HIFI FUNDAMENTALS, **Gradient ltd.1984-2000**
WHAT THE STEREO IS ALL ABOUT

From the beginning of Gradient Ltd. some fundamental aspects of loudspeaker design has frequently been questioned by our R&D Director and company's founder Jorma Salmi. Document below is a loosely constructed summary of his findings and thoughts.
It is by no means complete, but illustrates nicely the heart and soul of Gradient Ltd.

From time to time it is useful even for an expert to give a thought to the basics of sound reproduction.
For instance, what the stereo is all about?

In stereophonic sound reproduction we have two channels.
But what does this mean in practice?

In a recording session two microphones or its multiples can be used, the most important thing being the necessity to mix the results into two channels: the right channel and the left channel. In principle there are two signals, two wave forms. Acoustically these forms are the exact replicas of what was happening at the recording location.
These two sound waves represent the sound pressure level variations produced by the performers as captured by the recording engineer and the producer. These acoustic pressure wave forms are transformed into electrical wave forms and preserved on magnetic tape, analog or digital.

There are two electrical signals on CD. These signals are not similar and they are changing all the time. They include all the information we need to reproduce the width, the depth even the height of the performance and its acoustic space. All information there is and all there has to be is in these two electric signals. If those signals are paused for the moment, we?ll notice that they both have single values, voltage i.e. pressure. At a certain fragment of time there only exists two figures.
This is how the digital system works.

The big challenge here is, ***how to reproduce these signals without quality loss.***

We all know, that electronic equipment, like amplifiers, alter the signal very little.

So the real design challenge for all loudspeaker designers is, how to carry these two signals to the listener's ears in ordinary rooms without deteriorating the information.

STANDARDIZED CHAIN

Carrying the signal unmodified from control room to listener?s living room requires that used equipment are compatible with each other.
Program sources (CD, cassette, LP, DVD, MP3 etc.) and electronic devices are therefore manufactured according to international standards.
This is the reason why HiFi enthusiast can build a complete HiFi system using different manufacturers devices. It is even possible to mix tube and solid state equipment.
Biggest variations exist among power amplifiers and loudspeakers. Some speakers may have a very low impedance working only with certain amplifiers. But usually almost everything is compatible with everything.

LISTENING ROOMS ARE VARYING ACOUSTIC LOADS

Similar to amplifier-loudspeaker interface, listening room works as an acoustic load to the loudspeaker.
In recording studios monitor loudspeakers are integrated to the control room to obtain the best possible sound reproduction. However, this is not the case in normal living rooms and listening environments. When building and designing a house, there are no standards for the acoustic load. That is why rooms vary a lot from each other and usually are rather bad than optimal for sound reproduction.

The loudspeaker-listening room interface being unexpected, it is difficult to imagine a loudspeaker that suits all rooms.
Even the variations of bass level alone makes designing uniform speaker very challenging.
In a room manufactured from stone or concrete, you are most likely to get too much bass.
In the same time when speakers are taken into the wooden house, the result will be the other way around.
Simply, there is no such thing like an uniform loudspeaker.

WHY LOUDSPEAKERS SOUND DIFFERENT IN DIFFERENT ROOMS?

The problem has been studied to some extent by various loudspeaker designers and other authorities.
For instance the famous Bruel & Kjaer of Denmark (manufacturer of audio measuring equipment) published in 1974 an AES (Audio engineering Society) paper called "*Relevant loudspeaker test in studios, demo rooms and in the home using 1/3 octave pink noise".*

The B&K team took five different loudspeakers to three different rooms. Sound quality was evaluated by five listeners in a blindfold listening tests. Results were surprising. In advance one could not say which loudspeaker would give the best result in a certain room. None of the loudspeakers sounded best in all three rooms. This is easy to understand, because every room creates a different acoustic load to the loudspeaker.
When you change the load you get different results. This is exactly the same phenomena with amplifiers, where performance greatly depends on the load.

So what was the advice of the B&K research team to the customer wanting to buy a loudspeaker system?
Take different loudspeakers to your home and measure them using pink noise *).
Finally select the loudspeaker pair giving the smoothest results on the listening spot in the frequency range from 60 Hz to 6000 Hz.
Usually this loudspeaker also sounds the best in the listening room in question.

Before founding Gradient Ltd., *Jorma Salmi* studied the room-loudspeaker interface phenomena (1980). Instead of listening and measuring loudspeakers in ordinary rooms he did it into an anechoic chamber.
His findings are described below in "The Absolute Listening Test" chapter.

