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# In-body to Out-of-body Communication Channel Modeling for Ruminant Animals for Smart Animal Agriculture

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***Abstract*— Continuous real-time health monitoring in animals is essential for ensuring animal welfare. In ruminants like cows, rumen health is closely intertwined with overall animal health. Therefore, in-situ monitoring of rumen health is critical. However, this demands in-body to out-of-body communication of sensor data. In this paper, we devise a method of channel modeling for a cow using experiments and FEM based simulations at 400 MHz. This technique can be further employed across all frequencies to characterize the communication channel for the development of a channel architecture that efficiently exploits its properties.**

## I. INTRODUCTION

Animal welfare and overall farm productivity can be greatly boosted by real-time continuous health monitoring as suggested by the core principles of precision livestock farming. Rumen health is a great indicator of overall health of an animal such as cows, with biomarkers that can signal onset of diseases and metabolic function. The rumen is populated by microorganisms which assist in the digestion of the ruminant animal. Thus, the rumen environment can provide key insight to the processes involved in generating energy and producing food. However, collecting data from the sensors in the rumen is a challenge due to the significant attenuation of signals as it passes through the various layers of body tissue. Previous studies have used RF based communication protocols in an ad hoc manner without detailed investigation of the channel properties which may increase the power consumption for communicating the data efficiently. We introduce a method of channel analysis for *cannulated animals* to create a channel model which can be further used to create the architecture for efficient in-body to out-of-body communication for ruminant animals.

This paper further demonstrates a method of accurately modeling the morphological features of the cow's body for path loss results using FEM based simulations. We investigate the channel properties at 400 MHz band which is applicable for health monitoring standards such as MedRadio [1] as defined by Federal Communications Commission (FCC). A cannulated cow is used to perform experiments to get the channel loss at different positions on the body of the cow which are then compared with the simulation results.

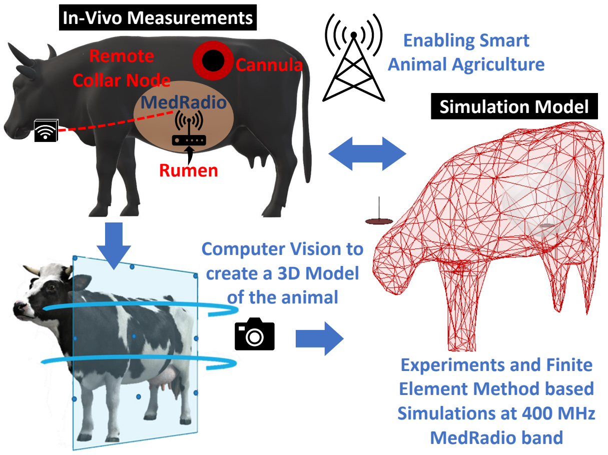

Fig. 1: A method for channel modeling of an in-body to out-of-body communication system for ruminant animals is demonstrated.

Previous attempts at channel modeling have used simulation models that don't deal with the features of the animals which affects the path loss of the signal reaching the collar. Previous simulation models [2], [3] use a simplified layered structure present in the model or use an animal surface layer phantom [4], [5] to emulate the channel loss which doesn't model the features of the animal that are essential in accurately determining the path loss of the channel from the transmitter inside rumen to the receiver outside the body. The simulation models will be further improved and made publicly available for use to facilitate accurate simulations in the future.

Smart animal agriculture will enable animals to be part of Internet of Things (IOT) space where the remote collar node shown in Fig. 1 from all animals in the farm will connect to a hub to generate huge data from various sensors which will be analyzed to enhance productivity. Data received from sensors dwelling inside the rumen can monitor important parameters and prevent diseases like sub-acute ruminal acidosis (SARA) in cow's preventing huge losses in the dairy industry and thus propelling efficient animal agriculture.

