Summary of USDA Handbook 696

Source and Cow Circuit Components
Cow Resistance
Contact Resistance
Measurement Methods
Cow Sensitivity

USDA 1992 Summary

- Consensus opinion of 15 credible researchers
- *distressed that our research results were being misinterpreted*
- *Recommend action levels from <u>2 to 4 Volts</u>*
  - *As conservative as possible to account for indirect losses due to problems resulting from inappropriate response of farmers to changes in animal behavior*

USDA 1992 Summary

- *To relate voltage measurements to current, the worst case (500 Ohms) and more realistic (1000 Ohms) impedances were used.*
- *Attempts to reduce cow contact voltages to below 0.5 to 1.0 V are unwarranted, and totally unnecessary*
- No contradiction to these findings in 2003 NRAES review.

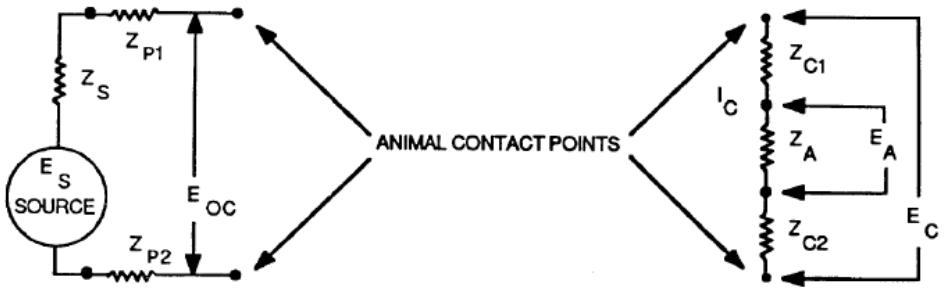


Figure 2-1. Diagram of a path through two animal contact points.

Voltage Drop and Impedances

The flow of current (I) in a path or circuit will be impeded or opposed by one or more of the following: 1) resistance (R), 2) capacitive reactance (X_C), and 3) inductive reactance (X_L). Resistance has to do with the physical properties and size of the conductive material. Capacitive reactance concerns conductors separated with a dielectric (insulation). Inductive reactance has to do with the laws of magnetism and inductors or situations which might exhibit inductive characteristics. Impedance (Z) of a path is the complex sum of two or more of these factors which are present in a circuit. Because no path in an outbuilding may be pure, that is, contains only one factor, the term "impedance" which includes all three factors, is often used.

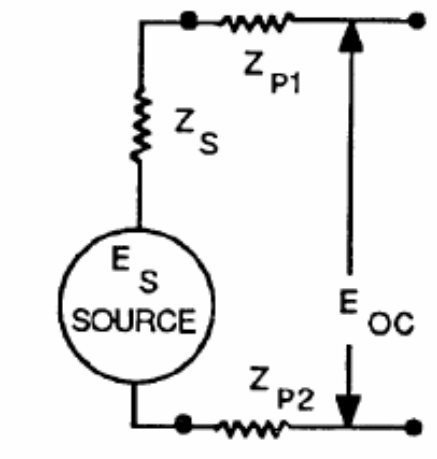
Example of Source, Path, and Impedance

The term "source voltage" (E_S) in this section is defined as the voltage between two animal contact points/areas measured *without* a shunt resistor in parallel with the meter (fig. 2-1). This measured voltage can also be referred to as the "open circuit voltage" (E_{OC}) (see chapter 5, "Detection and Measurement"). The current passing through the animal contacting these points will depend on the contact voltage (E_C), i.e., the voltage between the two contact points (e.g., water bowl and concrete floor) while the animal is making contact, and the sum of the contact and animal impedances. The contact voltage will be less than the open circuit voltage because of the voltage drops due to the current flow in the circuit impedances.

Important factors in determining the magnitude of the contact voltage are 1) the source impedance (Z_S), 2) the path impedances (Z_{P1}, Z_{P2}), 3) contact impedances (Z_{C1}, Z_{C2}), and 4) the impedance of the animal (Z_A). (Contact impedance (Z_{C1}) could, for example, be between the nose and metal water bowl and (Z_{C2}) between the hoofs and concrete floor. It is possible to include these contact impedances as part of the animal impedance (Z_A), but generally it is better to consider them separately, as they vary with conditions.) These impedances play a major role in controlling the current flow (I_C) through the animal. A high impedance in any single component of the circuit will limit current flow through the animal. However, only when one or more of the impedances Z_S, Z_{P1}, or Z_{P2} is high, will there be a large difference between the open circuit voltage and the contact voltage.

