Ingo Titze, Associate Editor

The Case of the Missing or Depressed Fundamental: Belting and Trumpeting

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Brass instruments are close cousins of the human voice. It was discovered prehistorically that sending sound over long distances (to locate, be located, or warn of danger) is made easier when a vibrating sound source is connected to a horn. It is not known which came first: blowing hollow animal horns or sea shells with pursed and vibrating lips, or cupping the hands to extend the airway for vocalization. In both cases, however, airflow-induced vibration of soft tissue (vocal folds or lips) is enhanced by a tube that resonates the frequencies and radiates them to the listener.

Man-made instruments are sometimes designed or played to mimic aspects of the human voice, and likewise vocalists try to mimic the sounds of man-made instruments. If flutes and strings accompany a singer, a "brassy" voice is likely to produce a contrast in timbre. Likewise, a "fluty" voice may stand in contrast to a brass accompaniment. Thus, singers are looking for ways to color their voice, or alter its timbre.

In the previous issue of this journal, I gave examples of how a call or belt can be produced without excessive vocal fold collision, or without a large closed quotient in the glottal cycle. Generally, a call or belt-like quality is achieved by strengthening the second harmonic frequency $2f_o$ relative to the fundamental frequency f_o. This can be done with resonance, choosing a vowel that puts the first formant just above $2f_o$. The fundamental will then have significantly less energy than the second harmonic.

Why does that resonance adjustment produce a brass-like timbre? To understand this, we first recognize that, in brass instrument playing, the harmonics produced by the lips are entrained (synchronized) to the resonance frequencies of the tube. There is general resonance-harmonic *tuning* simultaneously for most of the harmonics unlike in the human voice, where resonances of the vocal tract are only occasionally tuned to the harmonics of the source and don't have to coincide. Thus, the tones heard from the trumpet are the resonance tones. In vocal language, the formants sit exactly on top of the harmonics (Figure 1).[1]

There is a problem, however, in making this alignment work at all resonances with tubes that are closed on one end (the lips) and open on the other (the bell or mouth). The resonances don't form a complete harmonic series.

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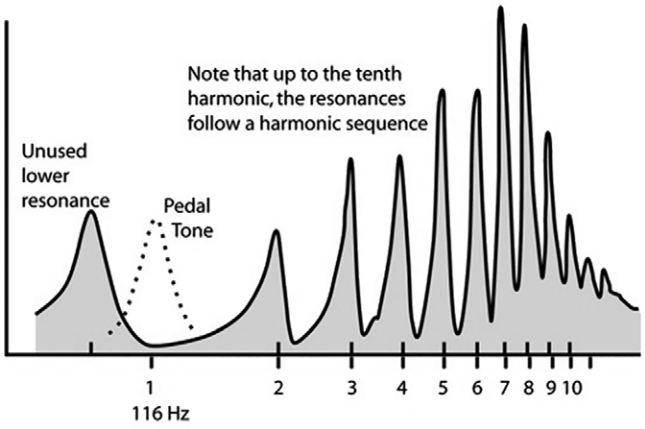

Figure 1. Resonance spectrum of a trumpet.

The frequency ratios are 1, 3, 5, 7, 9 . . . instead of 1, 2, 3, 4, 5 . . . The even multiples of the lowest resonance are missing. A trick is used, however, to make a nearly complete harmonic series by ignoring the lowest resonance and using only the overtone resonances. These resonances are then moved closer together (into harmonic relations) by using partially a cylindrical and partially a conical horn. This trick results in brass instruments having a missing fundamental, known as the pedal tone. The overtone resonances (3, 5, 7, 9 . . . . multiples of the lowest resonance) now make a new integer series (2, 3, 4, 5 . . . .) without the true integer-1 resonance. The fundamental of this new series is missing, however. It is 1/2 the frequency of the integer-2 resonance (Figure 1). This missing fundamental is a strong characteristic of the timbre of the instrument.

Perceptually, an imaginary fundamental frequency may be produced by our auditory system when a series of higher harmonics (equally spaced overtones) is heard. Thus, in the (2, 3, 4, 5 . . .) harmonically spaced series, the fundamental (pedal tone) may be perceptually present to some degree, but the highly dominant second harmonic determines the perceived pitch.

In vocal belting and calling, the fundamental is not eliminated, but suppressed relative to the second harmonic, which is nearly tuned to the first resonance (formant). The timbre of belt is related to the timbre of a trumpet due to the lack of energy in the fundamental frequency. Furthermore, to my ears, the belt timbre on a D_5 sounds higher in pitch than a classical soprano sound on the same note. Pitch perception is not only related to the fundamental frequency, but the entire spectrum of frequencies. Thus the strong second harmonic influences pitch perception in addition to timbre.

NOTE

1. John Backus, *The Acoustical Foundations of Music*, 2nd edition (New York: Norton, 1977), 1–368.

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Where are the songs of Summer?—With the sun,
Oping the dusky eyelids of the south,
Till shade and silence waken up as one,
And Morning sings with a warm odorous mouth.
Where are the merry birds?—Away, away,
On panting wings through the inclement skies,
Lest owls should prey
Undazzled at noon-day,
And tear with horny beak their lustrous eyes.

Thomas Hood,
"Ode—Autumn"