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Comparison of Galvanic and Capacitive Coupled Intrabody Communication Channel by using Isolation Transformer

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***Abstract*—Intrabody communication is an emerging technology that uses human tissue as a data transmission channel. This study experimentally investigates wearable galvanic and capacitive-coupling-based intrabody communication channels. The performance of different coupling mechanisms was compared by assessing the communication channel behavior using a tissue model. Experimental measurements were conducted with chicken breast tissue in the frequency range of 100 kHz to 1 MHz. Additionally, the effect of electrical isolation using isolation transformers, known as baluns, was studied to mitigate common-mode noise. Results indicated that the fluctuation of the channel gain in the frequency ranges between 100 kHz - 400 kHz occurred with the usage of baluns. A high-pass behavior was observed beyond 400 kHz with the termination of balun at P1 and P2, separately. Channel gain results exhibit flat behavior after 400 kHz, which permits a simpler system design. Additionally, the capacitive coupling technique demonstrated superior performance compared to the galvanic coupling method.**

Keywords—intrabody communication; galvanic coupling; capacitive coupling; isolation transformer; wearable technologies; electromagnetic compatibility

I. Introduction

With the development of technology, the transmission and control of data signals have become significant topics of interest. Wireless networks defined by international standards, such as ZigBee, Wireless Local Area Network (WLAN), blacktooth, and Radio Frequency Identification (RFID), are designed to communicate over distances of several meters [1]. However, devices using these methods increase energy consumption, and the privacy of transmitted information may be compromised.

The technology of intrabody communication foresees biological tissue as the signal transmission medium and offers several advantages, including energy efficiency, information security, and frequency band reuse [2], [3], [4]. The literature describes various techniques for intrabody communication technologies [5]. These techniques can be categorized as either ultrasound or electromagnetic, employing operational frequencies spanning from low to high depending on the specific method. Electromagnetic techniques offer several advantages compared to ultrasound techniques, including faster data transmission, deeper tissue penetration, broader application range, and reduced signal weakening While radio frequency (RF) techniques are commonplace, they cause high loss in biological tissues [6]. Therefore, other techniques, including galvanic and capacitive-coupling-based intrabody communication, are being investigated [7].

While existing studies have independently explored individual techniques within the 100 kHz to 1 MHz frequency range [8], [9], [10], a comparative analysis of galvanic and capacitive coupled intrabody communication [11] remains relatively unexplored. Grounding strategies are also a crucial problem in intrabody communications and should be addressed in light of electromagnetic compatibility considerations [12], [13]. In this study, galvanic and capacitive-coupled intrabody communication channels are experimentally compared in the frequency range of 100 kHz to 1 MHz for wearable applica-

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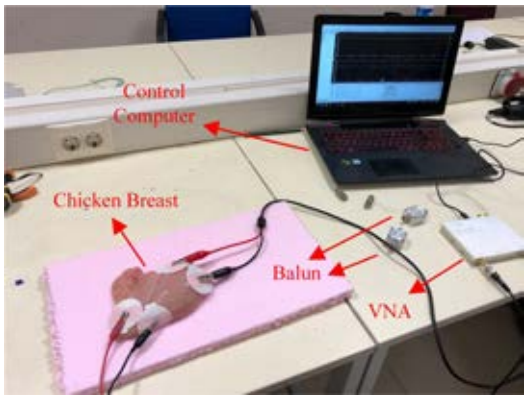


Fig. 1: Intrabody communication channel measurement testbed.

tions. Measurements were carried out with a vector network analyzer (VNA) using an isolation transformer, referred to as a balun, to investigate common ground issues as well. The following sections are organized as follows. Firstly, the theoretical background, and the methodology underlying this study are explained in chapter II. Subsequently, the findings are presented and discussed in chapter III. Finally, the results are evaluated in the conclusion section.

II. Materials and Methods

The ideal operating frequency must be defined because the electrical properties of tissue, and consequently the communication channel characteristics, are frequency-dependent [14]. The interaction between electromagnetic waves and body tissue at RF regions or higher frequencies can result in different outcomes [15]. In RF region-based intrabody communication applications [10], a significant amount of energy is absorbed because approximately 40-65% of human tissue is composed of water. In this study, experiments were carried out in the frequency range of 100 kHz to 1 MHz with a bandwidth of 900 kHz.

Bioelectrical signals, such as EEG and ECG, recorded from the human body have frequencies below 10 kHz. [16]. Therefore, to avoid interference with intrabody communication, the lower limit of the operating frequency was set to 100 kHz, with a broad safety buffer. The signal transmitted through the tissue has two components: conduction current and displacement current. Conduction currents are stronger at lower frequencies [17]. At higher frequencies, capacitive effects emerge, and hence displacement currents start to increase [9]. This can cause signal loss in the area surrounding the human tissue and consequently limit signal transmission to the receiving electrodes. The upper frequency in this study was set to 1 MHz to minimize this effect.