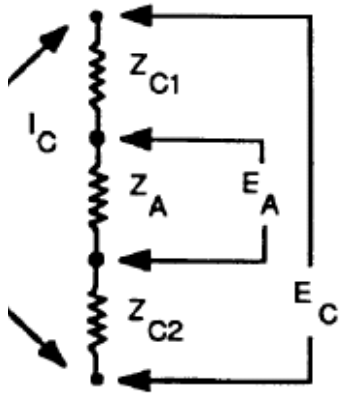
Elements of the Source Circuit

- Es = Voltage Source (I*R on a neutral wire)
- Zs = Source Impedance
- Zp1 = Path Impedance 1
- Zp2 = Path Impedance 2
- Eoc = Open Circuit souce Voltage

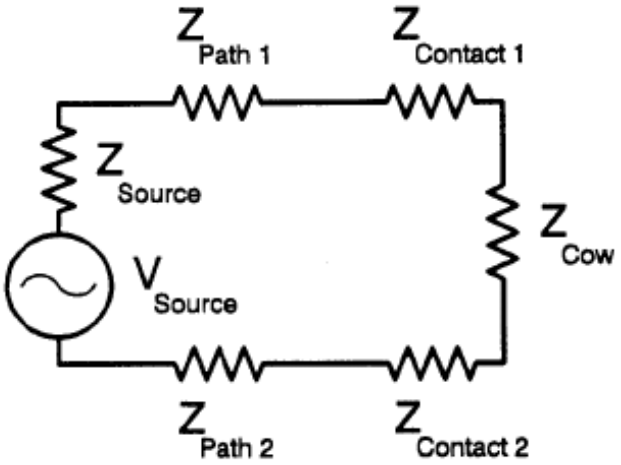


Elements of the Cow Circuit

- Ic = current through cow



Putting the Circuits Together



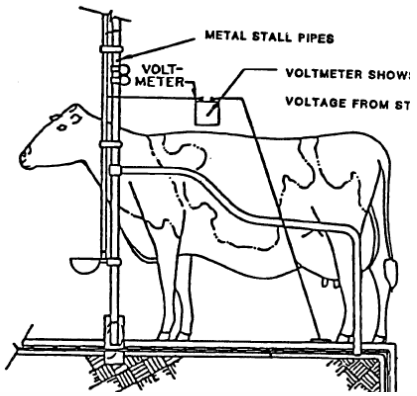
The impedances reported for 60 Hz differed among cows and among pathways and ranged from 250 to 3,000 ohms (table 3-1). Thus, at least two sources of variation determine the effect of a voltage on an individual dairy cow: the current sensitivity of that animal and the impedance of the body pathway through which the current is delivered.

Table 3-1. Resistances of various electrical pathways through the cow[1]

Pathway	n[2]	Resistance Mean (ohms)	Resistance Range (ohms)	Current Frequency (Hz)	References
Mouth to all hooves	70	350	324-393	60	Craine et al. 1970
	28	361	244-525[3]	60	Norell et al. 1983

The effect of a specific voltage on a cow is influenced by many factors, which together determine the distribution of current flow through the cow's body, namely, 1) voltage that is measurable between two points of contact, 2) source impedance, 3) the impedances of the electrical pathways between the cow's contact points and source voltage, 4) the contact impedances at the two points where the cow makes contact with the electrical conductors, 5) resistance of the cow's body pathway, and 6) the sensitivity of the cow.

The voltage required to elicit a response depends on the resistance of the pathway taken by the current through the cow's body. A number of such pathways have been examined. Differences among pathway resistances, including cow contact resistance, have been shown to be as great as sixfold or greater. While some pathway resistances approach 1,000 ohms or more, worst-case resistances of specific cows on specific farms may be as low as 500 ohms. Voltage levels required to elicit the various behavioral responses are shown in figure 3-4.



contact. For evaluation purposes, it is often sufficient to consider the worst case resistance, i.e., the lowest resistance likely to be encountered. We consider 500 Ω for the sum of contact and body resistances to be a very conservative estimate of the worst case, or minimum, resistance that is likely to be encountered.

