Modulation Distortion in Loudspeakers: Part III*

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Distortion in loudspeakers is shown to be nearly proportional to power output. Typically a plot of log distortion versus dB output shows a 1:1 relation. In one sample loudspeaker the slope of the distortion versus output curve was in excess of 45 degrees. Comparison is shown between a direct radiator of 20-cm (8-in) diameter, one of 30-cm (12-in) diameter, and a high-efficiency horn of 0.45 m^3 (16 ft^3). At 95-dB sound pressure level output measured at 61 cm (2 ft) the 12-cm cone showed 18% (−15 dB ref 100%), the 30-cm cone showed 6% (−25 dB ref 100%), and the horn showed 0.8% (−42 dB ref 100%). Each curve of distortion versus output shows a slope of at least 45 degrees.

INTRODUCTION: In the popular "hi fi" press it has been stated that distortion in loudspeakers increases only slightly with power. Intuition or common sense dictate that this is a fallacy. Since intuition and especially common sense are rare in the "high fidelity" art, tests were conducted to support the intuitive logic that dictates distortion to be proportional to loudspeaker power output.

EXPERIMENTAL PROCEDURE

The spectrum analyzer was employed to determine harmonic distortion at different output levels and the modulation distortion resulting from a mixture of two frequencies. Three loudspeaker samples were used as tabulated in Table I.

Test frequencies of $f_1 = 41$ Hz and $f_2 = 350$ Hz were chosen, since in each case these frequencies would be radiated from the same bass diaphragm. The horn system crossover is 400 Hz. Of course, use of 41 and 1300 Hz would have resulted in substantially zero distortion for the horn, and very high first-order distortion for the direct radiators.

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In the case of the 30-cm speaker and the horn, equal sound pressure levels were used for the two frequencies. In the case of the 12-cm speaker, the amplitude of the higher frequency was 6 dB lower than the amplitude of the lower frequency.

In each case, harmonic distortion of f_1 varied only slightly with presence or absence of f_2, and in all cases the harmonics of f_1 were smaller than the sideband amplitudes of $f_2 \pm f_1$ and $f_2 \pm 2f_1$.

Since harmonic distortion contributed negligibly to the total distortion, and it was desired to plot a single value of distortion versus power, the total rms value of all significant sideband amplitudes was computed and plotted in dB.

Table I.

Sample Number	1 Direct Radiator	2 Direct Radiator	3 Large Horn
Basket diameter	30.5 cm (12 in)	20 cm (8 in)	
"Effective" cone diameter	23 cm (9 in)	16 cm (6.5 in)	
"Rigid" cone diameter	20 cm (8 in)	15 cm (6 in)	
Total bulk (approximately)	40 000 cm^3 (1.5 ft^3)	30 000 cm^3 (1 ft^3)	0.45 m^3

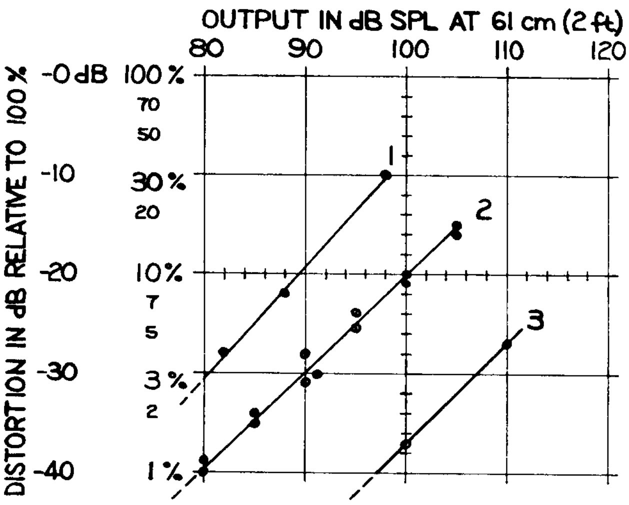

Fig. 1. Distortion versus output for 3 loudspeakers. Total distortion is mainly modulation (IM) resulting from mixture of $f_1 = 41$ Hz, $f_2 = 350$ Hz; harmonic distortion was from 7 to 10 dB lower than IM distortion in all cases. Curve 1—20-cm (8-in) direct-radiator loudspeaker in 30 000-cm³ box (1 ft³); peak power input at 98-dB output was 57 watts (limit of loudspeaker); curve 2—30-cm (12-in) direct-radiator loudspeaker in 40 000-cm³ box (1.5 ft³); peak power input at 105-dB output was 179 watts (limit of amplifier); curve 3—large-horn woofer, total bulk 0.45 m³ (16 ft³); peak power input at 110-dB output was 13 watts; no attempt was made to reach limits of either loudspeaker or amplifier.

