D3.1-Fat-IBC Antenna and transceiver

Project Number: 965044

Project Acronym: B-CRATOS

Project Title: Wireless Brain-Connect inteRfAce TO machineS

Deliverable Information

Project Title:	Wireless Brain-Connect inteRfAce TO machineS (B-CRATOS)
Project Number:	965044
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Approvals

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Executive Summary

This report presents the state of the art about Fat IBC and some basic Fat-IBC antennas. It consists of the basic design method of the Fat-IBC antenna and transceiver system and the Fat IBC. All Fat IBC antenna and tissue model approach has been simulated in CST software, simulated results, and some studies will be incorporated in the report. The simulated findings In D3.1 and detailed study of the fat IBC antenna with transceiver system optimized on the phantom, and some measurement data will be delivered in D3.2.

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1 Overview

1.1 Purpose

This document reports the requirements and the related preliminary design of the Fat-IBC antenna and transceiver system. This report will give a brief idea about the advantage of Fat-IBC and different kinds of Fat-IBC antenna and transceiver systems. This antenna-transceiver system results will be tested and verified in task 3.2.

1.2 B-CRATOS Partners

Short Name	**Full Name**
UU	Uppsala Universitet
SINANO	Institut Sinano Association
SSSA	Scuola Superiore di Studi Universitari e di Perfezionamento S'Anna
BRME	Blackrock Microsystems Europe GmbH
LINKS	Fondazione LINKS – Leading Innovation & Knowledge for Society
DPZ	Deutsches Primatenzentrum GmbH
NTNU	Norges Teknisk-Naturvitenskapelige Universitet NTNU

1.3 Responsibilities

U.U. is the lead beneficiary responsible for Task 3.1 and Deliverable 3.1. U.U. also has the responsibility to design the FatIBC system, which can be used for further monkey trail training experiments. The designed transceiver system will be tested in Task 3.2.

Prof. Robin Augustine (U.U.) is the scientific coordinator assuming the overall project, scientific, and technical responsibility of the project. As B-CRATOS coordinator, Prof. Augustine reviews approves and submits deliverables and reports.

1.4 Definitions

Term	**Description**
B-CRATOS	Wireless Brain-Connect inteRfAce TO machineS project

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Fat IBC	Fat Intra Body Communication
EM	Electromagnetic

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2 Fat Intra Body Communication Overview in context of B-CRATOS

2.1 Introduction

The human body comprises different tissues, organs, and bone structures. The human body parts such as arms, legs, and torso consist of three superficial tissues: the skin (composed of the epidermis and the dermis), the fat, and the muscle tissue [1]. The muscles attenuate the orthogonally transmitted signals, and they hardly reach the bone. Fat tissue is widespread around the body and generally surrounds all the major organs in the human body. Fat tissue is more suitable for intra-body communication because of its lower losses than muscle and skin tissue. Researchers demonstrated that the fat tissue is a viable transmission medium for in-body communication (Figure 1). Figure 1(c) shows the extraction method of the three-layered tissue model. It is evident that fat tissue is widespread around the model and generally envelops all the major organs in the human body.

Fat tissue sandwiched between the skin and the muscle tissues forms a structure similar to a parallel plate waveguide. In general, a parallel plate waveguide is formed by having two conductors on both sides of a dielectric material. The high contrast in dielectric properties between fat on one hand and skin and muscle, on the other hand, allows the signal to be confined within the fat layer [2].

The transmission of data out of many parts of the body is a challenging process [3], [4]. Utilizing fat tissue as a communication channel in order to establish communication between implanted devices separated by some distance is called fat intra-body communication, Fat-IBC. However, low-frequency propagation (kHz range) is not ideal for IBC as it results in lower bandwidth and data-rate. Microwave frequencies are highly attenuated by skin and muscle tissues due to the higher dielectric coefficient of skin and muscles[5]. It could be seen IBC works well for R-band (1.70 to 2.60 GHz) communication in previous work [6].

