

## The $F_0$ – $F_1$ Crossover Exercise



Ingo R. Titze

It has become a long term goal of this writer to understand and appreciate proven exercises and vocalises used by singing teachers. One such exercise is the downward glide in pitch on a vowel [u] or [o], beginning on about  $D_5$  (around 600 Hz) and ending one to two octaves lower. This exercise dictates a crossover between the fundamental frequency  $F_0$  and the first formant frequency  $F_1$  of the vocal tract. Because  $F_1$  is low for a vowel with nearly closed lips (around 300 Hz), and because the second formant  $F_2$  is also low (around 800–1000 Hz), there is ample opportunity for  $F_0$  and its harmonics ( $2F_0$  and  $3F_0$ , in particular) to be momentarily located on either side of a formant. This produces a variety of constructive and destructive interferences between the source of sound and the vocal tract (the filter).

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Figure 1 shows a spectrogram of an [u] vowel, simulated by computer, with noise excitation at the glottis. The two dark bands represent formants  $F_1$  and  $F_2$ , located at 370 Hz and 800 Hz, respectively. The top of the vertical axis is 2000 Hz. The horizontal axis is time; from 0 to 8 s. Everything remains steady over the 8 s, in the form of a hiss that has a bit of an [u] quality.

Now consider a case where the source of sound is a downward gliding pitch, with  $F_0$  and all its harmonics changing linearly from 600 Hz to 100 Hz. This is shown in Figure 2. The formants are in exactly the same place as in Figure 1, but they are less easily seen because acoustic energy is available only at the harmonics and not at all frequencies, as with the noise excitation. In this  $F_0$  glide, the computer simulation is designed so that the vocal tract is not allowed to change the harmonics at the source, but only

as they are transmitted to the mouth. We call this a linear (noninteractive) source-filter model. Note the slightly darker regions (shown by arrows) where the  $2F_0$ ,  $3F_0$ ,  $4F_0$  and higher harmonics are boosted in energy as they pass through the second formant at 800 Hz.  $F_0$  (the lowest line) passes through the first formant, but the transition is so gradual that the whole line is darkened.

What we have discussed so far is not remarkable and would be expected by most speech and voice scientists. The linear source-filter theory of vowel production is deeply embedded in all our minds. If it always held true in human phonation, the gliding  $F_0$  exercise would have little pedagogic value other than controlling a smooth glissando. A different story emerges, however, when the acoustic pressures in the vocal tract are allowed to interact (and interface) with vocal fold movement. This is known as the

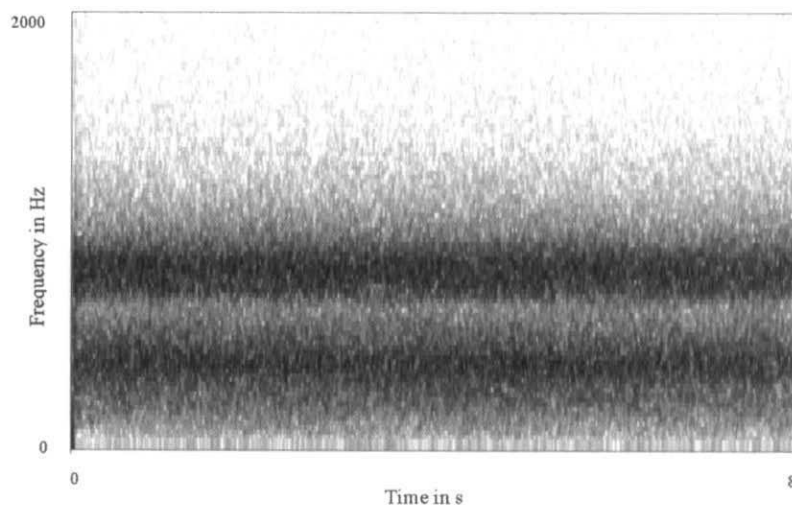


Figure 1. Spectrogram of simulated [u] vowel with noise excitation at the glottis.

