over conventional (dynamic) loudspeakers. Continuous active surfaces, needed in global 3D active systems, are easily realized with the actuator panels, even integrated with the sensors.

This White Paper provides a short introduction to active control of sound and a discussion of the applications of PanPhonics Panels in the active control of sound, the latter part concentrating on the active absorption and active sound insulation applications.

Active control of sound

Active control of sound is a technique where the original existing sound field (primary field), due to some original (primary) sound sources, is modified to something else (desired sound field) by the help of controlled sound sources (secondary sources). Its main area of application is Active Noise Control

(ANC) (also called Active Noise Cancellation). The active noise control can be based on three alternative approaches: Active Noise Absorption (ANA) (Active Acoustic Attenuation (AAA)), Active Noise Reflection (ANR) (active sound reflection) or active potential energy minimization. In the active absorption the secondary sources absorb the original sound field being directed to them. In the active reflection, the original sound field is reflected back towards the original sources by the secondary sources. In the active absorption the secondary sources act similarly to passive absorbents, and in the active reflection the secondary sources act as noise barriers, the absorption or the noise shielding effect only being due to proper active functioning of the secondary sources rather than their passive acoustic properties. In the active potential energy minimization, the sound pressure is minimized at selected points. The secondary sources are typically formed of audio loudspeakers, being fed by proper electric input signals.

Interference

The active control of sound is based on interference. The principle of the interference is introduced in Figure 1. When two sinusoidal signals with equal amplitudes are summed, the amplitude of the resulting signal depends on the mutual phase difference of the original signals: with zero phase difference, the sum is twice the original signal component; with opposite phases, the sum signal disappears totally. In the case of other than pure sinusoidal signals, the signal can be divided into sinusoidal components, and the interference can occur component by component.

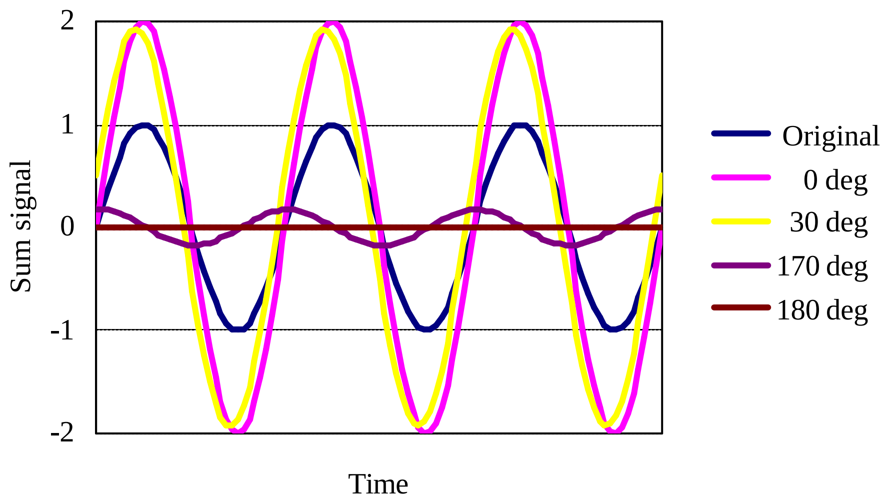


Figure 1. Sum of two sinusoidal signals with equal amplitudes and different phase differences.

In the active noise control the aim is to get the sound of the secondary source equal in amplitude but opposite in phase with the primary noise, to obtain total cancellation of noise. If the primary noise level is, e.g., 80 dB, the secondary source has to produce exactly the sound level of 80 dB in exactly the opposite phase with the primary sound for the total cancellation of noise. If there is an amplitude error or a phase error in the sound of the secondary source, the cancellation is not complete. The effects of the amplitude and phase errors are presented in Figure 2 and Figure 3. With an amplitude error of 1 dB, the maximum available attenuation is a little less that 20 dB. With a phase error of 6°, the maximum available attenuation is 20 dB. Typical attenuations available in real systems are of the order of 10 – 30 dB, depending on the accuracy of the control system giving the input for the secondary source loudspeakers.