The measurement testbed is depicted in Fig. 1. Here, two baluns (FTB-1-6, Mini Circuits) and a VNA (2-port 100 kHz - 6 GHz, LibreVNA) were used with appropriate cables and adapters. Cables were connected to the chicken breast with ECG electrode patch stamps according to the coupling type.

Ports of the VNA shares a common ground node [18]. This ground node causes common-mode noises, and needs to be mitigated. Therefore, baluns were employed in this study. A balun is a two-winding transformer used to decouple the single-ended signal to a differential signal, such as a balanced signal relative to the electrical ground [19]. In this study, two baluns were used: one connected to the TX side at Port-1 (P1) and the other to the RX side at Port-2 (P2), in accordance with the measurement scenario.

In intrabody communication, the electrical signal propagates through human tissue; thereby, the dielectric properties of the tissue become significant parameters. When a signal interacts with the human body, it causes the electric charges to move and the electrical dipoles to re-align within the tissue. This process is governed by the body's dielectric properties, which vary according to the type of tissue and the operating frequency. In this research, human tissue was modeled using chicken breast due to its human-like dielectric properties [20].

Circuit models of both galvanic and capacitive coupled intrabody commnunication channels were cited in [21]. The channel gain was evaluated using scattering parameters (S-parameters), which explain the performance of N-port networks [22]. In this study, a two-port network was modeled with TX signal at P1, chicken tissue as the communication channel, and RX signal at P2. The gain can be calculated as follows:

$$G = 20\log_{10}(|V_R|/|V_T|) \tag{1}$$

where $|V_R|$ and $|V_T|$ are the amplitudes of the received and the transmitted signals, respectively [18].

III. Measurement Results and Discussion

Measurements were performed more than 80 times under controlled room conditions at a temperature of 20 °C and were recorded to a control computer via the graphical user interface of the VNA. The distance between the TX and RX was 10 cm, with an inter-electrode distance of 4 cm for each TX and RX electrode pair. The VNA was calibrated by short-open-load-thru (SOLT) method in the frequency range of interest [23], [24]. The input power of the VNA was set to 0 dBm. The control computer ran on battery power to immunize it against electrical grid effects.

Fig. 2 shows the communication channel gain without the use of baluns. It can be seen that the capacitive coupled based intrabody communication channel exhibits higher gain compared to the galvanic coupled technique, with nearly 10 dB gap at 1 MHz.

Fig. 3 indicates the results when both P1 & P2 were terminated with baluns. In this case, an unstable frequency range was observed approximately from 100 to 400 kHz. Beyond 400 kHz, capacitive coupled measurements exhibited higher channel gain compared to galvanic coupled results.

Figs. 4 and 5 compare galvanic and capacitive-coupled measurements with balun connections at P1 and P2, respectively. Results show that while capacitive coupled measurements

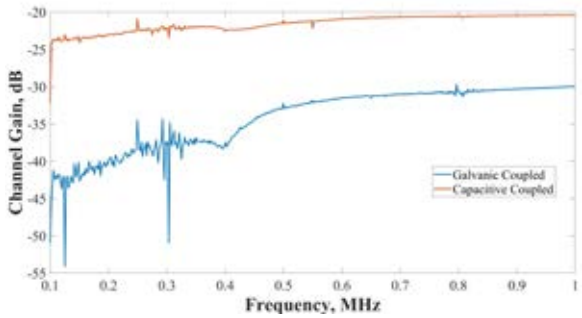


Fig. 2: Comparison of galvanic and capacitive coupled measurements without balun connections.

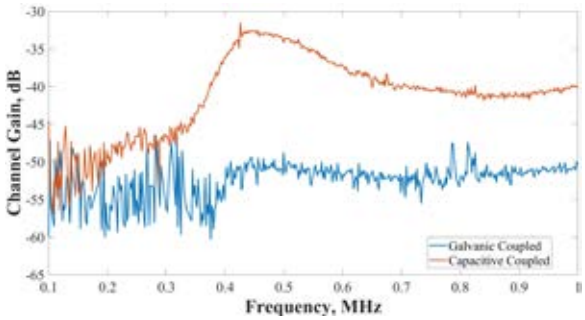


Fig. 3: Comparison of galvanic and capacitive-coupled measurements with balun connections at both P1 & P2.

exhibited consistent behavior, galvanic coupled measurements exhibited different patterns after approximately 400 kHz. Additionally, a high-pass behavior was observed beyond 400 kHz in each coupling case with the balun connected at P1 and P2, separately.

