Three-Dimensional Diaphragm Suspensions for Compression Drivers*

FANCHER M. MURRAY AND HOWARD M. DURBIN

James B. Lansing Sound, Inc., Northridge, CA 91329, USA

The half-roll, when executed in a hard material, is not very compliant. It acts more like a flat annular ring than a roll. The roll is still a flat annular ring at its second eigentone. If this frequency occurs within the operating region of a driver, it becomes a dynamic absorber and rolls off the frequency response most dramatically. Materials having higher modulus-to-weight ratios are available, but their use is costly and sometimes dangerous. Just as an I beam has a higher stiffness-to-weight ratio than does a solid bar, there are special designs that can be embossed with standard tooling into the surround which can obtain useful improvements with low-cost materials. Some aspects of this problem and its evaluation are discussed.

0 INTRODUCTION

The half-roll suspension used on most metallic compression driver diaphragms may be visualized as shown in Fig. 1(a), where the diaphragm material has been formed into a suspension. Using a modified narrow slice of this roll, as in Fig. 1(b), it is easy enough to picture a rolling motion in response to vertical forces applied to the free end [Fig. 1(c)]. However, the suspensions being used are not narrow slices; they are annular rings. The material cannot roll upon itself without experiencing large membrane stresses, and the effect is that the rolled annular ring bends just as if it were a flat annular ring, the roll adding only a small amount of compliance with a large amount of complication [Fig. 1(d). The entire compliance may then be compared with an annular ring having only two dimensions —the radial direction and the circumferential direction, with no real axial dimension acting.

It is instructive to reduce this further to one dimension (the radial direction) and compare the suspension with a clamped-free beam for a moment. Fig. 2(a) shows this concept, ignoring all effects of the diaphragm attached to it. An alternating force, as from a voice coil, will cause the beam to flex up and down in phase with the force. At resonance the mechanical impedance will drop to a very low value, reflected as a high electrical impedance in the voice coil. As the drive frequency is increased, the beam will approach an antinode f_2 [Fig. 2(c)] at the voice-coil position and present a mechanical impedance approximately equal to that of the mounting point at the other end of the beam. The reflected electrical impedance will then approach zero. As far as the electrical circuit is concerned, this is not an "allowed" frequency. The second allowed or eigenfrequency occurs as illustrated in Fig. 2(d), where the motion is again in phase with the drive force. Because this high mechanical impedance tends to cause a sharp reduction in voice-coil motion, it would appear that the transducer would cease to operate at the frequency of this antinode. In practice there is little or no tendency for this to happen. As shown later, the electrical reflection of the mechanical circuit drops very low at this antinode, but air loading of the diaphragm appears to apply sufficient damping so that actual transducer response is only slightly affected. The frequency of this antinode does, however, affect the frequency of the next node, and these two fre-

* Presented at the 63rd Convention of the Audio Engineering Society, Los Angeles, 1979 May 15–18; revised 1980 May 15.

quencies define the high frequency limits of the practical transducer.

In Fig. 2(e) we see that it is possible to make a variable-depth beam in a manner that will have only a small effect on the first resonance while having a much larger effect on the upper resonances. For the past several years we have been investigating this method of control using a true third dimension.

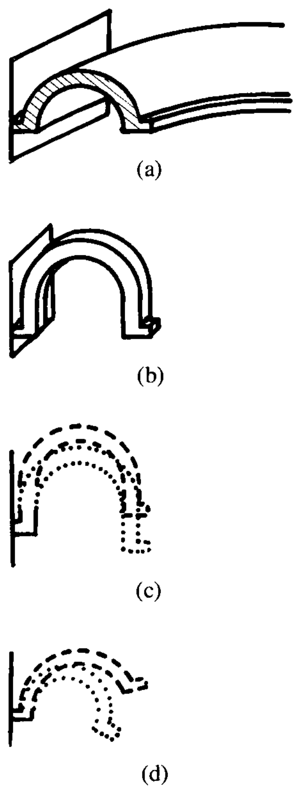


Fig. 1. Half-roll suspension. (a) Solid annular half-roll. (b) Sliced roll with legs. (c) Linear motion of sliced roll. (d) Complex motion of solid half-roll.

