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# Electro-Quasistatic Human-Structure Coupling for Human Presence Detection and Secure Data Offloading

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***Abstract*— The emergence of Human Body Communication (HBC), as an energy-efficient and physically secure mode of information exchange, has escalated the exploration of communication modalities between the human body and surrounding conducting objects. In this paper, we propose an Inter-Structure communication guided by Human Body while envisioning the need for non-contact sensing of biological objects such as humans with secure data offloading by analyzing the Structure-Human-Structure Interaction (SHSI) in Electro-Quasistatic (EQS) regime. Results show that the presence of a human between conducting structures (with Tx & Rx) can boost the received voltage by ∼8 dB or more. Received signal level can be increased further by ∼18 dB or more with a grounded receiver. Finite Element Method (FEM) based simulations are executed to study the positional variation of structure (with Rx) relative to body and earth's ground. Trends in simulation results are validated through experiments to develop an in-depth understanding of SHSI for EQS signals with low loss and enhanced physical security.**

***Index Terms*** Human Body Communication (HBC), Electro-Quasistatics (EQS), Human-Structure Coupling (HSC), Structure-Human-Structure Interaction (SHSI)

## I. INTRODUCTION

In the age of mobile and ubiquitous computing, non-contact omnidirectional detection of humans in indoor spaces have been the subject of interest for the last couple of decades. There exist various sensing techniques for the detection of human presence and movement in the surroundings, which are not limited to but include Capacitive[1], Inductive[2], Ultrasonic[3], and Infrared (IR)[4]. However, limitations of existing sensing methodology in terms of not preserving the subject's privacy such as for camera-based approaches, call for an in-depth analysis of a new promising modality in terms of the physically secured Electro-Quasistatics (EQS) Human-Structure coupling (HSC), that may be beneficial in some cases over the existing ones. This work envisioned the need for an energy-efficient sensing technique for human presence detection with secured data offloading in smart buildings like hospitals. The benefits of signal-confinement (signal leakage constrained within ∼5-10 cm around the body) in EQS[5] prompted us to use conducting structures as sensors performing non-contact detection of biomass such as humans and eventually, analyze the communication channel in Structure-Human-Structure Interaction (SHSI).

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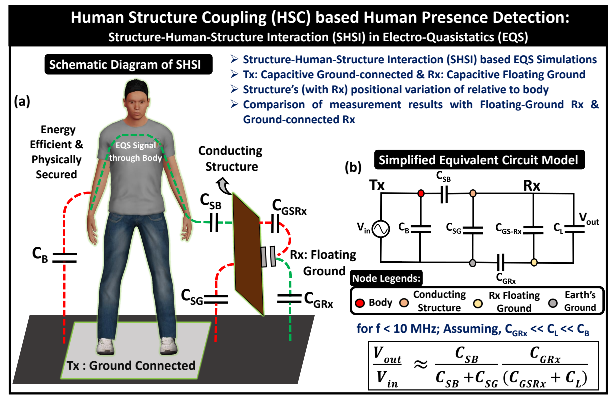


Fig. 1. Capacitive coupling-based Structure-Human-Structure Interaction (SHSI): (a) Schematic Diagram along with involved parasitic capacitances. (b) Simplified lumped-element based equivalent circuit model, when human is standing on the ground-connected transmitter (Tx) and the floating ground (FG) receiver (Rx) is mounted on the vertical conducting structure

In the low-frequency EQS-regime ($\leq$ 10 MHz), where the operating signal wavelength ($\lambda \geq$ 30 m) in air, is orders of magnitude larger than the dimensions of a human body ($\leq$ 2 m) and used communication devices ($\leq$ 1 m), it is fairly consistent to approximate the distributive nature of the bio-physical model of HBC with a combination of lumped circuit elements. From the previous lumped element based bio-physical models of HBC [6], [7], [8], a simplified equivalent circuit model along with involved capacitive couplings, present in SHSI is illustrated in Fig.1 ((a), (b). Combining the proposed HSC topology with previously shown wearable health monitoring using capacitive HBC [9], physiological signals can be sent securely to a structure like smart hospital beds in a non-contact way.

## II. STRUCTURE-HUMAN-STRUCTURE INTERACTION

In capacitive HBC-based SHSI, the structures with transmitter (Tx) and receiver (Rx) with the human body form the forward path and the parasitic capacitances between the devices floating ground and the earth's ground form the return path. To study the SHSI channel characteristics, Finite Element Methods (FEM) based EM simulations are carried out in EQS frequency regime ($f$=1 MHz) using Ansys High-Frequency Structure Simulator (HFSS), a Finite Elements Analysis (FEA) based EM solver.

