Feeding behavior contains important information that can enable producers to better manage livestock; similarly, researchers can benefit by better understanding the factors that influence feed intake. Initially, feeding behavior was recorded by human observers (Hoffman and Self, 1973) or by time-lapse video recording (Vasiliatos and Wangsness, 1980). Throughout the years, different systems have been designed using various methods, including weighing feeders (Brown-Brandl et al., 2000), sometimes in combination with photoelectric cells (Chase et al., 1976; Heinrichs and Conrad, 1987; Putnam and Bond, 1971; Wangsness et al., 1976). These methods impose limitations by requiring individual or at most pair-fed animals, unlike the group-penned animals used by industry. Individual or pair-fed animals have different feeding behavior from group-penned animals. A critical element that was needed was a method to identify the animals. Until recently, there was a lack of reliable, cost-effective, and rugged equipment that allowed electronic animal identification.

The advent of radio-frequency identification (RFID) systems has revolutionized animal identification and tracking. The animal industry has settled on the low-frequency HDX/FDX technology (Artmann, 1999). Basic ID systems include a reader and an electronic identification tag for animals ranging in size from pets to livestock. Tags of various sizes, form factors, and weights have been developed, including ear tags, injectable capsules, and rumen boluses (Rossing, 1999). The tags are reliable, lightweight, rugged, and have a long life because no battery is needed.

Application of the technology has been the foundation of many different systems that improve management and offer data collection opportunities for both production systems and research. Systems are currently available to measure feed intake in association with feeding behavior for cattle (Basarab et al., 2003; Chapinal et al., 2008; Kelly et al., 2010), swine (Andree and Huegle, 2001; Hyun and Ellis, 2002; Nienaber et al., 1991), and other small livestock (Basarab et al., 2003; Gipson et al., 2006; Gipson et al., 2007; Goetsch et al., 2010). While these systems provide the user with data on feed behavior in addition to feed intake, they are expensive and they are not representative of industry feeding (type and number of feeders per animal). Most of the current systems require single-animal access and a limited number of feeding stations (sometimes only a single feeding station is used per pen of animals). These systems can alter feeding behavior since access and timing can be influenced by dominance ranking (Chapinal et al., 2008; Soltysik and Ogalski, 2010; ValLaillet et al., 2008; Walker et al., 2008). While limiting the access to the feeder is necessary to obtain valid data, the system itself has influenced the results.

An alternative approach is needed to capture basic feeding behavior using a feeder typical of those used in the industry. Such a system needs to record multiple animals at a feeder, be capable of operation in harsh environments, and be constructed at a relatively low cost. Therefore, the objective of this article is to describe the development and validation of a feeding behavior monitoring system.

MATERIALS AND METHODS

CATTLE SITE

A cattle research facility was constructed at the USDA-ARS U.S. Meat Animal Research Center (USMARC) feedlot, consisting of 16 feedlot pens (fig. 1). Each pen was
Figure 1. Research facility consisted of 16 feedlot pens. Eight pens were partially housed under a shade structure (pens 1001 to 1008). The gray region indicates the shaded area of the pens. The feeding behavior system was installed in all 16 pens and was designed to be used with 128 feedlot steers or heifers (eight animals per pen).

designed to hold eight feedlot steers or heifers (7.3 m × 20.7 m). Eight pens (pens 1001 to 1008) were partially housed under a shade structure having 50% of the pen surface in the shade, thus allowing the animals access to a shaded environment. The remaining eight pens (pens 1009 to 1016) had no shade access. Automatic waterers provided ad libitum access to water in each pen. Feed bunks were centered on each of two pens, as shown in figure 1, and were designed for six individual eating spaces per pen. The feed bunks were made of heavy-duty polystyrene with a hollow core. The bunks were anchored with chains and bolts to the adjacent fencing.