Table 1 lists the descriptive parameters including maximum value, minimum value, mean and median values for each measurement, respectively. The maximum value observed without balun connection was -20.315 dB for capacitive-coupled measurements. For galvanic coupled without balun scenario, the result was measured as -29.696 dB.

The measurement results indicate that using baluns causes fluctuations in gain. The highest gain across the entire frequency band was achieved without baluns. When P1 & P2 were simultaneously terminated with baluns, a lower channel gain was observed compared to the no-balun case above approximately 400 kHz. This suggests that the signal at P2, which corresponds to V_R, was measured as lower, as per Eq. 1. This circumstance can be explained with grounding issues. In the literature, no difference was observed between balun usage at P2 and baluns usage at P1 & P2 in galvanic coupled systems [25]. In this study, a difference of about 3 dB was recorded at 1 MHz. The capacitive-coupled configuration of P1 & P2, terminated with baluns, measured around -50 dB at 1 MHz, consistent with previous studies [21].

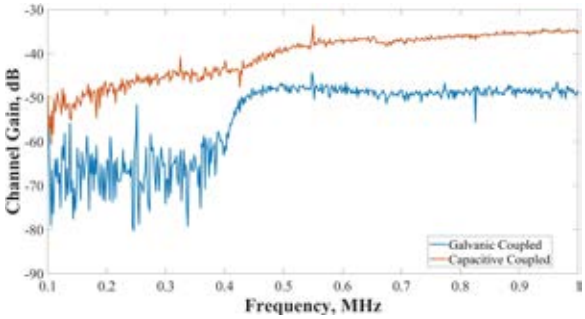


Fig. 4: Comparison of galvanic and capacitive-coupled measurements with balun connection at P1.

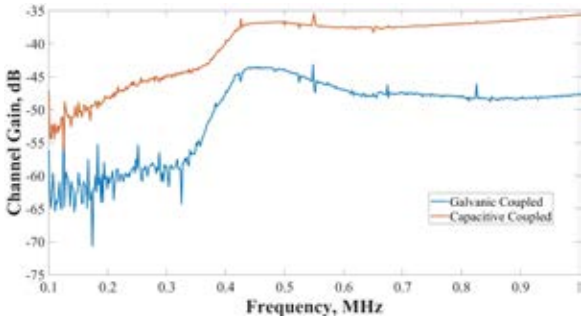


Fig. 5: Comparison of galvanic and capacitive-coupled measurements with balun connection at P2.

IV. Conclusion

In this study, a typical intrabody communication channel was examined within the 100 kHz – 1 MHz frequency band. This research explored a novel method for data communication through tissue and investigated the use of baluns for reducing common mode noise. Further design improvements may be developed based on these findings.

Results indicate that transmission occurs through the communication channel of tissue model with different gain values. Flat channel gain was observed above 400 kHz, enabling simpler design in intrabody communication systems. Capacitive coupling consistently outperforms galvanic coupling in terms of communication channel gain across all scenarios. Unstable frequency regions between 100 kHz to 400 kHz were observed when using baluns. Furthermore, a high-pass behavior was observed beyond the 400 kHz in Figs. 4 and 5, respectively.

It should be noted that unstable frequency ranges observed in the measurements, which could be occurred due to calibration issues, cables, or electrode connections.

This study models the intrabody communication channel for wearable systems, but the approach could also be adapted for implantable applications. Future research will focus on expanding the frequency range of the transmitted signal to improve communication channel parameters such as data rate and channel capacity. Additionally, evaluating the channel impulse response model will help address the communication channel behavior of the tissue. The proposed method offers potential solutions to various engineering problems and applications. As the results obtained are in the frequency domain, future

TABLE I: DESCRIPTIVE ANALYSIS OF MEASUREMENTS (GC: GALVANIC COUPLED, CC: CAPACITIVE COUPLED)

Coupling Type	Maximum Value, dB	Minimum Value, dB	Mean Value, dB	Median Value, dB
GC - No Balun	-29.696	-54.125	-34.249	-32.102
GC - P1 & P2 Balun	-46.199	-60.256	-52.574	-51.718
GC - P1 Balun	-44.445	-80.244	-54.445	-48.609
GC - P2 Balun	-43.159	-70.695	-50.436	-47.174
CC - No Balun	-20.315	-32.23	-21.542	-21.189
CC - P1 & P2 Balun	-31.542	-57.028	-41.209	-40.587
CC - P1 Balun	-33.393	-60.583	-40.313	-37.853
CC - P2 Balun	-34.657	-56.202	-39.856	-37.151

studies will aim to process and modulate the information signal using different modulation techniques to further enhance communication channel parameters.

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