### A. Simulation Setup

The simplified cross-cylindrical human body model, made up of skin and muscle tissues (dielectric and conductive

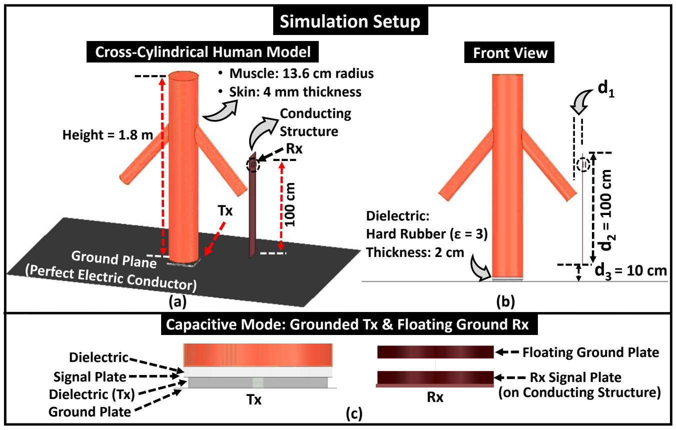


Fig. 2. Simulation Setup: (a) Simplified cross-cylindrical human model used for HFSS simulations and its dimensions with the position of ground-connected (GC) Tx and structure-mounted Rx shown, (b) Front View, (c) Capacitive mode of Tx and Rx used for simulations

properties of tissues have been adapted from the works of Gabriel et al. [10]), which possess identical electric-magnetic field distributions inside-around the body as the complex human body model - VHP Female v2.2 from Neva Electromagnetics, as shown by Maity et al. [11], is used for fast simulations with reduced complexity. The structural parameters of the model are shown in Fig. 2 ((a), (b)). A ground-connected (GC) Tx, is used on which the human stands, whereas the Rx, mounted on the vertical conducting structure, is a floating-ground (FG) one, shown in Fig. 2 (c).

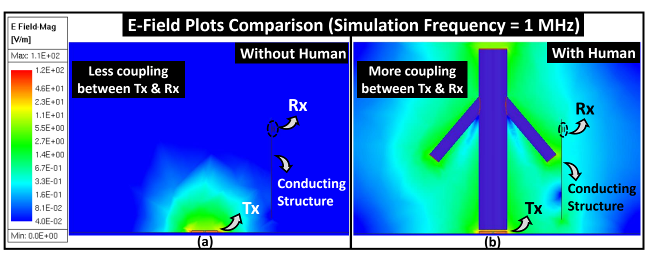


Fig. 3. E-Field Plot comparison: (a) No human is present between communicating structures (Tx & Rx), (b) Human standing on the Tx with structure (with Rx) 5 cm away from it. Presence of human results in an increase in EQS-coupling between the communicating structures

## B. Simulation Results

Comparing E-Field plots with and without the human body (on the GC transmitter) as depicted in Fig. 3 ((a), (b)), illustrates the improvement in EQS coupling between the structures when the human is present as a communication medium. Fig. 4 (a) representing the SHSI channel behavior in EQS-regime, quantitatively delineates the improvement in $V_{Rx}$ (∼23 dB) with human standing on the GC-Tx. The effect of moving the structure (with FG-Rx) away from the body while the human stays in contact with the GC-Tx is presented in Fig. 4 (b). Moving the structure (with Rx) away from the body decreases the capacitive coupling ($C_{SB}$, from the channel model illustrated in Fig. 1 (b) between the