**) This kind of method is still in use. For instance John Atkinson of Stereophile magazine uses a computerized system giving a curve averaged from 60 measurements on a single loudspeaker, totaling 120 measurements for a stereo pair. This kind of a measurement gives good correlation to subjective listening results. See Stereophile March 97 to notice, that the in room measurement of the Gradient Revolution is very good 32 Hz - 10 kHz +/-1.3 dB (see fig.5: http://stereophile.com/loudspeakerreviews/616/index5.html)*

THE ABSOLUTE LISTENING TEST

During his research *Jorma Salmi* arranged a listening test in a big anechoic room *).

He listened various loudspeakers on the room position where the measured frequency responses were as flat as possible (usually you can find this spot on the so called 'design axis').

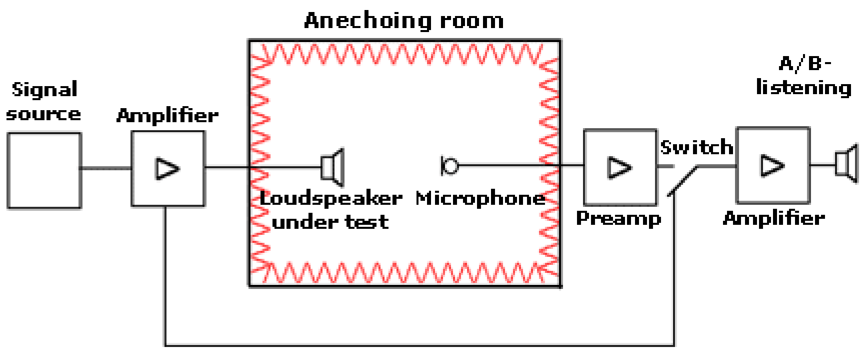
When listening high quality recordings with high quality speakers he was surprised to learn how good they sounded.
Here are Salmi's experiment's main findings:

- Sound was very clean and pure
- Imaging was excellent
- Acoustics of the recording venue were reproduced excellently
- Spatial information was much better reproduced, than in ordinary rooms
- Sound quality was much better than in ordinary rooms

**) Anechoic room is a room without reflections i.e. reverberation, standing waves, flutter echo etc. It is simply a room with no acoustics at all.*

The Absolute Listening Test

After listening loudspeakers in an anechoic room *Salmi* then arranged the ***'Absolute Listening Test' (ALT).***



ALT was conducted as follows:

1. Tested loudspeaker was situated inside an anechoic chamber.
2. High quality measuring microphone (B&K 4133) was placed on the design axis of the speaker.
3. Music program was fed to the speaker from a source (record player, microphone or tape recorder).
4. Monitoring took place outside the anechoic chamber.
5. By switching it was possible to detect the difference between the speaker/microphone combination and the source (a straight wire).
6. Both headphones and loudspeakers were used in monitoring.

ALT test produced the following rather surprising results:

When the frequency response curve of the test speaker measured by the microphone was flat, the listeners could not make a distinction between sounds arriving directly and those reproduced via test speaker.

Non-linear and phase distortion, delayed resonances and similar phenomena did not appear to have an audible effect upon the sound quality of high quality speakers.

Flat frequency response was the most important factor.

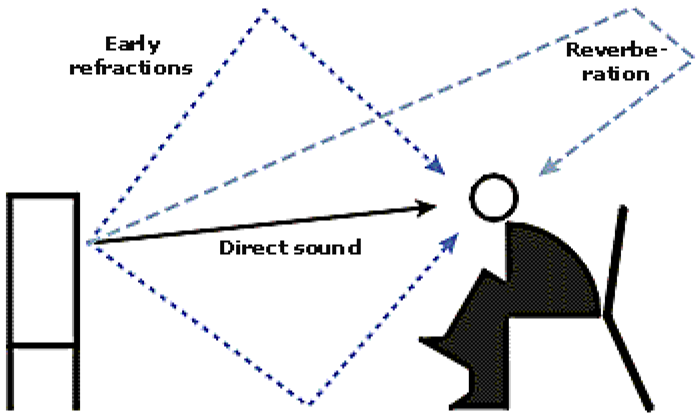
During the test listening good quality recordings in an anechoic room sounded excellent. The difference between the direct sound compared to that passing through the loudspeaker and the microphone was minimal.

