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Sound Radiation From the Chest of Bass Singers

Abstract:

Problem: What are the relative amounts of power radiating from chest and mouth?

Vibrations in the chest wall was studied in detail on two bass singers by means of an accelerometer, but phase differences across the chest made it difficult to make an exact computation of the radiation from the chest. The most efficient method turned out to be *integration of the intensity field across a surface area enclosing the chest.*

Observations:

1. We found the radiated power from head and from chest separately to be 28 -72% at 88Hz (F_2) on one of the subjects. Another subject showed 78-22% in favour of the chest at 78Hz ($E^b{}_2$), but close to 50-50% between 88 and 156Hz (F_2 - $E^b{}_3$). The signal source used was the voice fundamental of to bass singers.

2. Vibrations in the chest varied appreciably during expiration: We measured an acceleration increase of 10dB relative to the mouth SPL at the fundamental of F_2. The greater air volume seem to short-circuit (absorbate) more of the volume velocity generated by the vocal chords.

3. The chest acceleration was on one subject measured to be 20dB higher at F_2 than at F_3 relative to the sound pressure at the mouth. This is probably due to the mass-cavity resonance of the system made up by the mass of the chest and the enclosed air volume.

Motivation

Chest wall vibrations in bass singers can easily be sensed by the skin of your fingers. Such vibrations have previously been examined by means of accelerometer by Johan Sundberg, concluding that they have a significant contribution to the singers own perception.

Now, what about power radiation?

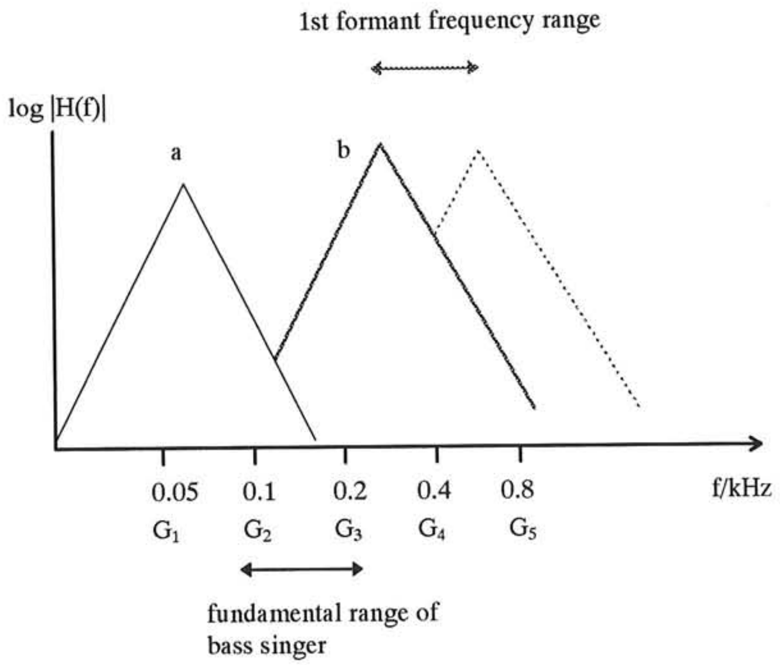


Fig. 1: Transfer function of the chest (a), and of the vocal tract (b).

Bass singers are of particular interest, since their Fundamental Tone is well below the lowest resonance of the vocal tract - namely the 1st formant frequency (fig 1.b).

Secondly, the resonance of the chests mass - cavity system (fig.1.a) may add some exstra boost to the low frequencies, quite similar to the effect of bass-reflex enclosures used with loudspeakers.

Also, knowing that larger surface areas are better radiators of sound, it is plausible to expect an appreciable amount of power coming from the chest.

