Stray Voltage Field Guide

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I. Introduction to Animal Sensitivity and Response

The widely accepted understanding of the way that stray voltage affects animals is through nerve stimulation. Nerves communicate through chemically produced electric pulses. A certain threshold is required for these electrical pulses to jump the gap between nerve cells. If the charge is below this threshold, no information or sensation will be transmitted by a nerve cell. These pulses act to communication between organs, contract muscles or transmit sensations of temperature, pain, and touch.

Externally applied electric current can produce the same sensations as the electric pulses produced by nerves. Externally applied current will spread out through the various tissues in the current pathway. It produces a current density depending on the voltage applied and the path through the body between contact points. A tingling sensation is commonly produced by contact with low-level electrical currents. As the current density increases muscle contraction occurs. This may result in a “quivering" sensation as alternating current causes muscles to alternately contract and relax. This level of current is normally perceived as annoying or painful. These low-level currents are not thought to produce any lasting damage to tissues. The main concern for animals is the behavioral responses to these sensations.

In order for electrical current to cause adverse animal response, it must first be of sufficient level to cause annoyance to the animal. The critical factors in ability of electric current to cause annoyance are the amount of current flow through the animal (and resulting current density) and the phase duration or frequency of the current (see section II).

The second consideration in the ability of electrical current to cause adverse animal response is the conditions under which the animal is exposed. These conditions include the location and number of times per day that the electrical event occurs (See Section III).

II. Nerve Stimulation and Annoyance

Current Flow

Animal tissue generally behaves according to Ohms law. At any fixed frequency the current flowing through animal tissue will be directly proportional to the voltage across it and inversely proportional to its resistance. The resistance of animal tissue decreases at high frequencies.

Cows present a larger cross sectional area than humans so it requires more total current to produce the same current density. In a study of the sensitivity of cows and people to 60 Hz current it was found that the average current perceived by people when applied to two adjacent fingers was 0.37 milliamperes, with discomfort noted at 0.45 milliamperes. The average current for which cows showed a behavioral response, when applied from one hoof to another was 3.7 milliamperes. It thus took about 10 times the current to elicit a response from a cow than from a person. This is mainly due to the smaller cross section of humans when compared to cows.

While the resistance of cow and human tissues is similar, the contact resistance is generally lower for cows than for humans, particularly if cows are in a wet environment. The resistance of a cow's body plus the contact resistance with the floor is commonly estimated as 500 Ohms. The resistance of a human can be as low as 1000 ohms for wet hand - foot contact to higher than 10,000 ohms for dry hand - foot contact. The contact voltage to produce sensation can therefore be higher for humans than for cows, depending on the conditions of the contact points. In most situations cows are less sensitive to current and more sensitive to voltage than people are.

	Cows	Humans
Average steady 60 Hz rms current to elicit response	3.7 mA	0.45 mA
Average steady 60 Hz Voltage to elicit response	1.9 V	0.9 - 9 V

Phase Duration and Frequency

There are three broad classes of contact voltages that animals encountered in animal environments.

1. 60 Hz Steady State and Motor Starts
2. Fencer Transients
3. Switching Transients

Animal and human sensitivity is very different for these three categories of voltage and current. The easiest way to determine the ability of an electrical pulse to excite nerves is to specify its phase duration and peak current. The following examples will help to explain these terms.

Electric power is distributed as Alternating Current (AC). The voltage and current alternate between positive and negative values at a frequency of 60 times per second (or 60 Hz). Current flows back and forth in a wire, rather than in a continuous flow like water in a hose. It takes 1/120th of a second, or 8.33 milliseconds (or 8,333 microseconds) for the voltage to cross zero, reach its peak value and return to zero. The time between these two zero crossings is referred to as the phase duration. A recording, typical of that obtained with an oscilloscope taken in a cow contact location using a 500 Ohms shunt resistor, for steady 60 Hz voltage is shown in Figure 1a. The time scale indicated is 20 milliseconds per division. The phase duration can be estimated as somewhat less than ½ of a division. This corresponds to the expected phase duration of 8.3 milliseconds for 60 Hz. The voltage scale indicated is 1 Volt per division. The peak voltage of this waveform is 2 Volts (note all peak voltages cited in this paper are from zero to peak, NOT peak to peak). This would correspond to an rms value of 1.4 Volts.

