AN INTRODUCTION TO HELMHOLTZ RESONATORS Revision B

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Introduction

A Helmholtz resonator is a volume of air which is enclosed in a container with at least one opening. It is also called a cavity resonator.

Perhaps the simplest example is a pop bottle. There are many other types. Some examples are:

1. A hollow sphere with a narrow neck
2. A large rectangular box or cylinder with a perforated cover

This tutorial focuses on the first type which is used for attenuating noise tones in pipes. The second type is used for sound studios and rocket engines, as discussed in Appendix A.

Additional examples are given in Appendix B.

The Helmholtz resonator has an acoustic natural frequency. It absorbs energy from the surrounding noise environment at this frequency. It can thus be used as an attenuation device for a narrow frequency band. It is effective for low frequency attenuation, say below 500 Hz.

Spherical Helmholtz Resonator

Spherical Helmholtz Resonators are used to attenuate noise tones in pipes or air conditioning ducts. An example is shown in Figure 1.

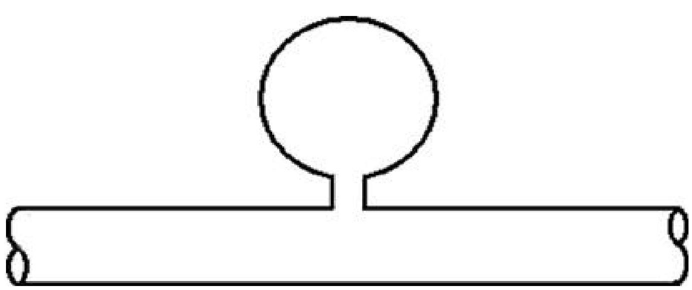

Figure 1.

The air in the neck acts as a mass. The air in the sphere acts as a spring. The spherical Helmholtz resonator thus behaves as a mechanical spring-mass system.

The natural frequency f_n is given by

$$f_n = \frac{c}{2\pi}\sqrt{\frac{A}{L_e V}} \tag{1}$$

where

- c is speed of sound in the fluid or gas,
- A is the cross-sectional area of the neck,
- L_e is the effective length of the neck,
- V is the volume of the chamber.

Note that equation (1) would also apply to other chamber shapes, such as a cylindrical or box-shaped cavity.

The effective length is

$$L_e \approx L + 1.5 r \tag{2}$$

where

- r is the radius of the neck,
- L is the length of the neck,

The effective length is longer than the actual length due to “radiation-mass loading.”

The frequency formula is taken from References 1 and 2.

Transmission Attenuation

Assume that there is no dissipation due to viscosity. The power transmission T_Π is

$$T_\Pi = \frac{1}{1 + \left\{ \dfrac{c}{2P\left[\dfrac{2\pi f L_e}{A} - \dfrac{c^2}{2\pi f V} \right]} \right\}^2} \tag{3}$$

where

- P is the pipe cross-section area,
- f is the forcing frequency.

Example

Consider that a 250-Hz noise tone must be attenuated in an air pipe line. Design a Helmholtz resonator.

The speed of sound in air is approximately

$$c = 1125 \text{ ft/sec} = 13{,}500 \text{ in/sec}$$

There are many possible solutions. Start by assuming:

$r = 0.5$ in
$L = 1.0$ in

Thus,

$A = 0.785 \text{ in}^2$
$L_e = 1.75$ in

Equation (1) can be rearranged as

$$V = \left[\frac{A}{L_e}\right]\left[\frac{c}{2\pi f_n}\right]^2 \tag{4}$$

$$V = \left[\frac{0.785 \text{ in}^2}{1.75 \text{ in}}\right]\left[\frac{13{,}500 \text{ in / sec}}{2\pi(250 \text{ Hz})}\right]^2 \tag{5}$$

$$V = 33.1 \text{ in}^3 \tag{6}$$

Again, this volume could be inside a sphere, cylinder, or other chamber shape.

Now assume that the resonator is attached to a pipe with a radius of 1 in. The power transmission curve is shown in Figure 2.

