INSTRUMENTATION & TECHNIQUES

An animal sound simulator

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A portable and inexpensive animal sound simulator is described, and the use of the simulator in the production of song mimics of male *Drosophila* species is illustrated.

Many arthropods produce biologically significant sounds that are important in, for example, sexual behavior, aggression, social behavior, and defense against predators. The majority of these sounds are produced by stridulation or vibration of hard chitinous body parts such as wings or legs and, less commonly, by drumming against the substrate or expellation of air from internal air spaces such as the trachea. Because of the mechanisms of sound production, the sounds themselves usually consist of pulses of pure tones that are easy to record and characterize and can be adequately displayed on a cathode-ray oscilloscope (CRO). In this they contrast markedly with the complex vocalizations of most birds and mammals. The relative simplicity of arthropod sound production and the mechanisms of sound reception involved allow experimental analysis of the communication systems. Many such studies have been carried out particularly in Orthoptera (Huber, 1974). One requirement for such research is a means of replicating the songs. This can be done with tape recordings or tape loops, but this is not easy for some groups of insects in which the sound levels are very low and a satisfactory signal-to-noise ratio is difficult to achieve. Also, it is a considerable advantage if different parameters of the song can be varied individually, and this is most easily done if the song patterns can be artificially simulated. Thus, for example, using a simple simulator, Bennet-Clark and Ewing (1969) could demonstrate that interpulse interval (IPI) and not intrapulse frequency was the important characteristic of the song of male *Drosophila melanogaster*, which sexually stimulated females. A simulator was also used to investigate the properties of the *Drosophila* acoustic receptor (Ewing, 1978).

The song simulator described in this paper reflects the separate interests of the authors; these are the songs of fruit flies (*Drosophilidae*) and bush crickets (*Tettigoniidae*). The former produce songs with funda-

mental frequencies of between 150 and 1,000 Hz, the latter between 1 and 100 kHz. This constitutes a considerable range of frequencies and the simulator is thus able to mimic the song patterns of most arthropods, whose songs consist of trains of pulses with a similar structure.

DESIGN CRITERIA

In both fruit flies and bush crickets, the fundamental frequency of the song can be approximated by a sine wave. Amplitude modulation of the sine wave can be used to produce tone bursts. However, in *Drosophila melanogaster*, the song is a series of pulses, each consisting of a single cycle produced by the upstroke of the wing. Thus, each cycle starts in the same phase of the sine wave. The simulator requires a phase detector to keep the modulating signal in phase with the fundamental.

It has been demonstrated that the modulation pattern of songs may be relevant. Thus, in *D. melanogaster*, alternating periods of song and silence (2 sec:2 sec) is far more effective in stimulating females than is a continuous song (Ewing, 1977). In the bush cricket *Ruspolia (Homorocoryphus)*, the number of pulses per second in the male song is species specific and is used as an isolating mechanism (Bailey & Robinson, 1971). The simulator, therefore, has provision for varying the mark: space ratio of the sound output between wide limits. Many animal songs have a hierarchy of temporal patterns, which in a simulator can be built up sequentially. In the present design, only two patterns have been used, but simple extension of the existing units would be easy if third, or higher order, patterning was required.

The simulator was designed to be portable and powered from dry cell batteries, so no power-supply design is included.

Figure 1. Block diagram of the simulator.

