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TRANSMISSION LOSS AND BACK PRESSURE CHARACTERISTICS FOR COMPRESSOR MUFFLERS

by

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ABSTRACT

Changing the typical definition of the transmission loss, which is the acoustic pressure amplitude ratio in a test arrangement consisting of anechoic pipes, the amplitude of the volume velocity ratio is recommended for transmission loss models of compressor mufflers. The theoretical calculation is based on the four pole parameter theory using the wave equation for each acoustic element. Transmission loss curves are plotted for typical silencer elements. Also, the amplitude and time lag of ratios of the pressure and volume velocity at the entrance of the muffler are shown, which can be used as indicators if the silencer is too restrictive to flow.

INTRODUCTION

This paper introduces a different definition of transmission loss compared to the typical one which is the acoustic pressure amplitude ratio [1].

The transmission loss is here defined as

$$\eta = \frac{Q_{in} - Q_{out}}{Q_{in}} \tag{1}$$

This definition has been used by the senior author and his students in the past, but not perhaps in the systematic presentation schema advocated here. In decibels, the transmission loss is

$$TL = 20 \log_{10}\eta = 20 \log_{10}\frac{Q_{in}}{Q_{out}} \tag{2}$$

The volume velocity has more physical meaning than the pressure in a compressor where the oscillatory valve flow is defined in terms of volume velocities.

Also, it is desirable to define the dynamic back pressures which develop in silencers and which may interfere with the proper operations of valves (valve flutter, energy loss). We define it in terms of the amplitude and time lag of ratios of the pressure and volume velocity at the entrance of the muffler, P_{in}/Q_{in}.

EXAMPLE CASE

Four Pole Parameters of Acoustic Elements

Two cases where harmonic volume velocities at the same frequency are defined at each end of a system are shown in Figure 2.

For example, the relationship between input pairs Q_{L1}, P_{L1} and output pairs Q_{L2}, P_{L2} of one acoustic tubular element, which has pipe length L_1, can be described as [2]

$$\begin{Bmatrix} Q_{L1} \\ P_{L1} \end{Bmatrix} = \begin{bmatrix} b_1 & b_2 \\ b_3 & b_4 \end{bmatrix} \begin{Bmatrix} Q_{L2} \\ P_{L2} \end{Bmatrix} = [B] \begin{Bmatrix} Q_{L2} \\ P_{L2} \end{Bmatrix}, \tag{3}$$

where $b_1 = \cosh(\gamma L_1) = b_4$, $b_2 = (j\omega A_1/(\rho C^2 \gamma))\sinh(\gamma L_1)$, $b_3 = ((\rho C^2 \gamma/(j\omega A_1))\sinh(\gamma L_1)$.

The four pole parameters of the second element can be described in the same way,

$$\begin{Bmatrix} Q_{L3} \\ P_{L3} \end{Bmatrix} = \begin{bmatrix} c_1 & c_2 \\ c_3 & c_4 \end{bmatrix} \begin{Bmatrix} Q_{L4} \\ P_{L4} \end{Bmatrix} = [C] \begin{Bmatrix} Q_{L4} \\ P_{L4} \end{Bmatrix}, \tag{4}$$

where $c_1=\cosh(\gamma L_2)=c_4$, $c_2=(j\omega A_2/(\rho C^2\gamma))\sinh(\gamma L_2)$, $c_3=(\rho C^2\gamma/(j\omega A_2))\sinh(\gamma L_2)$.

Combining Elements

Using boundary conditions which are $P_{L2}=P_{L3}$ and $Q_{L2}=Q_{L3}$, the four pole parameters of the whole system can be described by multiplying the two matrices. This results in

$$\begin{Bmatrix} Q_{L1} \\ P_{L1} \end{Bmatrix} = \begin{bmatrix} d_1 & d_2 \\ d_3 & d_4 \end{bmatrix} \begin{Bmatrix} Q_{L4} \\ P_{L4} \end{Bmatrix} = [D] \begin{Bmatrix} Q_{L4} \\ P_{L4} \end{Bmatrix}, \quad (5)$$

where [D]=[B]x[C].