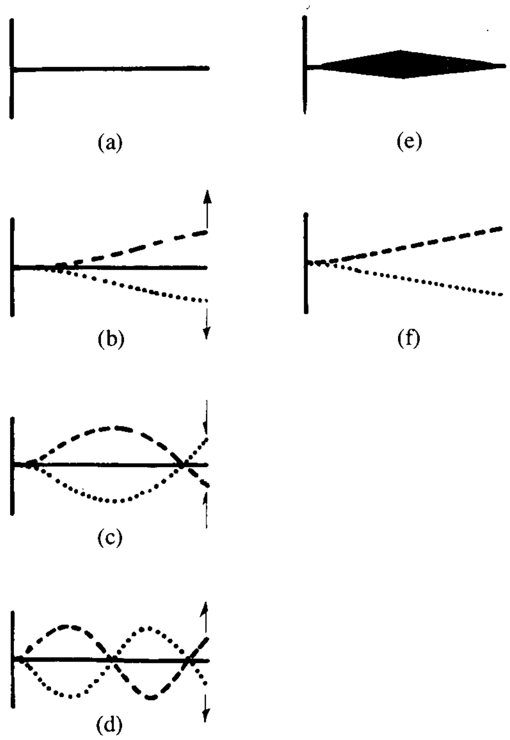


Fig. 2. Vibrational modes of a beam. (a) Clamped-free uniform beam. (b) First eigentone f_1. (c) Antinode $f_2 = 6.27f_1$. (d) Second eigentone $f_3 = 17.6f_1$. (e) Nonuniform beam. (f) First eigentone.

1 CONTROL OF THE HIGHER MODES IN THE HALF-ROLL

In late 1978 Kinoshita and Locanthi [1] reported an insight into the control of these higher modes through the use of different materials. In developing a beryllium driver they have shown that the ratio of the first and second suspension "cantilever" resonances f_1 and f_3 (f_0 and f_s in [1]) could be altered by using the higher modulus-to-weight ratio of beryllium as opposed to aluminum. Presumably this could be carried even further with materials having even higher ratios. However, the three-dimensional suspension illustrated in Fig. 2 gives the desired flexibility of control without resorting to metallurgy or material thickness as parameters. In practice it is not necessary to form a surround having a variable thickness to achieve this third dimension. Fig. 3 illustrates two concepts where a three-dimensional pattern in the surround has much the same effect as does a variable thickness. Fig. 3(a) shows the familiar "tangential" surround that JBL and others have used for many years in popular 45-mm diaphragms. The second concept [Fig. 3(b)] (patent pending) is an alternating diamond-shaped pattern extending below as well as above the mounting plane. Additionally this type of forming has the advantage that most membrane stresses are removed, and the remaining bending stresses are somewhat better behaved. This has resulted in a more uniform product with less dependence on material variations.

2 WHY CONTROL THE HIGHER MODES?

At this point let us look at some of these higher modes and see what effect they have on the response. This investi-

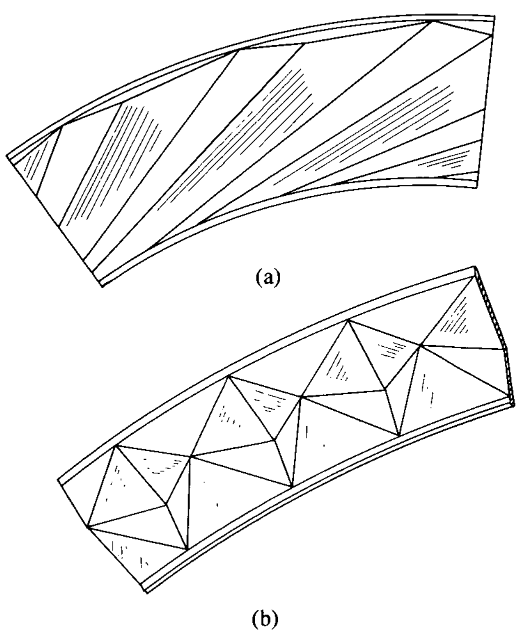


Fig. 3. Three-dimensional suspension concepts. (a) Tangential surround. (b) Diamond-shaped surround.

