With the aim of improving the sound quality of the loudspeaker system, it is essential to have a working understanding of the problems associated with sound reproduction. The most important parameter in describing the perceived sound quality is the frequency response. The smoother the spatially averaged frequency response in the listening area, the higher the fidelity rating. A flat on-axis frequency response is all very good, but of little use to a recording engineer moving along the mixing desk.

**Diffraction**

One of the important phenomena affecting sound radiation of a loudspeaker is diffraction. Explained simply this means that any edges, for example the loudspeaker cabinet edges, act as secondary sound sources. As the cabinet front panel usually has four edges, the system has five radiators operating at the same time, the actual driver and four secondary sources. The resulting frequency response at the listening position is the sum of all these sources (Figure 1a). The summed frequency response varies because of the summing of components with different arrival times. As the listener moves off-axis (Figure 1b), the relative distances of the secondary sources change. The summed response heard at the listening position is different due to the secondary radiations. The existence of secondary sources degrades the response of a loudspeaker. On-axis there is ripple due to the summing of coincident edge diffractions. Off-axis the summing is no longer coincident as the path lengths are different, which results in lower amplitude of ripple spread more evenly over frequency. This is usually seen at and above midrange frequencies due to the physical dimensions of loudspeaker compared to the wavelength of the radiated sound.

A reduction in sound level occurs when the difference of the direct radiation path and the path length of the diffracted sound equals half the wavelength ($\lambda$)

$$b + c - a = \lambda/2.$$
tom images in general. If the mono image is wide and fre-
quency dependent, then the stereo performance is usu-
ally also bad. Diffraction is not the only reason for poor
mono performance, but other reasons are beyond the
scope of this article.

Listening environment

The loudspeaker itself is not the only thing in the con-
trol room that can cause frequency response problems. In
fact, there are numerous objects and surfaces that reflect
sound energy towards the listening site. It does not matter
what the cause of a delayed signal is. Sound quality is
degraded if there is a delayed signal which arrives shortly
after the main sound from a direction close to the direct
sound (Haas effect).

Ideally the control room environment should be clear
of any equipment that might cause interfering reflections.
The mixing console and other rack equipment cause re-
flections. Traditional two and three way designs work in
geometrically well designed control rooms which are suffi-
ciently damped. In poorer environments their responses
may be degraded due to room reflections.

Power response

The power response is the loudspeakers total radiated
output, not just on-axis, but in all direction around it. It can
be measured in a number of ways (Olson, 1947), for ex-
ample by measuring sound pressure level in an anechoic
chamber at various angles along a sphere (or hemisphere),
and integrating the results.

Listening in a control room the engineer hears both
the direct sound and the reverberant field. The perceived
frequency balance at the listening position is linked to the
power response of the system. The more omnidirectional
the loudspeaker, the more the listener will hear of the room's
reverberant field.

Let us now imagine a true omnidirectional loudspeaker
with flat on-axis frequency response. It radiates identically

Haas effect

Precedence effect, also called Haas effect after its in-
ventor, refers to the ability of man to hear a sound that is
emitted shortly after the main sound, for example a wall
reflection or a diffraction from the loudspeaker cabinet
edge.

We do not hear a separate sound if the delay of the
second sound is less than about 30 ms, corresponding to
a time-of-flight for the sound of 10 meters (Buser, 1992). If
the delay is smaller, then the original sound takes prece-
dence over the secondary sound. This is called the Haas
effect.

The Haas effect several important consequencies for
loudspeaker design. If the delay of the wall, floor and ceil-
ing reflections is smaller than 30 ms, these can not be
discerned as separate sound. Instead they will modify
the frequency balance of the original sound. These reflections
have a special name, they are called the early reflections
because they integrate with the main sound modifying the
sound quality. Because of this, even a perfect loudspeaker
without the DCW will be spoiled in a room with significant
early reflections.

Balancing the intensity with time

When we listen to a loudspeaker stereo pair, we hear
a sound event in the middle between the two speakers, if
the distance to both speakers is equal and the level of the
sound input to both speakers is the same. If we change
either the input level or the time delay to one of the speak-
ers, the sound event appears to move to a new location.

Sound travels at a speed of 340 meters/second dis-
tance of one foot (about 30 cm) corresponds to about 1ms
of time-of-travel. If you move one foot closer to one of your
speakers, keeping the distance to the other constant, you
modify the delay difference between the two speakers by
one millisecond. The ear is sensitive to this delay differ-
ence, and you experience the location of your sound event
to move in front of you. The input level to your speakers
also moves the sound event. This is very familiar to us.
We use the balance potentiometer to move the sound in
our stereo system where we want to place it.

