INSTRUMENTATION & TECHNIQUES

A detector of sonic and ultrasonic vocalizations with frequency readout

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An electronic apparatus to detect vocalizations between 4 and 50 kHz and to provide frequency readout is described. A frequency-to-voltage converter changes vocalizations to their analog. A peak-and-hold circuit retains and gates the maximal value of this analog voltage while it is accessed by a chart recorder or computer. Provision is made to lock out noise by inhibiting the device's response to all signals lower than those associated with a selectable cutoff frequency. In preliminary tests of the apparatus, vocal signals of two rats in a common cage were recorded while the animals were subjected to a brief, intermittent bout of faradic shock to the feet. All recorded vocalizations occurred at frequencies below 26 kHz.

Most automatic recording-and-counting detectors of vocalizations that have been described in the literature employ some form of active resistance-capacitance (R/C) filtering (see, e.g., Harrison & Holman, 1978), tone decoding (e.g., Clarke, Smith, Justesen, Sheridan, & Cushman, 1984), or signal-heterodyning techniques (e.g., Pye & Flinn, 1964) to discriminate vocal signals from background noise. Such detectors monitor signals only within a restricted range of frequencies; excluded are vocalizations that fall outside the band that is passed by the R/C filter, by the tone decoder, or by the local oscillator and low-pass amplifier in combination.

A wide-band ultrasound digital recorder has been developed by Paranjape, Secord, and Voss (1983). This device uses digital techniques to record the frequency and amplitude of vocalizations between 10 and 90 kHz. The detection and classification by electronic means of the auditory correlates of aggression, dominance, submission, and so forth, which often occur at disparate frequencies, can obviously be useful in behavioral research (see Paranjape et al., 1983; Sewell, 1970a, 1970b).

In an attempt to generate simpler and less expensive solutions to the problem of direct-frequency indication of vocalizations (and hence the capability of continuously monitoring many types of calls and categorizing their concomitant behaviors with a computer or chart recorder), we have developed a vocalization detector based on the LM2907, an integrated circuit (IC) most commonly found in automotive tachometers.

CIRCUIT DESIGN AND OPERATION

The circuit diagram of the vocalization detector is presented in Figure 1. A tweeter (Radio Shack 40-1377) serves as an inexpensive (\$17) extended-range (4–50 kHz) sound transducer. The input 353-IC is configured as a differential amplifier and as a high-gain preamplifier. The differential amplifier cancels common-mode noise and eliminates the need for a matching transformer. The second 353-IC functions as voltage amplifier and follower.

The LM2907-IC is a linear frequency-to-voltage converter. Internally, it consists of an input amplifier, a charge pump, and an output amplifier. The components shown with this IC in Figure 1 provide a linearly increasing dc output over the usable frequency range of the transducer (see Table 1). The slope and frequency range are determined by the value of the capacitor attached to pin no. 2 of the LM2907 (100-pf). An increase in this value produces a steeper slope and shifts the curve downward (the curve reaches asymptote at a lower frequency). A decrease in the capacitance has the opposite effect. The maximal voltage obtainable from the LM2907 as employed is ~10 V—much more than is needed to capture vocalizations at 50 kHz and below.

The 100-k Ω resistors and the .022- and .044- μ fd capacitors in the converter circuit (Figure 1) form a two-pole Butterworth filter that reduces output ripple. For optimal operation, components should be hand-selected for the filter, so that $R1 = R2 = R3$, and $C1$ has exactly half the capacitance of $C2$.

The output of the frequency-to-voltage converter goes to a peak-and-hold circuit and to a comparator. The peak-and-hold circuit consists of a 353-IC, a 1N914 diode, a 1- μ fd tantalum capacitor, and an MPS3904 transistor. When the voltage across the 10-k Ω resistor in the output circuit of the converter rises, the output (pin no. 1) of the

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A Vocalization Detector 4 to 50 kHz

Figure 1. Schematic of the ultrasonic detector. All resistances are rated at .25 W. All capacitors are rated at 15 working volts or higher.