The distribution of behavioral reactions for dairy cows is shown in Figure 2. Cows are somewhat more sensitive to single hoof-hoof exposure than to muzzle - hooves exposure as indicated by the dashed and solid lines. A 60 Hz steady 2-Volt peak recording would elicit a behavioral reaction in about 5% of cows according to Figure 2. If the same voltage were recorded as a step potential about 10% of cows would be expected to show some type of behavioral response. More voltage and current would be required to produce an avoidance response as discussed below.

Motor Starts

Motor starts are generated by motors on the farm being investigated. The starting current of the motor and the resistance of the farm neutral determine the magnitude of a motor starting transient for 120 V motors and the primary neutral for 240 V motors. Motor starts typically produce multiple cycle 60 Hz transients. A typical motor starting transient is shown in Figure 1b. The phase duration can be estimated by noting that there are about 9½ zero crossings in 4 time divisions (80 milliseconds).

80 ms / 9.5 phases = about 8.4 ms phase duration

This again corresponds to the 8.3 ms phase duration expected for a frequency of 60 Hz.

The peak voltage during the motor start is 1.5 V – zero to peak, (or 3 volts peak to peak, note that the scale on the oscilloscope reads 0.5 volts / division). Referring to Figure 2, we see that only about 1% of cows would show a behavioral response to this voltage.

Controlled experiments have shown that the ratio between the current required to produce an aversive response, such as reduced water consumption, and the first behavioral response and is about 1.5:1. To determine the number of cows that would show an aversive response to this 1.5 V zero-peak pulse, divide the peak voltage by 1.5 and re-plot on Figure 2 (1.5V / 1.5 = 1 V, or about 1 cow in a thousand showing an aversive response).

Fencers

Most electric fencers and cow trainers produce a single mono-phasic pulse once per second (Figure 1c). These pulses typically have phase durations of 10 to 50 microseconds with a peak output voltage from 2000 volts to 10,000 Volts (shaded area in Figure 3). It has been known for almost 100 years that as the phase duration of a voltage/current pulse gets shorter, much more voltage and current is required to produced nerve stimulation and perception or pain. This knowledge has been used to design electric fencers that produce a very high voltage/current pulse that is of very short duration. The vast field experience with these devices suggests that these levels produce a painful shock but do not do physical harm to the animal.

Part of this high voltage fencer pulse can appear on grounded objects if fencers or trainers are improperly installed. An example of such a case is shown in Figure 1c. This is an example of a fencer pulse that was recorded using an oscilloscope at a cow contact location using a 500-

Ohm shunt resistor. It is important to use a shunt resistor for all cow contact measurements to eliminate erroneous measurement of induced voltages.

The time scale of the oscilloscope is set to 50 microseconds per division and the voltage scale set to 10 Volts per division. The phase duration of this pulse is estimated as 20 microseconds. The peak voltage is estimated as 38 Volts. The ability of this pulse to be perceived by animals can be estimated using Figure 3.

Note that there are 3 lines on Figure 3. The lower dashed line is for multiple cycle sine waves, as shown in Figure 1a. The upper dashed line is for a single cycle, biphasic wave. A biphasic wave goes from zero to some peak positive value, back through zero to some peak negative value and then back to zero (two phases, + and -). The middle line is for mono-phasic sine waves. The fencer pulse in Figure 1c is a mono-phasic wave. The voltage goes from zero to some peak positive value and back to zero (one phase, +).

From Figure 3 we can see that the fencer pulse (1c) falls below the sensitivity threshold for mono-phasic waves. This means that it would elicit a behavioral response for less than 5% of cows and a smaller percentage would show an aversive response.