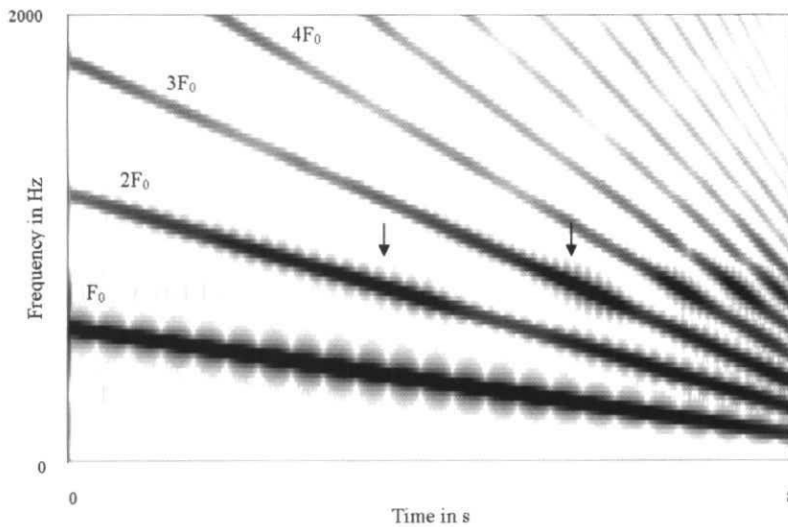


Figure 2.  $F_0$  glide from 600 Hz to 100 Hz for a linear source-filter model.

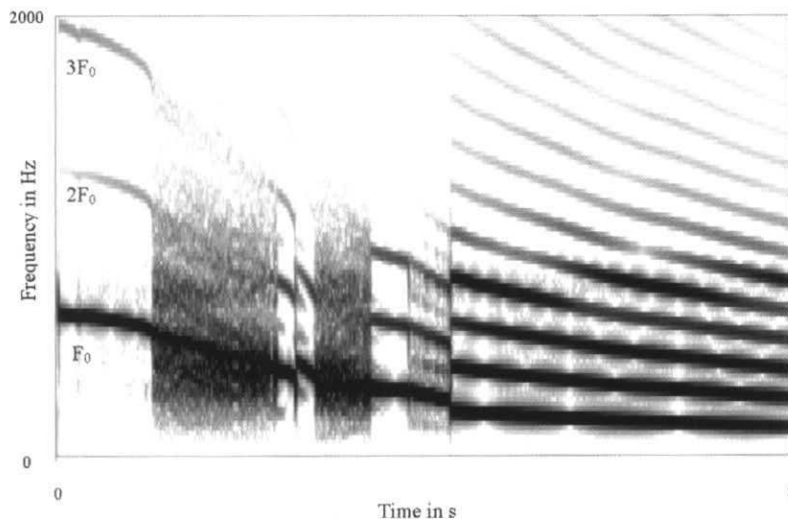


Figure 3.  $F_0$  glide from about 600 Hz to about 100 Hz for a nonlinear source-filter model showing multiple bifurcations.

nonlinear source-filter theory. Figure 3 shows the pitch glide under these interactive conditions. The beginning and the end of the glide are similar to what we saw in Figure 2, but in the middle there are abrupt changes known as bifurcations (sudden qualitative changes in the vibrational behavior of the source-filter system). The first bifurcation (addition of noise between the harmonics) occurs when  $F_0$  approaches the first formant from

above. Here, when  $F_0 > F_1$ , the vibration of the vocal folds becomes unsteady, which creates the noise. Another bifurcation occurs when  $F_0 = F_1$ . Here  $F_0$  and  $2F_0$  suddenly jump to a higher value. Noise due to unsteady vibration re-occurs shortly thereafter, ending with a short segment of pure descending harmonics. After another brief episode of noise and yet another  $F_0$  jump (downward this time), a final steady pattern emerges. In this sec-

ond half of the glide, where  $F_0$  is in the speaking range, the linear source-filter theory seems to hold.

What does this mean to us pedagogically? Some singers have tuned their source-filter system to be highly interactive. A primary mechanism for this is narrowing the epilarynx tube just above the vocal folds, which I have discussed often in previous *Journal of Singing* contributions. Strong interaction can increase the sound output and provide a greater variety of voice qualities. But the price that is paid for strong interaction is an occasional instability at pitches where harmonics interfere with formants. The  $F_0$ - $F_1$  crossover exercise makes us aware of these instabilities and allows our muscles to adjust appropriately. The more we learn to live in this unstable region, not labeling it a pathology or faulty technique, the better off we are. In fact, we can learn to *control* instability and noise in the voice, using it to an artistic advantage rather than being embarrassed by it. But it does take practice to reach any level of consistency.

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