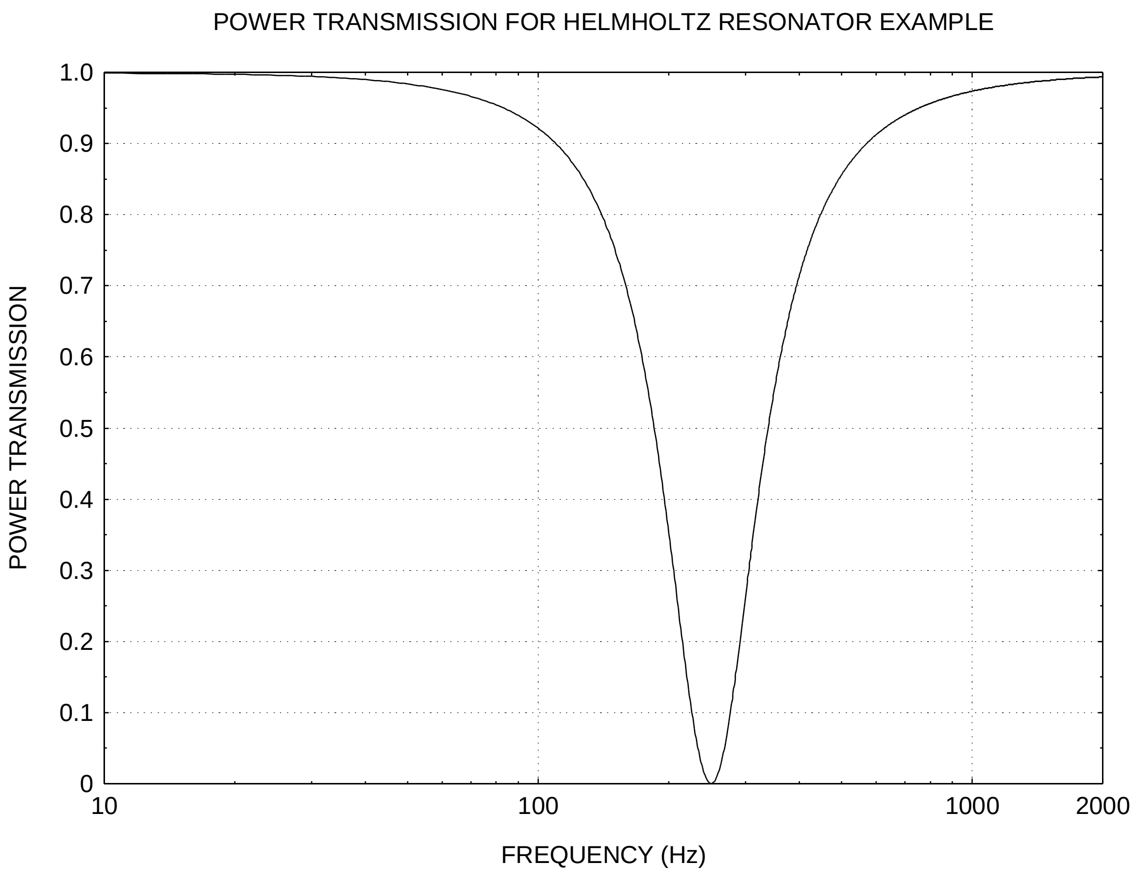

Figure 2.

Note that several Helmholtz resonators, each tuned to a different frequency, can be combined on a piping system. Attenuation over a wider frequency domain can thus be achieved for the system.

<u>References</u>

1. George Diehl, Machinery Acoustics, Wiley-Interscience, New York, 1973.
2. Lawrence Kinsler et al, Fundamentals of Acoustics, Third Edition, Wiley, New York, 1982.
3. G. Sutton, Rocket Propulsion Elements, Fifth Edition, Wiley, New York, 1986.
4. C. Harris, Handbook of Noise Control, McGraw-Hill, New York, 1957.

APPENDIX A

Rocket Engines

Rocket vehicles with liquid engines may experience combustion instability, which causes excessive vibration forces, as described in Reference 3.

Combustion in a liquid rocket engine does not occur in an ideal thermodynamic manner. The pressure, temperature, propellant flow rate, and exhaust velocity each experience fluctuations. Propellant pump cavitation and gas entrapment in propellant flow may contribute to these fluctuations.

The pressure fluctuation can interact with the natural frequencies of the propellant feed system or the combustion chamber acoustic volume. This interaction causes instability oscillations. A rocket with "smooth combustion" has pressure fluctuations that do not exceed ±5% of the mean chamber pressure, during steady operation.

There are different types of combustion instability as summarized in Table A-1.

Table A-1. Types of Combustion Instability

Type	Frequency Range (Hz)	Cause Relationship
Low frequency called chugging or system instability	10-200	Linked with pressure interactions between the propellant feed system and combustion chamber. May excite longitudinal vibration mode of entire vehicle.
Intermediate frequency, called acoustical, buzzing, or entropy waves	200-1000	Linked with mechanical vibrations of Propulsion structure, injector manifold flow eddies, fuel/oxidizer fluctuations, and propellant feed system resonances.
High frequency called Screaming, screeching, or squealing	Above 1000	Linked with combustion pressure waves and chamber acoustical resonance properties.

