3.3 Frequency Responses: A Closer Look

Now we can check again the frequency response measurements of the empty and filled tubes (Fig. 7) with the help of Table 1, looking for the notches that indicate the onset of the higher modes of vibration. In the case of the empty tube we find the first four notches in positions very close to the theoretical values (within 1% of the calculated frequency). For the filled-tube measurement the situation is slightly different. The notch for the (1, 0) mode is still there, but less deep; the notch at 13.2 kHz, corresponding to the (2, 0) mode, has disappeared; the one at 16.5 kHz, due to the first symmetrical mode (0, 1), is visibly deeper.

Those differences are due to the disposition of the absorbing material in the filled tube, which tends on the one hand to stop the propagation of asymmetrical modes and on the other hand to emphasize the axial symmetry of the system, making it easier for the symmetrical modes to propagate. That different blend of propagation modes can account for the differences beyond 8 kHz, with the filled tube being closer to the ideal situation of constant, resistive acoustic load, free from modes of vibration other than the simple plane wave.

The AES document [3] sets the high-frequency limit for plane-wave tube measurements at $1.22c/d$, where d is the inner diameter of the tube. Although this value corresponds to the third transverse mode of vibration ($1.22 = b_{01}/\pi$), we have seen that the asymmetrical modes are much less influential when the absorbing material is put in an axisymmetrical pattern, so this is a correct choice.

4 CONCLUSIONS

The construction of a plane-wave tube has led us to investigate the characteristics of sound propagation inside a cylindrical duct. We have devised a new method to test the tube for undesired reflections either from the

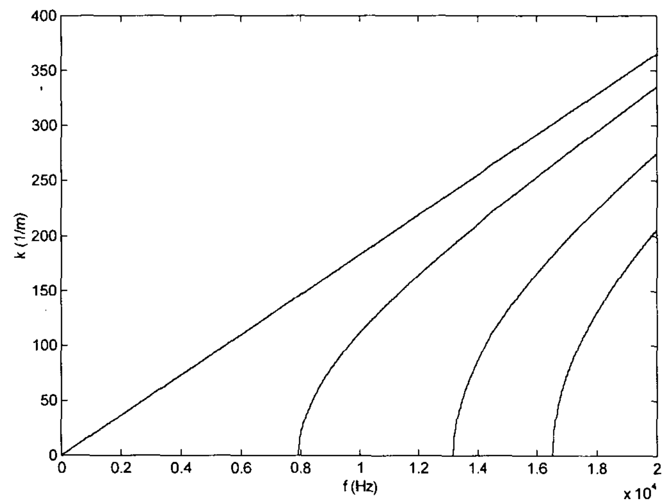

Fig. 6. Dispersion relation (wave number versus frequency) in free air and for first three transverse modes of 25.4-mm (1-in)-diameter tube.

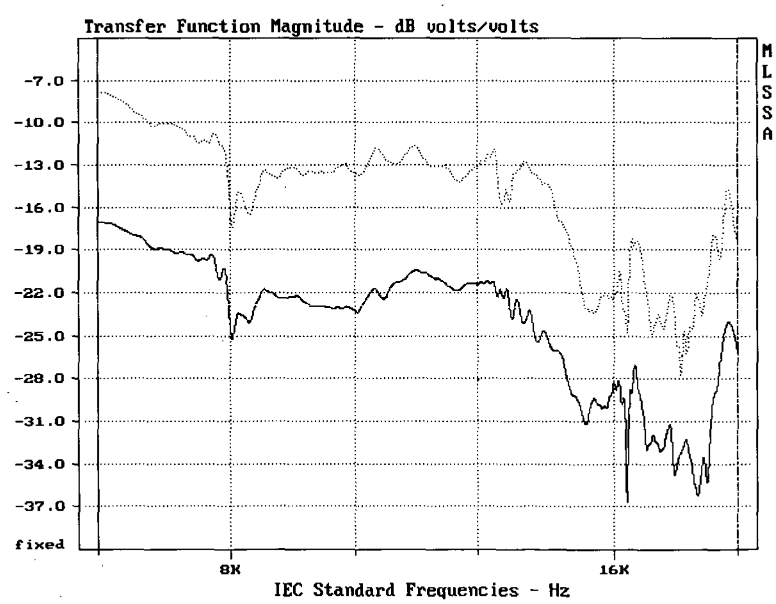

Fig. 7. High-frequency detail of Fig. 4. ... empty tube, displaced 9 dB up for clarity; — plane-wave tube.