Essentially, fat functions as a good communication channel for frequencies around 2.0 GHz [7]. The loss is smaller than for other tissues, and the bandwidth is higher, which means that functionalities such as cardiac pacemakers, implantable cardioverter/defibrillators (ICD), and neuro- prosthetics can be supported. It is worth mentioning that Fat-IBC research is in its early

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stage, and some applications with the present-day tools available cannot be realized today due to a number of reasons, including lack of bandwidth inside the body. One of the possible scenarios of the communication between the sensor and the external world is shown in Figure 1 (b). A wireless power receiver, rechargeable battery unit, and wireless communication system was implanted inside the human body [8].

2.2 Advantages of Fat IBC

Microwave communication through fat tissue is a viable technique for a wireless implant to implant communication. Developing a reliable wireless fat channel based intra-body area network will help with gathering information from multiple implanted medical devices. It will enable future implant-based monitoring, controlled drug delivery, and sensor communication systems. The studies, including the effects of blood vessels[7], take body movements into account[9], representing a more realistic working environment model. Moreover, safety issues, including the use of bio-compatible materials for implant antenna development and computing the specific absorption rate (SAR) will be investigated. The results obtained from the previous study pave the way for developing a new wireless communication platform for implanted medical devices[6].

The skin and the muscle tissues were found to function as conducting layers, and a formation of these two different materials with high permittivity strongly affects the transmission signal through the fat tissue by confining the microwave signal in the fat tissue. The studies based on the transmission coefficient evaluations and the E-field distribution indicate that the presence of skin and muscle tissue enhances microwave propagation through the fat tissue. Overall, the presented results show the validity of our proposed technique for using the fat tissue as a new intra-body communication medium at R-band frequencies.

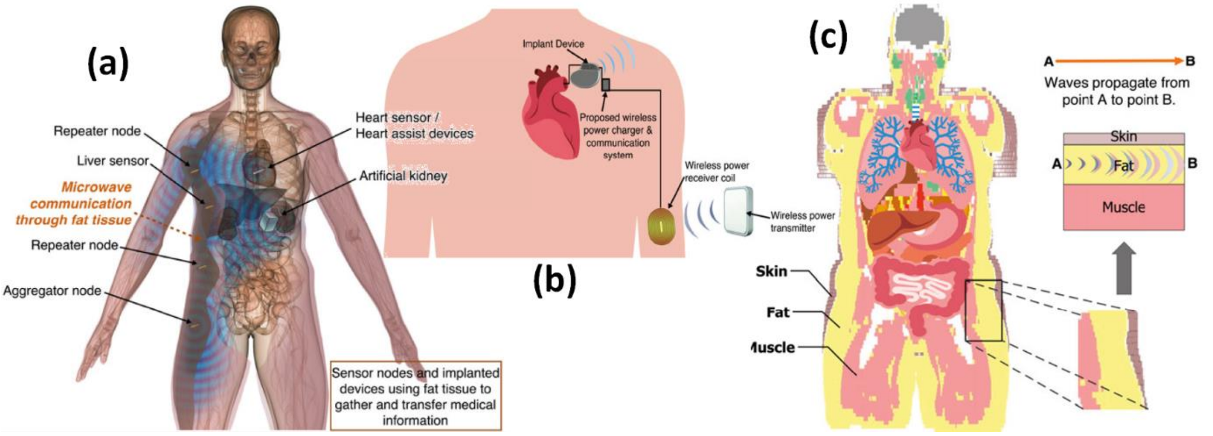

Figure 1. **(a) Conceptual rendering of fat intra-body microwave communication (Fat-IBC) network [3]; (b) Implantable medical device communicates with the external world [2], [8]; and (c) The model shows that the vital organs are surrounded by adipose tissue. The smaller picture of the 3 types of tissues outlines how the intra-body microwave is transmitted through the fat tissue [6].**

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2.3 Application of Fat IBC

Figure 1 (a) shows a human body with multiple implants such as an artificial kidney, heart sensor, and liver sensor. Wireless communication is an ideal method for communication between these sensors to take place. Besides this method, fat tissue could be used as a microwave communication between them. In the cases where a large distance separates the sensors, the signal strength may be attenuated as it propagates through the fat tissue [9]. In order to enhance the signal strength, a repeater node may be used as an amplifier stage. All the body vitals are collected by the aggregator node that transfers information to the outside of the human body [10].