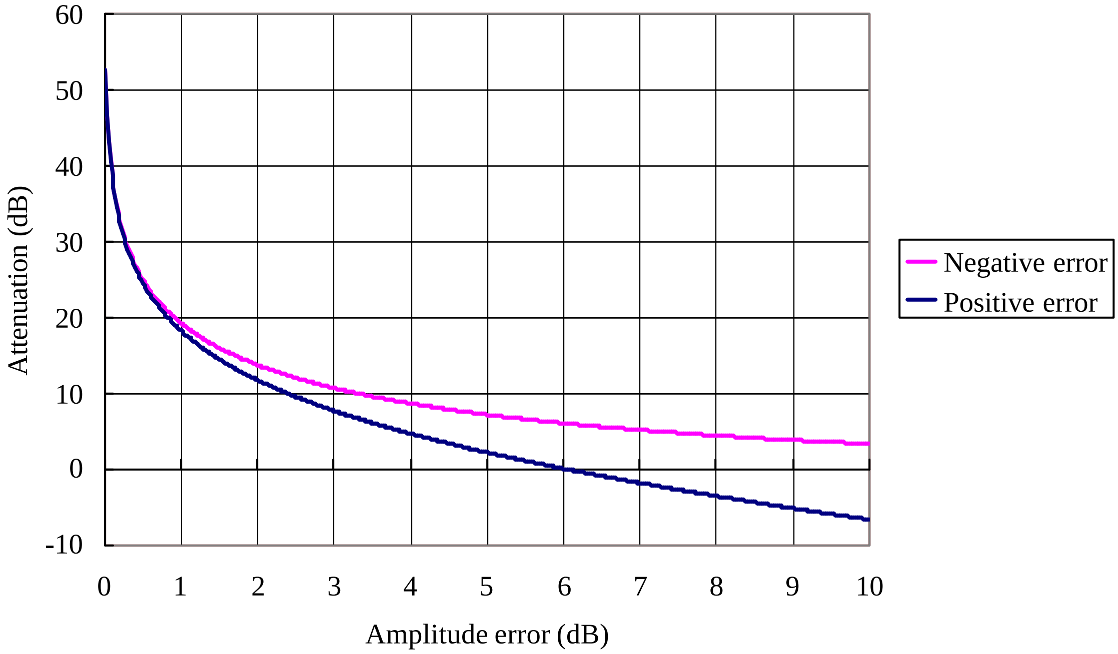


Figure 2. Maximum available active attenuation as a function of the amplitude error of the secondary source; no phase error.