SWINE SITE

An existing swine research building, currently used for swine genetic and genomic work, was chosen for the installation of the feeding behavior monitoring system. The facility had concrete slatted floors and was tunnel ventilated. The facility had six pens (pens 2 to 7) that were 6.4 m × 5.0 m (design capacity of 40 pigs) and two pens (pens 1 and 8) that were 2.9 m × 5.0 m, which were designed to be used as sick or overflow pens (fig. 2). Each pen contained a standard stainless steel feeder designed with five eating spaces and four nipple drinkers (two nipple drinkers in each of the sick/overflow pens). The monitoring system was installed in only pens 2 through 7, as pens 1 and 8 were used infrequently.

SYSTEM DESCRIPTION

Hardware

The core of the feeding behavior monitoring system includes an RFID system that was designed around a commercial reader (Series 2000 high-performance remote antenna-reader frequency module [RA-RFM], RI-RFM-008B-00, Texas Instruments, Dallas, Tex.). The RA-RFM operates by sending a 134.2 kHz RF power pulse of sufficient amplitude and approximately 50 ms duration to an antenna, where the radiated energy energizes nearby ID tags. The ID tags are a commercial half-duplex design used by the livestock industry. The magnetic field from the RA-RFM is “collected” by the antenna in the tag transponder that is tuned to the same frequency. The received AC energy is rectified and stored on a small capacitor within the transponder. When the power pulse has finished, the transponder immediately transmits back its data, using the energy stored within its capacitor as the power source (RF-ID, 2003).

The energized transponder in the ear tag transmits a 128-bit unique frequency shift code (low bit at 134.2 kHz and high bit at 123.2 kHz) over a period of 20 ms that is interpreted by the Series 2000 control module (RI-CTL-MB2A-02). The control module sends the interpreted tag ID data via a serial communication line to the host computer.

The antennas for this application were designed to provide sufficient range, to be rugged and relatively inexpensive, and to fit within the cavity of the plastic bunks for cattle (fig. 3) and on the face of the feeders for swine. Additionally, the antennas were tuned to be resonant at the RA-RFM operating frequency so that adequate energy was coupled to energize the ID tags. The design of the antenna and the tuning components were based on design criteria (Texas Instruments, 2000) and were accomplished at USMARC. The dimensions of the antennas were determined by the physical constraints of the installation in the cattle system. Antenna assembly involved constructing a form that fit within the feeder systems, and then precisely winding the antenna coils on the form to achieve the correct inductance. Tuning the antennas was ac-

Figure 2. Layout of the finishing swine facility. Dark gray rectangles represent the location of the stainless steel feeders. The light gray square represents the location of the equipment cabinet, and the small circles represent the location of the nipple drinkers. The feeding behavior monitoring system was installed in pens 2 through 7 and was designed to be used with 240 pigs (40 pigs per pen).
Figure 3. Schematic of the feeding behavior monitoring system including all components needed to collect feeding behavior data from one pen of animals. Eight additional multiplexer boards can be added to this system for expansion up to 64 antennas. Expansion beyond 64 antennas requires an additional microcontroller, RFM module, a feeder-selecting optical isolator board, an antenna-selecting optical isolator board, a feeder-selecting multiplexer, and a set of antenna-selecting multiplexer boards.

Complished by adding a combination of an inductor and capacitor to achieve antenna resonance.

One challenge of system design was to distribute the RF signals to the appropriate antennas frequently enough to determine when and where animals are eating. The antenna distribution system used fairly conventional concepts and devices to allow fast development, a robust design, and traditional maintenance methods. Multiplexers (MPXs) were designed to function as multiple (eight position) switches connecting the signal from the RA-RFM to the correct antenna. Figure 3 shows a block diagram of an MPX. An input to the MPX can be directed to any of eight outputs with double-pole switching. Multiplexer switching was controlled by a four-wire system (three control lines and a ground). The MPX control signal originated with the Series 2000 control module, where the control lines were latched under control of a TFX-11 microcontroller via RS-232 communication. The multiplexer control switching was designed as a current loop, with a 0 or 4 mA signal representing 0 and 1, respectively. Current loop control was chosen for noise immunity over long wire runs. The control currents were used to drive LEDs in optical isolators, making the MPXs electrically isolated and immune to potential ground loops. Optical isolator boards were designed to couple the control lines that originated at the Series 2000 control board to the MPXs. The TFX-11 microcontroller sent a serial command to the Series 2000 control board, which latched the correct binary code for the correct bunk and the correct antenna within the bunk. Binary-coded optically isolated lines then distributed the signal to the MPXs, which latched the correct relays, providing a pathway to and from the RA-RFM. In order to ensure that data could be collected in a timely fashion, a maximum of 50 antennas were used with each microcontroller.

