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ACOUSTIC ANALYSIS OF RESONANCE STRATEGIES IN THE SINGING OF AZERBAIJANI TENOR BULBUL ACROSS THREE VOCAL GENRES

Abstract. The article examines the vocal rendition of Murtuza Mammadov (Bulbul) in three genres—mugham, opera, and classical romance—using *Praat, VoceVista*, and *Sopran*. It shows that he amplified sound not through the classical singer's formant (2.5–3.5 kHz), but by tuning lower formants, creating peaks at 1.3–1.5 kHz. His unique "double tuning" (aligning F_1 and F_2 with harmonics) is documented for the first time, bringing his approach closer to L.Pavarotti and elements of belting. The study highlights Bulbul's synthesis of national tradition and academic technique, and suggests pedagogical value for modern vocal training.

Key words: Bulbul (Murtuza Mammadov), formant-harmonic tuning, acoustic analysis, cross-genre vocal strategy, vocal pedagogy.

Introduction. This study examines Murtuza Rza oglu Mammadov (Bulbul), who blended mugham with European bel canto, forming the basis of the Azerbaijani vocal school. For the first time, his resonance strategies are compared across mugham, opera, and romance-ghazal using advanced acoustic tools. Spectral analysis of /a/ and /i/ reveals how he tuned formants to achieve distinct expressive and stylistic effects.

Bulbul as a phenomenon of vocal synthesis: historical and pedagogical context. Bulbul occupies a central place in Azerbaijani music as founder of the national vocal school, uniting mugham with opera and classical romance. He became the first Muslim vocalist to study in Italy, including at La Scala, and by merging Azerbaijani singing with European bel canto "created a new vocal school" [3, p. 20]. This East–West synthesis secured him lasting fame

and a place in world vocal heritage [3, p. 6]. As a pedagogue, he stressed that academic technique should reveal rather than suppress the Azerbaijani voice, which explains his cautious adoption of vibrato and European methods in mugham [2, p. 36]. On his initiative, the first Scientific Research Music Cabinet was founded in 1931 at the Azerbaijan State Conservatoire to collect folklore and study professional traditions. In works of the 1930s–1950s, Bulbul pioneered the study of *khanende* and *ashiq* practice. He analyzed register features, introduced folk terms such as "ağ səs" ("white voice"), "cır səs" ("immature voice"), and "yağlı səs" ("fat voice") [4, p. 194], and emphasized high-register techniques like *hal, gushe,* and *zangule* as markers of mastery [2, p. 40]. His writings remain a key source for understanding mugham performance. Research gap. Despite many studies on Bulbul's legacy, including his own writings on *khanende* and *ashiq* technique [1], no comprehensive acoustic and physiological analysis of his performance strategies has yet been made using modern spectral tools or comparisons with Western practice.

The interpretation of the main material. Contemporary acoustic approaches to the analysis of singing voices. To understand Bulbul's resonance methods, one must recall the basics of vocal acoustics. Phonation produces a fundamental frequency (F_0) and harmonics that shape timbre. The vocal tract acts as a resonant filter, with formants—resonance frequencies determined by tongue, jaw, lips, soft palate, and larynx positions [19, pp. 2, 6]. The first formant (F_1) reflects pharyngeal volume and jaw opening, the second (F_2) – oral cavity resonance and tongue placement. These are key to vowel distinction. Formants shape not only vowels but also vocal power. When a harmonic aligns with a formant, resonance amplifies it, brightening the voice without extra effort [9, p. 184]. At low and mid ranges, harmonics align naturally, but at higher pitches vowel adjustments are needed to sustain clarity [9, p. 184]. Classical singing addressed this through formant tuning—articulatory shifts that let formants track F_0. The most common tenor strategy is $F_2 \rightarrow H_3$ alignment, producing a 1.4 kHz peak strong enough to cut through orchestral sound [10, p. 1024; 14; 16, p. 304]. Another is the singer's formant, a 2.5–3.5 kHz cluster of F_3–F_5 created by narrowing the epilaryngeal tube [19, p. 7; 20, p. 843], especially in baritones and tenors [20].