Fig. 1 gives the rms distortion in dB (referred to 100% of the amplitude of the modulated frequency), plotted versus power output measured at 61 cm (2 ft).

RELATIVE IMPORTANCE OF AM, FM, AND HARMONIC DISTORTION

There are those who contend that Doppler (frequency modulation) distortion is inconsequential, the reasoning being based on the small frequency deviation which occurs. Using the example of a diaphragm excursion of 6 mm (¼ in) at 50 Hz, the displacement would be

$$x = \frac{1}{4} \sin (2\pi \times 50t)$$

and the velocity

$$v = \frac{1}{4} \times 2\pi \times 50 \cos (2\pi \times 50t)$$

$$v_{\text{peak}} = 200 \text{ cm/s } (79 \text{ in/s}).$$

Since the velocity of sound is $c = 344$ m/sec (13 500 in/s), the frequency deviation of a higher frequency being radiated from the same diaphragm would be only

$$\Delta v/c = 79/13\,500 = 0.0058$$

or a trifle over ½%. But the amplitudes of the sideband frequencies are known to be [1]

$$d = 0.033\, A_1 f_2 \quad (\%)$$

where A_1 is the amplitude of the motion at the lower frequency f_1 taken in the example as ¼ in, f_2 is the frequency of the modulated signal, and d is the rms sum of the sideband amplitudes expressed in percent of the amplitude of the higher frequency signal. Assuming $f_2 = 350$ Hz, then

$$d = 2.9\%$$

which may not be impressively large, but experiments show that it is plainly audible.

Then the critics of FM distortion fail to realize that AM distortion is frequently larger than FM distortion.

In the case of the 20-cm (8-in) direct-radiator cone the performance of which is depicted as curve 1 in Fig. 1, the AM component exceeded the FM component of total IM distortion. The maximum total IM distortion in the 20-cm cone was nearly 30%, of which only about 5% could be accounted for by the FM components.

Devotees of direct-radiator speakers view with alarm the high throat pressures in horns which allegedly produce high harmonic distortion [2], [3]. In the case of the horn (distortion depicted in curve 3, Fig. 1) harmonic distortion was 9 dB below the curve of total distortion.

DISCUSSION

Note that 80-dB output, and 1% distortion or 40 dB below 100% together represent a distortion output of 40-dB sound pressure level. The noise level in the test room, unweighted, was nearly 50 dB. If the analyzer had not been highly selective, measurements could not have been made down to 40 dB. As it was, determinations below −40 dB ref 100% entailed careful examination of the spectrograms to distinguish between noise and an almost vague glitch identifiably due to a sideband amplitude. It is submitted that the reviewers who felt that distortion increased only slightly with power were working at too low a level and were probably reading the output on a meter instead of a scope so that distortion and noise were indistinguishable. Obviously below the noise level the distortion plus noise will be constant and the ratio of distortion plus noise would first flatten and then assume a negative slope. While this is expressed as an opinion, it seems to be supportable.

CONCLUSION

The fact of the case is that distortion is closely proportional to power output. Also the distortion is closely proportional to diaphragm excursion. The 30-cm direct-radiator cone had to move about ⅓ as far as the 20-cm direct-radiator cone for the same output, and the distortion was close to 10 dB lower. The horn diaphragm motion was too small to be measured but could be estimated to be about ⅛ that of the 30-cm cone, so the 17-dB difference in distortion is the right order of magnitude.

REFERENCES

[1] G. L. Beers and H. Belar, "Frequency Modulation Distortion in Loudspeakers," *Proc. IRE,* vol. 31, pp. 132-138 (Apr. 1943).

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[3] S. Goldstein and N. W. McLachlan, "Sound Waves of Finite Amplitude in an Exponential Horn," *J. Acoust. Soc. Am.,* vol. 6, pp. 275-278 (Apr. 1935).

Note: Mr. Klipsch's biography appeared in the October 1972 issue.