At this stage *Salmi* decided to investigate what kind of phenomena occurs in an ordinary room. Or more precisely, how ordinary listening room kills the sound quality.

THE ROOM-LOUDSPEAKER INTERFACE OR HOW AN ORDINARY LISTENING ROOM KILLS THE SOUND QUALITY

The fundamental question at this stage was:
Why did loudspeakers having similar frequency response curves sound different from each other in ordinary rooms?

Gradient's R&D department started on researching the effect the room has on sound reproduction.
In an ordinary reverberant space like a living room, only 20% of the dominant sound energy is transmitted directly to the listener, whilst 80% of the sound energy reaching the listener consists of reflections. The reflected sound is made up of sound components coming from the floor, the walls and the ceiling.



Since there are no acoustic reflections in an anechoic chamber, the origin of this phenomena must be the reflected sounds of the listening room.

This eventually proved to be the case.

The very essence of the problem was, *how did the reflected sound deteriorate the frequency response?*

Research done into the human sense of hearing shed some light on the matter.
The solution proved to be in the first reflected sounds received by the ear, since these sounds travel a longer distance than sounds arriving directly to the ear (3...70cm longer, or 0.1...2.0 ms in time). The human ear and brain perceive these early reflections as contiguous with the sounds received directly.
A "comb filter" effect occurs, and the frequency response curve dips and rises alternately. An apparently good speaker's response becomes worse. The extent of this deteriorating depends on the directivity of the speaker and its distance from reflective surfaces, especially the floor.

Next question to study at was, *what are the subjective effects of early reflections on the sound?*

- Imaging suffers
- Lack of spatial information
- Three dimensionality suffers
- the sound is coming from loudspeakers, not "out of nowhere" (loudspeakers do not disappear)

In addition to early reflections there are also other factors deteriorating the sound quality; *standing waves, uneven reverberation time vs. frequency and flutter echo.*

AFTER THE RESEARCH: FIRST PRODUCT GRADIENT 1.0 - A LOUDSPEAKER WITH CONT ROLLED DIRECTIVITY (1984)

Gradient's R&D department began to build a loudspeaker with the idea of encouraging the smallest possible amount of early reflections.

The stated design drivers were:

1. A minimum level of early reflections compared to the level of direct sound
2. Maximum time gap between early reflections and direct sound
3. Flat free-field and power response curves
4. Low distortion
5. Wide listening area
6. Sufficient acoustic power

After two years of experimenting with prototypes a production model, Gradient 1.0 was developed. This loudspeaker model not only combined the stated objectives as wanted, but also had a neat construction and was positioned to quite affordable price segment.

The hidden factor

With this model Gradient introduced it's leading design principle, the control of directivity. This meant that minimum early reflections were arriving to the listener and the listener would hear a frequency response which was as flat and even as possible. Controlled directivity also meant that the frequency response at the listener's ear height (while sitting down) in the horizontal plane remained constant over a wide area. Thus the frequency response curve measured at 45 degrees off the axis was almost identical with that on the axis. Very few speakers achieved such a good results. The optimum listening area of a pair Gradient 1.0 series speakers is extensive, early reflections are minimal, and the quality of the sound is clear and pure accordingly. The recording's spatial quality of sound is thus faithfully reproduced.
Best of all, the acoustics of the listening room do not affect the sound reproduction with Gradient speakers in the same way as with ordinary speakers.

In general It is not a particularly remarkable achievement to manufacture speakers which sound good in heavily damped rooms with dead acoustics.
It is far more difficult to create a speaker which sounds good in any given room. Such become the case with Gradient 1.0 series speakers.

Minimization of early reflections in the middle frequency range and in the treble range

According to research results early reflections are most harmful in the mid-frequency range. Directivity can be achieved in many different ways, for example by using a mechanical horn structure in front of the drive-unit, or by making use of the speaker's physical properties. Gradient employed the second of these methods. Directivity in the mid-range was attained in an ingenious manner: *a backwards tilted 30cm dynamic drive-unit* was used to deal with the middle frequencies.

Since the unit was open, it also radiated sound to the rear. The technical phrase for this device was "**a first order bi-directional gradient radiator**", this also gave the name for the company. By using an open drive-unit the resonances of a speaker cabinet and reflections caused by its edges were avoided.