To an extent it is possible to compensate the delay
change by a change in level. Many investigators have
measured the value of this time-intensity trade-off, and it
is typically expressed in microseconds/dB. This trade-off
is frequency dependent, and the typical values are between
25…90 microseconds/dB (Moore, 1989). The DCW de-
sign and the Genelec recommended way to aim the moni-
tors constructively exploits the time-to-intensity trade in
the human hearing system to provide a stable and wide listen-
ing area.
in all directions and has a flat power response. In reality loudspeakers are only omnidirectional when the driver’s physical dimensions are small compared to the wavelength of the radiated signal. As frequency increases (wavelength shortens) the radiator becomes increasingly directive. Consider a typical system consisting of a 250mm woofer and a 25mm tweeter. The woofer becomes increasingly directive with frequency and its radiation angle becomes narrow at the typical crossover frequency of about 2kHz. At this point there will be a radical change because the tweeter is virtually nondirective at this frequency. The power response will then peak up at the crossover point. As frequency increases the tweeter becomes more directive and the power response begins to decrease. If no effort is made to correct this and the on-axis response remains flat, the net result will be an uneven power response. The practical meaning of this is that when a peak occurs the proportion of the direct sound to the total sound output decreases. The net effect depends on the listening environment, resulting in the perceived frequency balance varying from room to room.

An alternative solution to soffit mounting could be considered. If there is no radiation towards the diffracting edge, nothing can reradiate from it. This can also be achieved by making the cabinet edges round at the frequencies of interest.

At mid and high frequencies the radiation angle can also be limited by a waveguide structure to avoid diffraction from cabinet edges. The benefits of a limited and controlled radiation angle become obvious as the acoustical conditions worsen. The controlled directivity improves the ratio of direct sound to early room reflections. The listener is more in the direct field and is able to hear more of the program material and less room effects. Subjectively this is perceived as improved imaging and better definition. If the radiation pattern is constant power response will be uniform and flat. The system will also be more immune to changes in room environment.

Directivity Control Waveguide
Genelec has developed the Directivity Control Waveguide technology already in 1982, and it is used in all our new full range monitoring designs. DCW is a novel acoustical device, which shapes the emitted wavefront allowing control of dispersion. It is a specially curved rigid surface fitted in front of the driver unit. It can be dimensioned for constant directivity extending down to fairly low frequencies depending on the DCW frontal dimensions. The DCW allows cabinets with sharp edges to be used without problematic diffraction effects.

Wide Stereo listening area
The main monitors are traditionally aimed at a focal point behind the engineer’s position, with equal distances between the speakers and the listener. The human ear uses both amplitude and time cues in the localisation of sound sources. The stereo imaging depends on both time and amplitude differences between the left and right signals. Moving to either side of the centreline between the speakers causes an image shift to the nearest loudspeaker.

Imagine a system where the dispersion pattern is constant and controlled at all frequencies. Its off-axis response is flat, but the level is lower than on-axis. We aim this pair at or in front of the listening position. Now assume that the

![Image](image.png)

*Figure 3. The Genelec 1038A DCW.*

**Optimizing in-room performance**
To avoid problems associated with diffraction the driver maybe flush mounted into a baffle. We can use this principle by flush mounting the whole loudspeaker into the control room wall. Flush or soffit mounting also has the added advantage of improving the low frequency response through avoiding a back wall reflection.
listener moves to the right of the centreline. As he moves off-axis, the signal level decreases. At the same time the distance to the right loudspeaker shortens and the level slightly increases. The listener moves increasingly on-axis of the left-hand loudspeaker. The level of the left loudspeaker increases. The net result is that it is possible to aim the speakers in such a way that the imaging remains more stable although the listener moves slightly off the centreline. In this way the DCW systems create a wide stereo listening area. Also the power response becomes more uniform without peaks or dips at the crossover (Figure 4). The DCW can be made an integral part of the enclosure construction.

**High sensitivity and low distortion**

Limiting the radiation space angle boosts the output. The sensitivity of a good DCW design can be up to 10dB better than the sensitivity of a typical direct radiating driver.

The distortion of a DCW loaded driver can be very low. For example, Genelec has achieved harmonic distortion of less than 0.5% between 500Hz and 4kHz at 110dB SPL (Table 1). This is one tenth of the distortion of compression drivers at the same SPL.

The DCW technology allows to control the directivity pattern in a predictable way. The frequency response becomes uniform in the listening area. Diffraction and distortion are minimised as the sensitivity increases. All of these aspects greatly enhance the overall fidelity of the system allowing reliable results in vastly differing acoustic environments.

**References**


Muller, Black and Dunn, J. Acous. Soc. Amer., Vol.10, No. 10, p.6, 1938


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**Table 1.** Harmonic distortion figure of the Genelec midrange driver at 110dB continuous SPL measured at 1m.