**Software**

The software was designed in two separate components. The first component was the host computer, which was designed for timing, data management, and display. The second component was the microcontroller, which was designed to control the sequence of the antennas and to capture the data. Multiple microcontrollers can be added to the system for larger installations; two were used in the cattle system.

The operational software for the host computer was written using HT Basic (HT Basic for Windows, ver. 9.5, Trans-Era Corp., Orem, Utah). The host system determined the timing of each scan (a sequence of powering each antenna and recording the EID number if present). This timing can be changed and was determined by the speed of the host computer. The swine feeder system used a 20 s time base, while the cattle system used a 30 s time base. After the host computer initiated the scan, it was available to summarize the number of EID reads (each EID read is defined as a hit) for each antenna or each animal upon the user’s request. At the end of the scan, the microcontroller sent an “end” statement to the host computer, which initiated a data transfer from each microcontroller in sequence. After the data were received, they were written to the comma-delimited file. The appropriate information was transferred to two history files (antenna history and animal history) for ease of creating summaries. The host computer remained idle until the time to initiate the next scan.

A test mode can be run at startup or when a problem is suspected. The display screen allows diagnostics related to the hardware by operating in test mode. In this mode, individual bunk/feeder and antenna combinations can be scanned and checked to ensure that all antennas are able to read a test EID tag. When the program is in test mode, the normal scans are...
not initiated, and no data are collected for the duration of the testing.

The TFX-11 microcontroller was programmed using TFBasic (TFTools, ver. 1.1.1.4, Onset Computer Corp., Pocasset, Mass.). The microcontroller provided the interface to the Series 2000 control board, with operational software written for the TFX-11 microcontroller for initiating scans and controlling the pen scan sequence, the antenna scan sequence, and the collection of tag ID information during the scan. At the end of a scan, the ID information was transferred from the TFX-11 microcontroller to the host computer. The microcontroller then waited until the next scan was initiated.

**INSTALLATION**

**Cattle Site**

The cattle site was divided into two systems: the north side of the facility (under the shade), and the south side of the facility or those pens without shade. The hardware used to instrument the facility was similarly divided, as the north side of the facility had one set of hardware controlled by a single microcontroller and the south side had another complete set of hardware controlled by another microcontroller. The north side bunk selector multiplexer and the optical isolator boards were located within the control building. The coaxial antenna cables and the multistranded control cable were placed in conduit, which was mounted in the rafters of the building. The bunk selector multiplexer and the optical isolator boards for the south side were located within a watertight control box mounted on the fence. The coaxial antenna cables and the multistranded control cable were placed in conduit that was buried under a road that provides access to the bunks.

The cattle site included feed bunks made of heavy-duty polystyrene with a hollow core that allowed installation of the antennas inside the bunks (fig. 4). The bunks were 2.4 m long; four antennas were inserted at 0.6 m intervals along the length of each bunk. Multiple bunks were connected together to achieve the six animal feeding positions per pen (three bunks spanned two pens). A PVC rack (fig. 5) was constructed and installed to ensure that only a single animal could access the bunk in the proximity of each antenna. These racks also ensured that the EID tag on the animal’s ear would be positioned close to the corresponding antenna, thus reducing or eliminating the potential for interference between tags. The bunks were connected using stainless steel bolts provided by the manufacturer. Each set of bunks had one connection point where the control lines and the coaxial cable entered the bunk. The two multiplexer boards (one multiplexer per pen) were installed in the center of the three bunks (fig. 5). Access and installation of the multiplexer boards was allowed by two 27 × 25 cm holes cut into the back side of the bunk. The multiplexers were mounted on a 32 × 29 cm PVC panel. This panel was screwed and then sealed to the outside of the feed bunk. The antenna coaxial cable was run from the multiplexer to each antenna through a watertight connection between the two adjoining bunks.

