THE ANALYSIS OF BIRD SONGS BY MEANS OF A VIBRALYZER

BY DONALD J. BORROR AND CARL R. REESE

TO analyze a bird's song one needs to determine its loudness, rhythm, and frequencies. Since these characteristics cannot be accurately determined by the ear alone, most published accounts of bird songs are merely subjective descriptions and not accurate analyses. Attempts have been made (*e.g.*, Arleton, 1949, and Mathews, 1904) to represent bird songs with the musical scale, but these are often inadequate because they cannot accurately indicate the unusual intervals, slurs, or erratic rhythms in many songs, and they do not indicate the frequency composition of the individual notes. Saunders (1935 and 1951) has devised a graphic method of representing bird songs, showing time on the horizontal axis and pitch on the vertical axis, and while his graphs are useful for identification they do not always show the minute details of rhythm, and no attempt is made to show frequency composition except by an accompanying description indicating the quality and phonetics of the song. Brand (1935) introduced a new method of bird song analysis—the microscopic study of songs reproduced on sound film. This method makes possible the accurate determination of the minute details of rhythm and the frequencies of the fundamentals, but it does not give any information on the harmonics or other frequencies present. A few other means have been used (*e.g.*, Metfessel, 1934, and Fish, 1953) to obtain graphic analyses of bird songs, and while some of these give an accurate picture of the rhythms they do not give frequency composition, a feature that determines the quality of a note. The determination of loudness in all these analyses has been entirely subjective. In this paper the authors wish to report briefly on a method of bird song graphing that has been little used (Bailey, 1950), one which not only gives a picture of the minute details of rhythm but shows all the frequencies present and gives some data on loudness.

Two types of graphs, or vibragrams, can be obtained with the Vibralyzer (manufactured by the Kay Electric Company, Pine Brook, New Jersey). One type shows frequencies along the vertical axis and time along the horizontal axis, and variations in intensity appear as corresponding variations in the darkness of the mark produced. A second type (a "section" vibragram) shows frequencies on the vertical axis and intensity on the horizontal axis, for any given point (actually integrated over 0.005 sec.) in time; this type gives more accurate data on intensities than the first type. Vibragrams are made on 5⅝ by 12¾ inch facsimile paper; frequencies are portrayed over a vertical distance of about 4 inches and time over a horizontal distance of about 12½ inches. This paper is fastened to a drum which rotates synchronously with a magnetic disc; the stylus is a 10 mil stainless steel wire. The marks on the paper are made electrically.

A simplified diagram of the principal circuits of the Vibralyzer is shown in Fig. 1. The input signal (from a tape recording of the song) is recorded on a magnetic disc (with the switch S_1 in the "record" position) by means of a record amplifier; once the

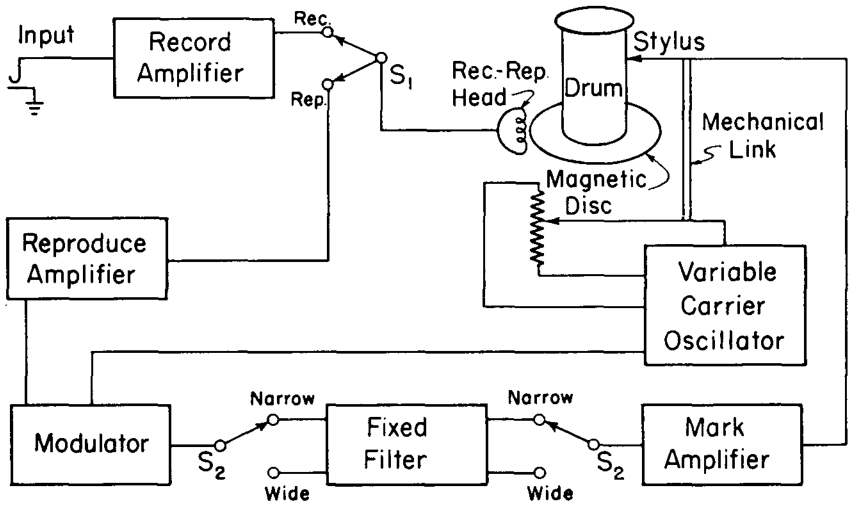

FIG. 1. A simplified diagram of the principal circuits of the Vibralyzer; several circuits are omitted, including the monitor amplifier, the erase head on the magnetic disc, and the sectioner.