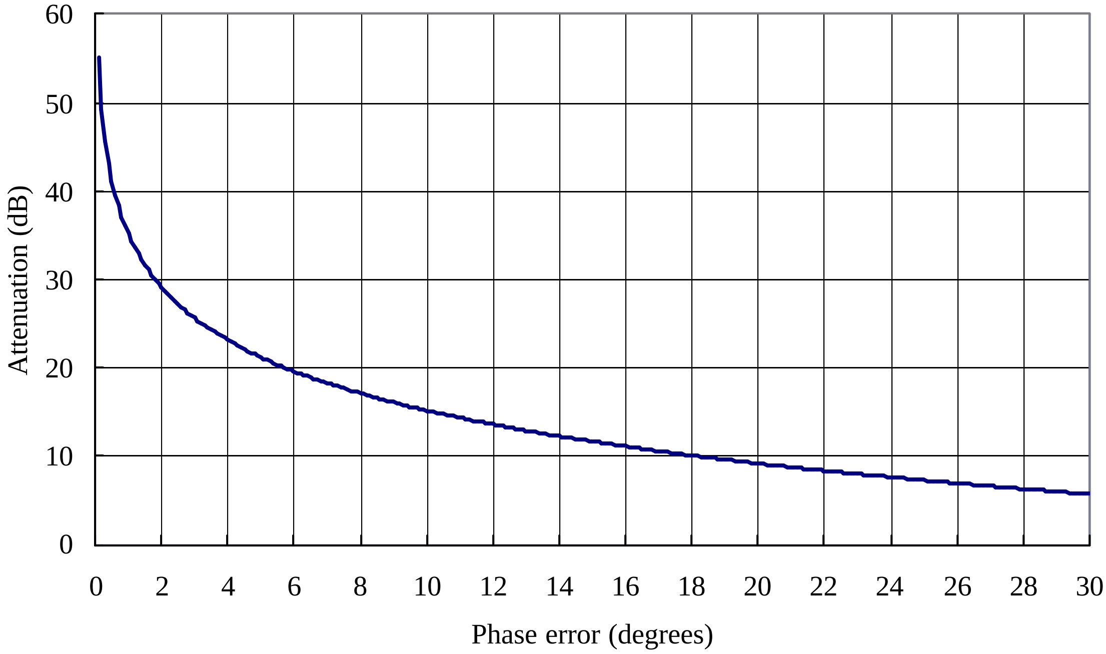
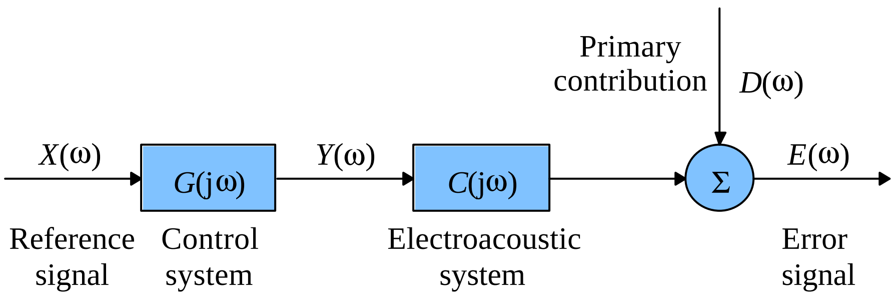


Figure 3. Maximum available active attenuation as a function of the phase error of the secondary source; no amplitude error.

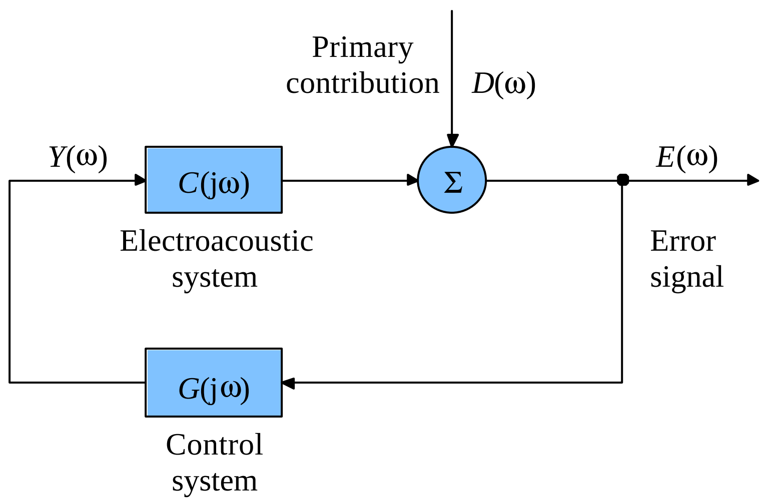
One typical example of the simple interference attenuation of noise is the active cancellation of the low-frequency humming noise of a transformer with a loudspeaker situated near the transformer.

Control system

In the active control of sound, a control system is always needed to control the electric input of the secondary source to give a correct acoustic output. In the active noise control, there are two ways to control the secondary source to give zero total field. In the feedforward control, a primary source related signal is used as a reference signal which is manipulated to make the actuator give the correct acoustic output at the error sensor(s) where the sound field is to be attenuated, see Figure 4. The reference signal can be obtained, e.g., from a tacho signal of the primary source (e.g., with rotating machines), from the existing primary sound field with a microphone, or from the vibration of the surface of the primary source with an accelerometer. In adaptive feedforward control systems, the transfer function of the control system is adjusted adaptively to minimize the error signal. In the feedback control there is no reference signal; the error signal is fed back to the input of the control system to minimize it, see Figure 4. The error sensors are typically microphones, situated in the predestined places where the sound is to be cancelled.