3 Fat IBC antennas

This section will discuss the primary fat IBC system design for the B-CRATOS project. We designed and simulated primary antennas for the B-CRATOS project for fat IBC communications.

3.1 Introduction

The human body is a heterogeneous medium for communication. The organs of the human body have different properties like the liver, heart, skin, bone, muscle, and fat will have different permittivity, permeability, and conductivity. One of the popular ways to characterize the human body model is to consider the three-layer body model [11-12]. Intrabody Communication is a multidisciplinary topic that combines several aspects, such as antenna design, electromagnetic (E.M.) wave propagation in a lossy dielectric medium, communication between transmitting and receiving antenna, low power consumption, reduced SAR, etc. [2]. Antenna design plays a crucial role to obtain robust Communication links. Apart from the design challenge and reliable communication, it must ensure biocompatibility and human safety issues.

In this section, Intrabody communication has been studied using fat tissue. Different type of fat IBC antenna is presented, and the simulated result will be discussed. An approach for Intrabody communication is presented using transmitting (Tx) and receiving (Rx) antenna. Transmission characteristics of microwave signals through these layers are modelled.

3.2 Dual ring shape Fat IBC Antenna

Ring shape rigid antenna has been designed Fat IBC communication. This antenna has been designed on very low-cost FR4 material, which dielectric constant, loss tangent and height is 4.4, 0.02 and 1.6, respectively. The antenna has been encapsulated inside the PDMS. We have simulated the antenna placing on three layers of the human tissue model and optimized the antenna to operate at 2.45 GHz. Figure 2 shows the antenna geometry, fabricated structure,

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and simulated reflection coefficient plot. Fig. 2 shows the basic schematic diagram antenna prototype and the three-layer tissue model.

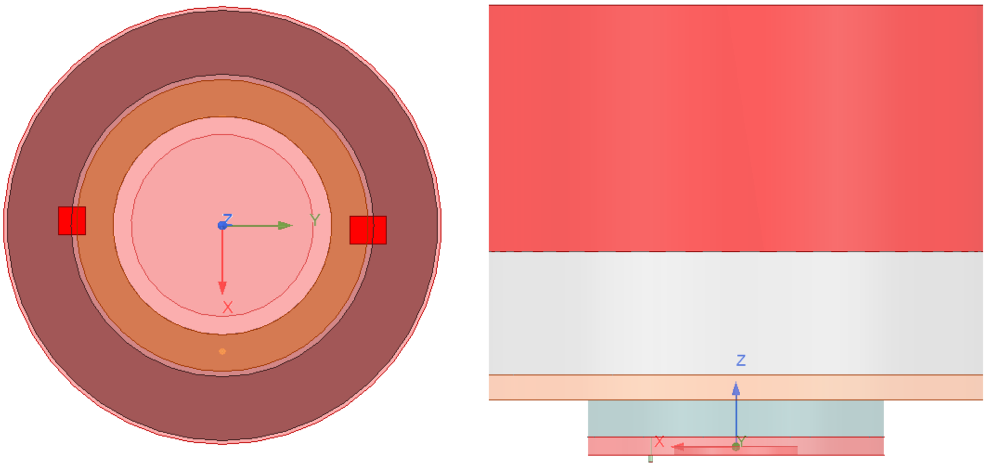

Figure 2. **Schematic diagram of Ring-Shaped Fat-IBC antenna with a three-layer model (Details dimension is not provided due to confidentiality)**

