MegaSound: Sound in Irish megalithic buildings

Author: Victor Reijs, Ireland, victormm@reijs.org

Keywords: megalithic, MLS, Ireland, ancient acoustics, architectural acoustics, 3aAA

Inspired by other people (like Devereux and Jahn [2001]) sound measurements were done in a few megalithic buildings as well as a few present day rooms. This study should be seen as getting acquainted with the subject and to determine the boundaries of equipment and buildings. No true conclusions can be gathered yet from this study, but it provides links to improve the measurements in an open-air environment and to broaden/extend the study. Acoustic measurements were done at two locations in the east of Ireland near the Boyne Valley (some 60 km north of Dublin): Fourknocks I and Dowth South. Both are megalithic passage monuments from at least 3000 BCE. Some reference measurements were done on a bathroom and bedroom at home.

The following sections will provide insight in the utilized equipment, the acoustic measurements and some considerations.

The equipment

Tools used: ETF computer program (using Maximum-Length Sequence (MLS)-techniques), sound card, bass guitar amplifier (Ampeg, SVT-15T, speaker is some 40 cm in diameter) and analogue SPL meter (RadioShack 33-2050).

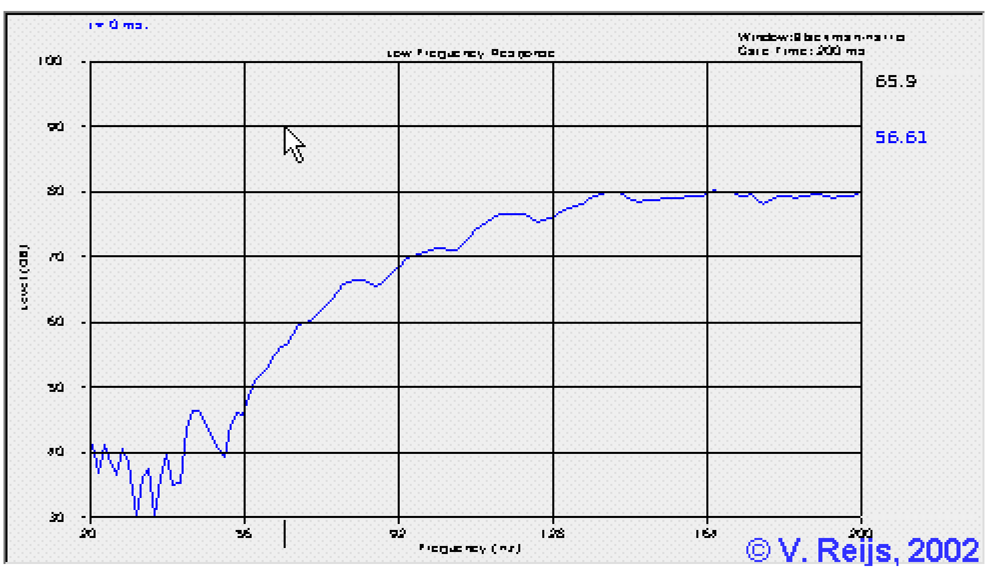
Some tips

- When using the RadioShack SPL meter, put it on *WEIGHTING C* for full frequency response.

- Use ETF in *Full Range* measurements.
- Give the equipment time to adjust to different temperature and damp environment (to reduce condensation).
- Check noise level with speaker muted. Check if there is constantly 50/60 or 100/120 Hz or other frequencies present (do this with the 3D low frequency waterfall graph). Try to eliminate these grid-power or other related spurious frequencies.
- Check noise level with microphone not connected, but connecting the cable, which would go to microphone in the computer.
- Measure the frequency response of the equipment, by putting the microphone just in front (maximum some 20 cm) of speaker and then measure the frequency response of this system.
- One can type in this frequency response of the measurement system into a microphone calibration file, and thus *compensating* the room measurements. After this is done, **don't** change any frequency control (like weighting or equalizing) on microphone or amplifier/speaker, otherwise repeat the measurement of the frequency response of the equipment.
  This procedure has not been used in the below measurements. So the power level at the peaks is a result of the room resonance **and** the output of the speaker **and** the output of SPL meter at that frequency. So one can only say that at a peak a resonance frequency exists, **but not** if it is the strongest!
- Put speaker as close as possible to a corner, just to excite as many resonance frequencies as possible.