There are several methods to control combustion instability, as given in Reference 3. One method is to use a perforated liner as shown in Figure A-1. The liner acts as a Helmholtz resonator as shown in Figure A-2.

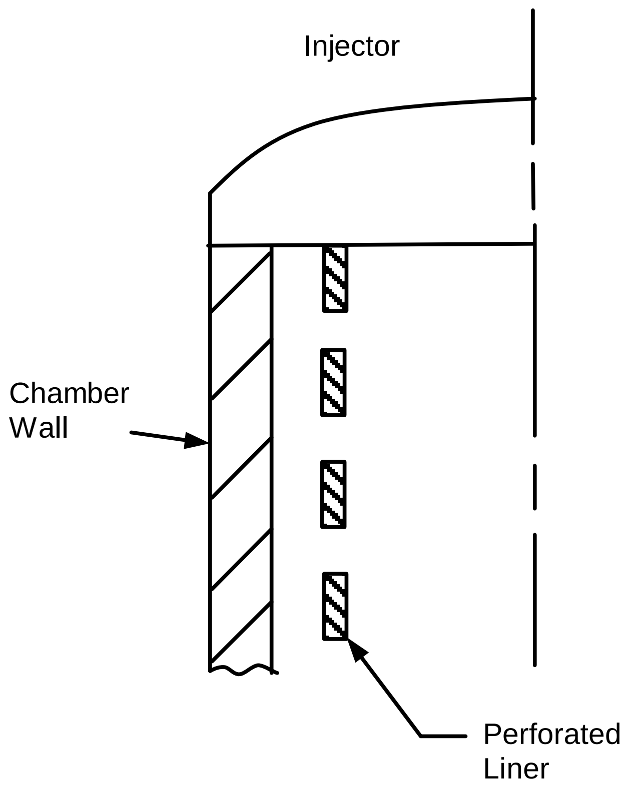

Figure A-1. Perforated Liner in Combustion Chamber

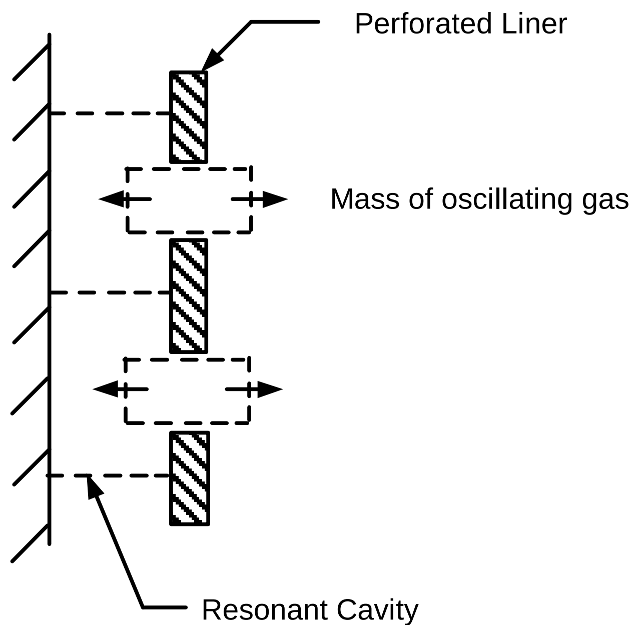

Figure A-2. Principle

APPENDIX B

Guitar

A guitar has a Helmholtz resonance. This resonance is due to oscillations of the air at the sound hole, driven by the compliance of air inside the body.

First, the air moves inward. It is thus compressed. Its pressure increases. The pressure then drives the mass of air outward. The air returns to its equilibrium position, but its momentum carries it outside of the body a small distance. This rarifies the air inside the body. The air mass is thus sucked back into the body. The cycle repeats itself.

The air thus vibrates like a mass on a spring.

Automobile

The following example is taken from Reference 4.

Consider an automobile with a window which is partially or totally open. The automobile is being driven at, say, 50 mph. The interior of the automobile thus becomes a Helmholtz resonator. The driver and passengers will be exposed to a wind pressure oscillation. The oscillation frequency depends on the volume, the neck area, and the neck length. The neck area is the area of the opening. The neck length is the thickness of the door and window frame. The volume is that of the entire automobile including the trunk.

Loudspeaker

A vented loudspeaker enclosure behaves as a Helmholtz resonator.