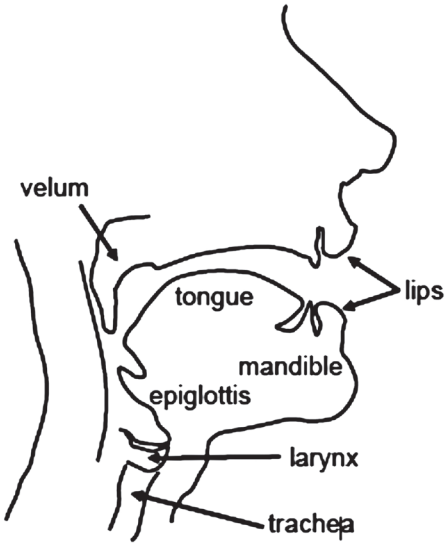


Figure 1. Midsagittal diagram of the articulators [19, p. 2].

Non-classical genres use other patterns: country and musical theatre rely on microphones [18, 21]; belting raises $F_1 \approx 2F_0$, boosting the second harmonic for a brassy sound [11]; chamber and mic-assisted singing often applies $F_2 \rightarrow H_4$ tuning (~1.9 kHz), enhancing clarity on /i/ and /u/ [15]. Some female belters also show a 3.8–4 kHz peak from laryngeal raising [12]. No single resonance setup fits all contexts. Pedagogically, singers must learn to sense where reinforcement is needed and shift formants accordingly, balancing projection, clarity, and vocal health [11, 14, 15, 16]. This framework informs the present study of Bulbul, analyzing how he adapted resonance strategies in mugham, romance-ghazal, and opera.

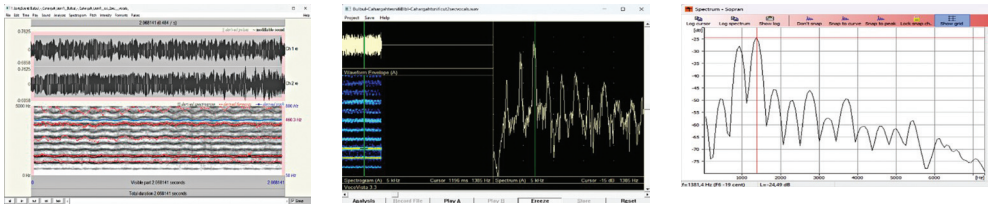
Research aims and objectives. This article analyzes Bulbul's vocal tuning on the vowels /a/ and /i/ in high notes across three styles: mugham, Azerbaijani romance-ghazal, and opera. Research questions: 1) how did Bulbul adapt his vocal tuning to different genres? 2) What acoustic strategies enhanced his timbre? 3) How comparable was his approach to Western singer's formant practice?

Spectral analysis identifies the presence of the singer's formant and the tuning of F_1 and F_2. The results are compared with data on tenors such as Luciano Pavarotti and Plácido Domingo, revealing how Bulbul balanced *khanende* timbre with academic vocal demands.

