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ACOUSTIC CHARACTERISTICS AND CANCELLATION PERFORMANCE OF A BASIC FREE-FIELD NOISE CANCELLOR

S.E. Wright, H. Atmoko

University of Huddersfield, School of Engineering, HD1 3DH, Huddersfield, United Kingdom

Tel.: 44 1484 473291 / Fax: 44 1484 451883 / Email: s.e.wright@hud.ac.uk

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ABSTRACT
A unique theory for generating electronically controlled acoustic shadows for environmental noise reduction was reported in [1]. The theory has been extended to complex high frequency sound from large non-compact sources in [1.2]. The implementation of the theory into hardware is considered in [1.3]. Practical extensions to the theory are considered in [1.4]. The effect of environmental change is considered in [1.5] and the fundamental cancelling system considered in [1.6]. Before the sound cancellation performance of multichannel freefield cancelling systems could be evaluated in detail, it was considered prudent to establish first the characteristics of a single channel system. The shadow characteristics are computed and compared with examples of measured performance. Good agreement is obtained, which can now be used to validate the far field sound cancellation predictions.

1 - INTRODUCTION

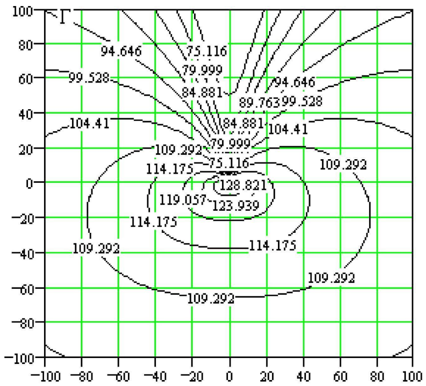
Active noise control systems, in enclosures, have been extensively investigated, however free field plant (propagation space) is quite different than that in enclosures. In enclosures the sound fields are complex, having standing waves and diffuse sound, with secondary sources and detectors non-aligned. This results in cancellation regions limited to a fraction of an acoustic wavelength. In free field electronically controlled acoustic shadow systems the basic cancelling element comprises of a cancelling secondary source (loudspeaker) and a detection system (microphone) placed in successive axial alignment with the primary source to be cancelled. This ensures cancellation in the direction of wave propagation, which in turn results in shadows extending to large distances from the primary source (now not restricted to a fraction of a wavelength).

2 - FUNDAMENTAL CANCELLER

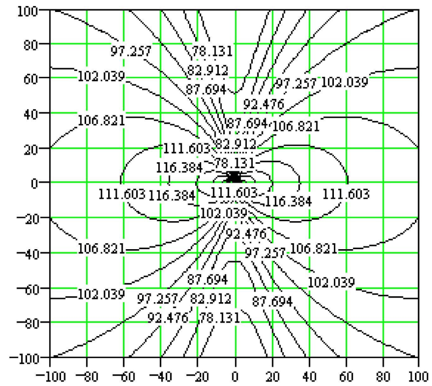
From an acoustics point of view, each freefield cancelling element behaves as a special phase controlled dipole. Here the secondary source combines with the primary source to form a dipole. A detection system is placed on the secondary source side and positioned along the so formed dipole axis to monitor the combined sound from both sources. Unlike the fixed phase of the classical multipoles, see for example [2], [3], the phase and amplitude of the secondary source is adjusted automatically to minimise the sound at the detector. This phase controlled dipole can simulate dipole, tripole and quadrupole like source directivities, depending on the source frequency and separation distance between the primary and secondary sources. The properties of these sources are considered in more detail in reference [1.4, Section 5].

3 - ACOUSTIC MODELLING

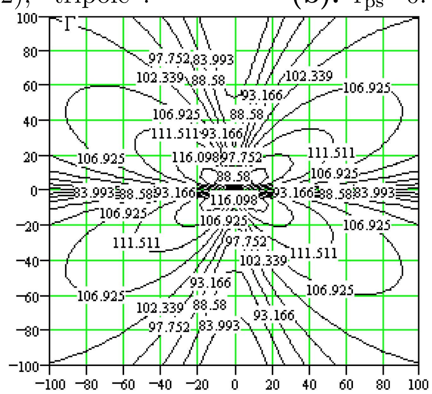
The acoustic modelling uses point sources. This is considered adequate for small but finite sources, [1.2, Section 3]. The sound pressure contours (equal levels) are given in dB's relative to the threshold of hearing (2.10^{-5} Pascals). In Figure (1) the sound pressure is computed up to a propagation distance of ± 100 m from a phase controlled dipole. Primary and secondary sources are situated at three source distances r_{ps}=0.3 m ($\approx \lambda/4$), r_{ps}=0.43 m ($\lambda/2$) and r_{ps}=0.86 m (λ), where λ is the acoustic wavelength. The



(a): r_{ps}=0.3 m (< λ/2), "tripole".



