CONF-930403--38

CONF-930403--38

DE93 010273

Instrumentation and Controls Division

# AN RF COMMUNICATIONS SYSTEM FOR THE WEST VALLEY TRANSFER CART

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*Research sponsored by the Office of Environmental Restoration and Waste Management, U.S. Department of Energy, and performed at Oak Ridge National Laboratory, managed by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400, and under contract AC07-81NE44139 with West Valley Nuclear Services, Inc.

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# AN RF COMMUNICATIONS SYSTEM FOR THE WEST VALLEY TRANSFER CART[a]

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## ABSTRACT

A prototype radio frequency communications system for digital data was designed and built by Oak Ridge National Laboratory for use in controlling the vitrification facility transfer cart at the West Valley Nuclear Services facility in New York. The communications system provides bidirectional wireless data transfer between the operator control station and the material transfer cart. The system was designed to operate in radiation fields of $10^4$ R/h while withstanding a total integrated dose of $10^7$ R of gamma radiation. Implementation of antenna spatial diversity, automatic gain control, and spectral processing improves operation in the reflective environment of the metal-lined reprocessing cells.

## INTRODUCTION

The West Valley Demonstration Facility is a vitrification plant for stored nuclear wastes. It is a project of the U.S. Department of Energy at the former Nuclear Fuel Services reprocessing plant in West Valley, New York. The primary objective of the West Valley project is to solidify high-level nuclear waste into a form suitable for transportation and disposal.

The facility consists of four cells connected by a track-guided material transfer cart. The cart transfers up to four 2400-kg canisters between the chemical processing and vitrification cells. The design of the transfer cart was a joint effort of West Valley Nuclear Services (WVNS) and Oak Ridge National Laboratory (ORNL), with the Instrumentation and Controls Division of ORNL having responsibility for the transfer cart control system. The radio-frequency (rf) communications system was developed to transmit digital control data between an operator station and the cart with a return link from the cart to the operator station for monitoring the electrical systems on the cart (Bradley et al. 1993).

The facility environment falls within the parameters generally associated with nuclear fuel reprocessing operations. The radiation field within the facility varies with proximity to the storage canisters but can reach levels of $10^4$ R/h near the canisters. The rate at the cart charging station decreases to ~0.01 R/h. The temperature within the facility will range from −10 to 50°C. The atmospheric conditions include a relative humidity ranging from 10 to 90%, with a nitric

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acid vapor content of up to 100 ppm under normal operating conditions.

The interior construction of the West Valley facility varies for each cell, with some cells primarily concrete and others constructed from a combination of concrete and metal linings. The maximum occurrence of metal is in cells with linings on the floor and walls providing ~80% coverage. A cell plan of the facility, shown in Fig. 1, illustrates the layout of the vitrification cell, the tunnel, the equipment decontamination room, and the chemical processing cell. The four cells are connected by a cart track and have metal or concrete doors at each cell boundary.

## SIGNAL TRANSMISSION ASSESSMENT

Bidirectional communication between the operator station and the cart is a critical aspect of the control system design. Operation of an rf system in metal cells produces multipath reflections for free-space radio communications with a resulting signal degradation due to multipath nulls. Several signal transmission methods were considered during the preliminary design of the system including directly wired links, leaky coaxial cable, directional rf systems, and omnidirectional rf systems. A detailed analysis of in-cell communications options along with theoretical computations for multipath interference to rf links in similar metal-lined cells is presented in Burgess et al. (1988).

### Transmission options

A directly wired link consists of an attached tether cable between the control station and the cart. A direct cable avoids rf multipath situations but introduces problems associated with cable spooling and handling, penetration at closed doorways, and cable breakage due to repeated flexing of radiation-hardened cable bundles.

A leaky coaxial cable design (Smith and Crutcher 1993) employs an rf radiating cable