Switching transients

Switching of electrical equipment produces the third category of electrical pulses found on farms. Switching transients are typically multiple cycle events that decay very quickly. An example of a switching transient recorded in a cow contact location with an oscilloscope and 500-Ohm shunt resistor is shown in Figure 1d. The time scale is set for 100 nanoseconds per division and the voltage scale to 1 Volt per division. The phase duration of this switching transient (1d) is estimated at 17 nanoseconds (6 zero crossings in 100 ns). The peak voltage (zero to peak) of the maximum single cycle is 3.3 Volts. The average peak voltage for the entire event is about 1.5 volts. From Figure 3 we can see that these levels are more than 1000 times below the reaction threshold for both the multiple-cycle or single-cycle biphasic behavioral response and is not of concern for animal welfare.

III. Exposure Conditions

Contact Resistance

With proper measurement technique, and using the information presented in Figures 2 and 3, we can determine if the potential exists to cause annoyance to dairy cows. The next step is to determine if the exposure conditions are such that adverse effects could occur. In all of the previous figures and calculations, it has been assumed that the body resistance of a cow plus the contact resistance is approximately equal to 500 Ohms. This is a conservative estimate and approximates the conditions if a cow is standing on a clean, wet surface. If a cow is standing on a dry surface or is standing on bedding the contact resistance is greatly increased and a value of 1000 or more is an appropriate estimate of the cow and contact resistance.

Location

The only studies which have documented adverse effects of voltage and current on cows had BOTH sufficient current applied to cause aversion AND forced exposures, (animals could not eat or drink without being exposed to voltage/current). It is typical for voltage levels to vary considerably at different locations on a farm. Decreased water and/or feed intake or undesired behaviors will result only if current levels are sufficient to produce aversion at locations that are critical to daily animal activity. These locations include feeders, waterers and milking areas.

Rate of Occurrence

Controlled research has shown that if an aversive voltage was administered to a water bowl once per second, water intake was reduced. However, when the same voltage was applied once every 10 minutes and once per day, no reduction in water intake was observed. If an aversive transient occurs only a few times per day, it is not likely to have an adverse effect on cow behavior. The more often an aversive transient occurs in areas critical to cows' normal feeding, drinking or resting, the more likely it is to affect cows.

Conversions

1 s =	1,000 ms (milliseconds)	**1 V** =	1,000 mV
	1,000,000 μs (microseconds)		1,000,000 μV
	1,000,000,000 ns (nanoseconds)		1,000,000,000 nV
	1,000,000,000,000 ps (picoseconds)		1,000,000,000,000 pV
1 ms =	0.001 s (seconds)	**1 mV** =	0.001 V
	1,000 μs (microseconds)		1,000 μV
	1,000,000 ns (nanoseconds)		1,000,000 nV
	1,000,000,000 ps (picoseconds)		1,000,000,000 pV
1 μs =	0.000001 s (seconds)	**1** μ**V** =	0.000001 V
	0.001 ms (microseconds)		0.001 mV
	1,000 ns (nanoseconds)		1,000 nV
	1,000,000 ps (picoseconds)		1,000,000 pV

Phase Duration	Frequency
0.0083 s	60 Hz
8.3 ms	60 Hz
8,333 μs	60 Hz
1.0 s	0.5 Hz
1.0 ms	500 Hz
1.0 μs	500,000 Hz = 500 kHz
1.0 ns	500,000,000 Hz = 500 MHz
0.05 s = 50 ms	10 Hz
0.5 ms = 500 μs	1,000 Hz = 1 kHz
0.5 μs = 500 ns	1,000,000 = 1 MHz

Figure 1.

