

EXPERIMENTAL EVALUATION OF ACOUSTIC SATURATION

BY

JASON MATTHEW SEMPSROTT

B.S., South Dakota State University, 1998

B.S., South Dakota State University, 1998

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Electrical Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2000

Urbana, Illinois

TABLE OF CONTENTS

CHAPTER	PAGE
1 .. INTRODUCTION TO ACOUSTIC SATURATION	1
1.1 Background.....	2
1.2 Motivation	4
2 NONLINEARITY IN PLANE WAVES	6
2.1 Development of the Acoustic Shock Parameter	6
2.2 Fourier Analysis of a Propagating Plane Wave.....	8
2.3 Saturation in Plane Waves.....	11
2.4 Summary.....	13
3 SATURATION IN SPHERICALLY CONVERGING WAVES.....	14
3.1 Saturation in Focused Waves.....	14
3.2 Theoretical Results for the Transducers Used	17
3.2.1 Determining the gain factor	18
3.2.2 Nonlinearity in converging waves.....	20
3.2.3 Determining the theoretical saturation.....	21
3.3 Summary.....	22
4 EXPERIMENTAL PROCEDURES.....	24
4.1 Data Acquisition	24
4.1.1 Manual setup	25
4.1.2 Determination of beam axis	25
4.1.3 Waveform collection	27
4.2 Data Processing.....	27
4.3 Summary.....	29
5 EXPERIMENTAL RESULTS	30
5.1 Results	30
5.2 Saturation in Varying Focal Lengths or Frequencies.....	31
5.3 Frequency Spectrum Analysis	35
5.4 Summary.....	42

6	CONCLUSIONS AND DISCUSSION	43
6.1	Discussion.....	43
6.2	Conclusions.....	44
7	SUMMARY AND FUTURE WORK.....	47
7.1	Summary.....	47
7.2	Future Work.....	48
	APPENDIX A TABLE OF TRANSDUCER CHARACTERISTICS.....	49
	APPENDIX B DATA ACQUISITION PROGRAM.....	50
	APPENDIX C DATA ANALYSIS PROGRAM.....	68
	APPENDIX D FREQUENCY ANALYSIS PROGRAM	75
	REFERENCES	77

LIST OF TABLES

Table	Page
3.1: Nominal and measured transducer characteristics.	17
3.2: Theoretical aperture angles for each nominal focal length.	18
3.3: Table of values used to calculate G two different ways.	20
3.4: Frequency, focal length, and gain used to calculate the theoretical pressure saturation level for each transducer.	21

LIST OF FIGURES

Figure	Page
1.1: Time-domain acoustic waves at the focus for (a) low and (b) high input voltages.	1
1.2: Axial profiles for P_{II} and $P_{II,3}$ versus distance from the transducer.	2
1.3: Axial profiles for p_c and p_r acoustic pressures and their derated acoustic pressures.	4
1.4: Axial profiles of $P_{II,3}$, $p_{c,3}$, and $p_{r,3}$ normalized to the same graph.	4
2.1: Progression of a continuous sinusoid in a liquid [8].	7
2.2: Plot of the relationship in Eq. (2.15).	10
2.3: Fundamental frequency characteristics.	11
2.4: Behavior of 1 st , 2 nd , and 3 rd harmonics as a function of shock parameter [8].	12
3.1: Geometry used for determining saturation in a converging wave [5].	15
3.2: Geometry of spherically focused transducer.	18
3.3: P_{sat} levels for 3 MHz (•), 6 MHz (–), and 9 MHz (•–) transducers at various focal lengths for G , ρ_o , c_o , and β equal to 30, 998 kg·m ⁻³ , 1500 m·s ⁻¹ , and 3.5, respectively.	22
4.1: Block diagram of experimental system with positive axes convention indicated.	25
4.2: Hydrophone movement along axes -2 and -3.	26
4.3: Max P_{II} positions are found along axis-2 and -3 in the axis-1 plane and those two positions correspond to the coordinates of the max P_{II} in the axis-1 plane.	26
4.4: Noisy RF collected data (–) and smoothed version (·) of noisy data.	27
4.5: A typical linear time-domain pressure waveform at the focus.	28
4.6: A plot of the frequency spectrum for Figure 4.5.	29
5.1: Peak average p_c (□) and p_r (×) along with the peak-to-peak average pressure (□) plotted versus applied voltage for the 9-MHz $f/3$ transducer.	32
5.2: Peak average p_c (□) and p_r (×) along with the peak-to-peak average pressure (□) plotted versus applied voltage for the 9-MHz $f/2$ transducer.	32
5.3: Peak average p_c (□) and p_r (×) along with the peak-to-peak average pressure (□) plotted versus applied voltage for the 6-MHz $f/2$ transducer.	33
5.4: Peak average p_c (□) and p_r (×) along with the peak-to-peak average pressure (□) plotted	

versus applied voltage for the 6-MHz f/1 transducer.	33
5.5: Peak average p_c (\square) and p_r (\times) along with the peak-to-peak average pressure (\square) plotted versus applied voltage for the 3-MHz f/2 transducer.	34
5.6: Peak average p_c (\square) and p_r (\times) along with the peak-to-peak average pressure (\square) plotted versus applied voltage for the 3-MHz f/1 transducer.	34
5.7: Peak average p_c (\square) and p_r (\times) along with the peak-to-peak average pressure (\square) plotted versus applied voltage for the 7.5-MHz f/4.5 transducer.	35
5.8: Peak-to-peak average pressure for 9-MHz f/3 (\square) and 9-MHz f/2 (\blacksquare) transducers plotted versus applied voltage.	36
5.9: Peak-to-peak average pressure for the 9-MHz (\square), 6-MHz (\blacksquare), and 3-MHz (\square) f/2 transducers plotted versus applied voltage.	36
5.10: Time-domain acoustic pressure waveform for 9-MHz f/3 during low applied voltage conditions (a), and the frequency spectrum of the time-domain waveform (b).	37
5.11: Fundamental, second, and third harmonic magnitudes for the 9-MHz f/3 transducer plotted as a function of distance from the transducer for a low applied voltage.	38
5.12: Time-domain acoustic pressure waveform for 9-MHz f/3 during high applied voltage conditions (a), and the frequency spectrum of time-domain waveform (b).	39
5.13: Fundamental, second, and third harmonic magnitudes for the 9-MHz f/3 transducer plotted as a function of distance from the transducer for a high applied voltage.	39
5.14: Time-domain acoustic pressure waveform for 9-MHz f/2 during low applied voltage conditions (a), and the frequency spectrum of the time-domain waveform (b).	40
5.15: Fundamental, second, and third harmonic magnitudes for the 9-MHz f/2 transducer plotted as a function of distance from the transducer for a low applied voltage.	40
5.16: Time-domain acoustic pressure waveform for 9-MHz f/2 during high applied voltage conditions (a), and the frequency spectrum of the time-domain waveform (b).	41
5.17: Fundamental, second, and third harmonic magnitudes for the 9-MHz f/2 transducer plotted as a function of distance from the transducer for a low applied voltage.	41