Ratio Q_{in}/Q_{out}

If the end of the system has acoustic pressure release condition, the volume velocity ratio, which is the transmission loss, can be calculated.

$$Q_{in}/Q_{out} = Q_{L1}/Q_{L4} = d_1 \quad (6)$$

Back Pressure

The amplitude and time lag of ratios of the pressure and volume velocity at the entrance of the muffler are very important from the viewpoint of valve action and energy loss, and can be described in the same way :

$$P_{in} = P_{L1} = d_3 Q_{L4} = (d_3/d_1) Q_{L1} \quad (7)$$

$$P_{in}/Q_{in} = P_{L1}/Q_{L1} = d_3/d_1 \quad (8)$$

Presenting this information in a systematic way when classifying silencers is the main contribution of this paper. Even if the system of interest is composed of many elements, simple four pole parameters can be generated relating input and output.

TRANSMISSION LOSS CURVES FOR TYPICAL SILENCER ELEMENTS

In the following, dimensions L_1, D_1 and D_2 were kept constant unless stated otherwise. Numerically, they are : L_1=20 mm, D_2=4 mm, D_1/D_2=4. The speed of sound was C=140 m/s.

Figure 3 shows a typical expansion chamber-tail pipe design. It is noted that the silencer becomes effective above its cut-off frequency, which is a function of the tail pipe length L_2. The region of ineffectiveness in the vicinity of 1800 Hz for $L_2=L_1$ corresponds to the first organ pipe resonance in the tail pipe. The back pressure plot shows that the back pressure at the low frequency end of the plot (it is known that this is the region which controls valve motion restriction due to back pressure build-up) increases as the cut-off frequency is decreased, which illustrates the fact that acoustic criteria and valve energy efficiency are basically at odds. Of course, phasing of the back pressure is also important. Figure 4 shows what happens when the diameter of the expansion chamber is doubled. There is an improvement in transmission loss, because the cut-off frequency decreases and the magnitude of the transmission loss increases. The back pressure build-up is in general reduced, except in the vicinity of the lowered cut-off frequency. The effect of adding a second expansion chamber shows (Figure 5) approximately a doubling of transmission loss, but the cut-off frequency increases slightly. The back pressure behavior remains essentially unchanged. Adding a third expansion chamber (Figure 6) continues the trend. In Figure 7, the behavior of a side branch resonator is shown if it is attached simply to a pipe section without expansion chamber behind the valve. As one can see from the back pressure build-up, this is essentially an undesirable design. It is necessary to provide for an expansion chamber behind the valve. This is illustrated in Figure 8, where two arrangements of the side branch resonator are explored. Figure 9 answers the question whether there is an advantage in dividing the original expansion chamber of Figure 3. From a transmission loss viewpoint, this is indeed the case (except that the cut-off frequency is higher), but the back pressure build-up is much increased.

CONCLUSIONS

A different way of characterizing silencers for compressors was advocated again, which utilizes a transmission loss definition based on harmonic volume velocity reduction. This is in contrast to the normal procedure where transmission loss is defined in terms of pressure ratios, based on a "test" section with anechoic terminations.

It was also advocated that back-up pressure information needs to be examined and presented.

A few example cases were discussed.

REFERENCES

1. C. Harris, *Hand Book of Noise Control*, McGraw-Hill Book Company, Inc., 1957.
2. W. Soedel, *Gas Pulsations in Compressor and Engine Manifolds*, Short Course Text Book of Purdue Compressor Technology Conference, Ray W. Herrick Laboratories, Purdue University, 1978.

