Nearfield Capacitive Communication Transceiver

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***Abstract*— Capacitive Near-Field Communication - CapNFC – acts as an ultra-low-power, touch or proximity-mediated alternative to existing wireless communication techniques. Existing smart objects can be easily adapted to use CapNFC as only a single microcontroller output pin is required for unidirectional communication. It employs capacitive coupling between nearby conductive electrodes to transmit information over distances of up to 15 cm through air. It utilizes frequencies of 1 kHz to 1 MHz, with wavelengths that are a multitude larger than the transmitting and receiving electrodes. In terms of form factors, CapNFC is extremely flexible, supporting the integration into beds as well as small objects, such as body-worn sensors. Therefore, CapNFC acts in the quasi-electrostatic regime, eliminating the necessity for high-frequency design and complex hardware components. This results in a very small displacement current flowing from a transmitter to a receiver electrode, enabling ultra-low power operation.**

Keywords*— *CapNFC, capacitive sensing; capacitive near-field communication; capacitive communication

I. Introduction

Recent advances in interaction technology have introduced a paradigm shift from traditional interaction methods, like graphical user interfaces, to ubiquitous interaction with a multitude of cooperating objects. Here, manipulations of objects or their perception of the environment influence the system's state - which allows for both implicit and explicit interaction. A key requirement for ubiquitous interaction is the communication between objects among each other and the external computing infrastructure.

When choosing a communication method, developers have to accept certain trade-offs which include cost, form factors, and power consumption. This challenge becomes even more relevant when considering a high number of interactive objects, which are supposed to be small, have heterogeneous form factors, run on a very limited power supply, and are required to be low-cost. Technologies like RFID or NFC represent a very suitable alternative to medium-range communication, especially when the information is exchanged in a short-range spatial context. Moving from the inductive to the capacitive domain, a human's conductive properties allow for indirectly incorporating the perception of body parts, touches and proximity into the communication technique. Especially in ubiquitous computing, this property leverages its full potential as a means for short-range communications using the air or the human body as a communication channel.

In this paper we present and discuss Capacitive Near-Field Communication - CapNFC - as an ultra-low-power, touch or proximity-mediated alternative to existing wireless communication techniques. Existing smart objects can be easily adapted to use CapNFC as only a single microcontroller output pin is required for unidirectional communication. In terms of form factors, CapNFC is extremely flexible, supporting the integration into beds as well as small objects, such as body-worn sensors. CapNFC employs capacitive coupling between nearby conductive electrodes to transmit information over distances of up to 15 cm through air. Furthermore, the technology allows for communicating messages through the human body or measuring the proximity to human body parts. It utilizes frequencies of 1 kHz to 1 MHz, with wavelengths that are a multitude larger than the transmitting and receiving electrodes. Therefore, CapNFC acts in the quasi-electrostatic regime, eliminating the necessity for high-frequency design and complex hardware components. This results in a very small displacement current flowing from a transmitter to a receiver electrode, enabling ultra-low power operation.

Capacitive coupling as a communication method has found interest in intrabody communications, information exchange using touchscreens or access schemes in proximity sensing. Instead of focussing on a specific approach, we propose a generalized methodology for Capacitive Near-Field Communication in UbiComp. Therefore, we offer the following contributions in our paper: 1. We introduce and evaluate a novel generic framework for Capacitive Near-Field Communications in ubiquitous environments. We identify a set of operating modes and the corresponding interaction techniques. 2. We describe, compare and evaluate the concepts of CapNFC in sufficient detail to allow others to re-implement it. Open-source schematics and source code enables the community to quickly implement CapNFC applications.

II. Generic Framework for Capacitive Near-Field Communication

CapNFC relies on capacitive coupling between a transmitter and a receiver electrode. Applying an alternating volt age to one electrode and connecting the second electrode to ground causes a changing electric field between both electrodes. With CapNFC, the induced displacement current is measured on the receiver side. The energy-saving potential in ubiquitous communications can be regarded by physical considerations. CapNFC acts in the quasi-electrostatic regime and thus without any wave-propagation at its electrodes. This property solely enables a very small displacement current to flow from the transmitting electrode to the environment. In order to communicate by means of capacitive coupling, voltages oscillating at low frequencies (≤ 1 MHz) are applied to the transmitter electrode.

The receiver amplifies the induced displacement current and decodes the message. Various encoding schemes may be used on top of this physical communication channel. Communication range and robustness depend strongly on the size of the transmitter electrodes and their voltages levels. Higher voltages increase the displacement current and lead to a better performance. Bigger electrodes allow for better capacitive coupling but also pick up more background noise. In our examples, electrode sizes vary from 1 cm2 to 100 cm2. In this work, we apply the concept of CapNFC to ubiquitous interaction with everyday objects.

Each object which is touched or manipulated by a user establishes an information flow and communicates its state to all objects within range. Devices with extended interaction capabilities, such as smartphones and computers, can interpret the information and generate a response to object manipulations in their environment. In the following, we discuss general operating modes, describe our reference implementation comprising hardware and communication protocol, present considerations for electrode placement, and document performance and energy consumption of our prototypes

III. OPERATING MODES

All communication techniques based on capacitive coupling do not only require a transmitter and receiver electrode, but also a connection to a common ground. Only when two objects share a common ground, a displacement current is able to flow from one electrode to the other. A common ground may be established by sharing a ground between both circuits or by connecting each circuit to the environment's ground. However, as only very small displacement currents flow back and forth, CapNFC also works if a transmitter and a receiver are grounded via weak capacitive coupling to the environment's ground. This connection can be generated by a user touching the object, or a table on which the object is placed