gation was an outgrowth of a problem affecting the high-frequency response of our 45-mm driver. It has been known that the high-frequency characteristic of the LE85 transducer has never conformed to available theory [2], [3], because there was considerable high-frequency output over that predicted by theory. This is the good news; however, the bad news is that it was found that certain material variations caused some assemblies to behave more like the theoretical response and thereby be rejected by the quality assurance department. Investigation of these anomalies revealed that the impedance curves of the "good" units showed a small "bump" between 15 and 20 kHz which was not shown by theory or by the "bad" units. Further investigation showed a slight hint of such a "bump" in the bad units around 22 kHz. At this point it became desirable to examine the transducer motional impedance without the encumbrance of the voice-coil or acoustic impedances.

3 IMPEDANCE MEASUREMENTS

3.1 Blocked Voice Coil

Careful measurements of the voice-coil impedance both in air and in the magnet (with epoxy blocking) produced the data of Fig. 4. The voice coil alone, separated from its dome, produces a classic inductance in series with a resistance, as shown by the dotted curve. The aluminum dome has the effect of shunting this, as shown by the dashed curve. Finally with the voice coil and its dome solidly cemented into a charged magnet, further shunting is illustrated by the solid curve. The resulting equivalent circuit, showing not only the shunting resistor but also the leakage inductance coupling to it is seen in the figure. This circuit can be shown to match the blocked impedance as close as measurements of that impedance will sustain over the entire 20–200 000-Hz range. This impedance, then, must be subtracted from the transducer impedance to obtain the motional impedance.

3.2 Motional Impedance

The simplest way to accomplish this was found to be with the bridge circuit of Fig. 5. The arm resistors are many times the transducer impedance and the oscilloscope has the facility of isolating the input and output sides of the bridge without the capacitive loading that a transformer would give. With the blocked transducer in the "STD" arm of the bridge and an operating transducer in the "UNK" arm, the difference output approximates the motional impedance and can be plotted directly on the graphic level recorder. The only other refinement required was to place the operating transducer in a vacuum chamber to remove the acoustic load. Since the oscilloscope has A, B, and B-A output switches, it becomes the control circuit for plotting either the "STD," the "UNK," or their difference. Fig. 6 is a plot of these three parameters for a "good" 2420 transducer and the blocked standard. Insofar as the voice coils of these transducers are identical, the solid curve represents the pure mechanical motional impedance of the transducer being investigated. The method seems to be reasonably accurate and considerably more sensitive than a measurement of the total impedance.

The impedance bump of the total curve is then clearly illustrated in the motional impedance curve, as is the zero impedance predicted by the simplistic analysis of Fig. 2(c). The curve is characterized by a pole, a zero, a pole, and then a rising curve. This rising characteristic has lately been shown [4] to be the result of small inductance differences between the blocked and active voice coils. A one-turn difference between the coils is sufficient to cause swamping of further evidence of the mechanical circuit. Subsequent investigation tends to show that the motional impedance of the pure mechanical circuit continues to drop as frequency increases.

4 SECOND POLE AT THE RIGHT FREQUENCY

Fig. 7 requires a change of reference since its frequency

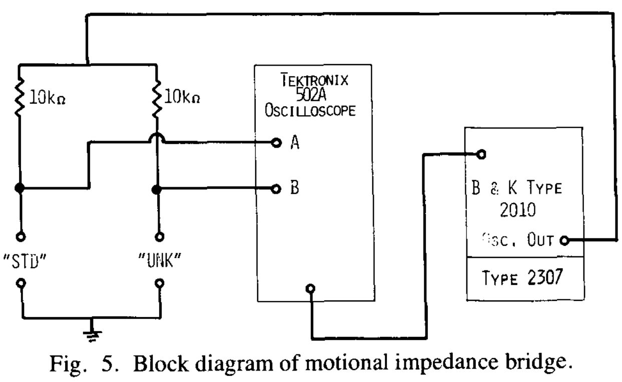


Fig. 5. Block diagram of motional impedance bridge.