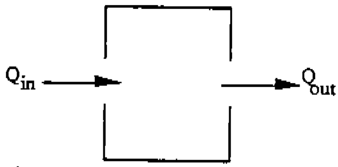


Figure 1 Acoustic element with input and output volume velocity

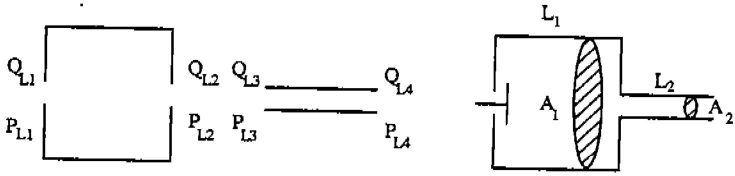


Figure 2 Two different acoustic elements

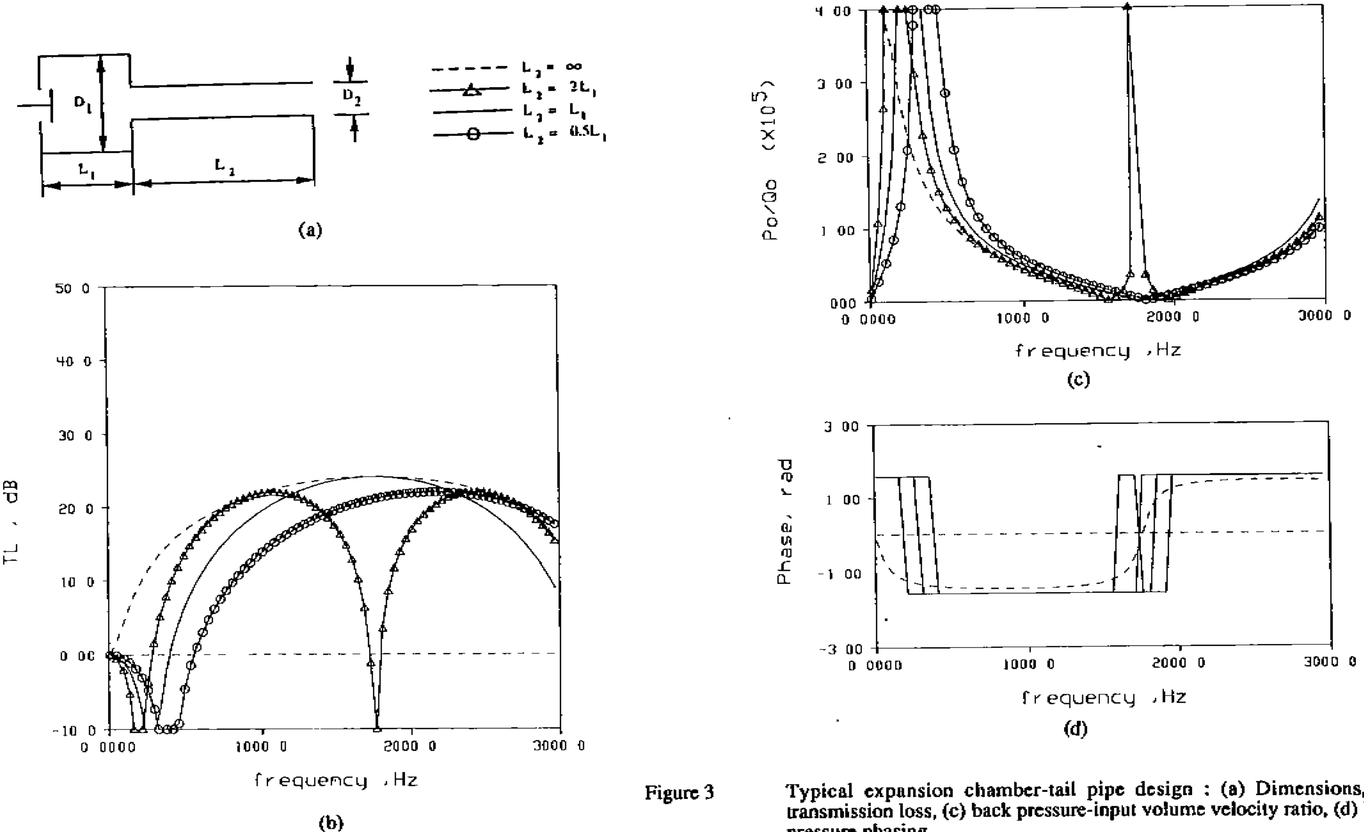


Figure 3 Typical expansion chamber-tail pipe design : (a) Dimensions, (b) transmission loss, (c) back pressure-input volume velocity ratio, (d) back pressure phasing