Frequency response of equipment

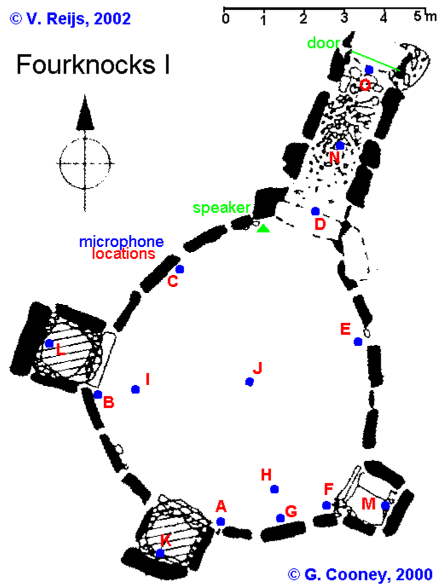
The frequency response of the equipment (speaker plus microphone and **not** the room) is:



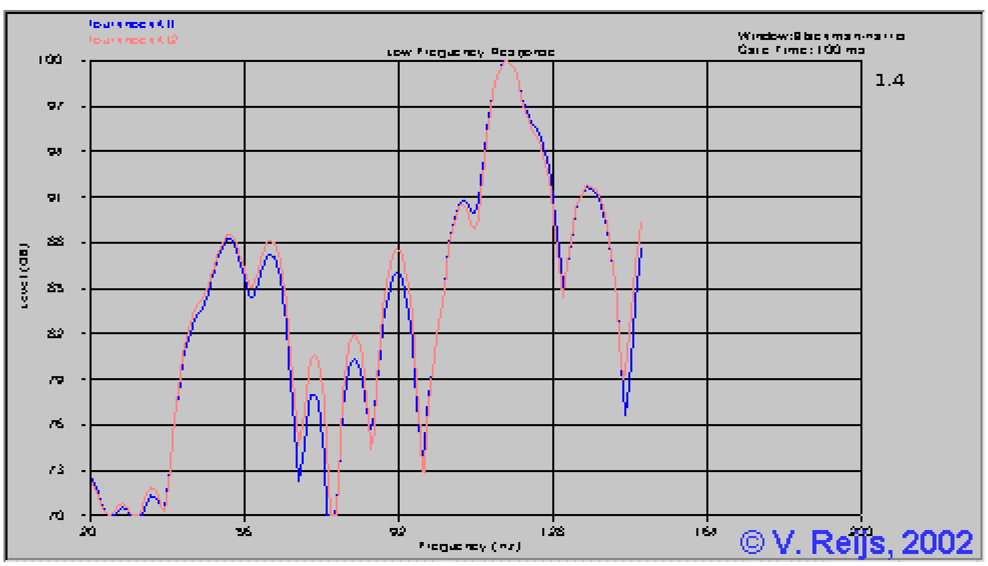
Frequency response of equipment (microphone some 20 cm from speaker)

The acoustic measurements

Fourknocks I

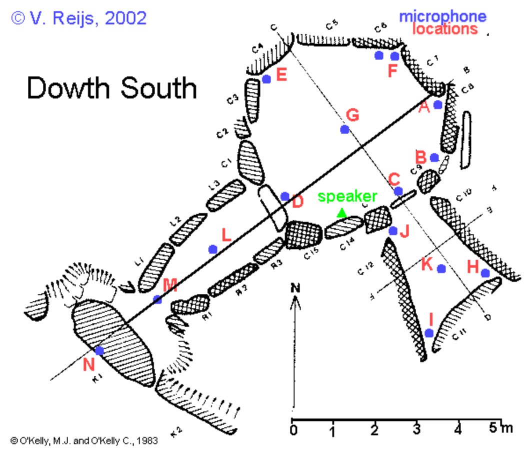


The height of the modern ceiling at the top is around 2.6 m and at the edges around 1.6 m (a concrete dome). It is expected that the original ceiling could have been a *framework of rafters* (Cooney [2000], page 104)
The orthostats are boulders of rocks and the floor is trampled sand.
30 measurements were done (most at Low level and some with door closed).
The outside temperature was around 7° C.
Speaker direction perpendicular to wall.
Crossover frequency F_2: ~60 Hz