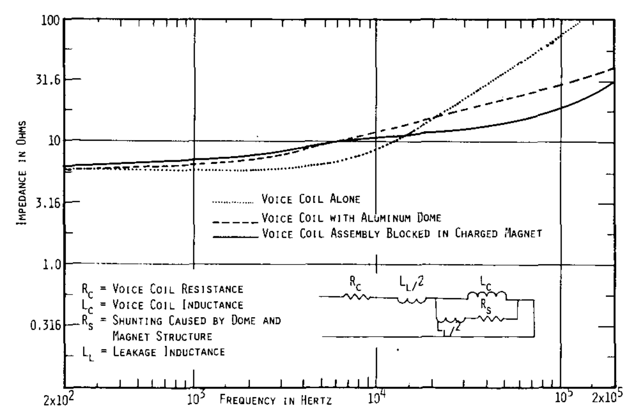


Fig. 4. Blocked voice-coil impedance.

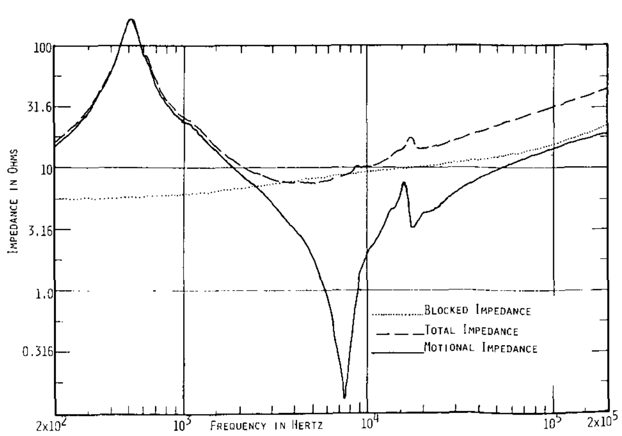


Fig. 6. Motional impedance in vacuum of a 2420 compression driver.

range is between 20 and 20 000 Hz. Here we show the total impedance and the motional impedance in air. An extra acoustic pole is shown around 2500 Hz, and considerable damping is added by the air. A solid curve also shows the measured response of the transducer driving a 25-mm-diameter anechoic tube. Note that the 17 000-Hz frequency of the second pole in the impedance curve seems to correspond with a rapid dropoff in the response curve.

5 SECOND POLE AT A TOO-HIGH FREQUENCY

Shifting back to a 200–200 000-Hz range, Fig. 8 shows the motional impedance of a rejected transducer. The second pole is just as high (amplitudewise) as it was in Fig. 6, but it now appears at 22 kHz, where it is swamped by the difference inductance mentioned above. Fig. 9 shows the response and impedance curves of this "bad" transducer. Because the second pole is at a higher frequency, it is unable to participate in lifting the frequency response in the 15-kHz region, and the transducer tends to follow a much more "theoretical" curve based on a simple parallel tank circuit for the motional impedance. There is some increased output seen above 19 kHz, resulting from this high-frequency pole, but it comes too late to be of use at audio frequencies. The response of the "good" transducer is shown for comparison. It is well to note that dimensional differences between these two transducers are of the order of 0.003 mm and cannot be readily determined before the transducer is assembled.

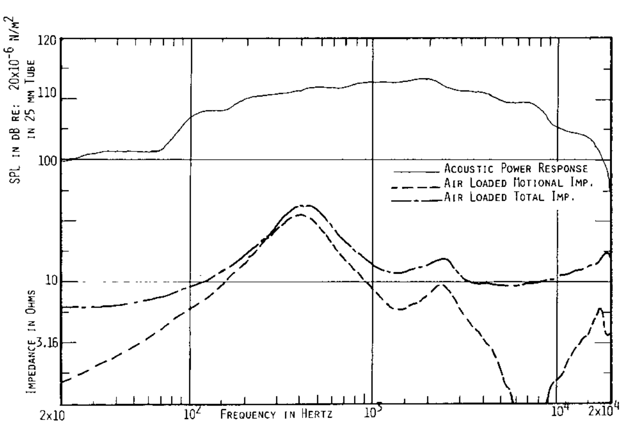


Fig. 7. Power response and air-loaded impedance of a 2420 compression driver.

