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The source spectrum of double-reed wood-wind instruments

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IV. MUSICAL ACOUSTICS

A. THE SOURCE SPECTRUM OF DOUBLE-REED WOOD-WIND INSTRUMENTS

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Part 1. The Bassoon

The frequency transform of a source-filter model for wood-wind instruments can be specified as $U(\omega) = G(\omega) \cdot H(\omega)$, where $U(\omega)$ is the output function, $G(\omega)$ the input or source function, $H(\omega)$ the transfer function, and ω the angular frequency.

The source function $G(\omega)$ for wood winds derives from a transversally or longitudinally oscillating air reed and the fundamental frequency of this air reed is governed by certain of the resonance frequencies of the instrument, i.e. the poles of the transfer function $H(\omega)$.

With respect to the transfer function $H(\omega)$ these instruments can be divided in two groups. In group A the resonance frequencies are $f_n \simeq n \cdot f_1$ and $n = 1, 2, 3, 4, \ldots$ To this group belong organ pipes, flutes, oboes, and bassoons. Group B may be exemplified by the clarinets and is characterized by resonance frequencies $f_n \simeq (2n-1) \cdot f_1$, $n = 1, 2, 3, 4, \ldots$ Accordingly in group A instruments both odd and even harmonics dominate ($n = 1, 2, 3, 4, \ldots$) whereas the output spectrum of group B instruments emphasizes the odd harmonics ($n = 1, 3, 5, 7, \ldots$) as is typical of clarinets.

The existence of at least one prominent peak in the spectrum envelope of the bassoon and oboe is of importance to the perceived timbre of these instruments. Herrmann (6) has adopted the word formant for this spectrum peak in analogy with the formants for vowels. Meyer (9) has made an extensive study of the spectra of wood-wind instruments and has indicated the significance of the "formants" to the vowellike timbre of the bassoon.

The term formant is according to Stevens and House (10), p. 318, restricted to mean a normal mode of vibration of the vocal system. Quoting Stevens and House ... "The theory considers a vowel sound to be the result of excitation of a linear acoustic system by a quasiperiodic volume velocity source. The transfer function of the acoustic system is completely described by a number of poles whose frequency locations depend on the vocal tract configuration ... This definition of formant means that the vocal tract has formants regardless of its excitation.

During the production of certain sounds (notably the vowels) the formants are manifested in the acoustic output as maxima in the spectra." For further discussions of formants in speech research, see refs.[2][3][8].

If this definition is extended to include wood-wind instruments, the formants would refer to the poles in the linear acoustic system, i.e. the transfer function. However, from the listener's point of view, any fairly broad peak in the spectrum of a musical instrument that is fixed in frequency can serve the same function as a vowel formant whether it is a result of resonances in the passive acoustic system of the instrument or of peaks in the source spectrum. An investigation of the bassoon has shown that the practically invariant peak at about 500 c/s in the output spectrum originates in the source.

Measurements

Fig. IV-A-1 is a display of spectrograms for three bassoons: No. 1, Old bassoon marked H. Grenser[5]; No. 2, Modern bassoon marked Buffet & Crampon, Paris; and No. 3, Modern bassoon marked H. Zuleger, Wien. All instruments were blown with the same reed and fives tones, g_2, a_2, b_2, c_3, and d_3 (98 - 147 c/s) and are played ascending and descending in rapid succession. The first and second peaks in the spectrum envelope are visible and especially the first peak is very pronounced and remains fixed with a pole frequency around 500 c/s.

Experiment I

In order to separate the influence of the passive acoustic system and the source on the formant structure of the bassoon a circular tube of 2.1 cm diameter and of about 1 m length was blown, first with a clarinet mouthpiece and then with a bassoon reed. The spectrograms are shown in Fig. IV-A-2. With the bassoon reed the first peak appears at about the same position as the corresponding peak of the true bassoon, see Fig. IV-A-1. The spectrogram of the sound produced by the clarinet reed shows no such peak. Thus the reed seems to play the most important role for the major peak of the bassoon spectrum.