Treble sound reproduction was dealt with *a line source*, which consisted of *four drive-units*. The effective length of the line source was shortened electronically. The lowest treble frequencies were reproduced by all four units, the highest by only one. Thus the directivity was controlled in desired manner. This pillar of tweeters reproduced frequencies up to the upper limit of hearing. These tweeters were also free of disturbing reflections caused by cabinet edges.

An even and 'boom less' bass reproduction

Bass reproduction always depends upon the placement of the speakers in relation to the shape of the room (floors, ceiling and walls). Proximity to these tends to increase the bass. This should be taken into consideration when designing speakers. If they are designed according to standards set in the anechoic chamber (i.e. bass level as high as middle and treble) bass frequencies are reproduced in a too powerful manner to the listener's position. The speaker will sound 'boomy' and tends to tire the listener.

Gradient has placed the bass drive-unit facing the bottom of the bass enclosure which works with the bass reflex principle.
Since the woofer is almost in contact with the floor, the difference between the direct and the reflected sound is small in relation to wavelength (at 50Hz it is 7m).
The reflection caused by the floor can thus be fully utilized. The material of the floor surface in practice hardly ever effects bass reproduction. The sensitivity of the low frequency unit in *Gradient 1.0-1.3* were set produces an even sounding bass in the living room.

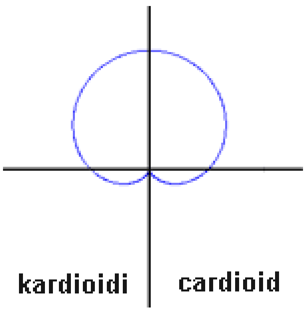
TOWARDS THE REVOLUTION

During the battle against early reflections generated from the loudspeaker itself or from the nearby boundaries, Gradient R&D department took the original ideas even further when designing Gradient Revolution model.

A cardioid loudspeaker

The loudspeaker designer has some tools to minimize or eliminate early reflections / room influence. One effective way is to make the radiation of the loudspeaker narrower.
Many panel loudspeakers have this property even to the extent that highest frequencies are audible only on a very narrow "sweet spot" position of the listening room.

Gradient?s R&D studied polar patterns - especially those of microphones - and found out that a radiation pattern of cardioid would be ideal for a HiFi loudspeaker.



Vocalists tend to prefer cardioid microphones, because a cardioid microphone takes the sound only from the front side, so there will be no problems with acoustic feedback.
Contrary to that a cardioid loudspeaker will radiate sound to forward direction only, not at all backwards and very little to the sides.

Acoustic resistance box

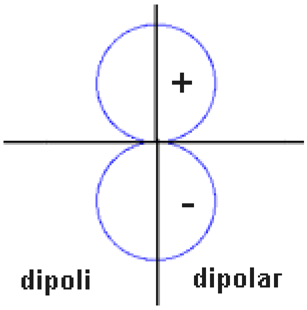
In theory this kind of loudspeaker is quite simple.
But how to make it work in practice?

Gradient began to develop a cardioid loudspeaker. It was based on an acoustic resistance box principle. The result was the upper module of the Gradient Revolution.
Frequencies over 200 Hz are reproduced by this ingenious system.

This unique technique has also been used in the Gradient Evidence and Gradient CC-1 center channel speaker.

Battle against standing waves

Especially in countries where lots of people are living in flats, the standing waves cause some problems.
All rooms with large parallel surfaces of massive material (concrete, stone, brick) will easily cause some strong standing waves. This means that certain low frequencies will be emphasized and thus will dominate the sound.
The only way to minimize this effect is to use a dipole bass (radiating in one dimension only, forwards and backwards in opposite phase).
Gradient has been using this system in the SW-63 subwoofer (technically a bi-directional gradient source of first order) tailored to the Quad ESL 63 electrostatic.



The bass section of the Revolution uses two long throw drivers giving a ruler flat response to 32 Hz in real rooms (see Stereophile, Follow-up by John Atkinson, March 97).
Due to the triangle shape of the cabinet the bass section can be orientated in three different ways. This means that low frequencies can be directed in three different ways. The annoying standing waves can always be tamed by this way and the bass response fine tuned according to the listener?s taste.

Further, Activation

It has been a logical progress to add an active crossover to the Revolution according to the QUAD ESL-63 & Gradient SW-63 system. This helps to extend the frequency range to 20 Hz and allows the customer to adjust the Q-value and the bass level. The net result of activation means that now we are one step nearer the our goal - the ideal loudspeaker.