signal is on the disc, S_1 is turned to the "reproduce" position. The signal on the disc may be heard by means of a monitor amplifier (not shown in the diagram) each time the disc rotates. When the vibragram is made the disc is rotated at the rate of 80 revolutions per minute and the signal is played back from the disc by means of a reproduce amplifier, and the output of this amplifier is fed into a modulator which modulates the playback signal with the output of a variable carrier oscillator. The frequency of this oscillator is determined by the position of the stylus, by means of a mechanical linkage. The modulated signal is fed to a fixed frequency filter, and the output of the filter actuates the mark amplifier which in turn supplies a marking voltage to the stylus. As the vibragram is made the stylus moves upward on the drum one inch for every 96 revolutions of the drum, causing the oscillator to sweep through its frequency range and thus effectively scan the recorded signal over this range. The frequency of the oscillator at any given position of the stylus determines what frequencies in the recorded signal will give rise to a difference frequency* that passes through the filter and results in a mark by the stylus.

The filter is set for a frequency of 15,000, and the carrier oscillator frequencies vary from 15,133 to 28,300; thus the reproduced frequency range is from 133 to 13,300 cps. The frequency range covered in any given vibragram depends upon the speed of rotation of the magnetic disc when the signal is being put on it; this disc can be rotated at four

*If one sine wave, $e_1 = E_1 \sin 2\Pi f_1$, modulates a second sine wave, $e_2 = E_2 \sin 2\Pi f_2$, the resultant signal (e) can be represented by $e = E_2 \sin 2\Pi f_2 + E_1 \cos 2\Pi (f_2 - f_1) - E_1 \cos 2\Pi (f_2 + f_1)$. The second term in this value of e gives rise to the difference frequency, $f_2 - f_1$. This difference frequency, due to the proper selection of parameters in the Vibralyzer, is the only frequency in the resultant signal which falls within the range of the analyzing filter.

TABLE I

FREQUENCY RANGE, RESOLUTION, AND RECORD DURATION OF VIBRAGRAMS MADE OF SIGNALS PUT ON THE MAGNETIC DISC AT DIFFERENT DISC SPEEDS

Speed of disc when signal is put on	*Frequency range of vibragram**	*Effective band width of filter*		*Duration of sample*
		Narrow	*Wide*	
Lowest	5–500 cps	2 cps	20 cps	20 sec.
Low	15–1500 cps	6 cps	60 cps	6.6 sec.
High†	44–4400 cps	20 cps	200 cps	2.25 sec.
Highest	133–13300 cps	60 cps	600 cps	0.75 sec.

* The range can be reduced to one-half this value by a switch on the control panel.
† Most bird songs are fed to the Vibralyzer with the disc rotating at this speed.

different speeds. Two band widths are available in the filter, a wide band and a narrow band. The degree of time and frequency resolution of the vibragram depends on the disc speed (when the signal is put on it) and the band width of the filter, the narrow band filter giving greater frequency resolution and the wide band filter giving greater time resolution. The characteristics of vibragrams made under different conditions are shown in Table I.

Vibragrams of any given song will vary in appearance depending on the settings on the control panel of the instrument; the controls can be set to bring out specific characteristics of the song. Time intervals can be measured with greater accuracy if the tape recordings fed into the Vibralyzer are run at a reduced tape speed.

The following general conclusions may be drawn from the few hundred vibragrams of bird songs that we have made to date:

(1) Relatively few bird notes are simple or "pure"; most of them are composed of many frequencies, and the most intense frequency is seldom the lowest in the note. Few notes show distinct harmonics. Most bird notes, except those that are clear whistles, are somewhat intermediate between musical tones and noises, *i.e.*, they may contain two or three predominating frequencies but also contain all (or nearly all) of the frequencies in between. If the frequency spread is narrow (*e.g.*, the second note in the Red-eyed Towhee song, Fig. 3), the note appears musical; if the frequency spread is an octave or so (*e.g.*, the lower notes of the Song Sparrow's trill, Fig. 6), the note appears more like a noise. The frequency of a musical note can be determined fairly accurately by ear by comparison with a standard, but it is difficult or impossible to determine any predominant frequency by ear in a noise-like note.

(2) Some birds may begin a note with a particular frequency composition, and before ending that note begin another containing a different (usually higher) group of frequencies (see Figs. 2 and 3).