Experiment II

A synthesis of a bassoon tone was next made by means of a simple electric analogue consisting of a pulse generator, a pole circuit and a

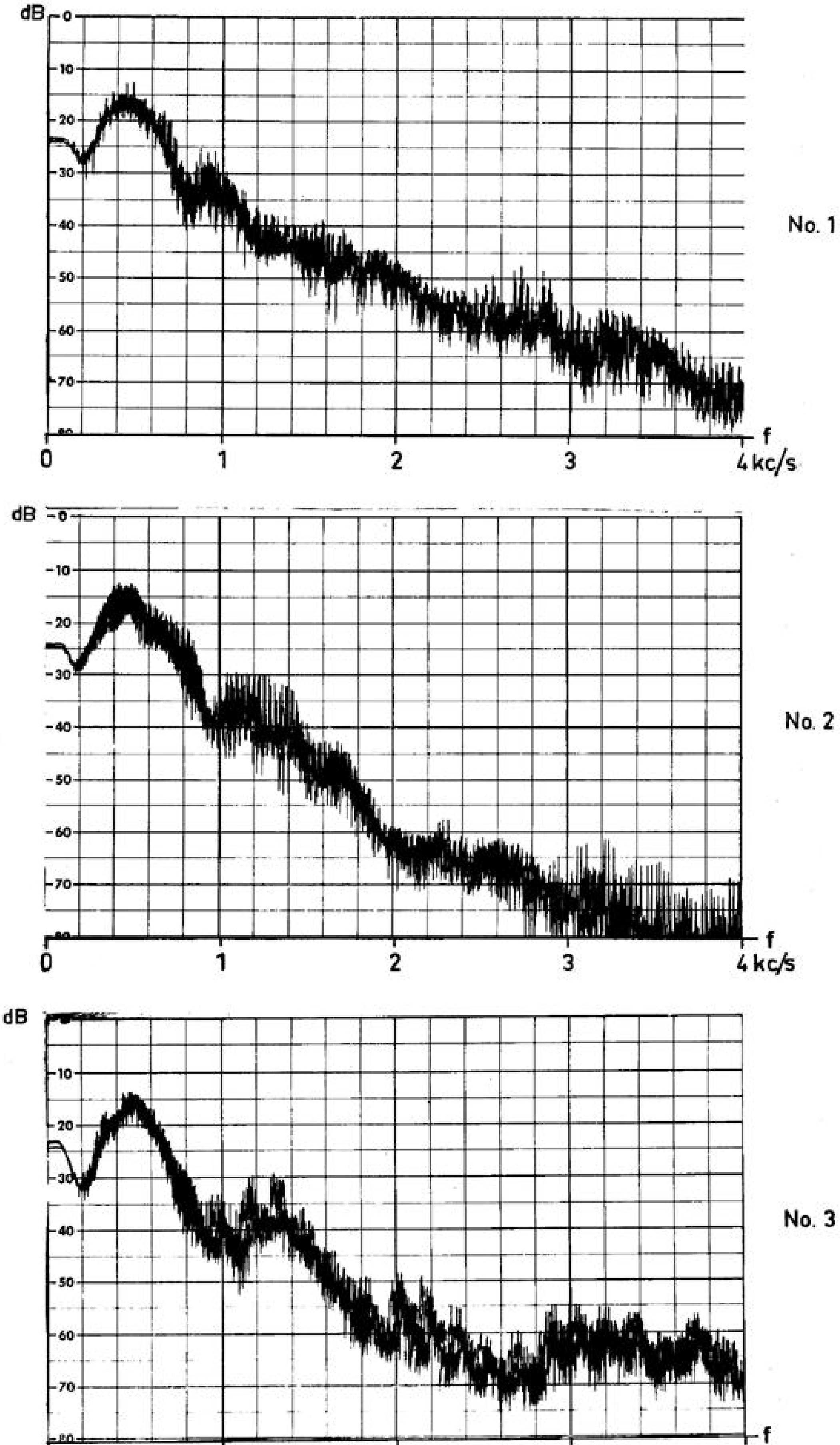
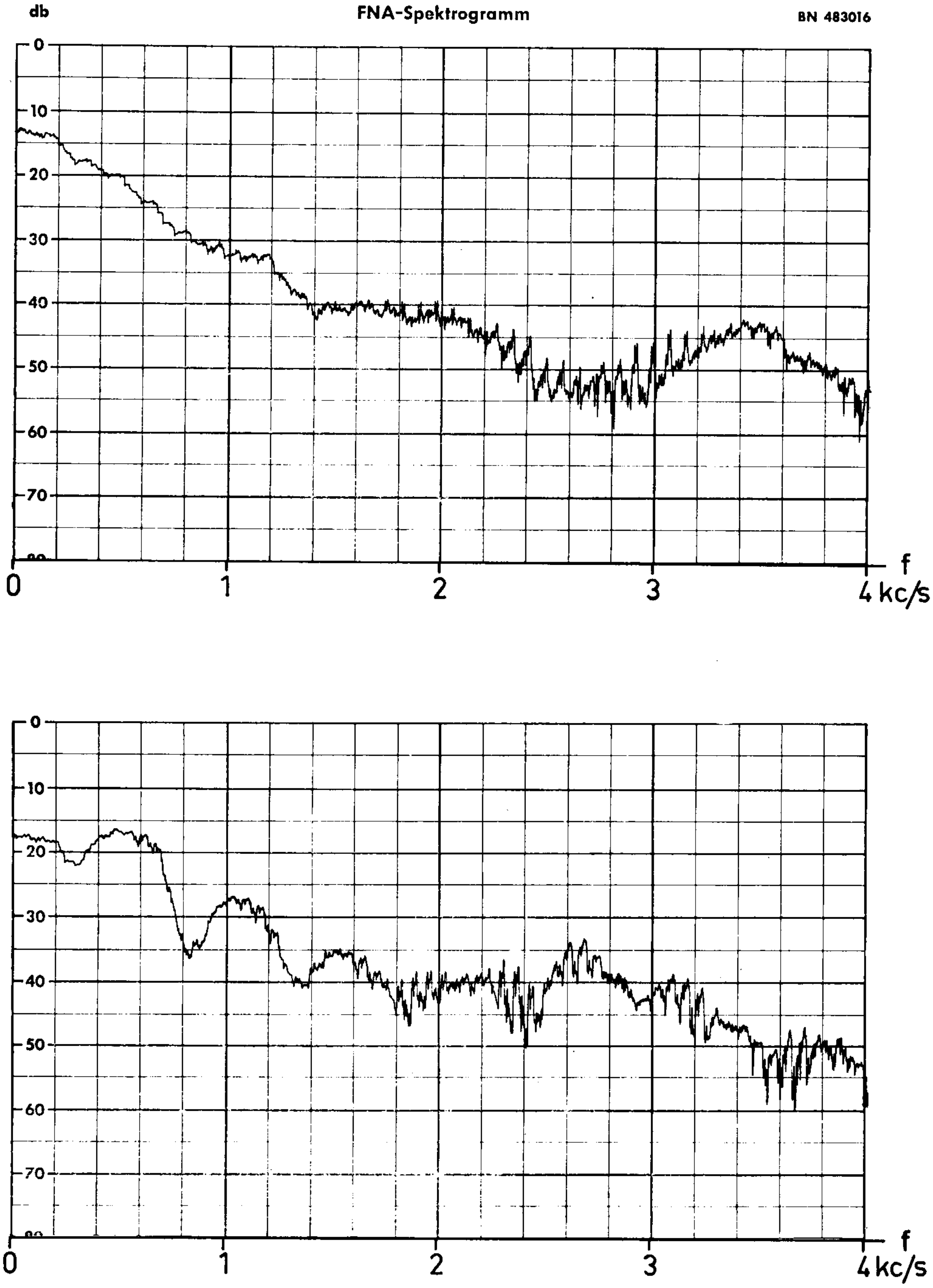