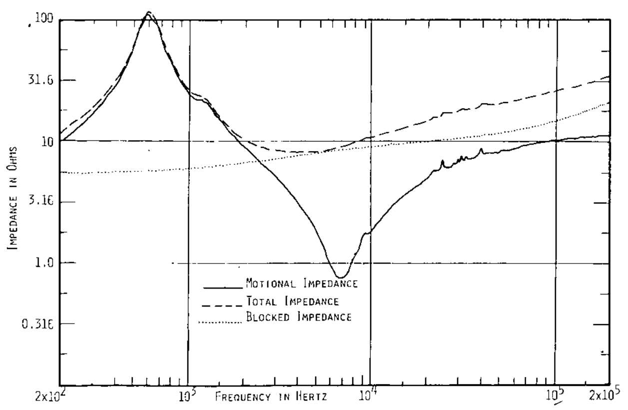


Fig. 8. Motional impedance in vacuum of a rejected 2420 compression driver.

6 A NEW TRANSDUCER

Because the tangential surround is so highly sensitive to small dimensional differences, the diamond-shaped pattern surround of Fig. 3(b) is being incorporated into the 45-mm transducer. This pattern appears to be less sensitive, and uniformity is easier to achieve.

The impedance curves for this new transducer are shown in Fig. 10. This shows a well-defined pole at 16 kHz plus some additional activity between 30 and 50 kHz. This additional activity will be investigated at a later date. The audiofrequency response range is illustrated in Fig. 11 and shows smooth response to the 16-kHz second pole.

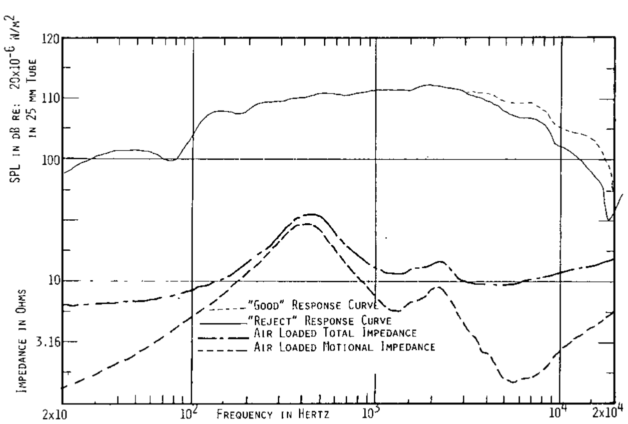


Fig. 9. Power response and air-loaded impedance of a rejected 2420 compression driver.

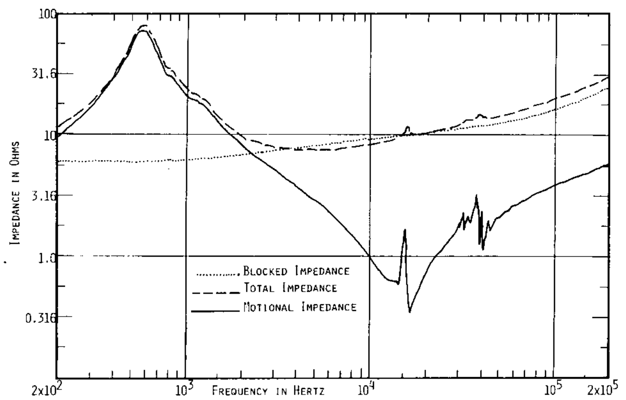


Fig. 10. Motional Impedance in vacuum of a 2421 compression driver.

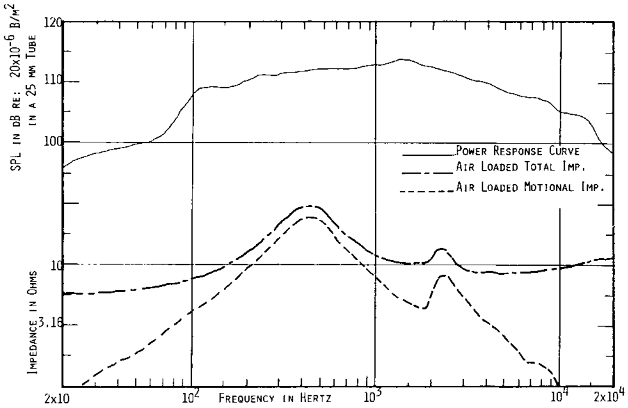


Fig. 11. Power response and air-loaded impedance of a 2421 compression driver.