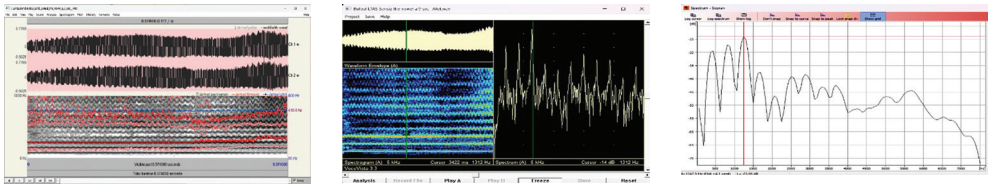
Method, methodology, instrumentation. For the analysis, three historical recordings by Bulbul were selected: the mugham *Çahargah Təsnifi*; the romance-ghazal "Sənsiz" (1941, U. Hajibeyli / N. Ganjavi); and the aria "Sevdim səni mən, ey Nigarım" from Hajibeyli's opera *Koroğlu*. High-note fragments on /a/ and /i/ were extracted as follows: *Çahargah Təsnifi* – [a], [i] on B♭4; "Sənsiz" – [a], [i] on A♭4; "Sevdim səni mən, ey Nigarım" – [a] on G4, [i] on F♯4. To compare Bulbul's resonance strategies with leading operatic tenors, these fragments were set against the final B♭4 of "Celeste Aida" (G.Verdi), specifically the vowel [o] in sol as sung by Pavarotti and Domingo, following Miller's analysis [14]. The vocal line in the commercial recordings was isolated from accompaniment, resampled from 48,100 Hz to 16,000 Hz to reduce high-frequency noise. The analysis employed three software tools. *Sopran* [17] generated Long-Term Average Spectrum (LTAS) curves, identified harmonics and formants, and detected spectral peaks in the 2–4 kHz range, enabling reliable assessment of the singer's formant. *Praat*, a standard tool in acoustic phonetics [7], measured fundamental frequency (F_0) and formants F_1–F_2, testing the hypothesis of formant–harmonic tuning. *VoceVista* [24] provided interactive visualization of amplitude spectra and resonant peaks.

Results of acoustic analysis. This section presents the acoustic analysis of Bulbul's vocal fragments. Figure 2A shows the vowel [a] on B♭4 from *Çahargah Təsnifi*. In *Praat*, the waveform (left image) and spectrogram (0–5000 Hz, right image) reveal F_2 aligned with the third harmonic (H_3), while F_1 stays near 931 Hz, reinforcing H_2. *VoceVista* confirms this with a clear spectral peak at ~1380 Hz, visible both in the spectrogram and amplitude spectrum. *Sopran* analysis (middle image) supports these findings. No peaks appear in the 2.5–3.5 kHz range of the classical singer's formant. Thus, Bulbul enhances the third harmonic by tuning F_2 upward.

A. Mugham *Çahargah Təsnifi*



B. Romance-ghazal “Sənsiz”



C. Aria “Sevdim səni mən, ey Nigarım” (opera *Koroğlu)*

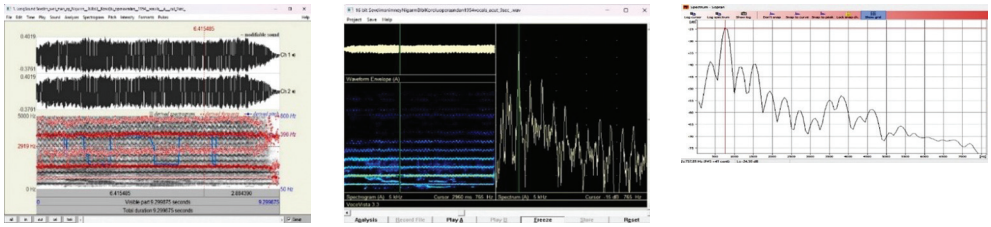
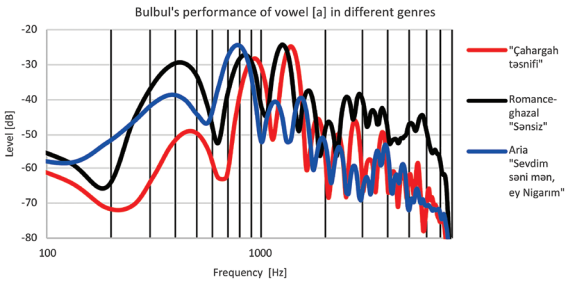


Figure 2. Acoustic representation of the vowel [a] in three genre fragments by Bulbul: left — *Praat* spectrogram; right — *VoceVista* amplitude spectrum; bottom — *Sopran* acoustic spectrum.