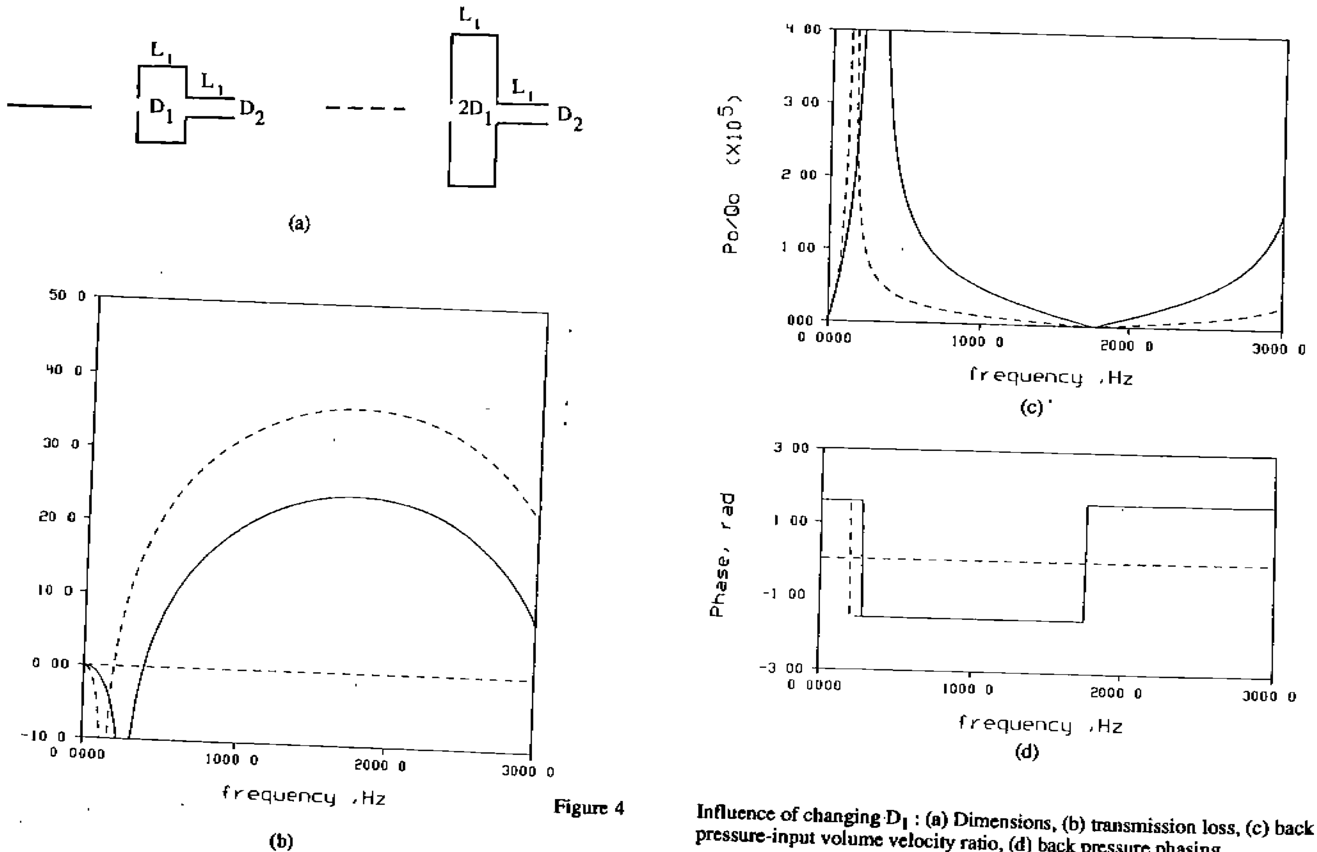
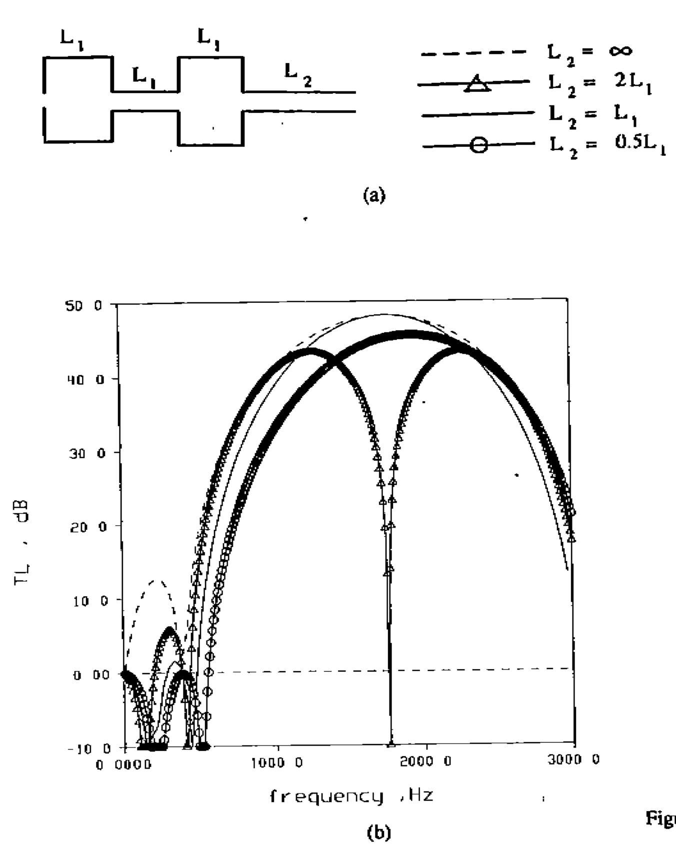