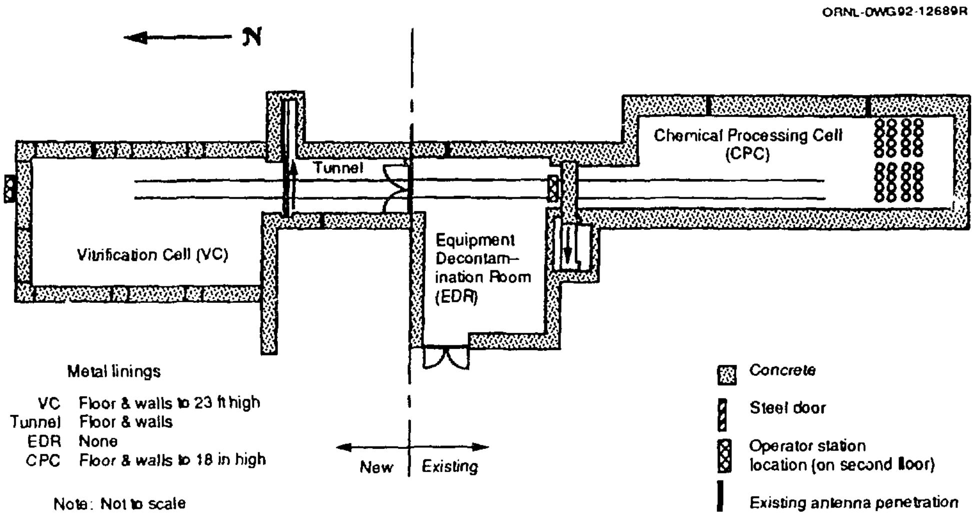

Fig. 1. West Valley facility cell plan.

installed parallel to the tracks so that a probe on the cart couples rf energy from the cable. This arrangement is much less susceptible to multipath interference than are other rf systems but requires installation of the cable along the tracks. Because the facility includes a cell with existing radioactive contamination, installation of a leaky coaxial cable was not considered to be a reasonable option.

A directional rf communication system (Smith, Crutcher, and Vandermolen 1989) uses transmitting and receiving antennas that concentrate the radiated energy into a relatively narrow beamwidth. Interference from multipath is reduced because the directional pattern of the antenna rejects most interfering signal paths within the cell. Because the multipath rejection improves immensely for narrow beamwidths, the use of highly directional antennas can be quite effective for multipath rejection. However, the use of highly directional antennas requires the beam alignment of the antennas to be maintained within a few degrees. Systems of this type that have been tested in process cells have aligned the antennas along the axis of travel to eliminate the need for complex steering mechanisms. Because the cell doors at the West Valley facility interfere with the capability to maintain a direct path along the axis of travel, a steerable link would be required. The steerable antennas increase hardware complexity, system cost, and maintenance problems. For these reasons, directional transmission was not practical for this facility.

The communication system that was chosen is an omnidirectional rf link. Omnidirectional antennas are half-wave dipoles that are mechanically and electrically simple. However, the omnidirectional antenna pattern increases susceptibility to multipath interference. The effects of the multipath were reduced through design methods applied to the electronic portion of the system.

### Experimental simulation

As part of the signal transmission assessment, experiments were performed inside a metal room to simulate the structure of the facility transfer tunnel. Because the tunnel has the highest percentage of metal coverage of any of the cells (floor and walls), it is considered to provide the worst-case conditions for multipath degradations.

The experiments were performed in a fully metal lined room 4.58 m long by 3.65 m wide by 2.46 m high. A test frequency of 1 GHz was chosen because the wavelength (0.3 m) is much smaller than any dimension of the metal room and the frequency is suitable for use with omnidirectional dipole antennas.

Experiments were conducted by using both directional and omnidirectional transmitting antennas in conjunction with an omnidirectional receiving antenna. Test signals consisted of both amplitude modulated (AM) and frequency modulated (FM) carriers, and the receiver outputs were evaluated for both signal strength and information distortion. The transmitting and receiving antennas were positioned both near the walls and in the center of the enclosure. A portion of the test was made with obstacles positioned to reject the direct line-of-sight transmission path.

Additional tests were performed by using an impulse generator to excite the transmitting antenna to produce broad spectral energy bursts within the metal room. A spectrum analyzer connected to the receiving antenna measured the frequency response of the antenna-to-antenna link in the metal-lined room. The received spectrum from the radiated impulse showed the characteristic frequency response of the transmission as affected by the multipath from the metal walls.

The results from these tests indicated that FM transmission with a 1-MHz bandwidth is feasible for a metal-lined room of dimensions much greater than one wavelength for frequencies near 1 GHz. Antenna position tests indicated that nulls occurred over various portions of the frequency band when the antennas were placed within 30 cm of the metal walls. On the basis of these results, a combination of wide-band FM distribution of the spectral energy and the use of spatially diverse receiving antennas was believed to be sufficient for adequate data transmission.