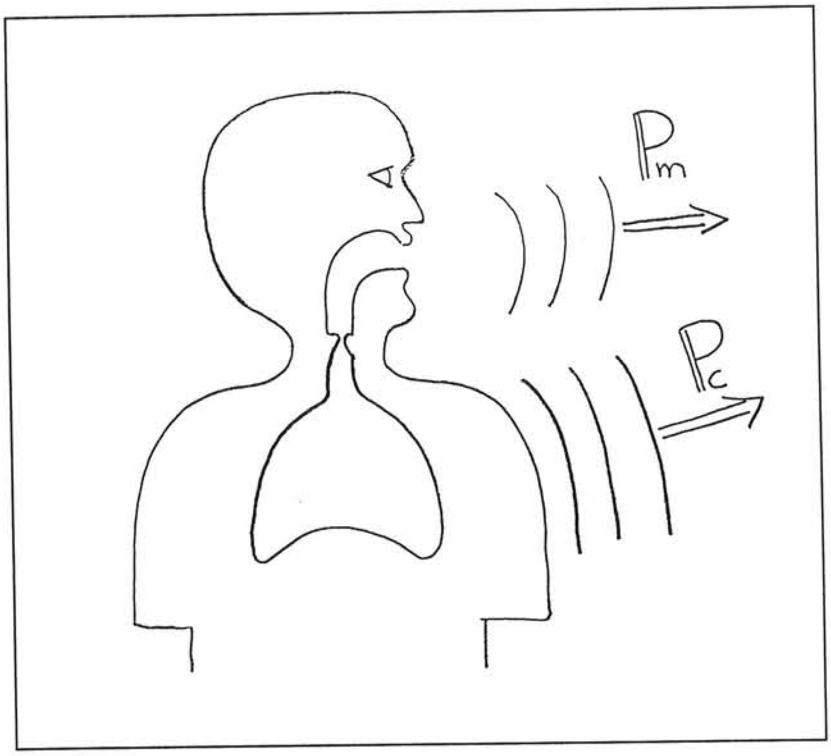


Fig. 2: P_m *= power radiation from the mouth*
P_c *= power radiation from the chest. Problem:* $P_m / P_c = ?$

Problem

The question that was to be answered, is:

- Does the sound radiation from the chest of bass singers contribute significantly to the total power at low frequencies?

Therefore, we wanted to find the relative amount of power radiated from the chest of some trained bass singers.

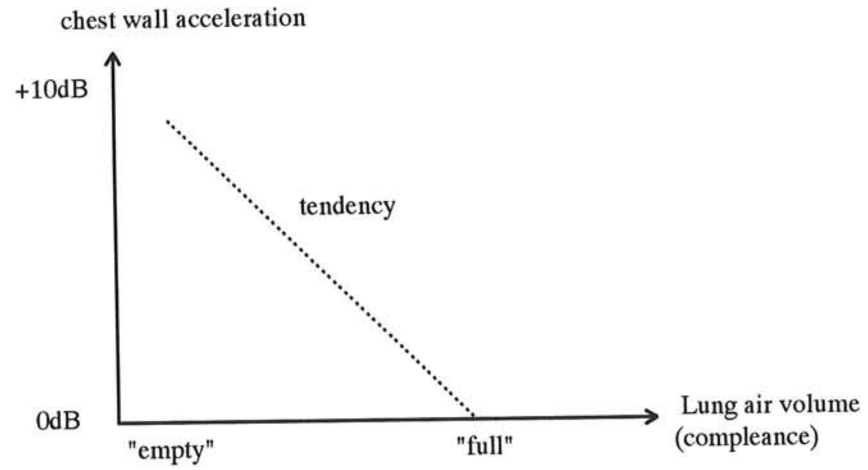


Fig. 7: The greater compleance short-cuts more of the volume velocity. Fundamental of F_2 - 88Hz.

2. The acceleration of the chest surface varies considerably with the air volume of the lungs (fig. 7). We measured an increase of 10dB during expiration with an accelerometer. The source was the 88Hz fundamental of F_2.

The reason is most probably that the greater air volume short-circuits more of the volume velocity created by the vocal cords. See electrical analogue, (fig.9).

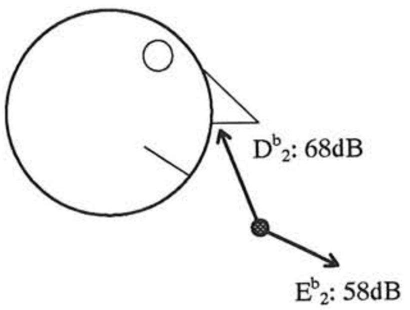


Fig. 8: Dipole effekt with low fundamental tone. Subject humming with a closed mouth. From E^b_2 to D^b_2 the intensity vektor is increasing, turning some 160°, and pointing into the nose.

3. The picture in (fig. 8) shows the dipole effect in front of the nose of subject IN at low frequencies. We see that the intensity vector is turning some 160 degrees from E_2 flat to D_2 flat, while increasing 10dB in magnitude.

The subject is singing con bocca chiusa - "humming" with a closed mouth - so we would expect the intensity to point out from the nose, not the oposite.

Result

	IN	RL
Head	28%	48%
Body	72%	52%

Fig. 5: A table showing % of radiated power from head and body. Subjects IN & RL. Fundamental of F_2 - 88Hz

As we can see from the table of (fig.5), there is a considerable percentage of the power coming from the body, presumeably from the chest. 72% on one of the subjects, and 52% on the other.

The source is the fundamental of F_2, with a frequency of 88Hz, on both subjects.

The differences between the to subjects are probably due to different chest resonance frequencies.