Table 1
Analog Output of the Vocalization Detector: Pure Tones Generated
by an Oscillator and an RS 40-1377 Tweeter

Input Frequency (in kHz)	Output Voltage
4	0.432
6	0.644
8	0.853
10	1.071
12	1.274
14	1.488
16	1.703
18	1.875
20	2.132
22	2.324
24	2.520
26	2.745
28	2.969
30	3.186
32	3.401
34	3.618
36	3.830
38	4.043
40	4.253
42	4.468
44	4.685
46	4.895
48	5.109
50	5.314

Note—All voltages reproducible within $\pm 1\%$.

first half of the 353-IC rises until the inverting input signal (pin no. 2) reaches an equal potential. In so doing, the $1\text{-}\mu\text{fd}$ capacitor charges to this value. When the voltage across the $10\text{-k}\Omega$ resistor falls, the 1N914 diode becomes reverse-biased and the voltage on the capacitor remains unchanged. The discharge of this capacitor is controlled by the MPS3904 transistor. This transistor is normally reverse-biased, and thus it presents a high-resistance path to ground until it receives a reset pulse from the sequencer. The second half of this peak-and-hold circuit is a 353-IC voltage follower. This circuit prevents inadvertent discharge of the capacitor when the detector's analog output is interfaced with a low-impedance input.

The comparator (741-IC) also receives the output of the converter and compares it with a second voltage determined by the user. This voltage is selected to be equivalent to that produced by the LM2907 when it is below the frequency in which the investigator is interested. As an example, suppose someone interested in the vocalizations of the rat wishes to exclude noises produced by such extraneous factors as gnawing or an animal rubbing against the sides of its cage. Such signals can be locked out, regardless of amplitude, by means of adjustment of the wiper of the $1\text{-k}\Omega$ potentiometer. The wiper places pin no. 2 of the comparator at the voltage equivalent to that produced by the maximal frequency of the noise signals (approximately 12 kHz in this case) that one wishes to exclude. From Table 1, it can be seen that the analog equivalent of 12 kHz is 1.274 V. With the comparator level set at this voltage, any lesser voltage is inhibited from triggering the sequencer. When the output of the converter exceeds this voltage, the output of the comparator (pin

no. 6) goes from negative to positive, and the voltage across the $10\text{-k}\Omega$ resistor in its output circuit goes from zero to approximately 10 V positive; it is prevented from going negative by the 1N914 diode. After a vocalization, and when the voltage on the converter falls below the comparator level on the $1\text{-k}\Omega$ potentiometer, the differentiator ($0.1\text{-}\mu\text{fd}$ capacitor and $10\text{-k}\Omega$ resistor to ground) produces the following-edge negative peak that triggers the sequencer. The sequencer, which controls the timing of the vocalization detector, produces a gate that tells the computer to read the voltage being held on the $1\text{-}\mu\text{fd}$ peak-and-hold capacitor. At the end of the gate pulse, during the second half of the sequence, the 556 applies a positive pulse to the base of the MPS3904 transistor. This reset pulse forward-biases the transistor and discharges the peak-and-hold circuit's capacitor. The detector is now primed for the next vocalization. If a chart recorder is used to access the voltage on the capacitor, the gate pulse may be used as a marker signal to verify the presence of a vocalization above whatever lower cutoff frequency is selected.

BEHAVIORAL VERIFICATION OF THE VOCALIZATION DETECTOR

Method

Subjects. Two male Sprague-Dawley rats at 450–456 g were supplied by Sasco of St. Louis, Missouri. The rats were individually housed in the Animal Research Facility of the Kansas City Veterans' Administration Medical Center. They were maintained on a 12:12-h light:dark schedule, and they had access to food and water, ad lib.

Apparatus. A shock grid of aluminum rods was placed on the floor of a $25 \times 25 \times 30$ cm Plexiglas cage. The vocalization detector was originally developed as one of several behavioral measuring devices to be used in a low-frequency magnetic-field exposure system. The cage was located inside a cubic-coil system designed to produce a uniform magnetic field (Rubens, 1945). The coils were not energized. The sound transducer for the vocalization detector was attached to the top of the Plexiglas cage. A faradic source of current (Justesen, King, & Clarke, 1971) to provide motivational stimulation was connected to the shock grid. The cage and cubic-coil system were separately shock-mounted inside an $86 \times 91 \times 142$ cm anechoic chamber. The rats were visible via a one-way mirror mounted on one side of the anechoic chamber. The faradic shocker was programmed to deliver a single 0.5-sec shock to the grid each time a switch held by the operator was depressed. The open-circuit shock level was approximately 275 V rms at a frequency that peaked at 10 kHz. The short-circuit current was below $10\text{ }\mu\text{A}$. A human observer who places his hand on the shock grid perceives a faradic shock at these parameters as similar to a sharp blow to the palm with the flat surface of a plastic ruler.