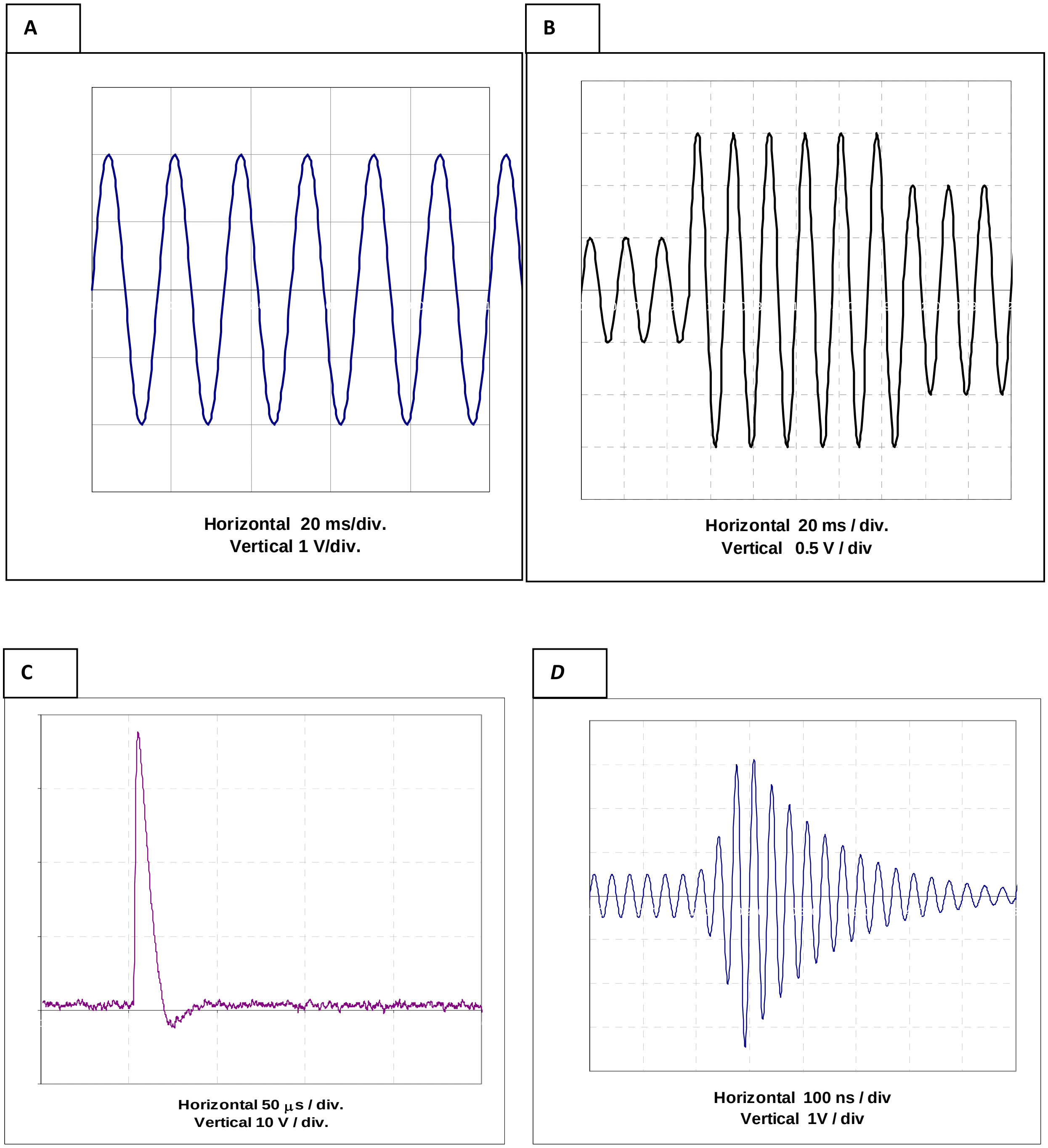

A
Horizontal 20 ms/div.
Vertical 1 V/div.
B
Horizontal 20 ms / div.
Vertical 0.5 V / div
C
Horizontal 50 μs / div.
Vertical 10 V / div.
D
Horizontal 100 ns / div
Vertical 1V / div

Figure 2.