Feedforward control



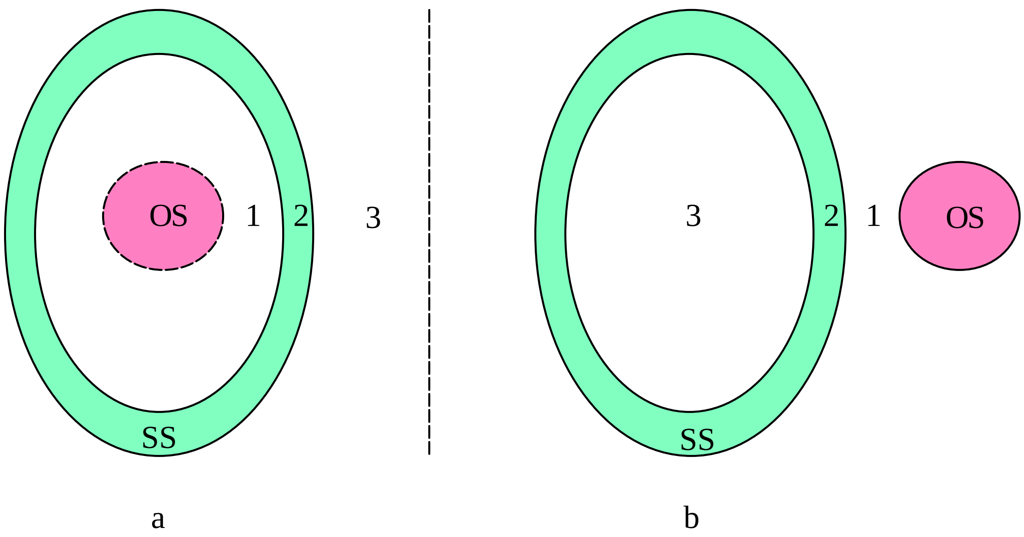
Feedback control

Figure 4. ANC system with feedforward and feedback control.

Three-dimensional spaces

The simple way of thinking presented above works only in spaces that can be thought to behave acoustically as one-dimensional ones (e.g., straight ducts at low frequencies). Generally, in a three-dimensional (3D) space the interference works differently in different points, so similar effects in large regions are very hard to obtain. In the active noise control with small original sources, the active system works in a restricted way if a small secondary source with similar radiation pattern is placed near the original source. This is the case with the low-frequency humming noise of a small transformer: the typical frequency of the noise is 100 Hz and the corresponding acoustic wavelength is 3.4 m; if the dimensions of the transformer are much less than 3.4 m, its sound radiation is nearly omnidirectional, and the noise can be cancelled with an omnidirectional loudspeaker mounted near the transformer. If the original source is not small, many secondary sources have to be mounted near the original source in order to obtain the desired effects.

There are two exact global solutions to the three-dimensional space, to enclose either (a) the original sources or (b) the zone to be modified with a continuous secondary source distribution (Huygens' sources), as presented in Figure 5. This kind of secondary source distribution is best achieved using actuators with continuous surfaces. The amplitudes and phases of the different parts of the secondary source zone have to be adjusted to get the desired modifications (normally absorption). In a general case, both monopole and dipole type secondary sources are needed. In the active absorption, the case (a) corresponds to enclosing the noise source in a housing, and the case (b) corresponds to enclosing people in a room with the noise source outside, the essential difference being that the passive sound insulating structures are replaced by the actively absorbing secondary sources.