Procedure. Both rats were placed inside the Plexiglas cage, and the door of the anechoic chamber was closed.

Figure 2. Signal frequencies of vocalizations elicited by faradic shock of two rats in a common cage. Only frequencies at 12 kHz and above were recorded.

To test the lower-frequency cutoff provision of the device, the comparator was set at the voltage equivalent of 12 kHz. Several shocks were then administered to the rats while their behavior was monitored through the one-way mirror. Shocks were immediately terminated when the rats adopted a threatening posture.

Results

In each of two trials separated by 10 min, the rats' vocalizations were monitored until a total of 200 vocali-

zations was recorded (see Figure 2). During much of this time, the rats were motionless, standing erect, facing one another, in a characteristic "boxer" pose. Actual physical combat never ensued.

DISCUSSION

Commercial microphones with wide frequency ranges are expensive, unlike the widely available tweeters with narrower frequency ranges, which can serve the same function. The price of the commercial microphones probably reflects their specialized nature rather than any inherent expense in their design or construction. Although condenser microphones are simple to construct (see, e.g., Pye & Flinn, 1964), they are inherently narrow in bandwidth and difficult to produce with frequency versus output characteristics that are identical. These defects are due to technical difficulties that arise in tensioning such small diaphragms and possibly because of the fact that even metalized Mylar film appears to possess some degree of plastic memory. If such microphones are to be used across a wide range of frequencies, and if highly accurate measurements of amplitude are desired, then the input amplifier's response characteristics will have to be tailored to compensate for the nonlinearity of the transducer. Such tailoring would introduce additional complexity in the design of the device.

We have obtained reliable results with microphones of our own making, by using Kynar piezo film (Pennwalt Corp.). Piezo film has the added advantage of simplifying the electronics. However, for the vocalization frequencies with which a commercial tweeter is compatible, there are many advantages to readily available transducers with fixed characteristics and reasonable prices. We have found that commercial tweeters, in contrast with microphones of our own making, have a much more linear voltage output over a broader range of frequencies.

One problem with vocalization detectors is illustrated by the work of Sales and Pye (1974), who have shown that the rat's vocalizations of at least one class can occur at intervals as short as 3 msec. If a series of such vocalizations should occur, and if the sequence time were longer than the intervocalization interval, then only the first bout of vocal activity would be recorded. Within the limits of the user-selected recording device, our detector circumvents the problem of brief intervals by means of adjustable sequences, which can vary the operational limits of the readout mechanism (i.e., through adjustment of the rheostats in the 556-IC circuit; see Figure 1). Both the gate pulse, which must be of sufficient duration to trigger a recording source, and the reset pulse, which controls the intervocalization interval, will be of greater relative length if an electromechanical chart recorder is used. If a computer is used to access the data, the cycle time of the sequencer may be reduced to any interval that is compatible with the computer's accession cycle. The reduction is easily accomplished by reducing the values of the 500-k Ω rheostat (gate pulse) and/or of the 100-k Ω rheostat (reset pulse).

During initial calibration of the detector, the common-mode rejection ratio (CMRR) of the differential amplifier should be optimized. This can easily be accomplished with an oscilloscope. In the differential amplifier, the CMRR rheostat (Figure 1) should be tuned to a setting that provides minimal noise at the amplifier's output when the sound transducer is shorted.

All simple vocalization detectors are information-filtering devices designed to respond to predetermined sets of parameters. Complex vocalizations are not resolved by our device, because we favored the detection of a vocal signal at the highest frequency, which mandated detection of the highest output voltage (see Table 1). If an investigator is interested in complex characteristics of vocalizations, and if a fast-response recorder is available, the voltage analog of a detected vocalization at any frequency may be taken directly from the frequency-to-analog converter (LM 2907).

Finally, we note that although examination of sound spectrograms from a number of murine species led us to conclude that peak frequency is an adequate indicator of ongoing behavior, this may not hold true for the vocalizations of other animals. A true rms average-and-hold circuit is also an electronic possibility. This circuitry, however, is more complex than the simple peak-and-hold seen on the lower right in Figure 1. A schematic of a fast average-and-hold circuit, suitable for inclusion in this device, may be obtained on request from the senior author. These circuits are not mutually exclusive. It is possible

to use a combination of them in an LM2907 converter-based detector to obtain real-time records of a vocalization's maximal and average frequencies.

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