(b): r_{ps}=0.429 m (λ/2), "dipole".



(c): r_{ps}=0.857 m (λ), "quadrupole".

Figure 1: Sound pressure contours of basic canceller for 3 primary-secondary source distances r_{ps}, p=1, s=1, f=400 Hz, r_{pm}=10 m.

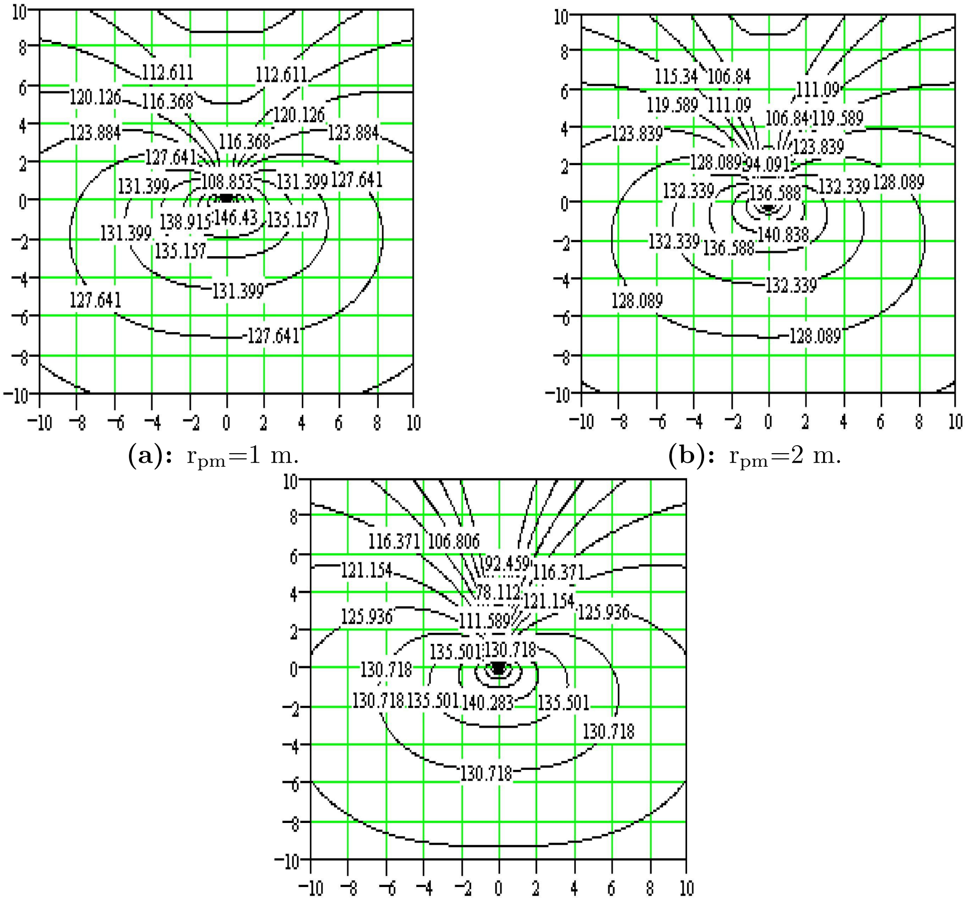
primary-microphone distance r_{pm} =10 m and the primary source strength and frequency are 1 m ^{3}/sec and f=400 Hz respectively. The cardiod, figure of eight and the four leaf clover shaped directivities, associated with the tripole, dipole and quadrupole, are clearly seen.

The cardiod has the deepest cancellation (shadow depth) situated on axis at 0°, followed by the figure of eight and then the four leaf clover. The shadows are defined here as the difference between the maxima and minima at the same primary source-observer distance r_{po}, minus 6 dB for doubling of sound pressure at the maximum contributed by both sources. The shadows are successively, for r_{po}=80 m, approximately 108-75-6=27 dB, 108-78-6=24 dB and 108-83-6=19 dB. They have roughly equal cancellation on one (0°), two (0°,180°) and all four (0°,90°,180°,360°) sides, respectively. These computations indicate that deep shadows, propagating into the far field, are theoretically possible using this basic cancelling element.