## II. EXPERIMENTAL VALIDATION

### A. Experimental Setup

Experiments were performed in a dairy farm to verify the channel loss at 400 MHz frequency band. This study was approved by the Institutional Animal Care and Use Committee (IACUC). A frequency synthesizer by Analog Devices (ADF4355) [6] along with a ANT700 antenna [7] was used to transmit at 400 MHz and was placed

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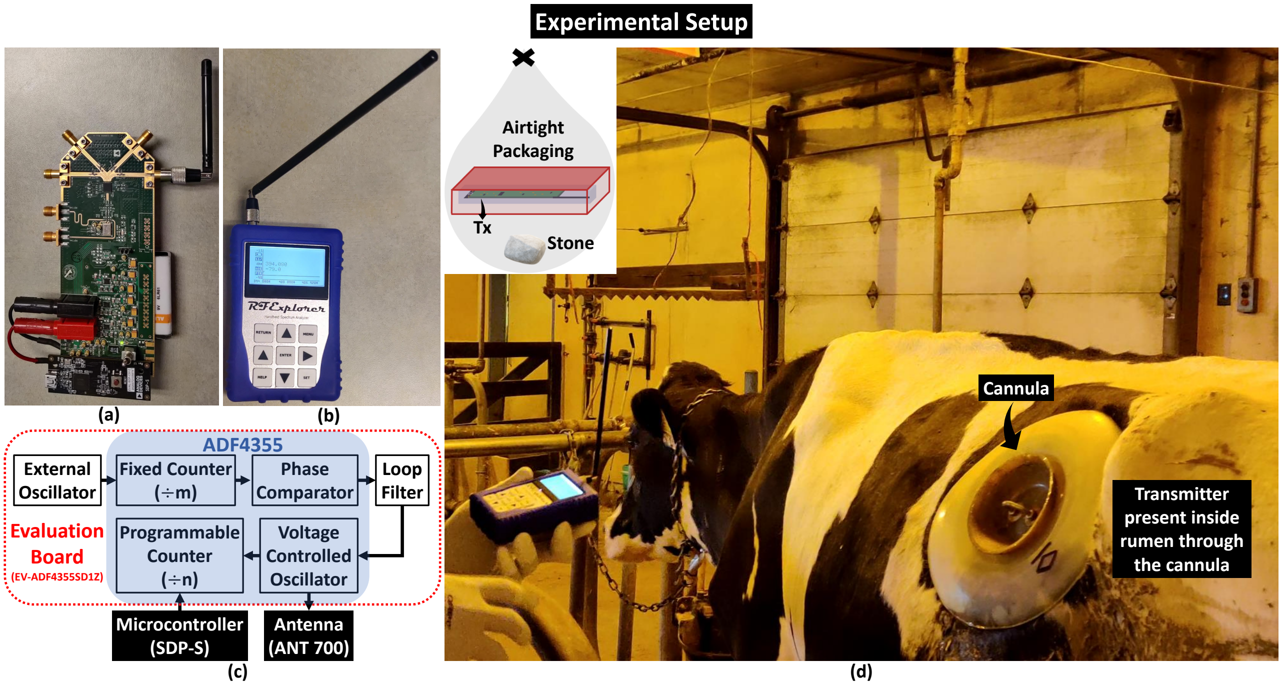


Fig. 2: (a) The transmitter setup - Frequency synthesizer board (EV-ADF4355SD1Z) with ANT500 antenna and a 9V alkaline battery. (b) Receiver setup with a handheld RF Explorer spectrum analyzer and ANT700 antenna. (c) Block diagram of the transmitter. (d) Experiments are performed in a dairy farm with a cannulated cow. The transmitter is packaged (inset) and inserted into the rumen of the cow via the cannula. A stone is used to ensure that the packaged transmitter sinks into the bottom of rumen.

inside the rumen of the cow. The transmitting frequency is controlled using a microcontroller (SDP-S) [8] which changes the programmable counter of the PLL to change the transmitted frequency. The transmitter setup shown in Fig. 2 (a) was placed inside the rumen via the cannula described in Fig. 2 (d). The transmitter must act as a standalone frequency synthesizer acting without any wired connections to a computer outside the body of the cow so that no leakage from the wires are caught at the receiver end. The block diagram in Fig. 2 (c) illustrates the components of the transmitter board. A handheld RF Explorer spectrum analyzer was used as the receiver along with an ANT500 antenna [9] as illustrated in Fig. 2 (b).

