OMNI DIRECTIONAL LOUDSPEAKER USING GIANT MAGNETO STRICTION TECHNOLOGY

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To my beloved mother and father

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ABSTRACT

Audio quality from a surround sound system is always dependent on the placement and configuration of the loudspeaker system. Audio formats such as the Digital Theatre Systems and Dolby Digital sound systems utilize various loudspeaker configurations to form various surround sound effects for listening rooms. Users who are inexperience in setting up a surround sound system will end up in incorrect speaker positions, thus unable to achieve optimal sound output from the system. The purpose of this research is to introduce an alternative loudspeaker system, which only a single speaker is needed for the user to experience a surround sound system regardless of the loudspeaker position. Using a conventional floor standing speaker system to benchmark the directionality of the design, the sound pressure level (SPL) responses of the alternative system at various angles were measured. The results obtained show that the SPL curves of this alternative speaker system are consistent at all angles, with a sensitivity of 77 dB (1W at 1 meter). Conventional loudspeaker system, on the other hand, maintains such values of sensitivity only on-axis listening. With consistent SPL and sensitivity, and omni-directionality, this alternative speaker system has wide listening coverage so that the same listening experience can be achieved regardless of listeners' position. The proposed loudspeaker system has been able to simplify the setup and to locate the correct loudspeaker placement.

ABSTRAK

Kualiti audio daripada sistem bunyi “surround” sememangnya bergantung kepada lokasi dan konfigurasi sistem pembesar suara. Format audio seperti sistem bunyi “Sistem Teater Digital” dan “Sistem Digital Dolby” menggunakan pelbagai konfigurasi pembesar suara untuk menghasilkan kesan bunyi “surround” dalam aplikasi sistem pawagam atau teater rumah. Lokasi pembesar suara akan menjadi kurang tepat bagi pengguna yang kurang berpengalaman dalam pemasangan sistem bunyi “surround” dan ini akan menyebabkan sistem bunyi yang optimum tidak dapat dicapai. Penyelidikan ini betujuan untuk memperkenalkan suatu sistem pembesar suara alternatif tunggal mudah yang boleh menghasilkan pengalaman sistem bunyi “surround” untuk pengguna tanpa mempertimbangkan lokasi pembesar suara. Dengan menggunakan suatu sistem pembesar suara konvensional sebagai tandaan dalam penentuan kearahan projek ini, graf SPL untuk pelbagai sudut telah diukur. Keputusan penyelidikan telah menunjukkan bahawa graf SPL sistem alternatif ini adalah konsisten untuk semua sudut ukuran, dengan sensitiviti sebanyak 77 dB (1W pada 1m) untuk semua arah. Sebaliknya, sistem pembesar suara konvensional hanya dapat mengekalkan nilai sensitiviti ini hanya pada arah paksi pendengaran sahaja. Sebagai kesimpulan, dengan tahap sensitiviti yang konsisten pada semua arah, dan ciri kepelbagaiarahannya, sistem pembesar suara alternatif ini mempunyai kawasan pendengaran yang luas supaya para pendengar dapat mengalami pengalaman pendengaran yang sama tanpa mengira kedudukan mereka. Cadangan sistem pembesar suara alternative tunggal ini dapat memudahkan pengguna dalam pemasangan dan lokasi perletakan pembesar suara.

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LIST OF ABBREVIATIONS

BEA	–	Boundary Element Analysis
DSP	–	Digital Signal Processing
DTS	–	Digital Theatre Systems
DML	–	Distributed Mode Loudspeaker
EBP	–	Efficiency Bandwidth Product
ESL	–	Electrostatic loudspeaker
emf	–	Electromotive force
FEA	–	Finite Element Analysis
GMSs	–	Giant Magnetostrictive Materials
HRTF	–	Head Related Transfer Functions
LPM	–	Linear parameter measurement
LEAP	–	Loudspeaker Enclosure Analysis Program
NXT	–	New Transducers Ltd
SNR	–	Signal-to-noise ratio
SW	–	Subwoofer
TS	–	Thiele-Small
TRF	–	Transfer Function Measurement