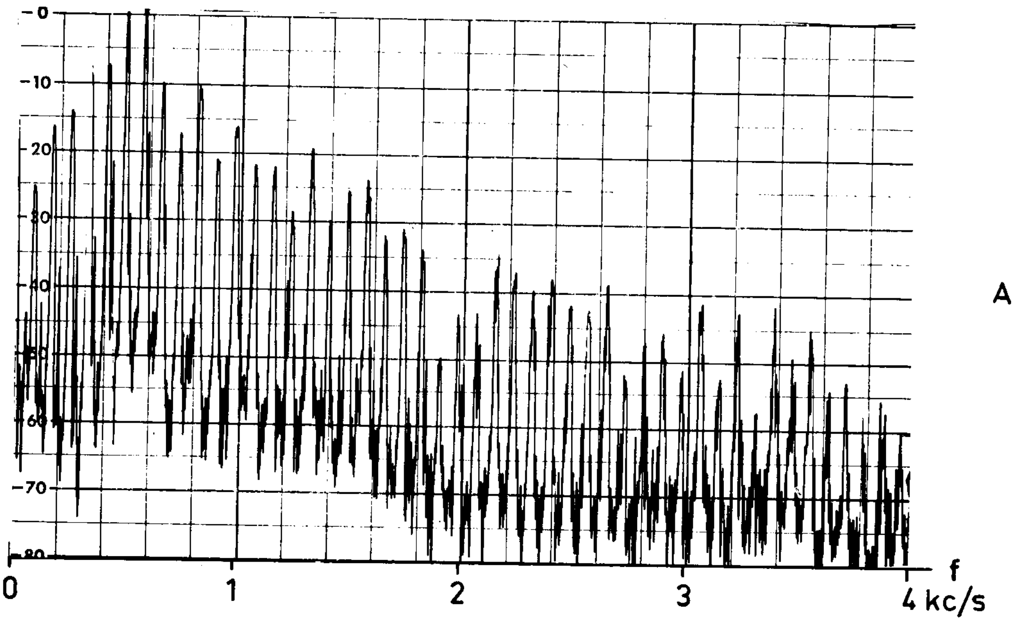
Fig. IV-A-1. Spectrogram of five tones, g_2, a_2, b_2, c_3, d_3, played in rapid ascending and descending succession on:
No. 1, Old bassoon marked H. Grenser;
No. 2, Modern bassoon marked Buffet & Cranpon, Paris;
No. 3, Modern bassoon marked H. Zuleger, Wien.