Approximate 60 Hz Steady State Behavioral Response Distribution

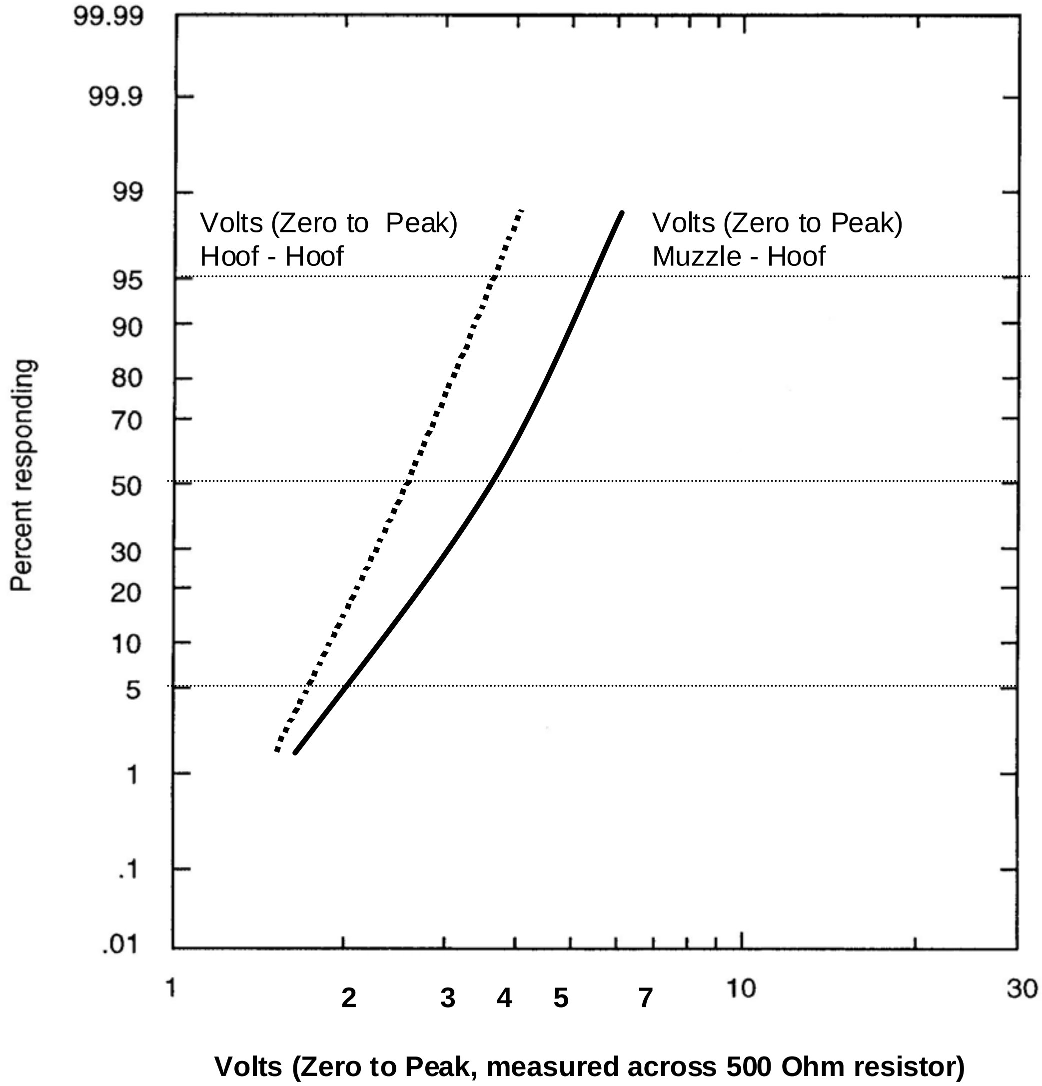
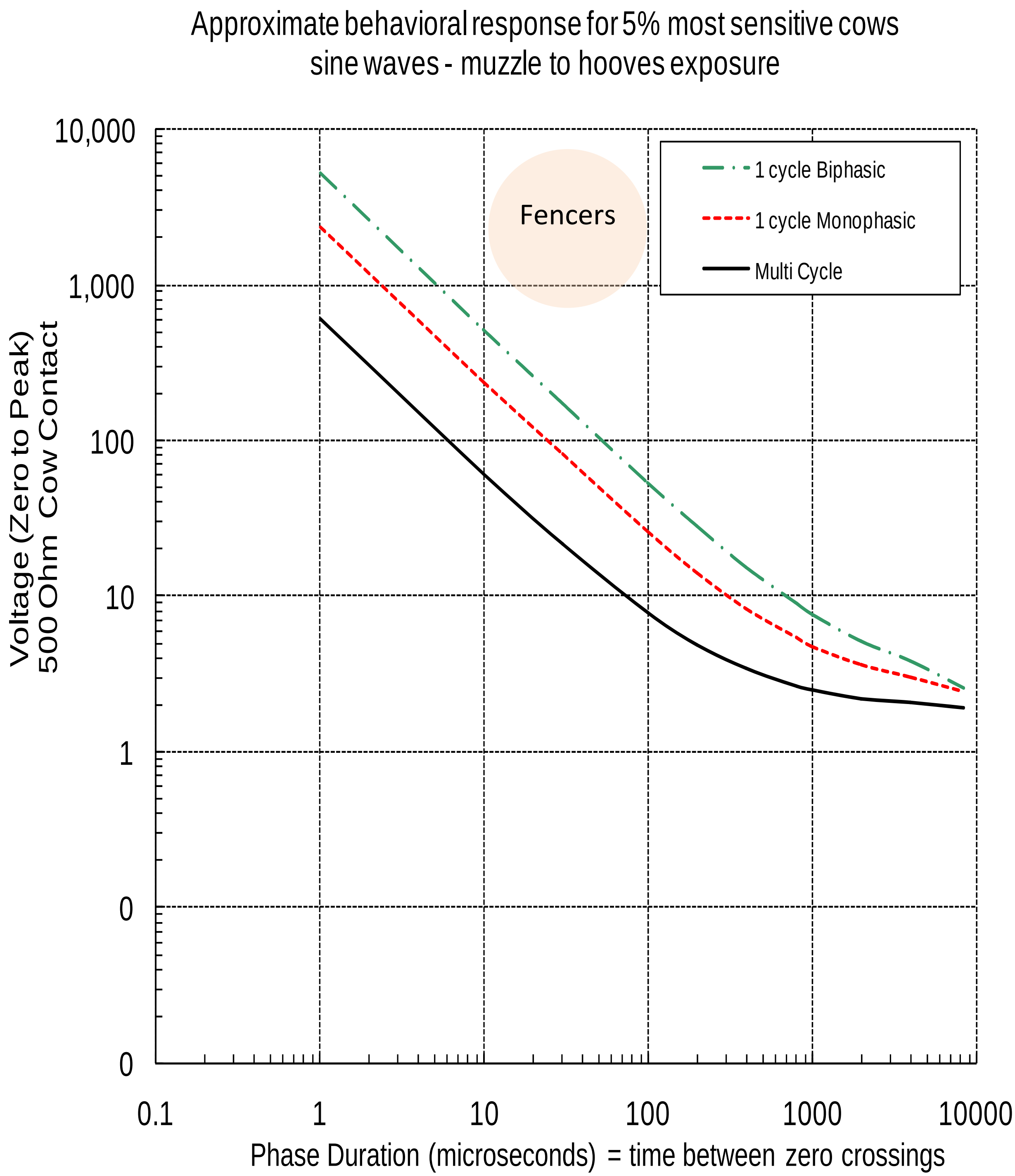


Figure 3.


Approximate behavioral response for 5% most sensitive cows
sine waves - muzzle to hooves exposure
10,000
1,000
100
10
1
0
0
Voltage (Zero to Peak)
500 Ohm Cow Contact
0.1
1
10
100
1000
10000
Phase Duration (microseconds) = time between zero crossings
Fencers
1 cycle Biphasic
1 cycle Monophasic
Multi Cycle