## COMMUNICATIONS SYSTEM DESIGN

The communications system will provide a wireless, bidirectional, digital data link between the facility and the transfer cart. Because cell walls and floors contain a significant amount of metal lining, signal multipath will degrade the quality of rf communication. The system was designed to overcome degradation associated with multipath reflections. The chosen technique employs two cart antennas so that if one is positioned in a multipath-induced null, the other antenna is selected. Additionally, wideband FM is employed to distribute the spectral energy over a significant bandwidth, allowing a portion of the spectral energy to be lost to multipath while retaining most of the energy. Further flexibility for multipath immunity is acquired through the use of multiple facility antennas that can be selectively activated to decrease the probability that the cart will become stranded in a null zone.

An additional constraint of the communications system design is the requirement for radiation-tolerant electronic hardware. The communications system was designed by using components of known radiation tolerance based on previous radiation testing experiments (Kennedy and Wu 1988) and the operating experience gained from other designs (Smith, Crutcher, and Vandermolen 1989).

### System design

The carrier frequency chosen for the rf communication system is 915 MHz in the industrial, scientific, and medical band. Operation at this frequency, along with power levels below 100 mW, eliminates concerns over licensing requirements. Additionally, this frequency provides a good performance trade-off for antenna size, distance between multipath nulls, and electronic design. A simplex transmission format was chosen so that the facility and cart time-share the same transmission channel.

Because the multipath cancellations induce amplitude variations in the received signal, AM was rejected as an option for signal transmission. The use of FM for the transmission inherently improves the rejection of the amplitude fluctuations. Additionally, the choice of FM allows implementation of automatic gain control (AGC) and hard limiting in the receiver to further reduce the distortions from multipath.

The 915-MHz carrier is modulated to a deviation of ±10 MHz. Data are transferred in packet burst mode with a peak data rate of 125 kbaud. Because the FM deviation bandwidth is much greater than the modulating data rate, the system operates in the wideband FM mode. Wideband FM provides improved noise performance over narrowband systems and provides a greater distribution of spectral energy to compensate for nulls in the spectrum due to multipath.

The circuit cards for the communications system were designed for compatibility with the commercial STD rack format. This design allows the communications boards to share an electronics enclosure with the system microcomputer and other control and processing circuitry.

### Antenna design

The antennas chosen for the communications link were vertically polarized, omnidirectional half-wave dipoles. The carrier frequency chosen for the system is 915 MHz, requiring a dipole length of 16.4 cm. The facility antennas were designed to deploy through existing 2.54-cm- diam cell wall penetrations by using a spring-loaded dipole with push-through guide. The guide extends into the cell to separate the dipole from the metal structure of the wall.

One antenna is allocated to each cell in the facility. The antennas are wall mounted and take advantage of existing penetrations into the cells. The antennas are combined by the receive electronics in such a manner as to select the strongest of the four antennas during receive mode. This feature allows the selection of the stronger antenna when the cart is positioned in a doorway area between cells. In the facility transmit mode, all antennas are driven simultaneously. An override feature on the engineer's console allows manual control of the transmitting antennas to subdue major multipath nulls (if necessary) when the cart is in the doorway area.

The cart uses two antennas to provide a spatial diversity receiving system. When one antenna loses signal because of cancellation at multipath nulls, the electronics switch to the other antenna at the beginning of the next transmission packet. Because the overall data rate is relatively low and redundant packet transmissions are sent, minimal information is lost during the antenna selection. Additionally, if the last valid packet was a command to move, the cart is programmed to continue moving approximately one-quarter wavelength (7.5 cm) in the event of a missing packet. This feature allows the cart to move out of the null in an attempt to receive a valid command.

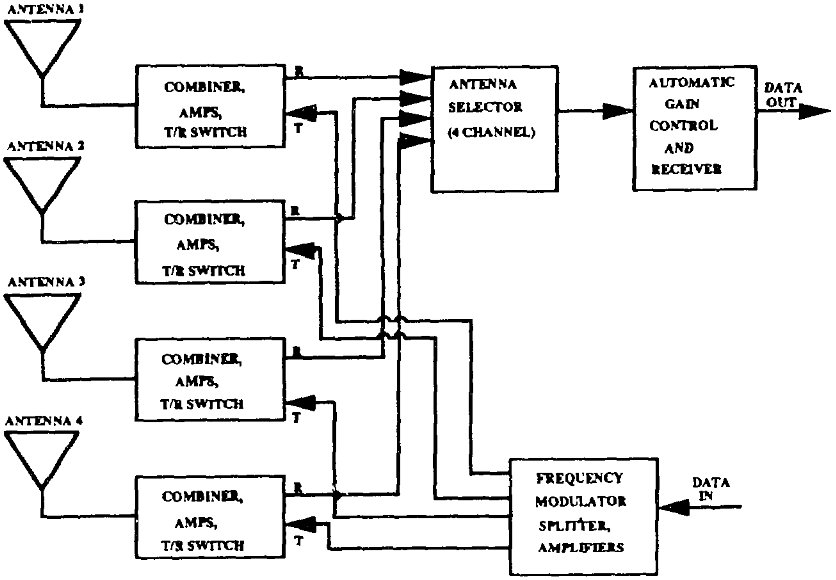

Fig. 2. Facility radio-frequency system block diagram.