Figure 2B presents the acoustic characteristics of the vowel [a] (nominally [ə] in the word *afət*) on A♭4 from the romance-ghazal “Sənsiz”. The spectrograms show a consistent alignment of F_2 with H_3, indicating the implementation of the “F_2-to-H_3” tuning strategy. The amplitude spectra generated by *VoceVista* and *Sopran* demonstrate a clear dominance of a peak around 1.3 kHz. Figure 2C presents the acoustic characteristics of Bulbul’s rendition of the vowel [a] on G4 from the aria “Sevdim səni mən, ey Nigarım”. F_1 is located around 757 Hz, aligning with H_2, while F_2 at approximately 1.5 kHz coincides with the H_4. However, according to the amplitude spectrum, H_2 appears as the most prominent peak, indicating the dominance of the “F_1-to-H_2” tuning strategy.

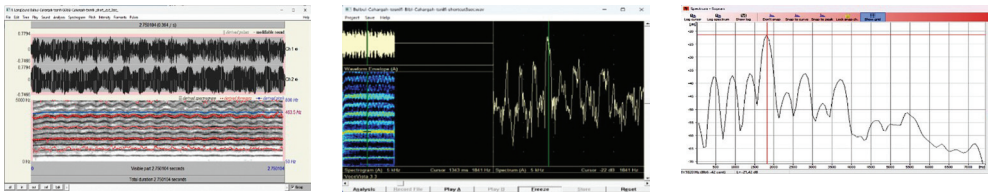


Graph 1. Superimposition of LTAS curves of Bulbul’s renditions of the vowel [a] in three different genres.

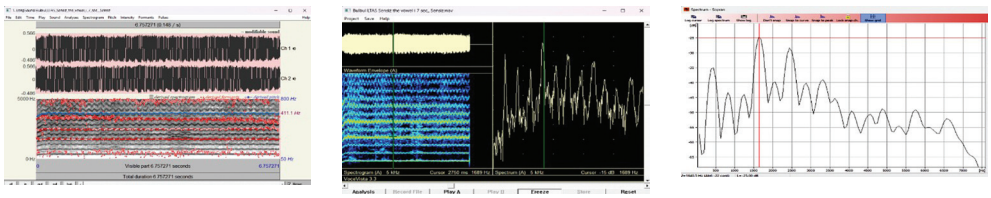
Graph 1, generated in Excel based on numerical data obtained through spectral analysis in the *Sopran* software, presents a superimposition of LTAS curves of the vowel [a] from three genres performed by Bulbul. The graph shows that in the typical singer's formant range (approximately 2.5–3.3 kHz), no pronounced peaks are present. In all three LTAS curves, the most prominent spectral peaks are concentrated below 2000 Hz. Thus, regardless of genre, Bulbul consistently reinforces the vowel [a] through formant–harmonic tuning by aligning F_1 and F_2 with a dominant harmonic.

Figures 3A–C below illustrate the acoustic features of the vowel [i] as sung by Bulbul across three genres.