Zone 1: contains original sources (OS)
Zone 2: contains secondary sources (SS)
Zone 3: field modified by secondary sources

Case a: primary source zone enclosed by secondary sources
Case b: modified zone enclosed by secondary sources

Figure 5. Active control of sound applied to three-dimensional space; the secondary source distribution can be a thin layer or a zone with finite thickness.

JMC element

As stated above for the global 3D active control of sound, the secondary source region will be constructed of monopole and dipole sources in a general case. The original field, which must be sensored to obtain the reference signal for the secondary sources, is also best detected using monopole and dipole sensors together, e.g., to obtain desired directivity properties. This kind of an entity is called a JMC element. Its name originates from the JMC method, the name of the method being based on its three pioneers, Jessel, Mangiante and Canévet.[1] The JMC element can approximately be realized with a sensor and an actuator having a cardioidic sensitivity or radiation pattern. The element is very versatile: besides the active absorption, also reflection and transmission properties of the device can be controlled actively. Also partial active barriers, instead of totally closed active surfaces or zones, can be constructed from the JMC element.[2]

The functioning of the JMC element needs feedforward control. The reference signal is best obtained quite near the actuator. This kind of an element can be called a locally controlled element (only the local original field at the actuator is used for the control).

The JMC element is best realized with continuous sensor and actuator surfaces so that the continuous Huygens' sources can be approximated with a proper combination of JMC elements. A combination of the monopole and the dipole in the sensor or actuator functioning can be obtained by the help of a two-membrane system. The active absorber can be constructed, e.g., with a two-membrane sensor and actuator, as presented in Figure 6.

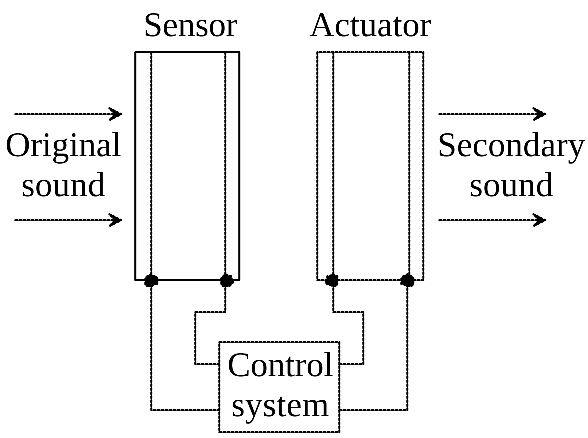


Figure 6. Planar sound attenuating element, sensor and actuator realized as a two-membrane device.

[1] Jessel, M. J. M. Active noise reduction as an experimental application of the general system theory. Proc. Inter-Noise 83, pp. 411–414.

[2] Mangiante, G. & Roure, A. Autodirective sources for 3D active control. Proc. Inter-Noise 94, pp. 1293–1298.

Applications of active control of sound, state-of-the-art

General

The first patent in the active control of sound was granted in 1931 to Coanda.[3] This patent is not very well-known, and usually the honor of the first patent in the active control of sound is given to Lueg's patent granted in 1936.[4] The research in the field of the active control of sound extended remarkably as late as at the end of 1960's. This was made possible by the development of algorithms and signal processors. Actual commercial control systems were available from 1990's. One remarkable problem even today is the lack of proper sound sources to be used as secondary sources in the active control of sound.[5]

Today, the main application areas of the active control of sound are in the field of active noise control, being active headsets, active mufflers in ducts, and active devices for machinery and equipment radiating low frequency tonal sound (e.g., transformers). In all the application areas mentioned, there are commercial products. In other application areas, the state-of-the-art of the active control of sound is more or less at laboratory level. Some examples of such application areas are: modifying acoustics of interior spaces (room acoustics), modifying sound to more comfortable (vehicles), and increasing the sound insulation (building acoustics).

Traditional active control of sound works best with low frequency, continuous sound whose possible fluctuations are slow. The sinusoidal sound is much easier to treat. The active control of sound also works in some situations where traditional passive means do not work (e.g., in control of engine noise in the cab of a vehicle with the side window open). The control system is much easier to be realized if it can be synchronized to some signal coherent with the original sound (e.g., tacho signal of rotating axis in the case of active noise control of rotating machinery).

