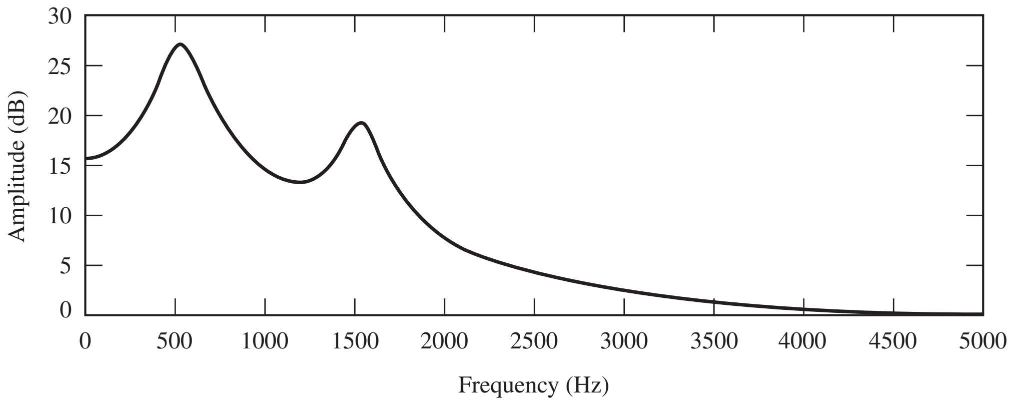

Figure 4.28 Measured spectrum from nonlinear channel output.

and the spectral envelope of the output during a vowel was measured (Figure 4.28). Estimate the true resonances of the vocal tract response for the original waveform $x[n]$. Assume a sampling rate of 10000 samples/s. What is the relation of the bandwidth of the original resonances to the bandwidth of the measured resonances?

4.5 Consider the time-varying tube created from a running faucet into a bottle shown in Figure 4.8. The initial length is 17.5 cm and changes as

$$l(t) = 17.5 - 3.5t$$

over a 5-second interval. Assume the speed of sound $c = 350$ m/s. Suppose the water hitting the bottom of the time-varying tube acts as an impulse train with a 1.0-second spacing (more of a thought experiment than what happens in reality). Sketch the spectrogram of the output over a 5000 Hz band and the 5-second interval, assuming that you are given "infinitely good" time and frequency resolution. Use MATLAB if you find it useful. In light of the uncertainty principle, what problems do you encounter in representing the signal properties with a wideband and narrowband spectrogram?

4.6 For the vowel /A/ (as in the word "a̲bout" or "u̲p"), the cross-sectional area of the vocal tract is roughly uniform along its length. For an adult male speaker, it can be approximated by a uniform tube of length 17 cm and cross-sectional area 5 cm^2, as shown in Figure 4.29. When the vocal folds are vibrating to produce this vowel, the area of the space between the vocal folds is zero during part of the cycle (Figure 4.29a), and has a cross-sectional area of about 0.015 cm^2 during the open phase of the vibration (Figure 4.29b). As a consequence of this variation in the glottal opening, there are modulations of the natural frequencies or formant frequencies of the tube. Find the maximum and minimum values of the lowest natural frequency, i.e., first formant F_1, corresponding to the open- and closed-glottis condition. In the open configuration, model the system as a concatenation of two tubes, one with cross-sectional area $A_1 = 0.015$ cm^2 and the other with cross-sectional area $A_2 = 5$ cm^2. In addition, assume the pressure is zero at the left end of the small tube when the glottis is open.