A. Mugham *Çahargah Təsnifi*



B. Romance-ghazal "Sənsiz"



C. Aria "Sevdim səni mən, ey Nigarım" (opera *Koroğlu)*

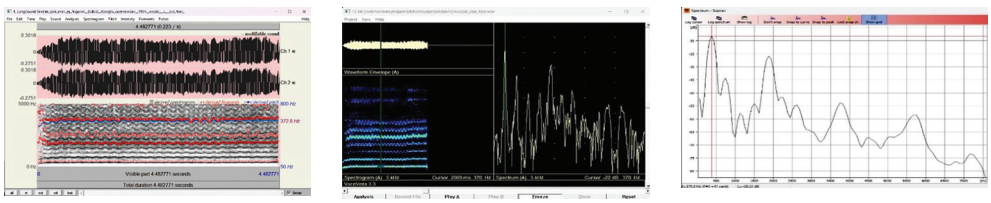
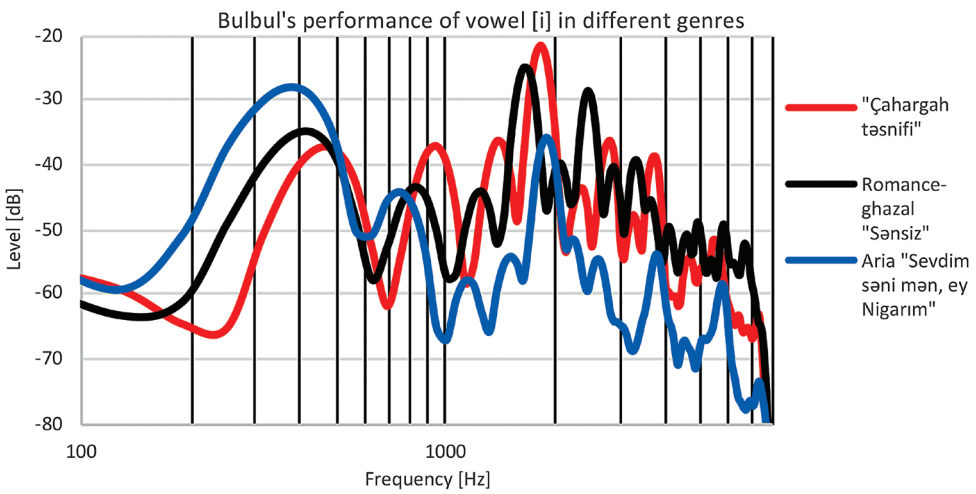


Figure 3. Acoustic representation of the vowel [i] in three genre fragments by Bulbul: left — *Praat* spectrogram; right — *VoceVista* amplitude spectrum; bottom — *Sopran* acoustic spectrum.

Figure 3A shows the acoustic characteristics of the vowel [i] on B♭4 from *Çahargah Təsnifi*. The spectrograms display a stable alignment of F_2 with H_4, which corresponds to a dominant spectral peak at around 1.8 kHz. Figure 3B presents the acoustic characteristics of the vowel [i] on A♭4 from the romance-ghazal "Sənsiz". The spectrograms reveal an alignment of F_2 with H_4, as well as F_3 with H_6. Since H_6 lies within the typical singer's formant region, this suggests that the performer may be employing two amplification strategies simultaneously. Figure 3C illustrates the vowel [i] on G4 from the aria "Sevdim səni mən, ey Nigarım". The spectrograms show F_1 aligned with H_1, i.e., the fundamental frequency around 378 Hz, and F_2 aligned with H_5. The amplitude spectra demonstrate the strongest spectral peak at H_1, indicating the dominance of the "$F_1 \rightarrow H_1$" tuning strategy.

Graph 2 compares LTAS curves of the vowel [i] across three genres. In the romance-ghazal and tesnif, a clear peak around 1.7–1.8 kHz shows F_2–H_4 alignment, with the romance also displaying a plateau near 2.5 kHz linked to H_6 and a singer's formant cluster. In the aria, the strongest peak is at the first harmonic (~370 Hz), with F_2 tuned to H_5. Overall, Bulbul applies varied strategies for [i], combining formant–harmonic tuning with occasional use of the singer's formant depending on style.



Graph 2. Superimposition of LTAS curves of Bulbul's renditions of the vowel [i] in three different genres.

Discussion. The analysis shows that Bulbul consistently reinforced high notes through formant–harmonic tuning. Most fragments displayed peaks below 2 kHz, with only the vowel [i] in the romance-ghazal producing a singer's formant cluster (~2.5–3.5 kHz). For [a], reinforcement appeared at 1.3–1.5 kHz: in mugham and romance via F_2–H_3 alignment, and in the aria via F_1–H_2. These strategies enhanced brightness and projection without strain, exemplifying the "$F_2 \rightarrow H_3$" technique [14, 16]. Bulbul achieved this intuitively through vowel modification, as in mugham [i], which shifted toward an [e]/[a]-like quality with F_1 raised (~0.9 kHz) and F_2 lowered (~1.8 kHz) [9, p. 184]. The romance-ghazal also showed dual alignment (F_2–H_4, F_3–H_6), while the aria displayed F_1–H_1 and F_2–H_5 with the fundamental (~378 Hz) dominant. Overall, Bulbul demonstrated flexible control of F_1 and F_2, adapting resonance strategies to balance brilliance with stylistic demands.