PanPhonics Panels in active control of sound

One of the main advantages of PanPhonics Panels when applied to the active control of sound, especially in global 3D applications, is the possibility to form true continuous and even closed active surfaces with integrated actuators and sensors. This is advantageous in both absorption and sound insulation applications. Some possible applications of PanPhonics Panels are discussed below.

PanPhonics control system

Digital control systems for ANC applications are typically complicated, and in many application areas, such as sound insulation, they introduce delays too long for the system to work in real time with all kinds of sound. To avoid these limitations, PanPhonics has developed analog control systems, combined with PanPhonics Panels forming locally controlled elements. Actuators, sensors, and real time analog controller are integrated into each element. With these elements, the active part of the operation works from 50 Hz to 500 Hz, and the passive part from 500 Hz to 20 kHz and more.

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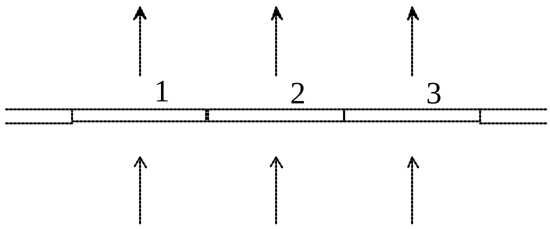
[3] Coanda, M. H. Procédé de protection contre les bruits. French Patent No. 722274. December 29, 1931.

[4] Lueg, P. Process of silencing sound oscillations. U.S. Patent No. 2043416. June 9, 1936. 3 p.

[5] Uosukainen, S. Modified JMC method in active control of sound. Acustica – Acta Acustica **83**(1997)1, pp. 105–112.



Incoming sound

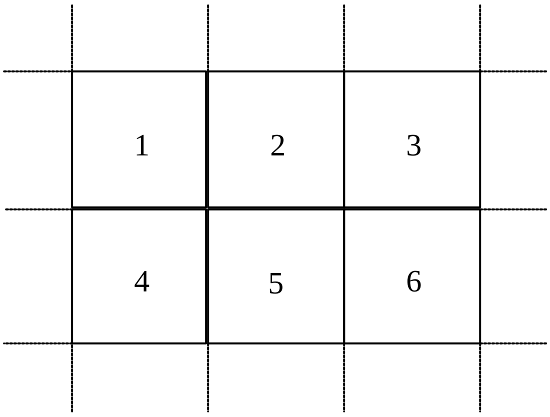


Figure 7. Locally controlled panels, 300 mm x 300 mm or 600 mm x 600 mm.

Hybrid absorber

A hybrid absorber (local absorbing element) is formed of a passive absorbent by enhancing its absorption coefficient by active means. The passive losses of an absorber are proportional to the square of the acoustic particle velocity. The normal component of the particle velocity is very low near reflecting surfaces where the absorbents are typically mounted. The idea is to use the hybrid absorber in reverberant fields and to synthesize the maximum of the acoustic particle velocity at the location of the passive absorbent, yielding thus to higher absorption at low frequencies. The maximum of the particle velocity is obtained by minimizing the sound pressure at the location of the passive absorbent. This is based on the fact that in reverberant fields the local maxima of the particle velocity occur at places with local minima of the sound pressure, frequency by frequency. A schematic presentation of the hybrid absorber is presented in Figure 8.

The hybrid absorber is very effective at the whole audio frequency range because at high frequencies where the active system is ineffective the passive absorption works anyway.

Besides to absorb the incoming sound, the hybrid absorber can also be adjusted to insulate the sound coming from the opposite direction through the backplate. Thus, the functioning of the hybrid absorber is bidirectional.

The control system of the hybrid absorber is of feedforward type.