7 HOLOGRAPHIC CONFIRMATION OF SUSPENSION ACTIVITY

Since the second impedance pole has been found responsible for significant effects on the transducer response, a holographic study was made of the different 45-mm diaphragms to verify that the surround was, indeed, responsible for this pole. Interference holograms clearly show considerable activity in the surround at each of the respective second-pole frequencies and greatly diminished activity at nearby frequencies.

8 SECOND POLE AT A TOO-LOW FREQUENCY

For the case where the second impedance pole is at too low a frequency it is only necessary to examine a transducer having an aluminum half-roll suspension.

Such a transducer is illustrated in Figs. 12 and 13. Fig. 12 shows the vacuum motional impedance of the model 2440 transducer having a 100-mm diaphragm. The second pole appears at 8000 Hz. Fig. 13 shows the result of this in the frequency response curve. This curve is legion with transducers going back to early times and clearly illustrates that the second pole, rather than the preceding zero, marks the end of the frequency response range.

Again, the three-dimensional diamond-shaped pattern comes to the rescue. Through control of the pattern depth, the second-pole frequency can be placed at any reasonable frequency as shown in Fig. 14 at 15 kHz. With this the 100-mm model 2441 transducer shows a smooth response to the highest audio frequencies on a 50-mm-diameter anechoic tube (Fig. 15).

9 CONCLUSIONS

It has been demonstrated, at least for a metallic suspension, that the useful high-frequency range of a compression driver is defined by the second resonance of its suspension in addition to the parameters normally considered. Therefore it is possible to expand the response range beyond that found in the common half-roll suspension without resorting to exotic materials. The reported bridge circuit, apparently not described in previous literature, can be used to accurately determine the position (in frequency-amplitude space) of the second resonance of a given design. This greatly facilitates empirical design efforts.

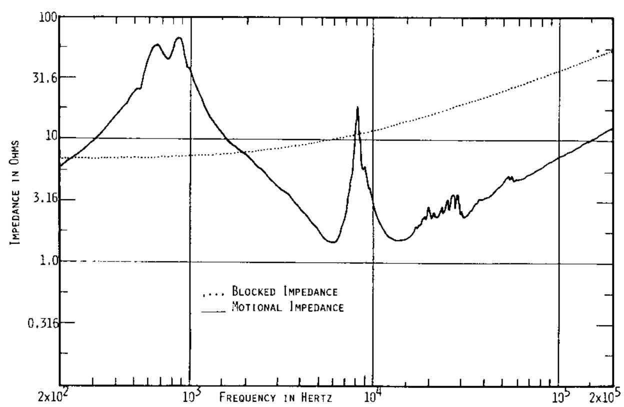


Fig. 12. Motional impedance in vacuum of a 2440 compression driver.

10 REFERENCES

[1] S. Kinoshita and B. N. Locanthi, "The Influence of Parasitic Resonances on Compression-Driver Loudspeaker Performance," presented at the 61st Convention of the Audio Engineering Society, New York, 1978 November 3–6, preprint no. 1422.

[2] D. B. Keele, Jr., "Low-Frequency Horn Design Using Thiele/Small Driver Parameters," presented at the 57th Convention of the Audio Engineering Society, Los Angeles, 1977 May 10–13, preprint no. 1250.

[3] L. E. Kinsler and A. R. Frey, *Fundamentals of Acoustics*, 1st ed. (Wiley, New York, 1950), pp. 309–317.

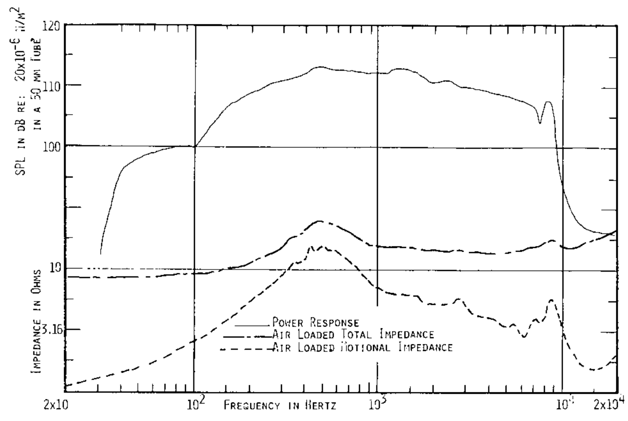


Fig. 13. Power response and air-loaded impedance of a 2440 compression driver.