Figure 4 **Influence of changing D_1 : (a) Dimensions, (b) transmission loss, (c) back pressure-input volume velocity ratio, (d) back pressure phasing**



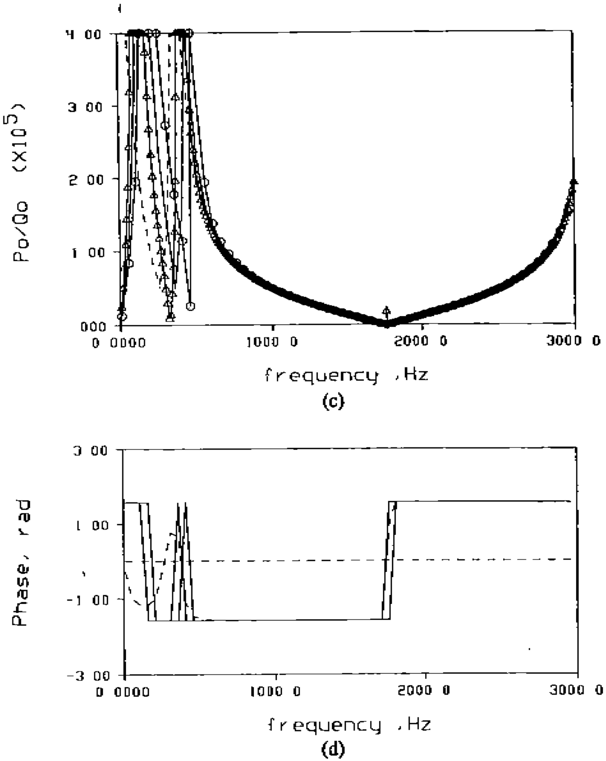


Figure 5 Two-expansion-volume muffler : (a) Dimensions, (b) transmission loss, (c) back pressure-input volume velocity ratio, (d) back pressure phasing