A

B

Fig. IV-A-2. Spectrogram of a tone blown on a circular tube, 2.1 cm diameter and 1 m length:
(A) with a clarinet mouthpiece,
(B) with a bassoon reed.



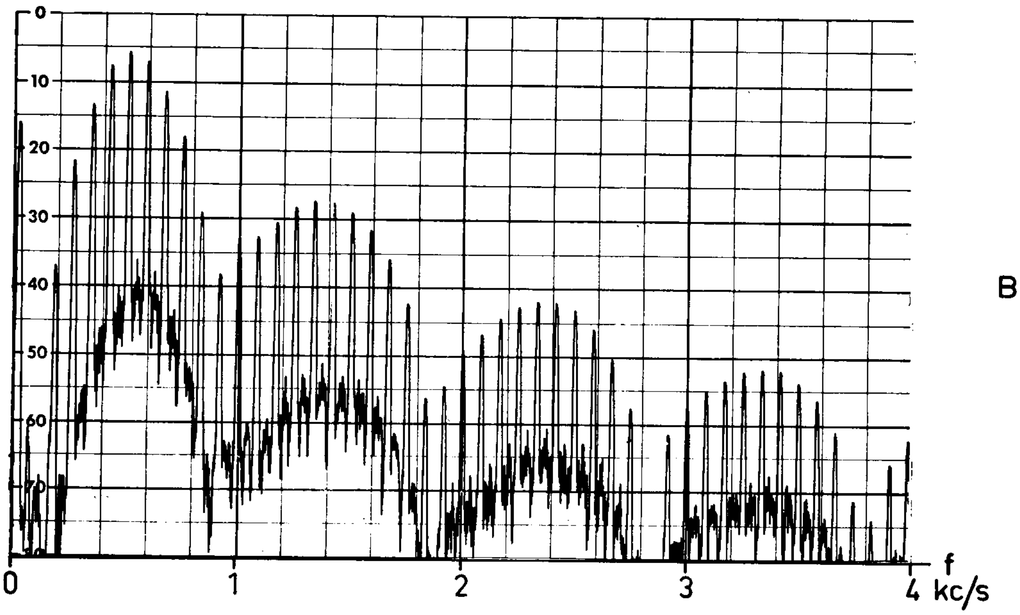


Fig. IV-A-3. (A) Spectrogram of a blown tone e_2 (82 c/s) on bassoon No. 3.

(B) Spectrogram of corresponding synthetic tone from an electric analogue.