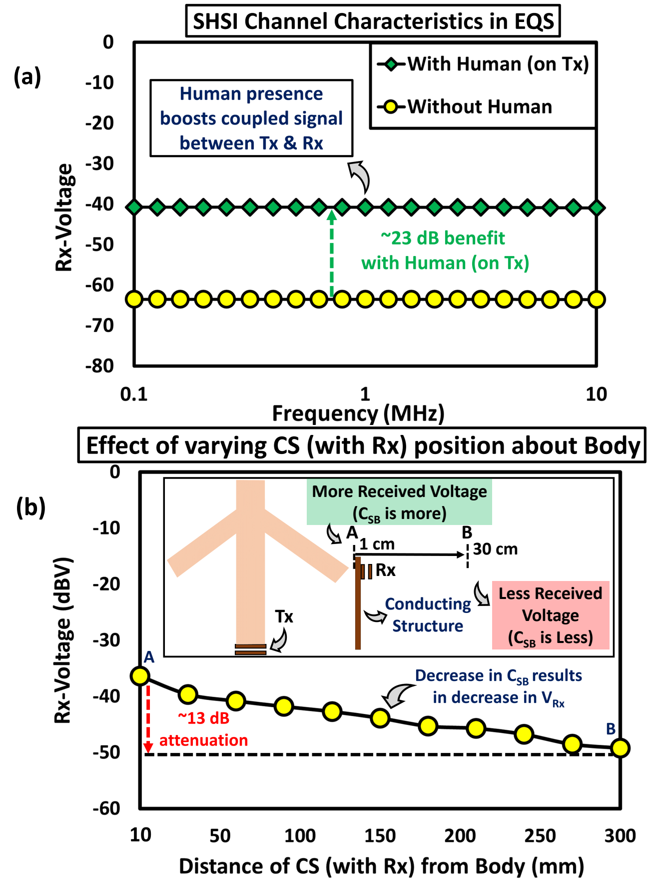


Fig. 4. Simulation Results: (a) Comparison of SHSI channel characteristics in EQS-frequency domain in the with and without Human on Tx, (b) Effect of moving the conducting structure (with Rx) away from Body (on Tx).

body and conducting structure, which reduces $V_{Rx}$ (∼13 dB attenuation over a distance of 30 cm). The variation in the $V_{Rx}$ with the distance of conducting structure relative to the earth's ground is presented in Fig. 5 (a). $V_{Rx}$ improves by ∼15dB with a 90 cm movement of the structure (with Rx) away from the earth's ground due to the attenuation in structure-to-ground coupling ($C_{SG}$, from the channel model illustrated in Fig. 1). Fig. 5 (b) depicts the identification of the direction of human travel, which can be decided by the phase change of the differential voltage at different body positions (on Tx) across the two conducting structures.

## C. Experimental Setup

The experiments were conducted in a standard laboratory environment and were approved by the Institute Review Board (IRB). The GC Tx setup (Fig. 6 (a), (b)) comprises a GC Function Generator and an aluminum foil, emulating the signal plate of the Tx and fixed on the ground, to which the output of the function generator is connected. The Rx setup was either FG (oscilloscope of wearable form factor) or GC (ground-connected oscilloscope), connected to an one-sided conducting plate (facing body) as depicted in Fig. 6(b). Measurements were taken with steady body posture for the subject, shown in Fig. 6(d). For capacitive FG Rx, one of the electrodes is kept floating for the single-ended

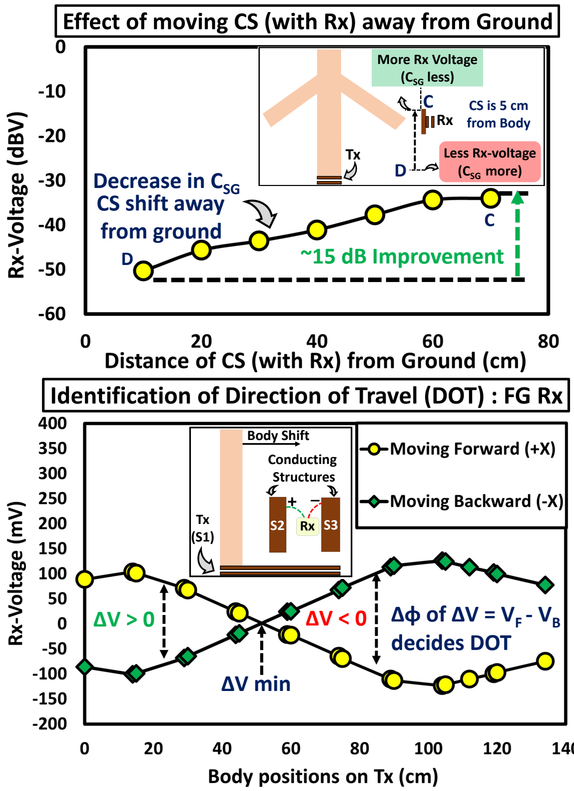


Fig. 5. Simulation Results: (a) Moving the structure (with Rx) (Size: 20 cm × 17.5 cm × 1 mm) away from earth's ground, (b) Identifying the direction of human travel