**Swine Site**

The swine system had six pens; each pen had one feeder designed for five animals to eat at a time. With this configuration, 30 antennas were used to instrument this facility. The swine system was designed with only one microcontroller controlling 30 antennas and transferring the data within a 20 s scan time.
Existing stainless steel pig feeders were used at the swine facility, so a method for the installation of the antennas had to be developed. The installation needed to ensure protection of the antennas and multiplexer, while not interfering with the pigs’ ability to access feed. Other considerations were to allow access to the equipment for servicing and repair, provide smooth edges for animal safety, and to complete the system with minimal alternation of the feeders.

A multiplexer and a series of five antennas were mounted on a single sheet of PVC (1.18 m wide × 0.65 m tall × 5 mm thick). This PVC sheet, with the equipment mounted, was then slid inside a hollow PVC panel (1.2 m wide × 0.7 m tall × 0.04 m thick), shown in figure 6. A single watertight connector was added to the back of the panel to run the coaxial cable and the multistranded wire for control and data collection. This PVC panel was installed externally to the feeder using an aluminum channel along the bottom edge for support and an aluminum flange to hold the top edge. The panels were installed on the existing feeders with a total of seven 2 mm screws to hold the flanges and a single 2.4 cm hole to run the wires through the feeder and into the panel (fig. 7). Tests with EID tags demonstrated sufficient range and sensitivity for the pig feeder system.

**VALIDATION PROCEDURE**

The cattle system and the swine system were both validated using video recording. A pen of eight steers (in the shaded portion of the installation) was recorded for a 24 h period using a time-lapse VCR and monochrome analog cameras. Seven of the animals were red, one was black, and of the seven red animals one had a white stripe on its face and another had some white markings on its face. The three animals with distinctive color or face markings were used in the validation since they were easily identifiable. The video was watched by a single observer. Eating events were recorded on the three animals noted. Data were only collected during the daylight hours, as it was difficult to identify individual animals after dark. An eating event was defined by a steer standing at the feed bunk with its head down in the bunk or actively chewing feed. An animal standing near the feed bunk without putting its head into the feed bunk was not considered eating. The test of the feeding behavior monitoring system was performed over the same time period as the video recording. The monitoring system recorded animals on a 30 s time basis. Steers with their heads in the bunk were identified by storing the shortened EID number (hit) with a time stamp, and the location of the hit (pen and antenna). The information was saved in an ASCII text file. Eating events were determined by analyzing the record of hits; data were concatenated into one meal if there were two periods of hits recorded by a single animal less than 2 min apart.

A similar approach was used for the swine system. A pen of 40 barrows was recorded for a 24 h period using a digital video recorder and a color video camera. Three easily identifiable pigs, with distinctive markings, were used for the validation. Of the 40 pigs, 37 of the pigs were white and difficult to distinguish, the remaining three animals were easily recognizable (one was red with black spots and white legs, one was dark red with black spots, and one was white with black spots). The video was watched by a single observer. The data were collected only during the hours that the lights were on, as it was difficult to distinguish the animals without lighting. An eating event was recorded when an animal had its head in the feeder, but not when the animal was next to the feeder. The monitoring system recorded hits on a 20 s time basis. The animal’s EID, a time stamp, and the location of the hit (pen and antenna) were recorded and saved to an ASCII text file.
Eating events were determined by analyzing the record of hits. If there were two periods of hits by a single animal that were less than 2 min apart, the data were combined into a single meal event.