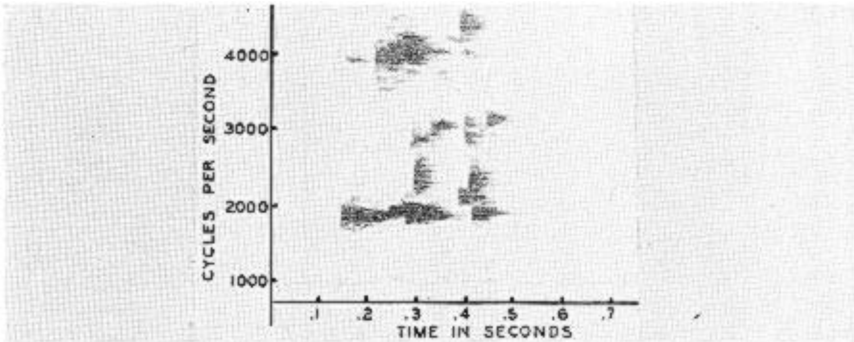

Fig. 2

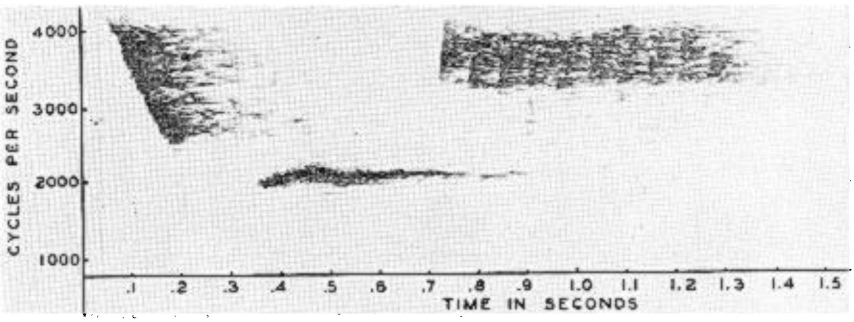

Fig. 3

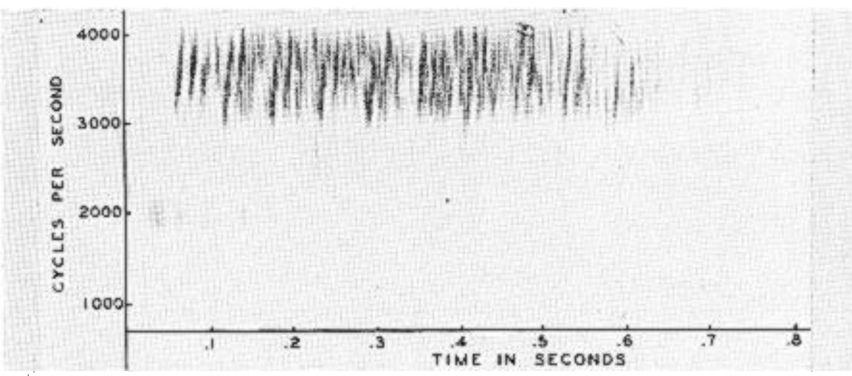

Fig. 4

FIGS. 2–4 (top to bottom). Vibragrams of bird songs, from tape recordings made in central Ohio. Fig. 2, the somewhat squeaky "song" of the Blue Jay (*Cyanocitta cristata*); Fig. 3, the *drink-your-tee* song of the Red-eyed Towhee (*Pipilo erythrophthalmus*); Fig. 4, the final *teeee* of the same song shown in Fig. 3, made to give better time resolution and showing the pulses in this note. The vibragram in Fig. 4 was made using the wide band filter; the other vibragrams were made using the narrow band filter.