pickup of the received voltage. Comparative analysis of the

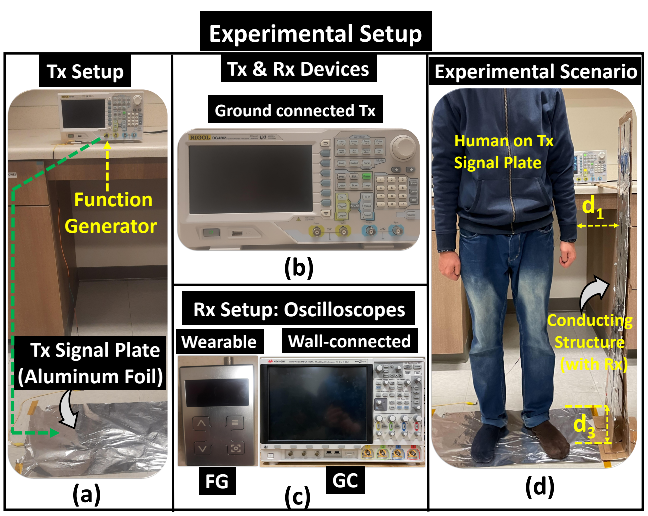


Fig. 6. Experimental Setup: (a) Tx Setup, (b) Ground-Connected Function Generator, (c) Floating Ground Rx: Wearable Oscilloscope & Ground Connected Rx: Wall-connected Oscilloscope, (d) Experimental scenario along with Body posture during measurements

experimental results while using a large GC oscilloscope (which provides an optimistic path loss due to the large size of its ground plane) with a FG oscilloscope of wearable form-factor (which offers higher path loss due to smaller ground plane size resulting in smaller return path capacitance $C_{GRx}$), has been delineated in the subsequent results section. An operating frequency of 1 MHz (to have higher specificity of detection through better confinement of EQS signal for secure data-offloading) [5] is chosen while performing the experiments. The transmitted signal is kept at a voltage level of 5 V (peak-peak) and received voltage measurements were carried out using FG and GC oscilloscopes.

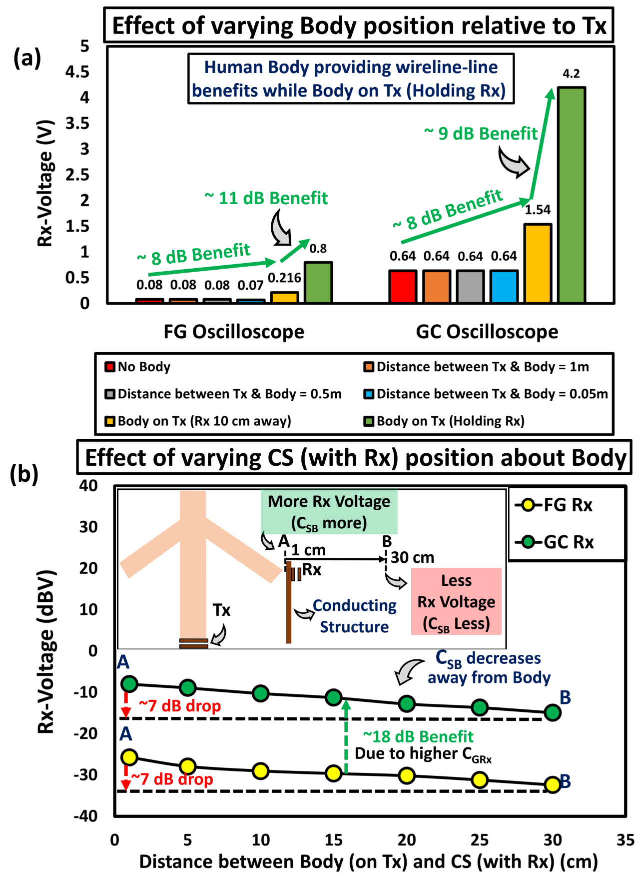


Fig. 7. Experimental Results: (a) Effect of variation in body positions about GC-Tx. (b) Effect of positional variation of conducting structure (with Rx) about Body. Moving the structure away from the body lowers $C_{SB}$.

## *D. Experimental Results*

Measurement results, validating the trends in received voltage variations as shown in simulation results (Fig. 4), are plotted in Fig.7. The bar graph captures the effect of the absence or presence of a human in between the structures with Tx and Rx (Fig. 7 (a)) for the GC and FG oscilloscope setups for the Rx. The presence of a human (on the Tx-signal plate) provides ∼8dB improvement in $V_{Rx}$ with a Rx as a FG oscilloscope. ∼18dB improvement in $V_{Rx}$, is observed with a large GC oscilloscope as a Rx. With human standing on the Tx-signal plate, when the distance between the body and structure (with Rx) was increased by changing the position of the structure relative to the body for two Rx setups, ∼7dB improvement is obtained for both cases, shown in Fig 7 (b). GC Rx setup has offered ∼26 dB benefit over FG Rx due to its higher $C_{GRx}$, illustrated in Fig. 1. The result of moving the structure of fixed dimension (with Rx) towards