### Electronics design

The communications system can be divided into facility electronics and cart electronics. Figure 2 is a block diagram of the communications equipment on the facility side of the link. In the facility transmit mode, digital data from the facility engineer's console are processed through a data encoder/decoder board and are frequency modulated onto a 915-MHz carrier. The carrier power is split into four identical signals and amplified. Each signal is routed through coaxial cables to a transmit/receive (T/R) module that is positioned outside the cell near the cell antenna penetration. The T/R module amplifies the signal to a 100-mW level and routes it through a circulator combiner to the facility cell antenna.

In the receive mode, the signal from the cell antenna is routed through a circulator combiner and an electronic switch to a low-noise amplifier. The signal level is boosted by 40 dB and routed through coaxial cable to the electronics at the facility operator station. The amplitudes of the received signals from each of the four cells are compared at the antenna selector, and the strongest of the four signals is chosen. The antenna selector determines this choice at the beginning of the cart transmission and locks the preferred antenna into the system until the end of the transmission packet. This feature prevents transmission errors that would occur if the antenna selector switched during a data packet. The antenna selector routes the signal to an AGC and receiver card. The AGC provides 40 dB of gain control, allowing consistent operation over a signal power variation of 10,000:1. The AGC compensates not only for distance between the transmit and receive antennas but provides additional signal leveling to reduce the effects of multipath. The signal is then hard-limited to eliminate amplitude variations that are faster than the attack time of the AGC. The amplitude-limited signal is demodulated by a delay line discriminator, lowpass filtered, and amplified before being sent to the facility data encoder/decoder board.

A block diagram of the cart communications electronics is shown in Fig. 3. In transmit mode, the cart data encoder/decoder supplies digital data to the frequency modulator. The 915-MHz carrier is amplified to a level of 50 mW and routed through an electronic switch to one of the two cart antennas. Because the cart has no way of determining which antenna is optimum during transmission, the same antenna is always used for transmitting.

In receive mode, the antenna selector on the cart determines the stronger of the two antenna signals. The selector latches that antenna at the beginning of a facility transmission to avoid errors due to antenna switching during a packet transmission. The signal from the antenna selector is routed to AGC, limiter, and demodulator circuits that are identical to the ones described for the facility receiver. The data are then sent to the cart encoder/decoder board.

The design for the cart communications electronics is based on designs that had been tested in similar in-cell applications. The selected electronic components were identical vendor and model numbers of components that had been shown to operate in $10^4$-R/h radiation fields while withstanding a total integrated dose of $10^7$ R. Based on this design approach, the communications system electronics should be robust in the radiation environment.

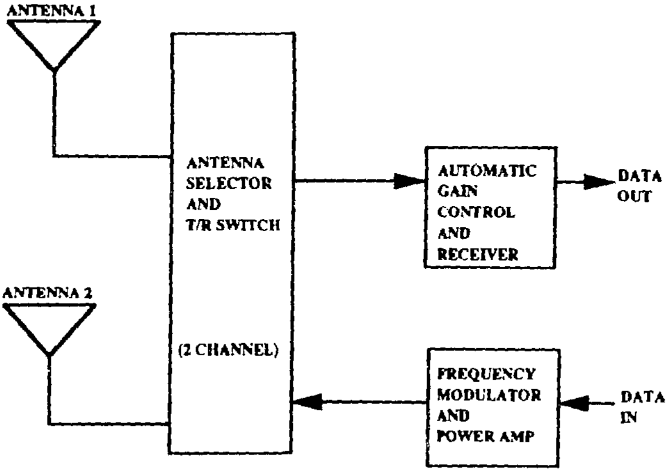

Fig. 3. Transfer cart radio-frequency system block diagram.

## CONCLUSIONS

A communications system was designed for bidirectional digital signal transmission between a materials transfer cart and the operator control station in a nuclear reprocessing facility. A prototype of the design was built and tested in a mockup of the cart and facility controls. Results of the testing were favorable, and several sets of hardware are now being procured for the facility.

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