Two different tests were conducted to test the performance of the feeding behavior monitoring system. The first test was to compare the agreement on a 20 s (swine system) or 30 s (cattle system) time basis; both hits and no hits were compared, as it was determined that both situations (hit and no hit) were equally important for a successful system. In the second test, the data were aligned on a time basis to ensure that the number of meals and the meal times recorded by the two systems were associated.

**VALIDATION RESULTS**

The cattle and the swine feeding behavior monitoring systems were both compared with video recordings. Both systems were tested for a 12 h period (0600 to 1800 h). The swine system had a total of 2161 cycles (one sample every 20 s for 12 h plus one sample to end at 1800 h). The cattle system had a total of 1441 cycles (one sample every 30 s for 12 h plus one sample to end at 1800 h). The number of hits and time periods not receiving hits were in agreement between 97.9% and 99.4% of the time over the 12 h that the systems were compared (table 1).

The number of meals and average length of a meal event were calculated and are shown in table 2. For the cattle system, the number of meals determined by the video recording was fewer than with the feeding behavior monitoring system (table 1). The monitoring system recorded the animal at the bunk at the same time as the video recording, but due to the 2 min event filter one of the meals for each animal was broken into two meals instead one continuous meal (fig. 8). Consequently, the average meal length was shorter. For the swine system, two of the three pigs used for validation were detected by both the video and the monitoring system with the same number of meals and with similar average meal length. However, the third animal was detected by the video as having four meals, while the monitoring system detected six meals. The discrepancy resulted from a condition similar to

![Figure 8](image)
the one discussed earlier with the cattle system, i.e., the meal was divided into two meals instead of one continuous meal. It was also noted from the video footage that this pig tended to eat at the feeder when no other pigs were present and tended to eat with its body parallel to the feeder. This resulted in the pig positioning its tag either right next to the antenna or completely out of the range of the antenna.

**DISCUSSION**

The cattle system has been in operation since 2005, and the swine system has been in operation since 2009. The systems have been rugged and reliable under normal circumstances. However, in summer 2007, the cattle system was struck by lightning and needed to be repaired. Normal precautions were taken, i.e., the computer and hardware power was supplied through a battery backup system, and the hardware was appropriately grounded using a grounding rod buried in the earth. However, when the shade structure was struck by lightning, the IC chips on the multiplexer boards were damaged. The system has been repaired and is back in operation.

Otherwise, the system has proven reliable with very few repairs needed. The cattle system has not had a single antenna fail. The swine system has had two antennas fail. Both of the failures involved a broken wire on a connection, and both failures occurred after the barn was cleaned. The feeders in the swine area are moved during the washing process, so the broken wires most likely occurred during the moving and turning of the feeders.

The system installation is flexible and could be used to determine the locations of individual animals in various applications for single-animal monitoring, such as identification of animals passing through a gate or spending time at the drinker. A limitation of the system is that only one tag at a time can be read by the system due to the design of the low-frequency EID system. This is not a problem for feeding behavior, as only one animal can occupy a single feeding location at a time. However, in other applications, this single-animal read needs to be reconsidered, and an appropriate design will need to be adopted.

**CONCLUSIONS**

A low-cost, rugged feeding behavior monitoring system was developed, tested, and validated. The system used a commercially available RFID reader and HDX EID tags, and a combination of multiplexers and optical isolator boards to read antennas located on or inside commercial livestock feeders. The antennas were placed in such a way that they could read the EID tag when an animal’s head was in the feeder, but the antennas did not interfere with the animal’s ability to eat. A computer was programmed to ensure proper timing of the antenna scans and managed the data collection and summarization.

The system was validated using 12 h of video recording. Three animals (three steers and three barrows) were chosen based on their identifying markings, and the 12 h of video was watched by a single observer. Validation determined that the cattle system was in agreement with the video 98.3% of the time, and the swine system was in agreement 98.7% of the time. There was no occurrence of the monitoring system reporting an individual animal at the feeder when the animal was not visible at the feeder in the video. Both systems have proven to be rugged and reliable in settings similar to those found in industry.

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