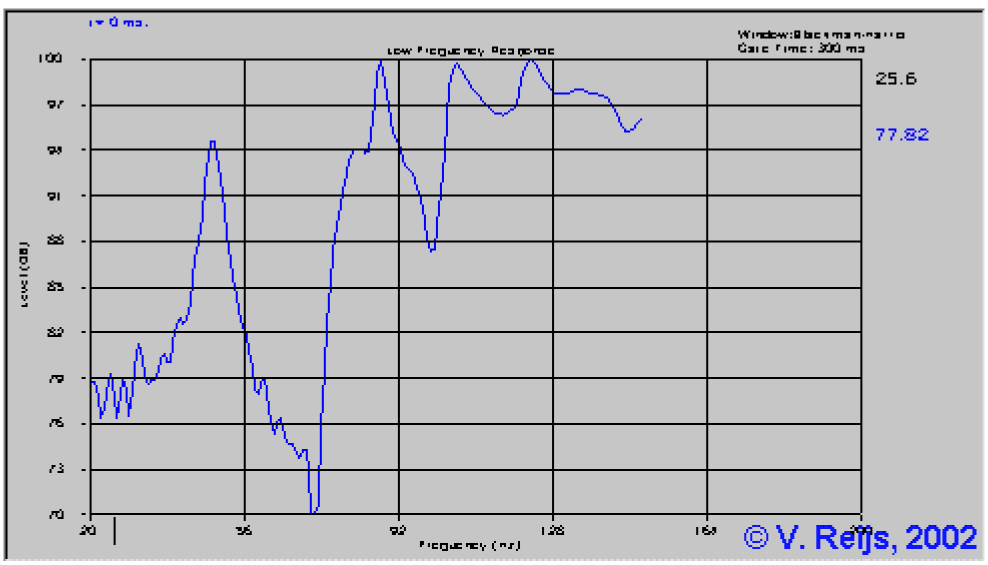


Frequency response (between 20 and 200 Hz) at point K (Low level and door open)

Dowth South



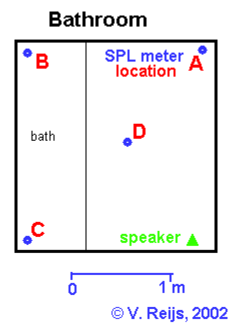
The average height of the modern ceiling is 1.9 m (almost a flat concrete ceiling). It is expected that the original ceiling would have been corbelled (O'Kelly [1983], page 156)
The orthostats are boulders of rocks and the floor is trampled sand.
40 measurements were done (most at Low level).
The outside temperature was around 10° C.
Speaker direction perpendicular to wall.
RT_{60}: ~600 msec (between 30 and 3000 Hz)
Crossover frequency F_2: ~100 Hz



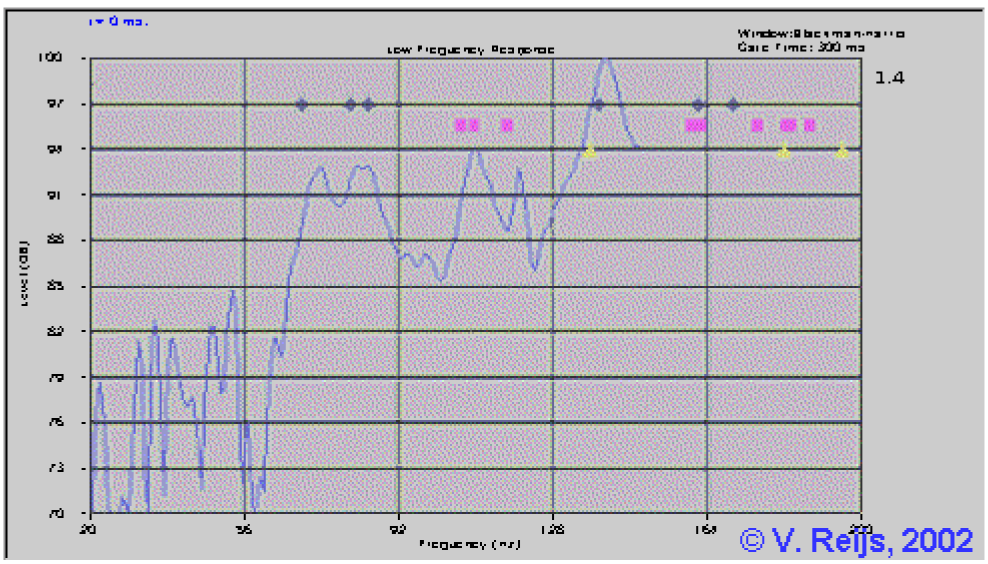
Average of frequency response (between 20 and 200 Hz) at Low level

After the white noise of ETF, a clear tone was heard inside the chamber. It was at least audible for some 0.25 sec and its frequency somewhere around 600 Hz (although I have no musical ears, it could be off with a few 100 Hz). This phenomenon was not visible in the RT_{60}.

Bathroom at home



The height is 2.45 m (plastered ceiling, brick walls).
Temperature around 15° C.
Speaker direction towards point B.
RT_{60}: ~600 msec (between 40 and 9000 Hz)
Crossover frequency F_2: ~415 Hz



Average of frequency response (between 20 and 200 Hz) at High level

The blue lozenges, purple squares and yellow triangles are the theoretical resonance frequencies resp. axial, tangential and oblique modes.