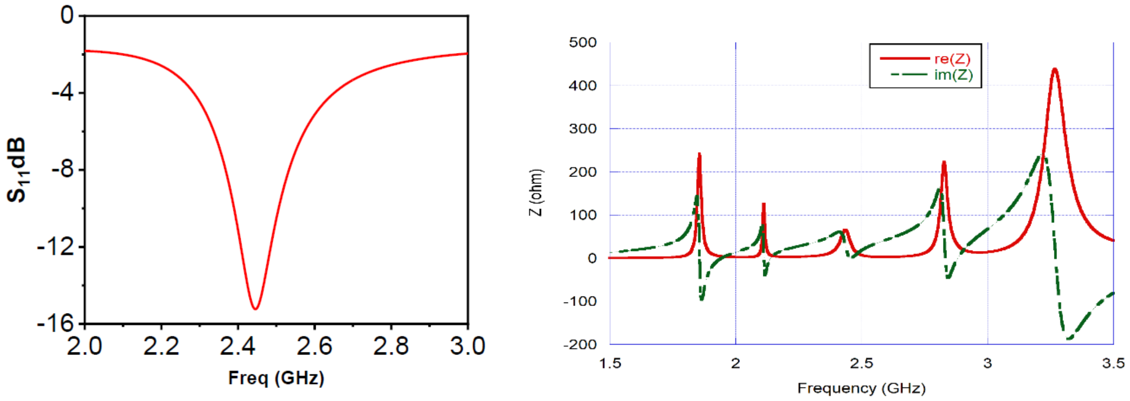

Figure 3. **Reflection coefficient and input impedance plot of Ring-Shaped Fat-IBC antenna with three-layer tissue model**

In the fig. 3 shows the antenna's simulated reflection coefficient and input impedance plot placed on the skin layer. The antenna has been optimized to work at 2.45GHz and the simulated input impedance at the desired frequency near about 50 ohm.

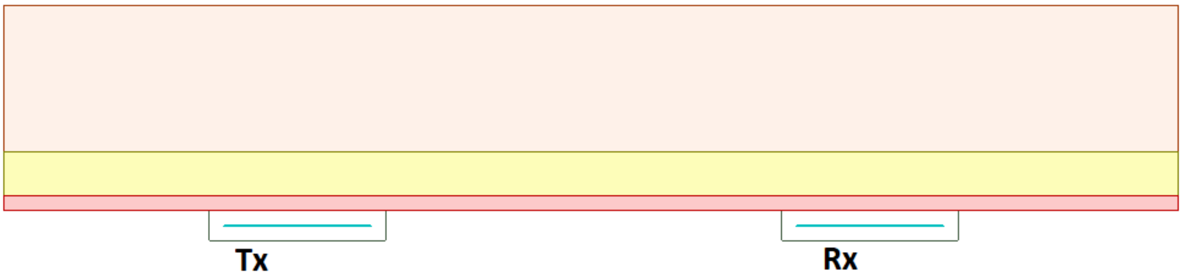

Figure 4. **Fat Channel characterization at different distance**

We have simulated and characterized the fat channel using a ring-shaped antenna placed on the skin tissue at different distances. In fig. 4 shows the Tx and Rx node in a certain distance.

3.3 Circular Loop Patch Antenna

In this design, the circular patch antenna is chosen for the transmitting and receiving element on the skin tissue. For this design, ceramic material Rogers RO3003™ (loss tangent/tanδ = 0.0013 and ε_r=3) is taken as the substrate with height 0. 76mm [14].