Older recommendations for tolerable levels of cow contact voltages (0.5 - 0.7 V) were based on the lowest values of perceived current and low values for body, contact, structure, and source impedances. These past recommendations need to be reviewed in light of recent research on the economic impact of electrical currents. Recent research indicates that current levels below 6 mA have no direct effect on production, reproduction, or animal health; furthermore, there is no evidence that hormones naturally released during milking and stress are adversely impacted by elevated current levels. Some moderate behavioral changes are seen in cows exposed to currents of between 3 and 6 mA. If exposure to such currents it also appears that the large majority of cows probably do not demonstrate problem behaviors until voltages are above 3.0 to 4.0 V. Direct economic effects, including reductions in milk yield, have been shown for a small percentage of cows (7 percent) at voltages of 4.0 V and above.

It is impossible to quantify the total circuit impedance for all conditions and situations. For evaluation purposes, it is often sufficient to consider the worst case impedance, i.e., the lowest circuit impedance possible, and a more realistic impedance, i.e., the lowest circuit impedance likely to be encountered. For the worst case circuit impedance, the assumption is made that the source and all path impedances are zero, an extremely unlikely occurrence. The worst case impedance then becomes the sum of the contact and animal impedances. From experimental tests and field experience, we consider 500 ohms to be a very conservative estimate of this worst case impedance.

We also consider 500 ohms to be a conservative estimate of total source and path impedances. Adding these two impedances results in an estimate of 1,000 ohms for the more realistic impedance (table 7-2).

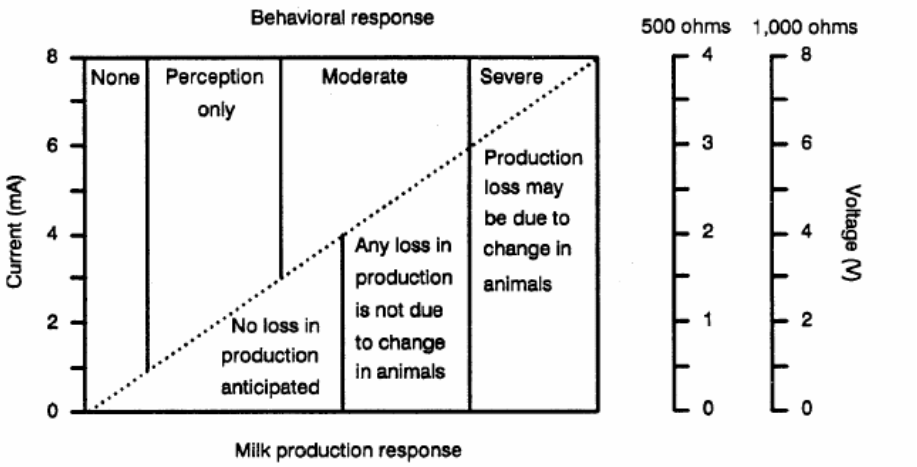


Figure 7-2. Behavioral and milk production responses to increasing current levels. Voltages, on the right, were estimated using a worst case circuit impedance and a more realistic impedance.

Although cows do not respond uniformly to electrical currents, 97 percent of cows tested showed a general uniformity in their behavioral responses to currents of different intensities (fig. 7-2).

Table 7-2. Estimates of worst case and realistic circuit impedances for translating currents to voltages

	Impedances (ohms)		
	Path + Source	Contact + Animal	Total
Worst case	0	500	500
Realistic	500	500	1000

Direct Current Voltages and Direct Currents

Measurements have not been properly made on enough farms to characterize the possible dc problems on farms. Using proper measurement techniques is highly important. The different metals used in the instruments, in the voltage/current contacts, and the various metal structures in contact with the farm soil and soil environment all can form a galvanic couple that may be interpreted as a real source when, in fact, a dc voltage or direct current is present only upon attachment of the measuring equipment. Dissimilar metals such as copper, aluminum, steel, galvanized steel, lead, and zinc may be used or be present in the damp or wet farm soil environment. Urine and manure are often present also in the farm environment and can provide electrolytes. Combinations of dissimilar metals and an electrolyte can form crude batteries. For example, where corrosion is observed on a farm, electrolysis from galvanic action may be present.