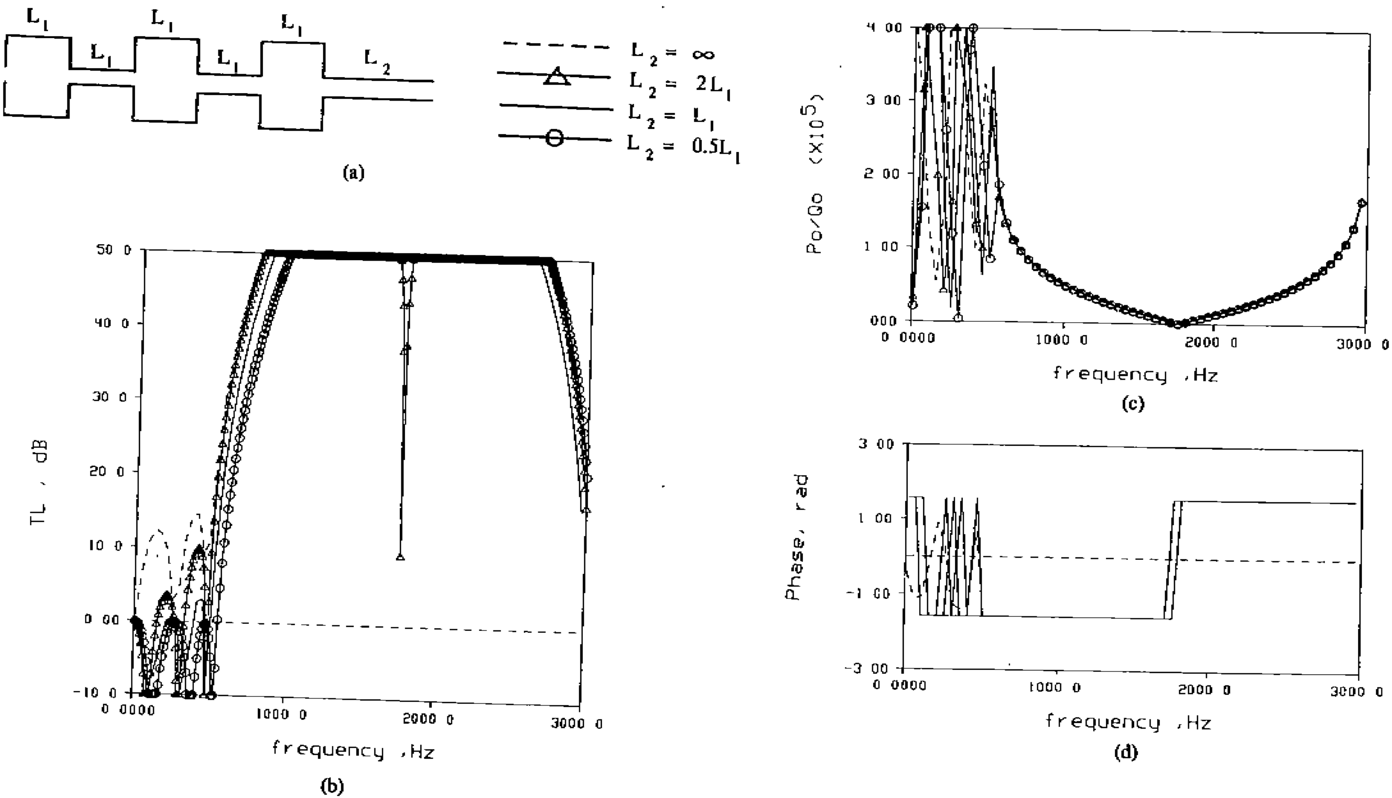
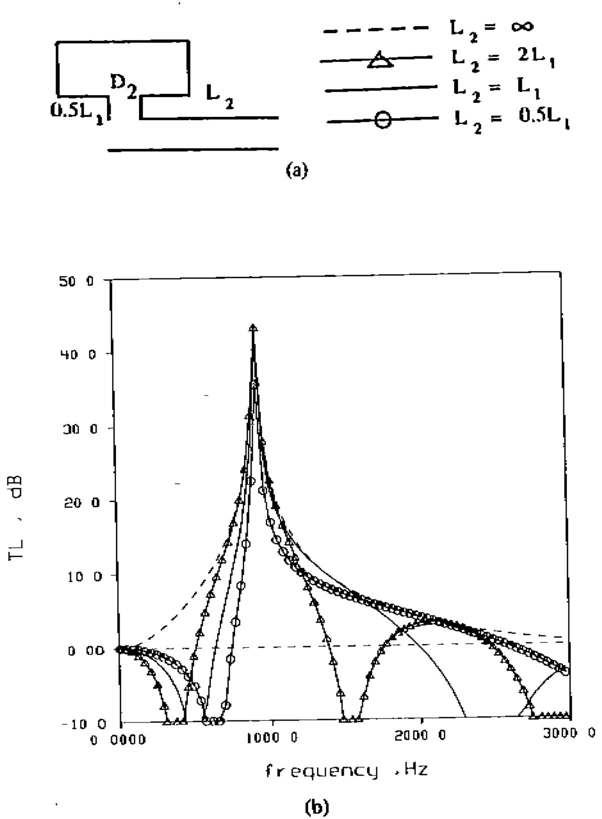


Figure 6 Three-expansion-volume muffler : (a) Dimensions, (b) transmission loss, (c) back pressure-input volume velocity ratio, (d) back pressure phasing