LIST OF SYMBOLS

A	–	the absorption of the material (m^2 *Sabine*)
α_n	–	absorption coefficient of the actual surface
c	–	speed of sound
dB	–	Decibel
E	–	the Young's modulus (or modulus of elasticity)
f	–	frequency
γ	–	the gas constant equivalent to the thermodynamic ratio of specific heats
p	–	quiescent gas pressure
ρ	–	density of gas/material.
R	–	the absolute temperature of the gas
S_n	–	area of the actual surface (m^2)
RT_{60}	–	Reverberation Time
λ	–	wavelength
k	–	Wave number
Hz	–	Hertz
µ	–	micro
G	–	Giga
Pa	–	Pascal
F	–	Force
m	–	mass
a	–	acceleration
ϕ	–	phase
$g(t)$	–	harmonic variation of a quantity with time
c_{ph}	–	phase velocity
ω	–	angular velocity
η	–	transverse displacement

β	–	transverse rotation
B	–	bending stiffness
$v(\omega)$	–	bending wave velocity
T_{ij}	–	tensor
S_{ij}	–	strain tensor
ω_{ij}	–	rotation tensor
$d\mathbf{B}$	–	magnetic flux density
dW	–	magnetic work
dU	–	change of the internal energy
d_{33}	–	magnetostrictive constant
k_{33}	–	longitudinal coupling coefficient
SPL	–	Sound Pressure Level
fs	–	free air resonant frequency of a driver
f_C	–	resonant frequency of a driver in an enclosure
Q	–	measure of the amount of control of a driver
Q_{TS}	–	Q of a speaker in free air
Q_{TC}	–	Q of a speaker in an enclosure
Q_{MS}	–	mechanical Q of the driver
Q_{ES}	–	electrical Q of the driver
V_{AS}	–	volume of compliance
C_{MS}	–	mechanical compliance
S_D	–	cone area of driver
V_B	–	box volume
f_B	–	box resonance frequency
f_3	–	system cut-off frequency
L_v	–	length of port
R	–	port radius
F_c	–	Crossover frequency
R_T	–	tweeter’s (or in this case, the midrange’s) rated impedance in ohms
C	–	crossover series capacitance
R_W	–	woofer’s rated impedance in ohms
L	–	crossover series inductance in henries
kOe	–	kilo-oersted

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Proper loudspeaker placement is the most important part for the setting up of an audio system. This is to ensure that the system performs at its most optimum condition. Proper placement of loudspeaker is crucial to the quality of the sound, as improper loudspeaker placement can make a good audio system sound bad or distracting, and degrades the quality of the loudspeakers itself.

1.2 Background

Improper speaker placement, perhaps due to the listener's lack of experience or knowledge in speaker placement can significantly affect the sound quality as perceived by the listener. Howard (2009) states that it is pointless to have a wonderful listening room if the speakers are not in an optimum position. Figure 1.1 shows the optimum layout for stereo speakers and typical speaker layout for a 5.1 channel surround sound system. According to Howard (2009), they should form an equilateral triangle with the center of the listening position. If one has a greater angle than this, the center phantom image becomes unstable, creating the so-called "hole-in-the-middle" effect. However, having an angle of less than 60° results in a narrower stereo image. Narrow stereo image is where all the sound seems focused in the middle and the sound ambience and atmosphere is absent here causing the music to sound dead and flat.