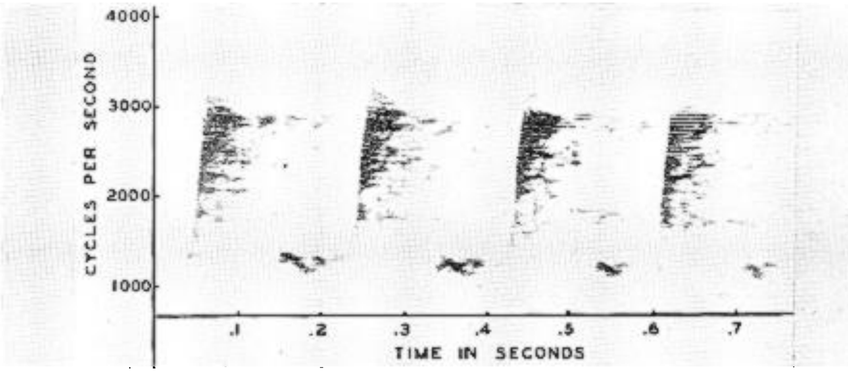

Fig. 5

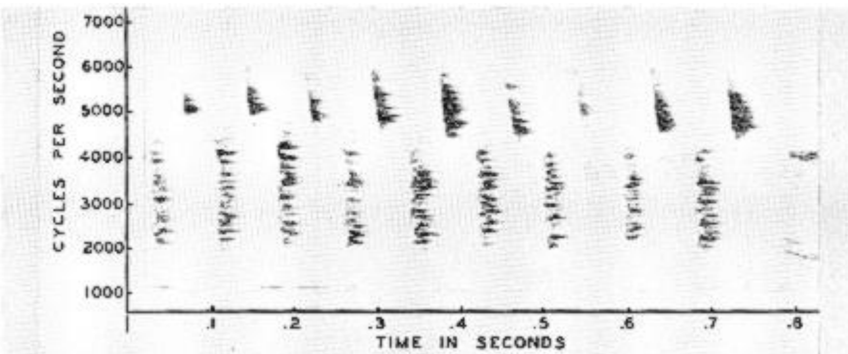

Fig. 6

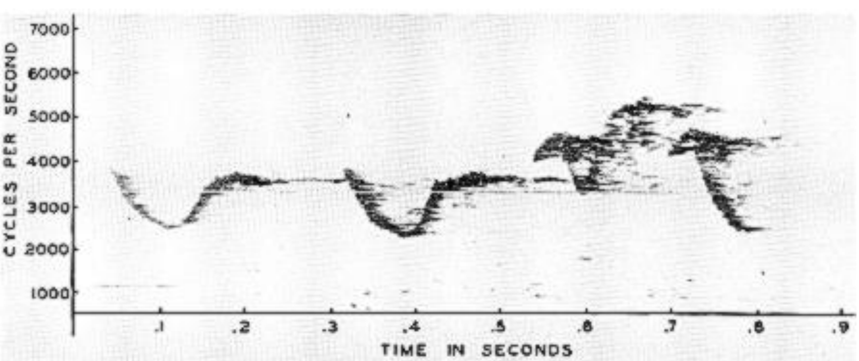

Fig. 7

FIGS. 5–7 (top to bottom). Vibragrams of bird songs, from tape recordings made in central Ohio. Fig. 5, part of the song of a Cardinal (*Richmondena cardinalis*); Fig. 6, a trill in the song of a Song Sparrow (*Melospiza melodia*); Fig. 7, the song of a Hooded Warbler (*Wilsonia citrina*). These vibragrams were made using the narrow band filter.

(3) Many bird notes are slurred upward (*e.g.*, Fig. 5) or downward an octave or so in 0.01 second or less.

(4) Notes which appear buzzy to the ear (*e.g.*, the final *teeee* of the towhee's song, Fig. 4) usually contain a wide range of frequencies and are modulated, with pulses coming at the rate of 100 or more a second.

(5) Many bird songs contain more individual notes than are apparent to the ear (note particularly Fig. 2).

(6) Some bird notes (*e.g.*, the final note in the Hooded Warbler's song, Fig. 7) consist of two groups of frequencies, one maintained steady and the other slurred; or, such a bird might be said to sing two notes at once, one a steady note and the other slurred.

Analyses of this sort will provide objective data that are more detailed and accurate than those obtained by most of the methods heretofore used in studying bird songs, and should be of value in behavior and taxonomic studies. They suggest some interesting lines of future investigation, *e.g.*, a study of the intraspecific variation in bird song, and a study of the syringeal mechanism to determine how these vocal gymnastics are produced.

We wish to express our appreciation to Dr. J. Allen Hynek, Department of Physics and Astronomy, Ohio State University, for making a Vibralyzer available for these studies, and to Mr. William Protheroe, of the same department, for his assistance in the operation of the Vibralyzer.

Literature Cited

Arleton, A. V.
1949 Songs and other sounds of birds. Eklund Printing Co., Hoquiam, Washington.

Bailey, C. E. G.
1950 Towards an orthography of bird song. *Ibis*, 92:115–122.

Brand, A. R.
1935 A method for the intensive study of bird song. *Auk*, 52:40–52.

Fish, W. R.
1953 A method for the objective study of bird song and its application to the analysis of Bewick Wren songs. *Condor*, 55:250–257.

Mathews, F. S.
1904 Field book of wild birds and their music. G. P. Putnam's Sons, Inc., New York.

Metfessel, M.
1934 Strobophotography in bird singing. *Science*, 79:412–413.

Saunders, A. A.
1935 A guide to bird songs. D. Appleton-Century Co., New York.
1951 A guide to bird songs (revised edition). Doubleday and Co., Inc., Garden City, New York.

Department of Zoology and Entomology, The Ohio State University, Columbus 11, Ohio, February 11, 1953