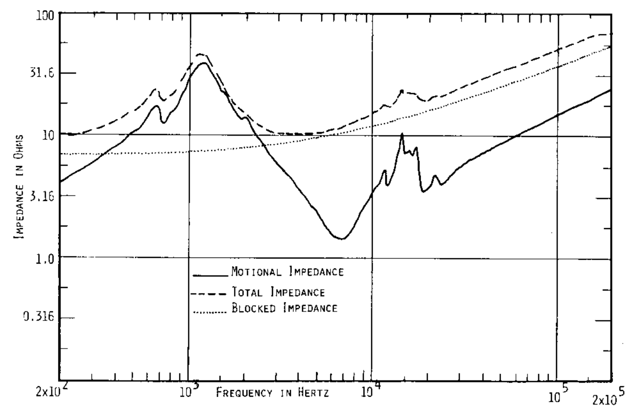


Fig. 14. Motional impedance in vacuum of a 2441 compression driver.

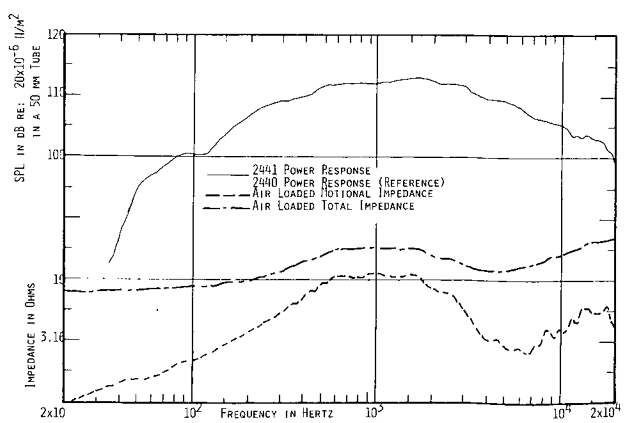
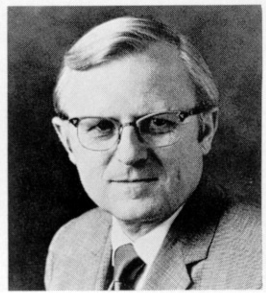


Fig. 15. Power response and air-loaded impedance of a 2441 compression driver.

[4] F. M. Murray, "The Motional Impedance of an Electro-Dynamic Loudspeaker," presented at the 98th Meeting of the Acoustical Society of America, Salt Lake City, 1979 November 19, paper T12.

THE AUTHORS

F. Murray



H. Durbin

Fancher M. Murray was born in Alhambra, California, in 1932. He received the B.E.S.A.E. degree in acoustical engineering from Brigham Young University, Provo, Utah, in 1959. After graduation he worked at the Boeing Company on airplane and spacecraft acoustic problems. In 1963 he joined Wyle Laboratories, working on acoustic problems associated with the Saturn rockets. Before joining James B. Lansing Sound, Inc. in 1977, he was employed for three years as an acoustic consultant for Bolt Beranek & Newman, Cambridge, Massachusetts. Since then, he has specialized in transducer design problems.

Mr. Murray is a member of the Audio Engineering Society and the Acoustical Society of America.

•

Howard M. Durbin was born in South Bend, Indiana, in 1925. He received a B.S.E.E. degree from Purdue University, Lafayette, Indiana, in 1945. After graduation he worked for RCA in advance development for acoustic devices and with airplane marine instruments. In 1947 he joined Electro-Voice as chief engineer in Buchanan, Michigan, where he later became senior vice president and technical director.

Mr. Durbin joined James B. Lansing Sound, Inc. in August 1973 as vice president, research and engineering. He directs the efforts of transducer engineering, electronic engineering, drafting services, and applied research and advance development.

He is a member of the Audio Engineering Society and has served as a member of the Board of Governors. He is also a member of the Institute of Electrical and Electronics Engineers and the American Association for the Advancement of Science.