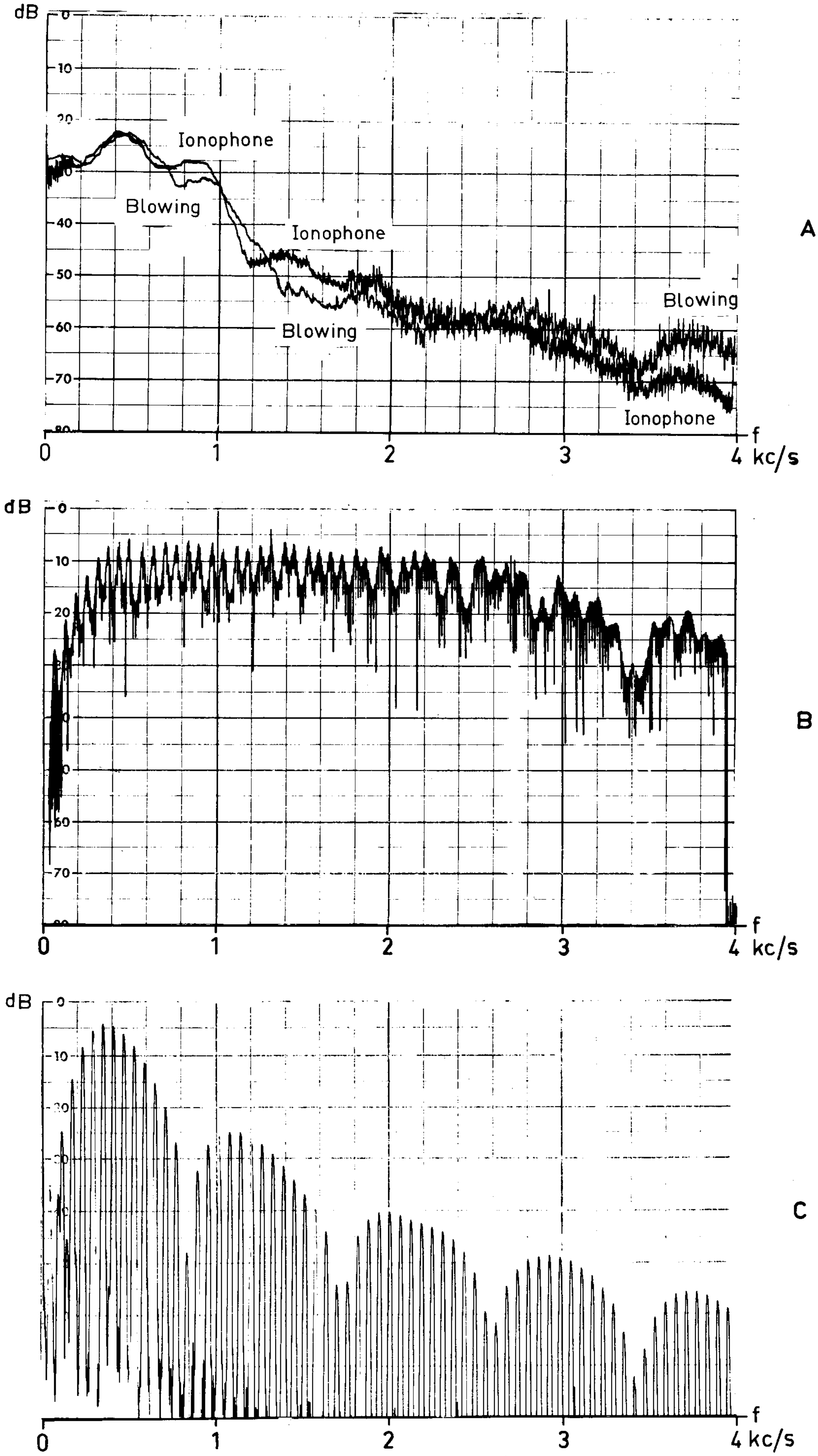


Fig. IV-A-4. (A) Spectrograms of tone $\breve{b}_1$ (60 c/s) produced from bassoon No. 1 by regular blowing and by ionophone excitation.

(B) Corresponding transfer function.

(C) Source spectrum produced by ionophone excitation.

high-pass filter. The pulse time was 1.2 msec, the repetition rate corresponded to the fundamental frequency of the matched tone e_2. The impression of a similarity in timbre of the blown bassoon tone and the synthetic tone was quite good. The spectrum of the blown and synthetic tone can be compared in Fig. IV-A-3.

Experiment III

A synthesis of the bassoon source function was attempted by means of ionophone [4] excitation of the old instrument No. 1. A small container, about 0.5 cm^3, with the ionophone electrodes was applied to the crook of the instrument instead of the reed and the ionophone was modulated by pulses about 1.2 msec in duration, with a repetition rate corresponding to the fundamental of the blown tone, i.e. $^{\flat}b_1 \cong 60$ c/s. The matching of the produced synthetic tone to the blown tone was made by a pulse shaping network.

Fig. IV-A-4 shows the spectrum of the blown and synthetic (ionophone) tone, the synthetic source spectrum, and the transfer function. The source spectrum of the bassoon is evidently characterized by a $\frac{\sin x}{x}$ pulse function.

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