SIMULATOR FUNCTION

A block diagram of the simulator is shown in Figure 1 and a simplified diagram in Figure 2. The phase detector (2 and 3 in Figure 1) incorporates a variable-gain buffer to match the sine-wave generator to the rest of the circuit. A Schmitt trigger is included in the phase detector to provide fast rise-time pulses for the digital

Figure 2. Simplified timing diagram. The six traces are: (1) sine input, (2) output of phase detector, (3) output of control latch (6 in Figure 1), which sets the number of cycles per pulse, (4) output of reset latch (7), which sets the inter-pulse interval (IPI), (5) gate (9) input, which sets pulse-train length, and (6) pulse train. The shaping provided by the waveform generator is not shown.

section. The trigger output (Figure 2, Trace 2) of one square pulse per sine-wave cycle is fed to a decade counter (4), whose outputs are used to select, via a switch (5), the number of sine cycles included in each sound pulse. The first square pulse sets the counter-reset latch (7), and a control latch (6) that provides a square pulse whose duration controls the length of the sound pulse (Figure 2, Traces 3 and 4). Both latches are reset by the counter output selected by the rotary switch (5). The counter-reset latch (7) triggers a monostable (8) that resets and disables the counter. The duration of the monostable pulse can be varied, and this controls the IPI of the sound output. The control latch (6) output is fed to the voltage-controlled amplifier (11) via a gate (9) that sets the sound pulse train length (Figure 2, Trace 5). The gate can be operated manually or automatically, and both options are shown in the detailed circuit diagram (Figure 3).

A waveform generator, used to shape the sound pulse, can be inserted between the gate and the voltage-controlled amplifier, as shown in Figure 1.

CIRCUIT DETAILS

The detailed circuit diagrams of the prototype are shown in Figures 3-6. A detailed diagram of the sine generator is not included, since a commercial instrument or a standard application of the Intersil 8038 integrated-circuit (IC) waveform generator can be used.

The circuits controlling pulse-train length, IPI, attack, and decay use resistance-capacitance timing, and the values of the timing components can be varied over a wide range to suit individual requirements.

The voltage-controlled amplifier (Figure 6) is designed around the MC 3340 electronic attenuator for simplicity

Figure 3. Circuit diagram of counter and digital section. VCA = voltage-controlled amplifier. *This capacitor is selected to suit the range of interpulse intervals required.

Figure 4. Circuit diagram of phase detector.

Figure 5. Circuit diagram of waveform generator. *This capacitor is selected to suit the attack and decay times required.

Figure 6. Circuit diagram of voltage-controlled amplifier. *The control voltage on Pin 2 of IC2 must be between 3.5 and 6.0 V. These resistors are used to trim the voltage to this range.

Figure 7. Songs of three *Drosophila* species (upper trace in each pair) and their simulations (lower trace).

and economy. However, a more versatile design, based on a linear multiplier (Orr & Thomas, 1973), has also been used. This design requires a control voltage of opposite polarity to that of the electronic attenuator, so the inverting amplifier shown in Figure 6 is not required.

PERFORMANCE

The performance of the simulator in reproducing the songs of three *Drosophila* species is shown in Figure 7. The top trace of each pair represents an oscillograph of the actual song, the lower trace the simulator output. The ability of the simulator to produce accurate mimics of insect song is clearly demonstrated, and this instrument, or derivatives of it, should find applications in many areas of behavioral research. For applications where the number of pulses within an envelope is not critical, or where phase control is not required, there are a number of devices available that provide adequate

alternatives. A simple tone-burst generator can be built using the Signetics 556 dual timer. General Radio Corporation markets a relatively inexpensive tone-burst generator with variable envelope shape and phase control.

Certain animals produce sounds that are frequency modulated, for example, frequency sweeping by some bats. Frequency modulation can be realized by using a control waveform to drive a voltage-controlled oscillator. We recently designed and built a frequency-sweep generator using a new Texas Consumer IC, the SN76477N. This IC contains a number of circuit blocks designed to produce sound effects for TV games and toys, but among these are a low-frequency oscillator, a voltage-controlled oscillator, an envelope shaper, and a mixer amplifier that form the basis of the frequency-sweep generator. This circuit can generate a wide variety of sounds and is useful as a general-purpose animal sound simulator, but it is not capable of the phase control and pulse counting that the circuit described in the text achieves. Design information for the SN76477N is given in a preliminary information sheet issued by Texas Instruments, Inc.

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