The most obvious application area for this element is room acoustics where it can be used as an absorbing and sound insulating element. It is advantageous that the absorption coefficient of the hybrid absorber can be controlled by electrical means to a certain extent. One specific way of application is using it as a modal absorber in a room to diminish the effects of the low order modes. It can also be applied as an absorption muffler in ducts when mounted at duct discontinuities (sudden area changes, bends, etc.).

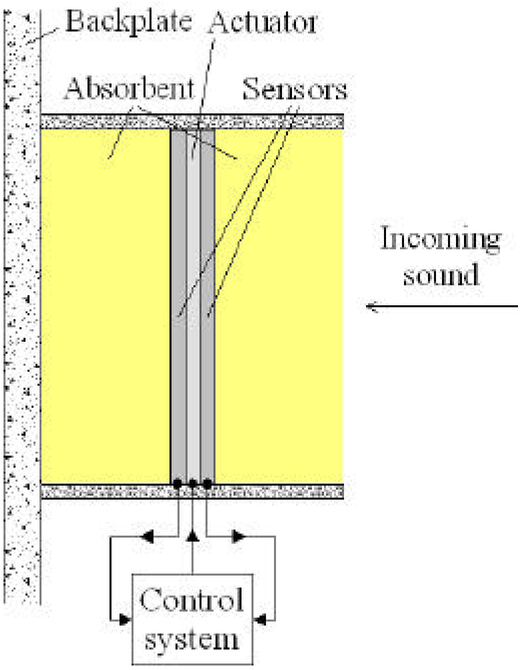


Figure 8. Hybrid absorber.

Impedance element

Sound reflection occurs in places with discontinuous characteristic impedance. The characteristic impedance is a material constant of a medium, being the ratio of the sound pressure and the particle velocity of a plane wave in that medium. The specific acoustic impedance is the ratio of the sound pressure and the particle velocity of an actual acoustic wave. The impedance element is based on the hybrid absorber, but it is constructed so that a desired specific acoustic impedance is achieved at the actuator surface. The desired impedance is selected to match the incoming sound field so that no reflections occur. Thus, with this element type the target is not maximizing the particle velocity but rather impedance matching at the device. This also makes it possible to realize the system purely actively without the passive absorbent. The functioning of this construction can be realized as unidirectional or bidirectional. The principle is presented in Figure 9. The element can simultaneously be used as an audio loudspeaker.

The control system of the impedance element is of feedforward type.

The application areas of the hybrid absorber are suitable for this element as well. Due to the passive absorption of the porous PanPhonics Panels, the elements work moderately well at high frequencies. The absorption coefficient of the impedance element can be controlled by electrical means to a much greater extent than that of the hybrid absorber because of the lower passive absorption of the impedance element.

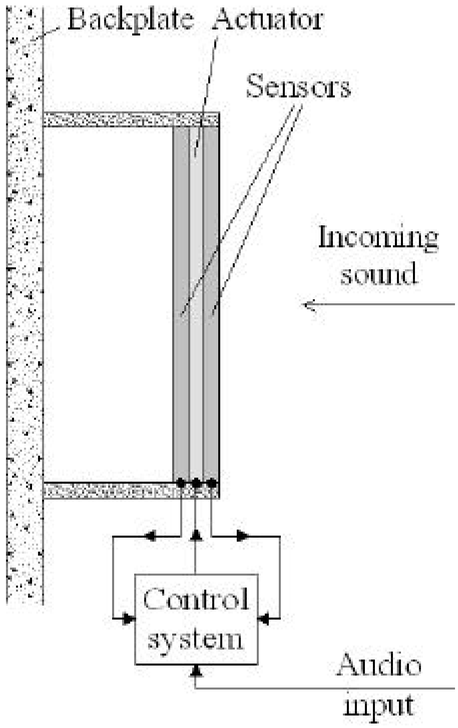


Figure 9. Impedance element.

Mass actuator

A dynamic vibration absorber is a mechanical device to be attached to a vibrating structure to reduce its vibration. In a traditional dynamic vibration absorber the vibration reduction takes place only at a narrow frequency band around the resonance frequency of the absorber. A typical vibration absorber is a mass-spring system whose resonance frequency is adjustable to the mid-frequency of the frequency band to be attenuated.