## B. Experimental Results

The experiments were primarily carried out to measure the channel loss at positions on the body of the cow where a receiver device can be placed. The collar of a cow has been previously used for cattle health monitoring purposes due to its accessibility. Further, the receiver can also be placed at the back of the cow close to the cannula to get a lower path loss due to shorter channel length from the transmitter. Thus, the receiver was moved along the width of collar and the around the body of the cow opposite to the cannula to get the path loss at the identified critical points. The measurements were carried out with the receiver on the surface of the body of the cow opposite to the cannula to get the worst case channel

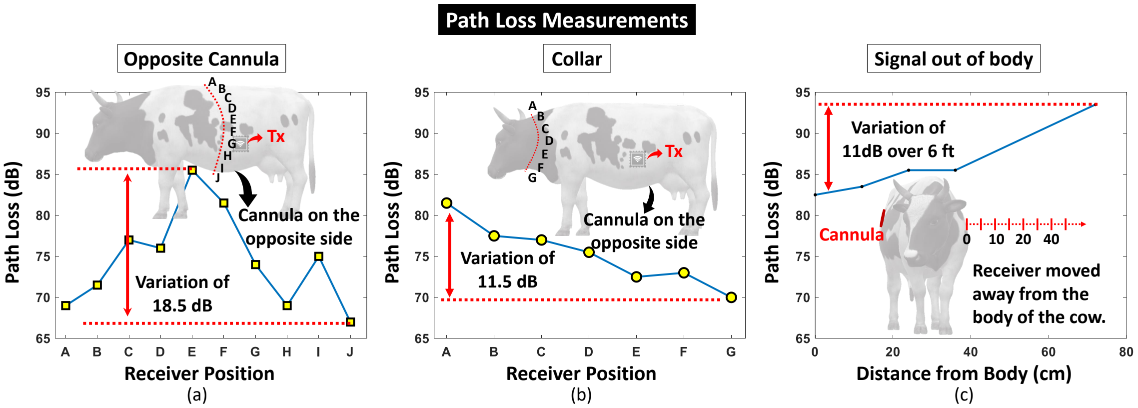


Fig. 3: (a) Receiver is rotated along the body of the cow to measure the path loss at different points opposite to the cannula. (b) The receiver is moved along the collar of the cow to measure the path loss values. (c) The path loss is measured away from the body of the cow to observe the amount of signal available outside the body.

loss results. The presence of cannula decreases the channel loss close to the cannula region due to absence of attenuating body tissue.

*1) Measurements near canula:* The receiver was moved around the body of the cow opposite to the cannula as shown by the figure inset in Fig. 3 (a) to capture the channel loss. The channel loss characteristics show that the path loss is highest when the receiver is placed opposite to the cannula as shown by position E on Fig. 3 (a). At this position, the signal traverses the highest distance through the various tissues on the body and thus results in the highest attenuation. Further, the channel loss progressively decreases as we move to the top (position A) or to the bottom (position J) on the body of the cow. The channel length through the body progressively decreases along these paths.

*2) Collar measurements:* The channel loss is measured with the receiver moving along positions around the collar opposite to the side where the cannula is placed and is illustrated by positions A to G in the figure inset in 3 (b). The channel loss results show that the highest loss is obtained when the receiver is placed on the top of the collar (position A). Further, the channel loss gradually decreases as we move down the collar towards position G. The transmitter is placed at a similar height as the bottom of the collar shown by position G. Thus the channel length through the body for the signal to travel is highest in case of position A and gradually decreases as we move towards position G. Further, due to the presence of bone dense (spinal chord) region on the back of the cow, the attenuation of the signal is higher than that for the lower positions.

*3) Signal radiated out of body:* Signal radiated out of the body is measured to check the distance till which transmitted signal is available from the cow's body. Fig. 3 (c) illustrates the measurement setup. We measure the signal towards the opposite side to the cannula away from the body. Here, the channel loss results indicate that the attenuation outside the body is a function of the distance in air away from the body. A channel loss of close to $95dB$ is observed around $6ft$ away from the body of the cow.