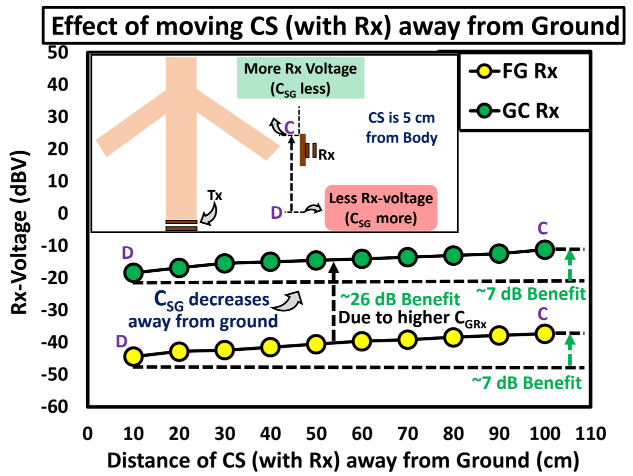


Fig. 8. Experimental Results: Effect of moving structure (20 cm × 17.5 cm × 1 mm) (with Rx) away from Earth's Ground. Structure's movement away from earth's ground lowered $C_{SG}$, which leads to higher $V_{Rx}$.

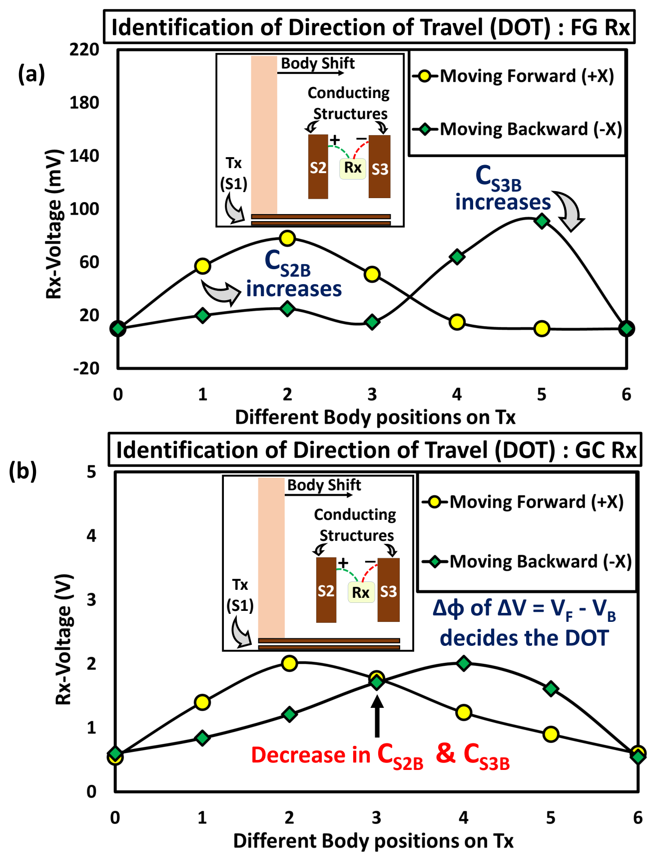


Fig. 9. Experimental Results: Identifying the direction of human travel: using (a) Wearable Oscilloscope, (b) Wall-connected Oscilloscope

the earth's ground is presented in Fig. 8. In EQS-HBC, channel variability in different subjects is well understood [6], and can be a future exploration of the proposed SHSI.

## III. Identification of Direction of Travel

Information on a human travel direction in a building (i.e., hospitals) can be obtained by employing capacitive SHSI topology at the entrance or exit of buildings. This requires incorporation of an additional conducting structure (S3) at a fixed distance away from the present structure (S2), and the measurement of the induced differential voltage ($\Delta V = V_F - V_B$) as the human walks on the Tx with the Rx structures present at the side. Measurement results, presented in Fig. 9 ((a), (b)) shows the change in phase ($\Delta\phi$) of $\Delta V$, which confirms the trend as illustrated previously in Fig. 5 (b).

## IV. Conclusion

In this paper, we propose a physically secure mode of Human-Structure Coupling (HSC), namely capacitive SHSI, for human presence detection in hospitals or smart buildings. Results show that the channel loss depends on the separation between the conducting structure (with Rx), body, and earth's ground. GC Rx showed significantly lower channel loss with its larger ground size compared to FG Rx. The improvement of Rx-voltage differed in experiments from simulation due to the setup difference of the conducting structure i.e., though, a two-sided conducting plate has offered more benefit in simulation, to minimize coupling from additional grounds in the surroundings, an one-sided conducting plate (facing body) is used in experiments. A design topology for the structure (with Rx) has been proposed to identify the Direction of Travel through differential signal measurement.

## Acknowledgment

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