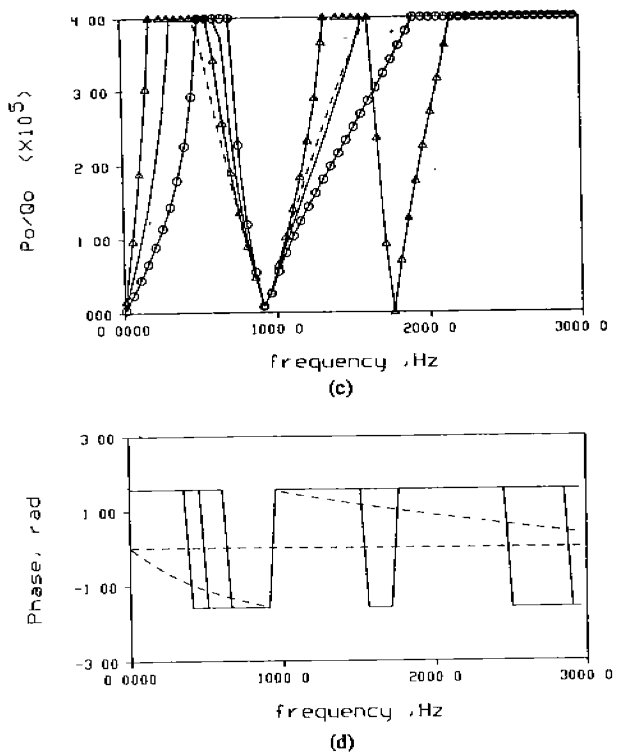


Figure 7 Behavior of tuned side branch resonator, as function of changing L_2 : (a) Dimensions, (b) transmission loss, (c) back pressure-input volume velocity ratio, (d) back pressure phasing