## III. FINITE ELEMENT METHOD BASED SIMULATIONS

### A. 3D Modeling of the Bovine Body Structure

In order to precisely model the morphological traits of the animal under study, a series of experiments were conducted where data was collected by scanning a bovine. We utilized both RGB-D (Realsense D435i) (Fig. 4 (a)) and stereo cameras (Zed Stereo Camera) (Fig. 4 (b)) to conduct 360° scans of the animal. The scans were conducted at 0.8m, 1.5m and 1.8 m above the ground level as illustrated by Fig. 4 (c). At these different heights, we first identified points around the animal in a circle to capture the point clouds (Fig. 4 (d)). Similarly, we recorded videos using the stereo camera around the same paths. These scans mapped the surface of the animal using depth perception and the depth data is stored in the point cloud. Multiple such point clouds were collected to ensure precision in data collection. These point clouds were then used to generate the 3D meshes of the morphology as shown in Fig. 4 (d). The overlaps present in the scans were used to identify points for stitching the meshes to create a full 3D morphological model of the animal using Meshlab. Further, to convert this surface model into a solid, we used Autodesk Fusion 360 (Fig. 4 (e)). Since the placement of organs and the rumen is asymmetrical inside the body of the animal, we used ultrasonic measurements to approximate the placement of the rumen cavity in the animal model.

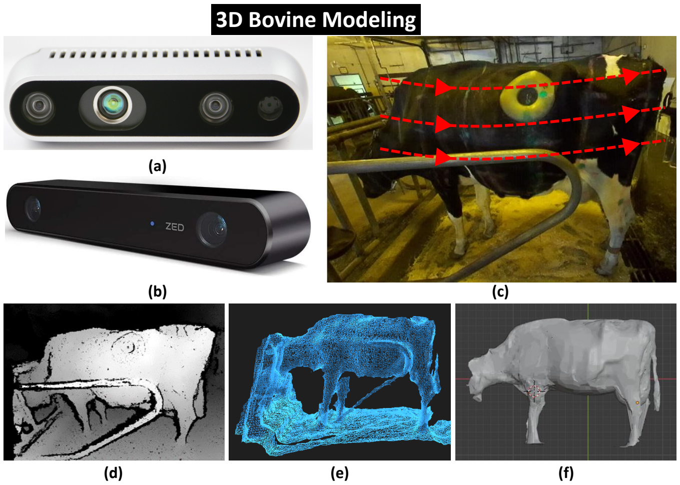


Fig. 4: The simulation model is prepared by capturing the images using (a) Realsense D435i depth sensing camera, and (b) Zed 2 Stereo camera. (c) The images are captured by moving the camera across the body of the cow at different heights. (d) Point cloud generated by the images. (e) A mesh is created from the point cloud which is then used to create the solid model of the cow shown in (f).

### B. Simulation Setup

The simulation setup uses a 3D model of the cow (Fig. 5 (a)) which is made of muscle tissues [10] to perform FEM simulations to compare with the experimental data. A ground

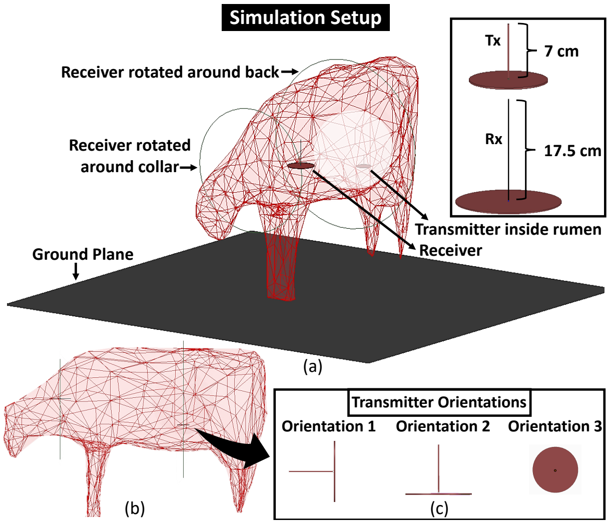
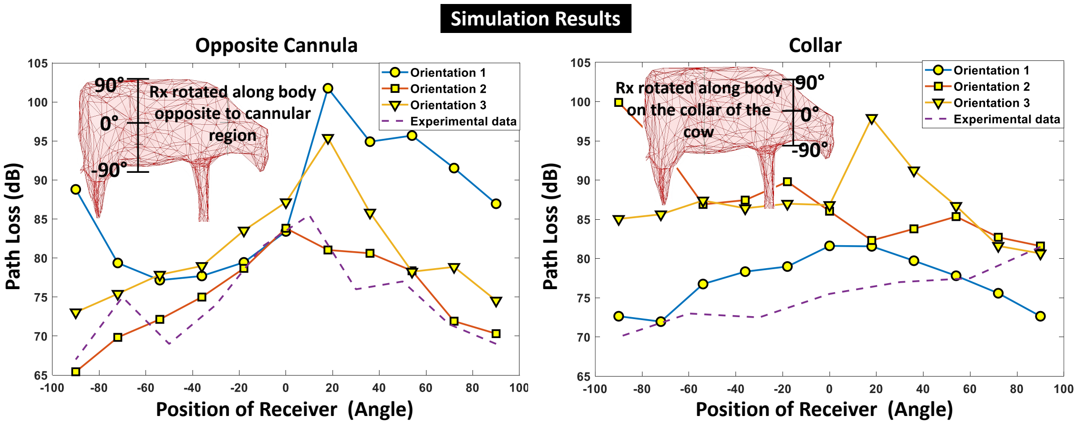