Some secondary observations

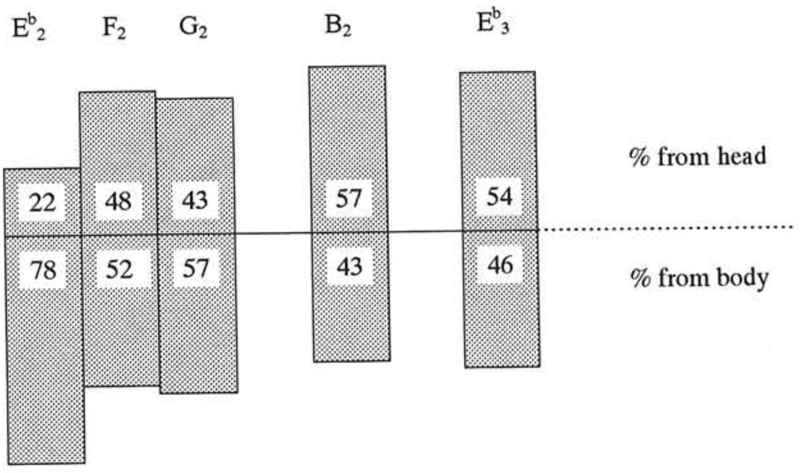
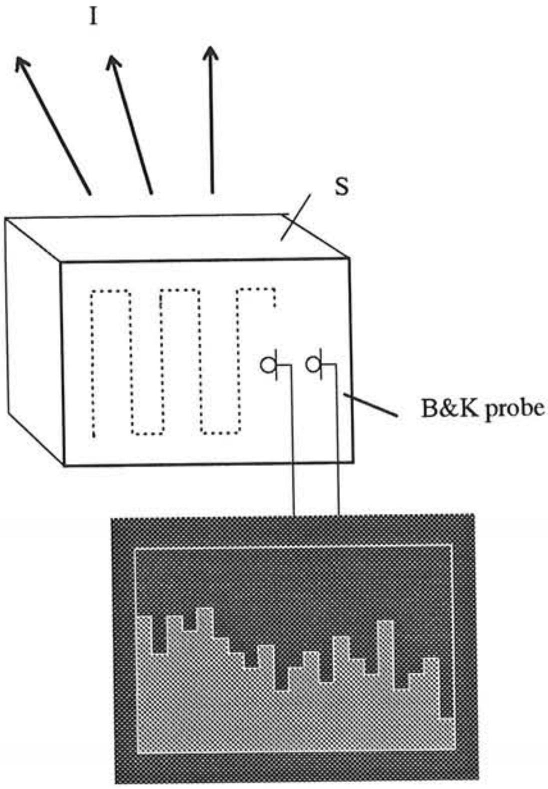


Fig. 6: Radiation of the fundamental tone. Head-body power percentages. Subject: RL.

1. The somewhat "disappointing" 52% from the chest of subject RL, made us extend the investigation, wanting to know how this percentage varied over an octave.

The diagram in (fig. 6) shows that singing one tone deeper makes the chest percentage increase rather drastically on subject RL.

Down at E_2 flat there is coming 4dB more power from the body than from the head, while the percentage is rather close to 50-50 over the rest of the octave.



Nortronic 830 1/3 octave analyzer

Fig.4: Sweeping a closed surface with a dual microphone intensity probe.
Emitted power: $P = \oiint_S I \cdot dS = S \cdot I_{mean}$

Method

Several methods were discussed, but the most efficient one turned out to be:

Integration of the intensity field across a closed surface area, according to Gauss' Theorem.

The total radiated power from a source must be equal to the Intensity Flux through a closed surface that is containing the source.

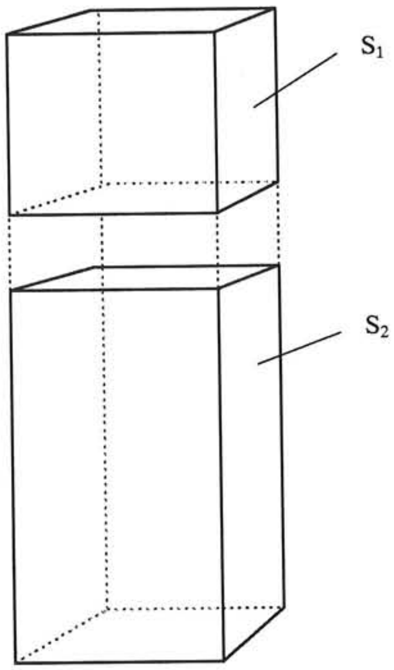


Fig.3: Two imaginary surfaces. S_1 enclosing the head, and S_2 enclosing the body.

In practice, we let the subject be surrounded by two imaginary boxes (fig.3), letting one box enclose the head, and the other one the rest of the body.

Then we sweeped the surfaces seperately with a dual-microphone intensity probe, letting the Nortronic 830 integrate the intensity in 1/3 octave bands (fig. 4).

Knowing the surface area and the intensity mean, it is easy to calculate the radiated power of the Fundamental Tone.

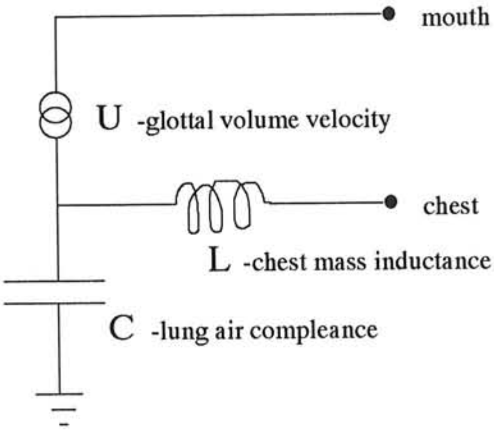


Fig. 9: Simplified electrical analogue of the mouth-chest system.