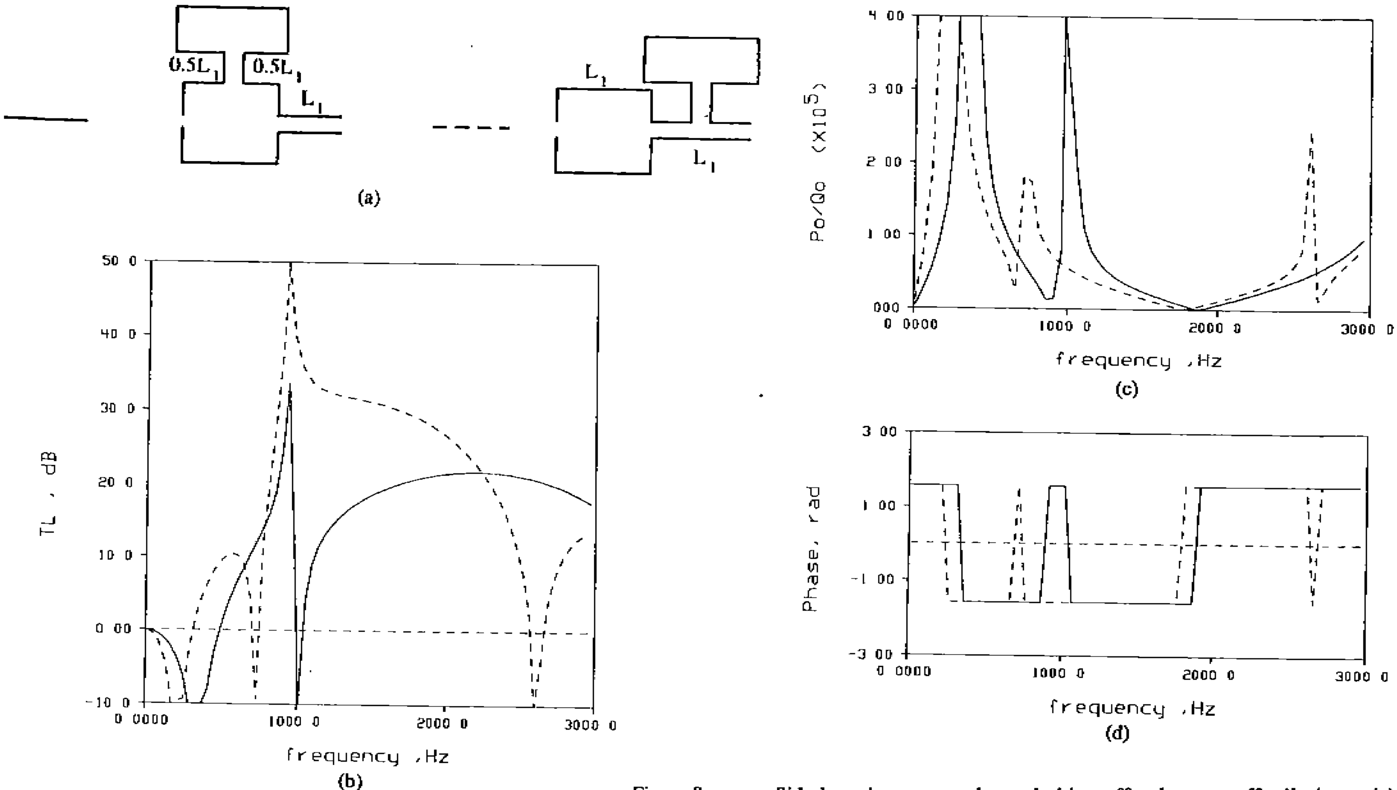


Figure 8 Side branch resonator located either off volume or off tail pipe. : (a) Dimensions, (b) transmission loss, (c) back pressure-input volume velocity ratio, (d) back pressure phasing

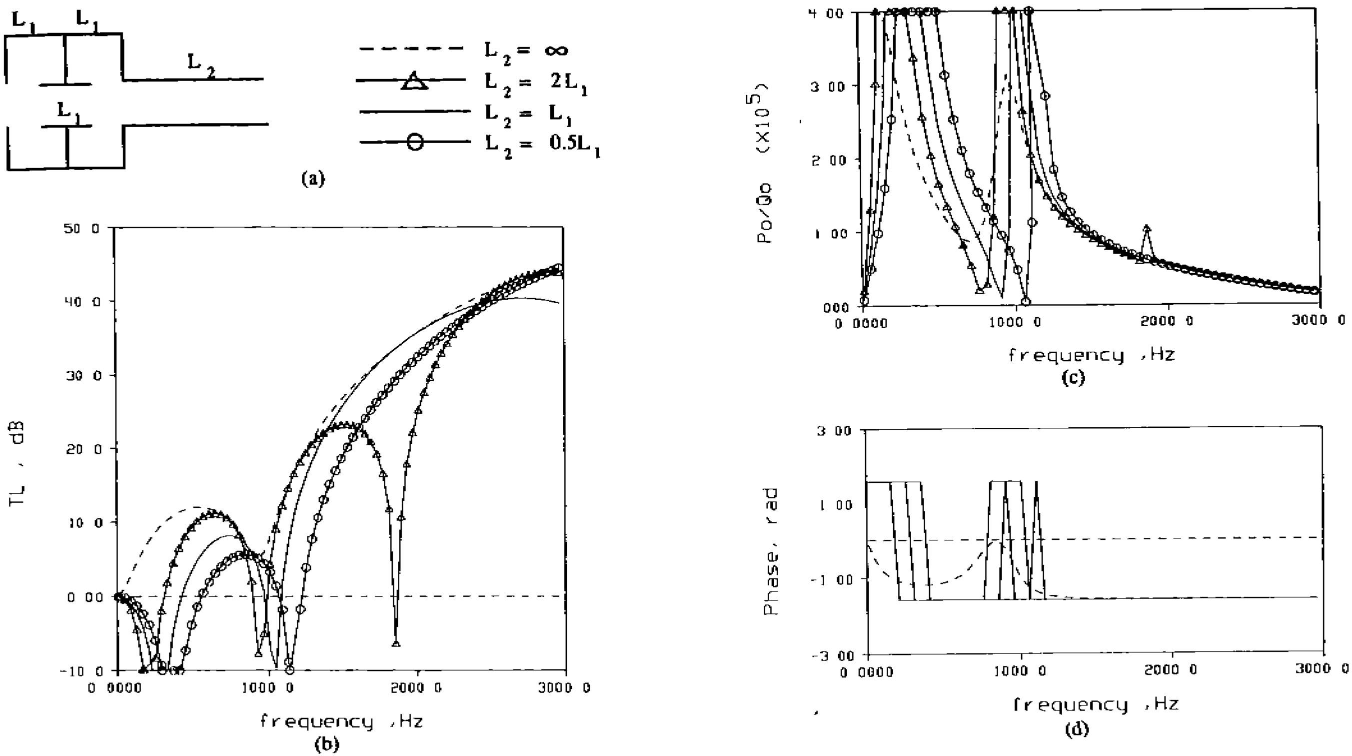


Figure 9 Influence of expansion chamber subdivision : (a) Dimensions, (b) transmission loss, (c) back pressure-input volume velocity ratio, (d) back pressure phasing