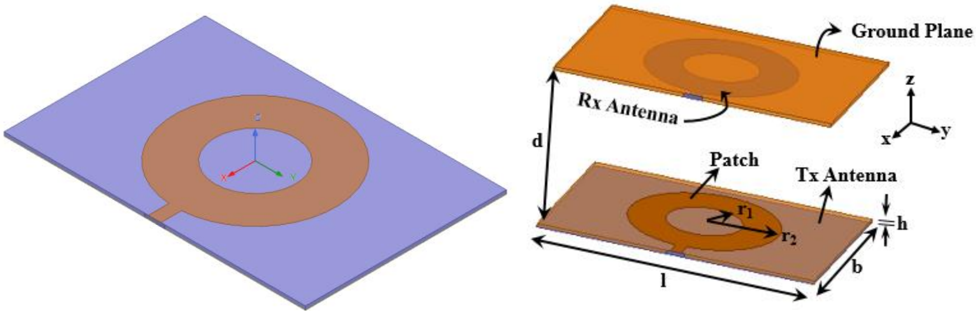

Figure 5. **Schematic view of the Antennas**

Fig. 5 shows the basic schematic diagram of the circular loop patch antenna. In the case of IBC, the antenna performance is highly influenced when it comes very close to the human tissue. Antenna basic parameters like resonance frequency shifting, reduced directivity, and deterioration in the radiation pattern. The 3-layer body model is taken in a symmetric manner. The electrical properties of these layers as chosen according to the IFAC database [13]. One antenna is placed below the skin, and the other is placed at the top of the skin layer shown in Fig. 6. The thickness of the skin, fat, and muscle layers are 't1', 't2' and 't3', respectively denote 2, 10 and 20 mm. A significant change in antenna performance is observed.

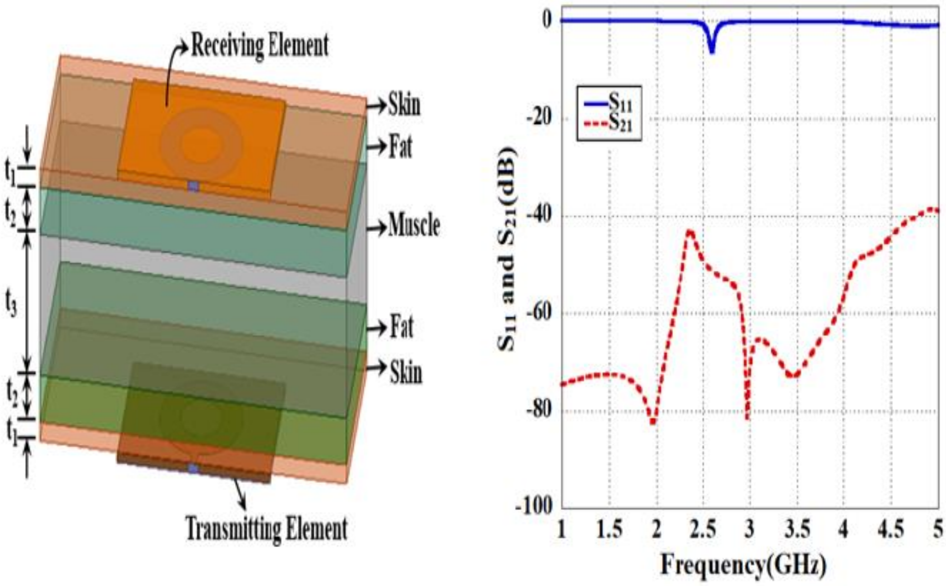

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Figure 6. **Antennas are placed over a 3-layer model & Simulated S_{11} and S_{21} when antennas are placed over the body model.**

The performance of the antenna is also studied over the human left Arm model, which is predefined in CST. The resonance frequency in this study (2.45 GHz) is well within the range of the ISM band, as shown in Fig. 6(a). The variation of transmission coefficient (S_{21}) with the relative position of both antennas is also performed. The reflection coefficient and transmission coefficient plot over the hand has been shown in Fig. 7.