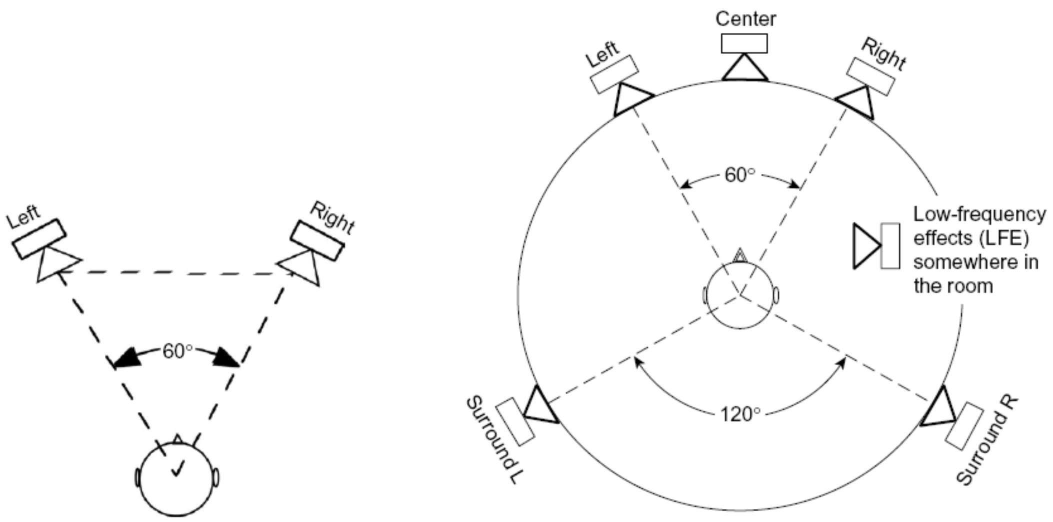

Figure 1.1 The optimum layout for stereo speakers and typical speaker layout for a 5.1 channel surround sound system (Howard, 2009).

Also, conventional speakers are designed such that the optimum listening positions are limited, and therefore, only a limited number of listeners are able to enjoy a truly immersive listening session. The research by Strohmeier (2008) examines an optimum loudspeaker set-up for audiovisual environments using a 15" auto-stereoscopic display to present video. By varying the number of loudspeakers and their distance from the listening point, they performed subjective assessment tests on four different setups with 32 participants. Their results showed that four loudspeakers in a distance of one meter to listener was the most pleasant combination for providing an immersive user experience. This means that optimum position in a conventional loudspeaker setting must be carefully selected, and only a limited number of listeners are able to enjoy a truly immersive listening session.

To further complicate matters, setting up a conventional audio system is even more of a challenge when the user wants to set up the system to fully utilize the Digital Theatre Systems or Dolby Digital multi-channel sound system option that is available on most amplifiers nowadays. Multi-channel setup can be messy and tedious, and if set up wrongly, it may result in a bad sound image which the user may unfortunately blame the poor sound quality on the performance of the audio equipment, when what happened actually was just the wrong positioning of the speakers.

1.3 Problem Statement

This research will attempt to design a single loudspeaker system that is capable of reproducing 360° wide-angle soundstage with excellent sound quality, where the users' listening experience will be independent of the distance and position from the loudspeaker. Based on the distributed mode loudspeaker (DML) concept, an acoustically conductive surface is coupled with giant magnetostriction devices (GMS) to produce an omnidirectional sound from the single speaker system. This alternative loudspeaker system will also be a user-friendly system that is versatile and easy to setup since it involves only a single loudspeaker, and it can be placed in any position in a room.

1.4 Objective of the Study

The objectives of the study are as follows:

a. To design a versatile and high-quality loudspeaker system that can be placed in any position, in a particular room.
b. To fabricate a quality single speaker system that is capable of reproducing 360° wide-angle soundstage (in the horizontal plane) that is independent of distance and speaker position.
c. To design a user-friendly loudspeaker system that is easy to setup.

1.5 Scopes of the Study

The scopes of the study are as follows:

a. Adopt conventional loudspeaker design for construction of the subwoofer system
b. Design suitable crossover network to cut-off at the high frequency and midrange frequency band
c. Research suitable material to use for the DML panel and the GMS actuator for the high frequency area.
d. Verify the completed system performance by measuring the directionality of the loudspeaker system.
e. Use standard listening room with the dimensions of 7.3 meter long by 3.5 meter high and 5.9 meter wide for evaluation.

1.6 Contribution of the Study

The significance of this study are as follows:

a. An alternative loudspeaker device using GMS material as an actuator is implemented to achieve a single-loudspeaker system. Users find it easier to setup a single-loudspeaker system, rather than the complicated setup of a conventional speaker system, as verified in Section 4.3.
b. The alternative loudspeaker system is capable of delivering enough and consistent sound pressure level with a sensitivity of 77 dB/1W at 1m, to all the listeners, at all angles (0º – 360º) in the horizontal plane, as verified in Section 4.2.4.
c. New loudspeaker sound waves reproduction concept, the DML concept, is used to achieve an omni-directional sound field. The omni-directionality of the alternative loudspeaker system is verified in Section 4.3.