Figure (2) shows the sound pressure contours computed over ±10 m, for 400 Hz, the cardiod source (r_{ps} =0.3 m) and for three primary-microphone distances r_{pm} =1 m, 2 m and 4 m. The shadows increase and become narrower with increasing r_{pm}. At a primary source-observer distance r_{po}=4 m, the shadow depths are approximately 131-116-6=9 dB, 132-106-6=20 dB and 132-92-6=34 dB, respectively, increasing more than 10 dB per doubling in distance. The sound level at r_{po} ≈4 m is very small, at r_{ps}=4 m the level is, of course, theoretically zero (a singularity). Therefore the level measured with the observer microphone down stream and close to the detector microphone, where the shadow level is fairly constant, is used.

4 - MEASUREMENTS

Figure (3) is an example of measured data given in [1.6], after full convergence of an adaptive hardware implemented system. It shows the shadow depth as a function of primary source-observer distance r_{po} along the alignment axis, for r_{ps}=0.3 m, r_{pm}=2 m and three source frequencies 200, 400 and 800 Hz. The maximum shadow depth of course occurs for the observer microphone close to the detector microphone (within a microphone diameter from r_{pm}=2 m), the levels at the actual detector being > 60 dB (dynamic range of the system). The shadow increases fairly uniformly from the source to the detector. Beyond the detector the shadow levels are approaching about 15 dB for all three frequencies. This compares with



(a): r_{pm}=1 m. **(b):** r_{pm}=2 m.

(c): r_{pm}=4 m.

Figure 2: Sound pressure contours of basic 'tripole' canceller for 3 primary source-microphone distances r_{pm}, f = 400 Hz, p=1, s=1, r_{ps}=0.3.

the theoretical value of about 20 dB, as predicted in Figure (2). Level variations can occur, which are reduced by minimising reflections particularly between the primary and secondary source.

5 - CONCLUSIONS

The radiation characteristics and sound cancellation performance of a fundamental cancelling, element, both theoretical and hardware implemented, are given. The laboratory measurements compare well with the theoretical predictions given by computer modelling. This gives confidence in predicting the radiation properties in the far field and supports the notion that deep shadows generated by multi-channel systems, implemented into hardware, can be realisable.

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REFERENCES

1. **S.E.Wright and B Vuksanovic** , Active control of environmental noise, *Journal of Sound and Vibration*, Vol. 1.1-190(3)1996, 1.2-202(3)1997, 1.3-220(3)1999, 1.4-222(4)1999, pp. 565-585, 313-359, 469-496, 636-668.

2. **P.E.Doak**, Multipole analysis of acoustic radiation, In *Proc. of the Fifth International Congress on Acoustics Liege.*, pp. 56, 1965

3. **S.E.Wright**, Sources and observers in motion I, *Journal of Sound and Vibration*, Vol. 108(3), pp. 361-378, 1986

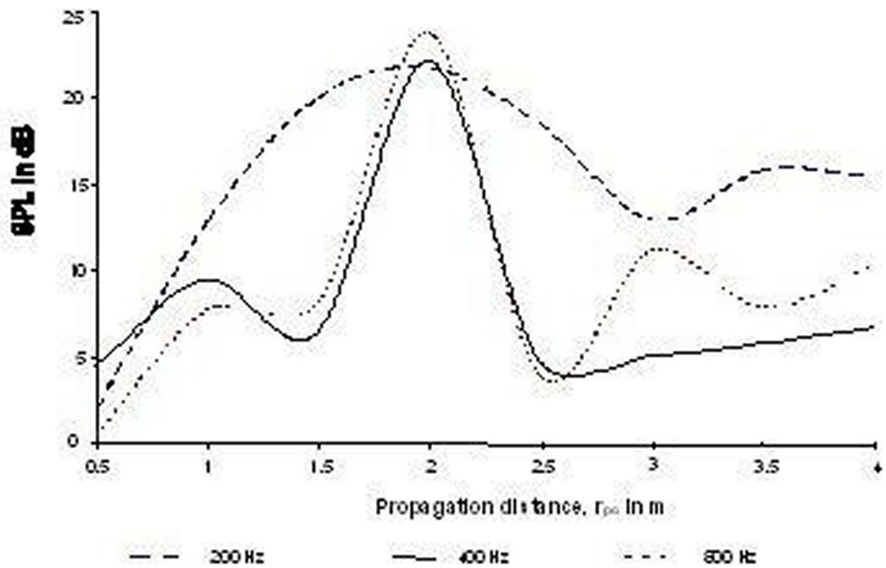

Figure 3: Measured shadow depth versus propagation distance r $_{po}$ for three frequencies f=200, 400 and 800 Hz, r_{pm}=2 m, r_{ps}=0.3 m.