The mass actuator is a dynamic vibration absorber the damping of which is enhanced by active means. Inside the outer sides of the system there is a resiliently mounted mass that can receive vibration energy from the other parts of the system through the mounting points, and thus reduce the vibration there. The vibration reduction works passively near the resonance frequency of the mass-mountings system, and the operational frequency range is broadened towards lower and higher frequencies through proper active control. The electric control signal makes the mass vibrate properly so that it absorbs the vibration energy from the rest of the system.

One realization principle of the mass actuator for sound insulation purposes is given in Figure 10. The elastic actuators on the sides of the mass element form the active part of the system, and the signals for the control system are obtained from the pressure sensors and accelerometers on the surface plates. The principle of the system is essentially bidirectional.

The control system of the mass actuator can be realized with simultaneous feedforward and feedback control. The reference signal for the feedforward control is obtained from the distributed pressure sensors, being proportional to the average sound pressures (acoustic excitation) impinging on both sides of the actuator. The feedback control signal is obtained from the accelerometers, being proportional to the vibration of the surface plates of the mass actuator. The mass actuator works with both control systems working simultaneously, with only the feedforward control on, or with only the feedback control on.

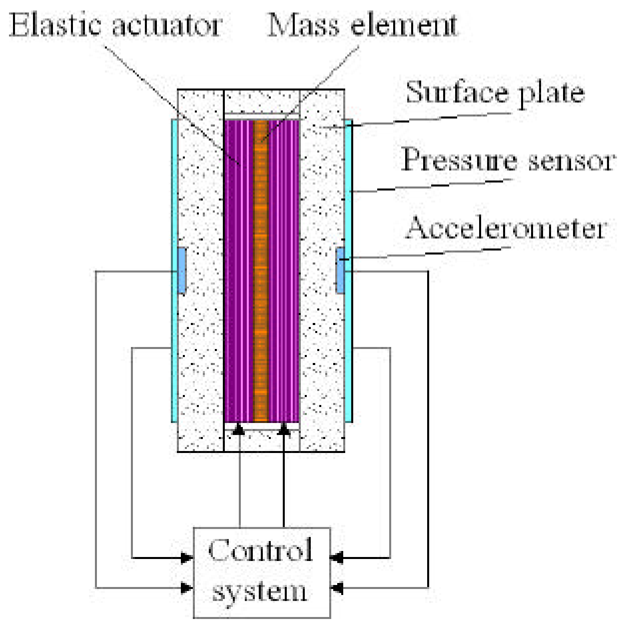


Figure 10. Control system of a mass actuator.

The ratio of the weights of the mass element and the primary mass (surface plate) can be varied to a much larger extent than in traditional dynamic vibration absorbers, which makes it possible to optimize the passive and active properties of the actuator more efficiently.

The principal application area of the mass actuator is sound insulation. Suitable products are building elements, such as doors, walls, floors, and suspended ceilings. An important advantage of using the mass actuator for sound insulation purposes is the reduced mass of the sound insulating elements.

Conclusions

The active control of sound is based on interference. In three-dimensional spaces the proper interference is achieved by using continuous closed secondary source distributions (Huygens' sources), containing both monopole and dipole type secondary sources. This can be realized with continuous surface JMC elements, needing also monopole and dipole type continuous sensor parts for the reference signal.

One of the main advantages of PanPhonics Panels in the active control of sound is the possibility to form continuous active surfaces with integrated actuators and sensors. This is advantageous in both absorption and sound insulation applications. The hybrid absorber (local absorbing element) is formed of a passive absorbent by enhancing its absorption coefficient by active means. The impedance element is based on the hybrid absorber, but it is constructed with the impedance matching principle. Both of them can be used for active absorption, e.g., in room acoustics and in ducts. The mass actuator is a dynamic vibration absorber the damping of which is enhanced by active means. The principal application area of the mass actuator is sound insulation of building elements.