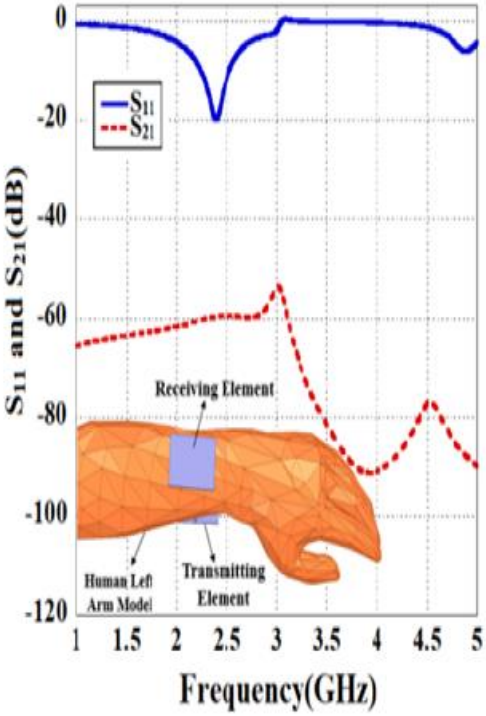

Figure 7. **Transmitting and Receiving antenna over human arm model,**

We will validate all simulation results with the measurement result. All experiments will be performed over a three-layer phantom model consisting of skin, fat, and muscle, which will reflect in task 3.2.

3.4 Pixel-optimized patch antenna

In this design, the topological layout of a simple patch antenna is optimized using a Genetic Algorithm (GA) interfaced with full-wave simulations performed in COMSOL Multiphysics [15] to improve the radiation coupling into the body and favor the signal transmission in the subcutaneous fat layer. A Genetic Algorithm (GA) is a search-based optimization technique based on the ideas of natural selection and biological evolution [16]. The algorithm starts from a randomly-generated population of candidate solutions (called *individuals*) having a set of properties (*chromosomes*), usually coded in a string of bits, which can be mutated and altered. The “quality” of each individual is estimated by means of a fitness function, which is usually

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the objective function in the optimization problem being solved. At each iteration, a selection is performed on the individuals in order to decide which are more likely to reproduce based on their fitness. Through successive generations, the population "evolves" towards an optimal solution until a termination condition, or a fixed number of generations, has been reached.

The application of the GA to the considered simple patch antenna is schematically described in Fig. 8. As a first step, the metal patch of the antenna is partitioned into a certain number N_g of square cells (*pixels*), forming the set of elements on which the genetic algorithm acts. Each pixel is then associated to a bit in the chromosome, with 1 and 0 indicating the presence and the absence of metal, respectively. In this way, each sequence of N_g bits represents a single individual, which corresponds to a particular configuration for the considered antenna [17,18]. The fitness function for each individual is then computed using a full-wave electromagnetic simulation software.

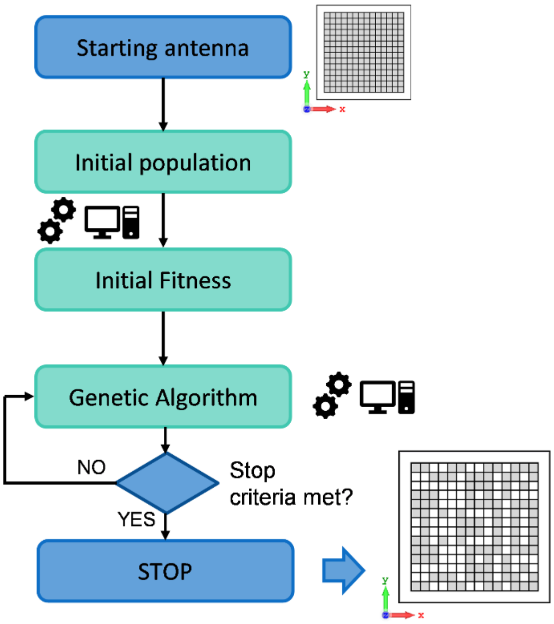

Figure 8. **Flowchart showing the optimization of the patch antenna using a Genetic Algorithm.**