Bulbul's resonance strategy can be compared with 20th-century tenors Luciano Pavarotti and Plácido Domingo, both noted for their B♭4 in "Celeste Aida". Bel canto schools differ in reinforcing this pitch. Miller [14, p. 2] found that Domingo used a classic singer's formant cluster near 2.8 kHz by amplifying H_6, while Pavarotti employed precise formant tuning, aligning F_2 with H_3 to produce a peak around 1.4 kHz—about 500 Hz above average speech F_2—enhancing clarity and ring [14, p. 3].

Pavarotti achieved loudness through formant–harmonic tuning ($F_2 \rightarrow H_3$), while Domingo relied on clustering higher formants (F_3–F_5). Bulbul's approach was closer to Pavarotti's: he consistently reinforced a 1.3–1.5 kHz peak and avoided the ~3 kHz singer's formant, preserving the open timbre of mugham. This absence can be seen as a deliberate artistic choice to maintain national color in operatic contexts. A recent study [5] identified a distinct "mugham formant," different from the classical singer's formant [5, p. 41], and noted that mugham singers often retain chest register in the high range (zil), resembling belting. Features such as a raised larynx and a megaphone-shaped tract—common to both mugham and belting—are relevant to Bulbul's strategy.

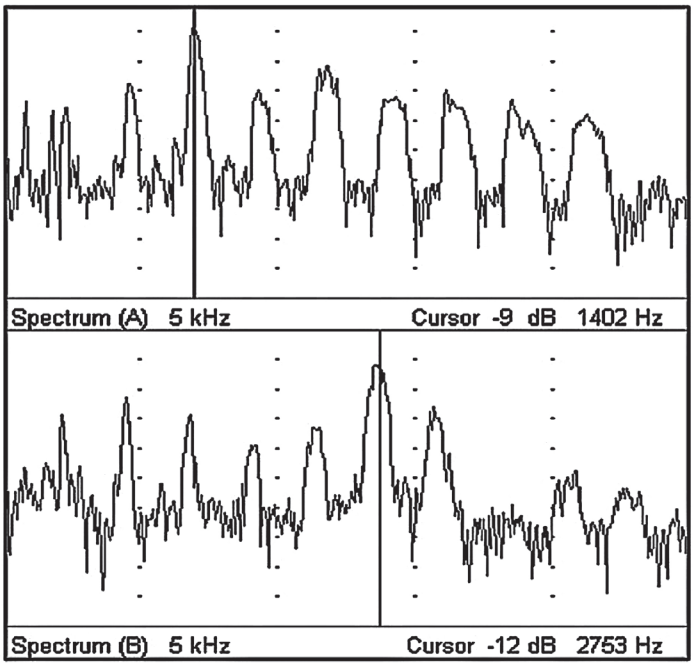


Figure 4. Energy spectra of the B♭4 from "Celeste Aida" by L. Pavarotti (top) and P. Domingo (bottom), showing dominant harmonics [14, p. 2].

