Study of the performance of an ultrasonic acoustic generator producing an audible directive beam

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Introduction

It is possible to generate a good quality audible frequency signal with a small emission angle by using a "small" plane antenna that produces ultrasound. This type of acoustic generator is very interesting for many applications: for example, it is possible to communicate with certain people in a large meeting without interfering with others. This study aims to assess the performance of the existing systems.

First, the theoretical principles of a directive ultrasonic generator are summarized. Next, two devices that are based on different technologies are presented and tested.

Physical Principles

This generator is based on the nonlinear interaction of two sound beams with neighbouring frequencies. Given two primary waves, with angular frequencies ω_1 and ω_2, we obtain the combination harmonics $\Omega = k\omega_1 + n\omega_2$ (where k and n are integers). The difference-frequency is interesting because the dissipative effects are smaller than for the primary waves, and the directivity is almost the same.

The space dimensions in which the waves interact – the so-called parametric array – are limited by two parameters:

i. the dissipation of the waves (which increase with the frequency),

ii. the nonlinearity (when a wave propagates in a nonlinear medium, harmonics increase until the formation of a discontinuity – at the distance L_p – where a strong attenuation occurs). L_p decreases when the frequency or the amplitude of the primary waves increases.

The amplitude of the difference-frequency increases almost linearly along the parametric array[2]. For an amplitude modulated signal, in the far-field – when the primary waves have disappeared – the difference-frequency on the axis of propagation is given by:

$$p_\Omega(z,\tau) = \frac{p_\omega^2 S\beta}{16\pi\rho_0 c_0^4 z\alpha}\frac{\partial^2}{\partial\tau^2} f^2(\Omega\tau)\,, \qquad (1)$$

where f is the envelope function. The equation (1) underlines the fact that the efficiency of the self-demodulation increases with the frequency – due to the second derivative – and that distortions appear – due to the squared function.

Therefore, the parameters of the input signal are particularly important:

- the carrier frequency has an influence on the penetration in air, the distance L_p and the directivity;
- a small modulation rate decreases the distortions as well as the level of the demodulated signal;
- the type of preprocessing used to reduce the distortions.

Other parameters have an influence on the performance:

- the type of transducer (bandwidth and efficiency),
- the size of the antenna (directivity),
- the emission power (more power decreases the dissipation effect but also reduces the distance l_p).

Tested Generators

Two devices have been tested. The first one is developed by the American Technology Corporation (ATC) and is called "*Hypersonic Sound*" (*HSS*) [3]. The second one is made by Sennheiser and is named "*Audiobeam*" [4].

"HSS"

The emission of the sound is based on the use of a PVDF (polyvinylidenefluoride) film. This film allows us to get a lot of "elementary loudspeakers" working all in phase. The generator processes the input signal to obtain a good compromise between the distortion and the maximum difference-frequency amplitude: a single-sideband amplitude modulation is used with a 40 kHz carrier frequency and the modulation rate varies according to the frequency. This variable modulation rate allows a constant sound level to be obtained regardless of frequency.

"Audiobeam"

The emission of the sound is based on the use of an antenna made of many individual ceramics. These ceramics must emit in phase in order to obtain a good output signal; therefore, a specific electronic system is used. The carrier frequency is 40 kHz and the modulation rate is limited.

Experiments and Results

In order to get rid of the possible meteorological disturbances, a lot of experiments were performed in an anechoic room.

Bandwidth of the audiofrequency

HSS: the maximum response is obtained at 3 kHz, (-6 dB bandwidth: 1 kHz to 7 kHz). The level is almost constant between 2 kHz and 5 kHz.

The *Audiobeam*: there is a strong resonance at 10 kHz (-6 dB bandwidth: 8 kHz to 11 kHz), but there is another plateau, with a significant level, between 700 Hz and 3 kHz.

Directivity

In order to study the directivity, we placed a microphone at a 4 m distance and we rotated the antenna. We tested four different frequencies. The results are given in table 1.

Frequency (kHz)	0.5	1	5	10
HSS	2°	5°	7°	3°
Audiobeam	10°	17°	9°	7°

Table 1: Half-angle measured for both generators (at -6 dB)

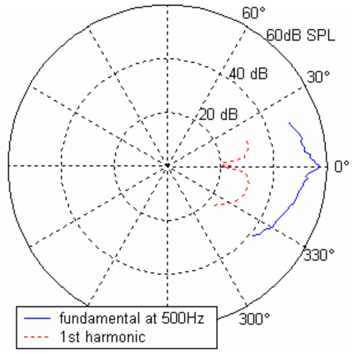

Figure 1: Directivity of the *Audiobeam* (f = 500 Hz)

We measured the level of the first harmonic in order to evaluate the distortion as a function of the azimuth. For both generators the distortion is about 5% or less – on the propagation axis but quickly increases with the azimuth (figure 2).

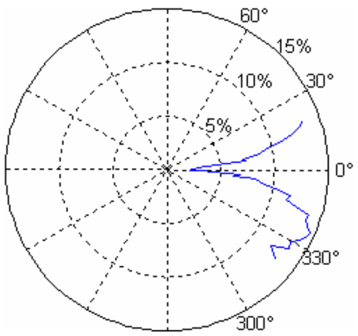

Figure 2: Distortion rate for the *Audiobeam* (f = 500 Hz)

Far-field measurements

Outdoor measurements were carried out up to a 50 m distance with the HSS device in order to study:

- the level of the audible frequency as a function of the distance;
- the directivity as a function of the distance;
- the parameters of the carrier wave at different distances.

The level of the demodulated signal decreases from 2 m down to 20 m and then remains stable up to 50 m (figure 3).

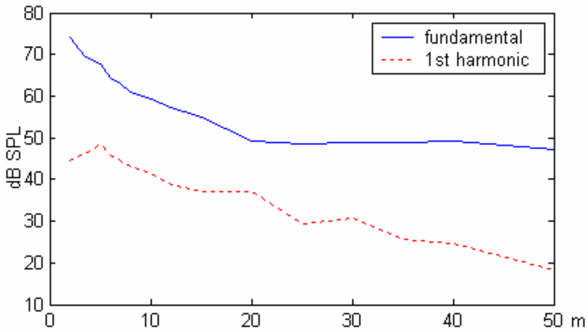

Figure 3: Level of the audible frequency (1 kHz) and of its first harmonic as a function of the distance from the generator

Beyond 10 m, the directivity is almost constant (table 2).

Distance	5 m	10 m	20 m	50 m
Half-angle	3°	11°	14°	12°

Table 2: Outdoor directivity of the *HSS* for 1 kHz signal

The shock formation occurs at a shorter distance (L_p) than calculated. The origin of this discrepancy is still unknown (preprocessing of the signal or the atmospheric conditions).

Later we will build a prototype to study the effects of the modulation parameters on the signal range and the influence of the cavity shape behind the PVDF film.

References

[1] Auger E., "Générateur acoustique à faisceau dirigé", ISL-RV 224/2003, 2003.

[2] Novikov B.K, "Nonlinear Underwater Acoustics", New York, 1987

[3] Reference to the ATC homepage
URL: http://www.atcsd.com

[4] Reference to the Sennheiser home page
URL: http://www.sennheiser.com