Fig. 5: (a) Model used for FEM simulations showing the dimensions of the transmitter and receiver. (b) Side view of the simulation model. (c) Simulations are performed with 3 different orientations of the transmitter.



(a)

(b)

Fig. 6: (a) Receiver rotated along the body of the cow opposite to the position of the cannula. (b) Receiver rotated along the collar of the cow.

plane is used to model the earth's ground. This simplified model is used for the FEM based HFSS simulations to validate the channel loss response of the system at 400 MHz frequency band similar to the experimental studies.

A spherical space is created inside the 3D cow model to emulate the ruminal space of the cow where the transmitter is placed. The spherical space is filled with air in the simplified simulation model. The transmitter and the receiver is modelled as per the monopole antennas (ANT700 and ANT500) used in the experimental study. Two lumped ports are defined with $50\Omega$ terminations to calculate the path loss at various positions for the receiver. The transmitter in the experiments may change orientation during the course of the experiments due to contractions in the rumen. Thus, we use three different orientations of the transmitter antenna as shown in Fig. 5 (c).

### C. *Simulation Results and Discussion*

The simulations are conducted with the receiver rotated along the body of the model of the cow along the same path as done in the experiments for the three different orientations of the transmitter antenna. The results in Fig. 6 (a) illustrates the case where the receiver is rotated along the body of the cow along the region opposite to where the cannula would be in the experimental case. The simulation results are a close match in terms of magnitude of path loss with the experimental results. Further, it can be observed that the path loss is highest when the receiver is placed directly opposite to the region where the cannula is (close to 0° in the simulations) for all the orientations of transmitters. This behavior was also observed in the experimental results. Further, the path loss decreases as we move towards the back of the cow (90° position) or to the bottom ($-90°$ position) as seen by the experimental results as well. Fig. 6 (b) shows the variation in path loss when the receiver is moved along the collar of the cow. We observe again that the path loss magnitude for experiments and simulations are a close match thus validating the simulation model.

The simulation results and path loss magnitudes obtained in the experiments have similar magnitudes. However, the simulation results are not an exact match with the experimental trends observed. This can be attributed to the simplified nature of the model with only muscle tissues to model the body of the cow. The results can be further improved with a more detailed model with more experimental data at different frequencies across the RF spectrum and with a denser simulation model which will be part of our future work.

## IV. CONCLUSIONS

We present a method for analyzing the communication channel model for an in-body to out-of-body setup in animals. We perform experiments at 400 MHz frequency band on a cannulated cow where the transmitter is placed inside the rumen of the cow. Further, depth sensing cameras are used to create a 3D model of the cow which is then used to perform FEM based simulations. These simulation results yield path loss of a similar magnitude to that of the experiments. The proposed method can be used to analyze the channel model for different animals at any frequency. It has also been illustrated that an in-body to collar communication channel can be used for data transfer from sensors inside rumen to enable smart animal agriculture.

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