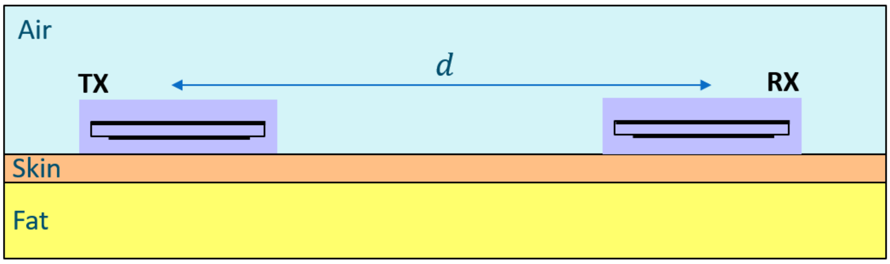

Figure 9. **View of one of the considered antenna layouts for a TX-RX link.**

To maximize the radiation coupling inside the fat layer at a central frequency $f = 2.44$ GHz and the signal reception through a link distance d (see Fig. 9), different layouts for the patch antenna have been considered (varying the antenna geometry and the dielectric properties of the materials forming the substrate and the coupling medium) and several optimization have been performed using different fitness functions (i.e., proper combinations of S-parameters and electric field values). These preliminary optimizations have led to a quite good radiation coupling into the body, and transmission losses lower than 5 dB/cm.

Performance optimization using a longer link distance (d up to 30 cm for the NHP arm), a muscle layer under the fat channel, and fitness functions considering more frequency points (to achieve a sufficiently large bandwidth) is in progress.

4 Fat IBC Transceiver

In this section, we will discuss about the transceiver system for B-CRATOS. This is the preliminary proposal for the Fat IBC transceiver system.

Figure 10. **B205-Mini SDR board, equipped with a AD9364 RF Transceiver**

The main objective of the transceiver is to establish a bidirectional communication channel between the neural readout board and the AI board, providing a reliable and fast communication channel within the fat layer. We have initiated an preliminary evaluation system using the Software-Defined Radio (SDR) board B205-mini by Ettus Research, shown in Figure 10, a platform that’s suitable for the implementation of custom algorithms for the TX and RX path given the presence of a powerful Field-Programmable Gate Array (FPGA) core (Xilinx Spartan-6) and a AD9364 Radio Frequency (RF) transceiver by Analog Devices.

Two different data channels will be established: a high-speed one for relaying the large data-rate (Approx. 32 Mbps) collected by the neural implant to the AI processing board, and a low-speed (Approx. 2Mbps) control channel to control the brain stimulation.

Following the development of the antennas, the system operates in the ISM band and, more specifically, with a central frequency of 2.45GHz and two separate channels for the uplink and downlink data streams. Given the limitations imposed to the transmitted power level and the

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heavy losses estimated for the propagation in the Fat IBC channel we carefully evaluated the link budget, ensuring that it is indeed possible to establish a reliable link over distances spanning few tens of centimetres.

We are currently experimenting with the implementation of different modulation and synchronization schemes for the transmitting and receiving ends to maximize the throughput and minimize the latency, while still ensuring a reliable and error-free communication between the two attached boards.

The transceiver implementation will be tested for its performance both when directly connected with a cable and when using the optimized Fat-IBC antennas presented in the previous sections.

5 Revision history

REVISIONS			
Version #	**Date**	**Type of Change**	**Lead Author**
1.1	21-12-2021	First draft Started	Bappaditya Mandal
1.2	06-01-2022	Including Circuit part in the draft	Pramod K.B
1.3	06-01-2022	Final draft and sent to Group leader for comments	Bappaditya Mandal
1.4	13-01-2022	Contributions from Fondazione LINKS	Rossella Gaffoglio
1.5	17-01-2022	Review by WPL	Robin Augustine

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