Some considerations

- The human voice pitch (f_0: the fundamental frequency of the human vocal cords) is at present days for normal male speaking voice between 110-130 Hz and for normal female speaking voice between 200-230 Hz. Children is around 300 Hz. Singing can produce different pitches of course. Remark: Pitch is sometimes also used just as a synonym to frequency of a sound and sometimes it is related to the perceived frequency of a sound (expressed in [mel] instead of [Hz]). But on this web site it is used only for the fundamental frequency of the vocal cords f_0.

- In former times people were smaller, so it is expected that the pitch would have been higher. Now a days British males are around 174 cm, so compared to European neolithic times (164.2 cm) the pitch could have been some 6 % higher (assuming a linear behavior between pitch and height). So this gives the following average pitch frequency:

	Present times Avg. speaking pitch (f_o) [Hz]	**Neolithic times Avg. speaking pitch (f_o) [Hz]**
Male	~120	~127
Female	~215	~228
Child	~300	~320

- Looking at the frequency response of my measurement equipment it has some 32 dB at 56 Hz attenuation. That is quiet a lot. According to a web source, the SPL meter has some 8 dB at 20 Hz (or around 2 dB at 50 Hz) attenuation, so it looks my speaker/amplifier is not really a sub-woofer system;-) A better system is needed to be able to measure frequencies lower than 60 Hz better.

- The above mentioned frequency response of my measurement equipment also causes the peaking around the 100 Hz range. If one would compensate for the measurement equipment, the peaks of the resonance frequencies would be quite flat in the 20 - 200 Hz range.
  The equipment that Devereux and Jahn ([2002], pers. comm.) used, had a frequency range between 20 - 200 Hz (speaker) and 32-10,000 Hz (microphone).

- The peaks found by Devereux and Jahn ([2002], pers. comm.) were done by listening to the sound. Because the equal-loudness contours of the human ear are quite steep at low frequencies (difference of some 30 dB between 20 and 100 Hz at 70 phons), real peaks below 100 Hz are perhaps not heard due to this.

- Looking at the above measurements in rooms, the frequency responses of the measured (*badly* rebuild) megalithic chambers are not very different from modern house rooms.

- When the crossover frequency F_2 is high (like in the bathroom), the theoretical normal modes can be easily seen back in the frequency response graph. For the other rooms an easy one to one mapping of the normal modes and the peaks in the graphs is not that apparent.

- The crossover frequency for Fourknocks I and Dowth South are resp. around: 60 and 100 Hz. Above these frequencies, normal modes will not be able to explain the measured freq. response, but also the sound ray theory comes into play (angle of incidence equals angle of reflection).

- It is quite difficult from the above measurements to determine a possible preference (coloration) for male or female usage of the buildings, because only measurements up to 200 Hz have done. The same is true for the measurements done by Devereux and Jahn [2001].

- On coloration (quote from Everst [2001], page 351):
  "Colorations caused by acoustic anomalies of ... rooms are devastating to speech quality. Gilford states that axial modes spaced approximately 20 Hz or more, or a pair of modes coincident or very close, are frequent sources of colorations. He also states that colorations are likely to be audible when an axial mode coincides with a fundamental (f_0) or first format (F1) of at least one vowel sound of speech, and are in the region of high-speech energy. Speech colorations below 80 Hz are rare, because there is so little energy in speech in that part of the spectrum. There are

essentially no speech colorations above 300 Hz for either male or female voices. Modal colorations are more noticeable in speech than in music."

- All the above measured megalithic rooms have rebuild ceilings. It is recommended to do measurements also in as intact as possible chambers like; Cairn L (Loughcrew) and Newgrange. This also will provide a better comparison with already measured megalithic rooms by Devereux and Jahn [2001].

Acknowledgments

I would like to thank the following people for their help and feedback: Raymond Balfe, Paul Devereux, Paul Kelly, David Lubman, Cees de Laat, Doug Plumb and Franz Thomanek. Ideas and any remaining errors are my responsibility of course.

References

Cooney, G., *Landscapes of neolithic Ireland*, Routledge, London, 2000, ISBN 0-415-16976-1.

Devereux, P., *Stone age soundtracks*: The acoustic archaeology of ancient sites. Vega, London, 2001, ISBN 1-84333-019-9

Everest, F.A., *The master handbook on acoustics*, McGraw-Hill, 2001 (Fourth edition), ISBN 0-07-136097-2

O'Kelly, M.J., *Newgrange: Archaeology, art and legend*, Thames and Hudson, London, 1982, ISBN 0-500-27371-5