Parallels with contemporary belting are also evident: raising $F_1 \approx 2F_0$ makes the second harmonic dominant in the 1–2 kHz range [11; 22; 23]. A similar effect appears in the aria fragment on /a/, where F_1 aligns with H_2. Overall, Bulbul applied several tuning mechanisms ($F_2 \rightarrow H_3/H_4$, $F_1 \rightarrow H_2$, $F_1 \rightarrow H_1$), sometimes in combination with the singer's formant, balancing operatic projection with *khanende* timbre. His "dual" resonance amplification—aligning multiple formants with different harmonics—shows refined vocal-tract control gained through long training. The novelty of this study is that Bulbul's resonance strategies are documented acoustically for the first time. While earlier works noted his synthesis of mugham and bel canto, the mechanisms remained unclear. The findings show that he fused Eastern tradition with Western technique not only stylistically but acoustically, through integrated formant tuning. In conclusion, Bulbul created a unique resonance signature, distinct from both opera and traditional singing yet incorporating both, enriching the understanding of resonance strategies among singers.

Conclusion. The analysis of Bulbul's resonance strategies offers valuable lessons for vocal pedagogy. It shows that effective projection need not rely solely on the classical singer's formant [13, p. 48], but can also be achieved through flexible, auditory-based formant tuning. Bulbul exemplified this long before acoustic tools existed, demonstrating how singers can adapt formant positions to context while preserving vocal health and stylistic clarity [2, p. 36]. Spectral analysis further suggests practical applications: exercises that train singers to reinforce different harmonics (e.g., $F_2 \rightarrow H_3$ or $F_1 \rightarrow 2F_0$) can expand timbral options and foster safer, more expressive performance [8; 14]. Integrating such strategies into pedagogy encourages a holistic approach that unites cultural identity with acoustic awareness, equipping singers to navigate both traditional and modern genres [12].

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AZƏRBAYCANLI TENOR BÜLBÜLÜN İFASINDA ÜÇ VOKAL JANR ÜZRƏ REZONANS STRATEGİYALARININ AKUSTİK TƏHLİLİ

Məqalə Murtuza Məmmədovun (Bülbülün) muğam, opera və klassik romans janrlarında vokal ifasını *Praat*, *VoceVista* və *Sopran* proqramlarının köməyi ilə təhlil edir. O, səsi klassik oxuma formantı (2,5–3,5 kHz) hesabına deyil, aşağı formantları tənzimləyərək (1,3–1,5 kHz) gücləndirirdi. İlk dəfə onun "ikili tənzimləmə"si — F_1 və F_2-nin harmoniklərlə uyğunlaşdırılması — sənədləşdirilir; bu, onun texnikasını Pavarotti və beltinq üslubunun bəzi elementlərinə yaxınlaşdırır. Tədqiqat Bülbülün milli ənənə ilə akademik texnikanı sintez etdiyini vurğulayır və bu yanaşmanın müasir vokal hazırlığı üçün pedaqoji dəyərini göstərir.

Açar sözlər: Bülbül (Murtuza Məmmədov), formant-harmonik tənzimləmə, akustik təhlil, janralararası vokal strategiya, vokal pedaqogikası.

Александрия фон Брюсельдорфф *(США/Азербайджан)*

АКУСТИЧЕСКИЙ АНАЛИЗ РЕЗОНАНСНЫХ СТРАТЕГИЙ В ПЕНИИ АЗЕРБАЙДЖАНСКОГО ТЕНОРА БЮЛЬБЮЛЯ В ТРЁХ ВОКАЛЬНЫХ ЖАНРАХ

Статья анализирует вокальное мастерство Муртузы Мамедова (Бюль-бюля) в мугаме, опере и классическом романсе с помощью программ *Praat*, *VoceVista* и *Sopran*. Он усиливал звук не через классический певческий формант (2,5–3,5 кГц), а за счёт настройки нижних формантов (1,3–1,5 кГц). Впервые зафиксирована его «двойная настройка» (F_1 и F_2 с гармониками), сближающая его технику с Поваротти и элементами бэлтинга. Работа подчёркивает синтез национальной традиции и академической школы, а также её педагогическую ценность.

Ключевые слова: Бюльбюль (Муртуза Мамедов), формантно-гармоническая настройка, акустический анализ, межжанровая вокальная стратегия, вокальная педагогика.