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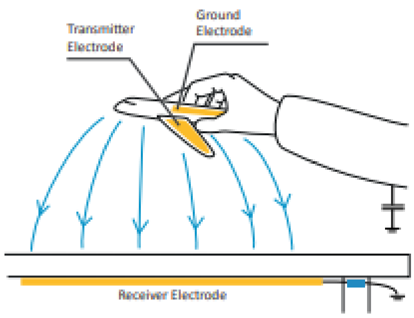
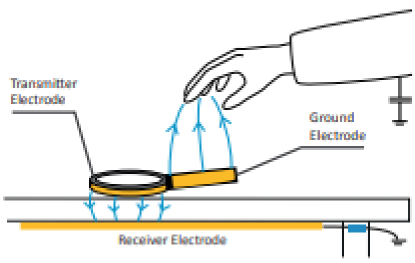
1. Ground-Coupling by Touch



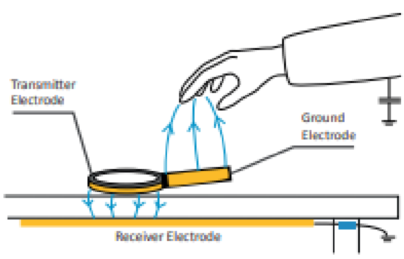
In this mode, the receiver object is connected to the environment's ground, and the transmitter is a battery-powered object. Whenever the user is in very close proximity to this electrode or touches it, the weak capacitive coupling to the grounded human body enables an information flow from the transmitter to the receiver.

2. Ground-Coupling by Proximity

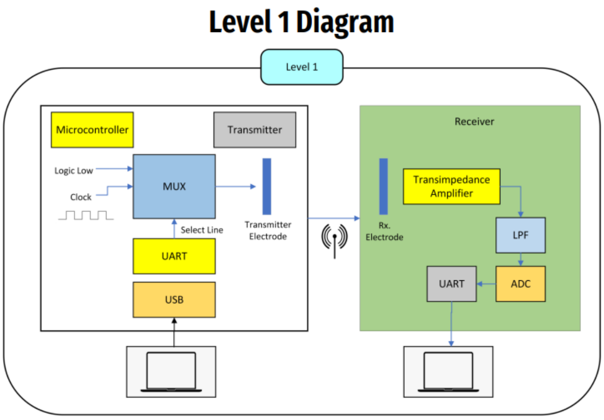


In this operating mode, a receiver is connected to the environment's ground, and a battery-powered smart object is located in close proximity to the receiver. In addition to the transmitter electrode, the battery-powered object has a builtin ground electrode.

3. Intrabody-Communication with a Common Ground

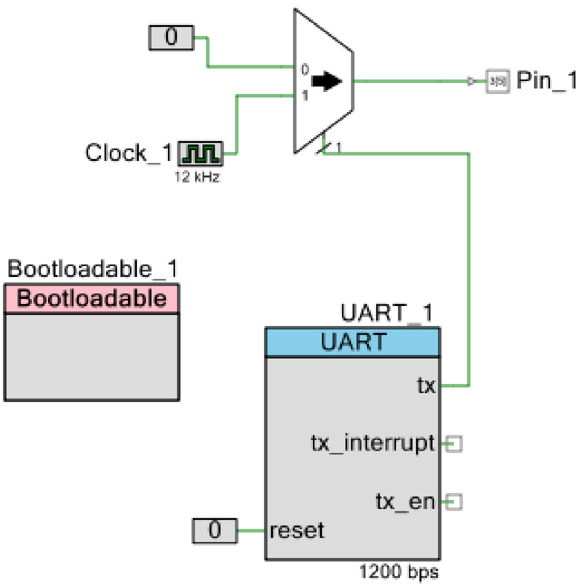


When both objects are directly connected via a common ground, an information flow can be established through the user's body. This enables the user to touch two objects and thus establish communication between both of them.



This is the Level 1 diagram for the NFC project which illustrates the different components required to implement the same. For transmitting data, we are using one of the simplest form of ASK that is ON-OFF Keying (OOK). In OOK, while transmitting '1 (Logic High)' we send a series of pulses (high frequency) and while transmitting '0' (Logic Low) we send a binary zero. The input signal is generated through UART whose baud rate is set at 1200bps. This means that 1 bit requires (1/1200) seconds. Now let's say we need a signal containing 100 pulses (higher frequency clock signal) while transmitting '1'. Hence, the pulse signal can be generated with a time period of (1/1200*100) seconds

IV. TRANSMITTER

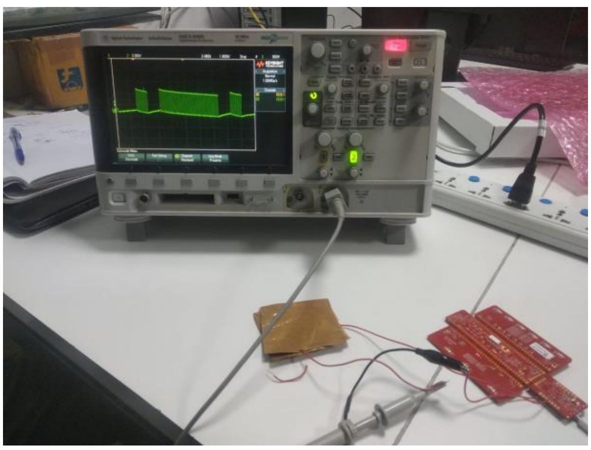


The objective is to transmit 8-bit data via UART and receive it using Capacitive Near Field Communication (Cap NFC). The data is transmitted from one electrode and received through another electrode placed in close proximity. UART encodes data by using a low start bit followed by 8-bit data reversed (LSB first and MSB last) and then a high stop bit.

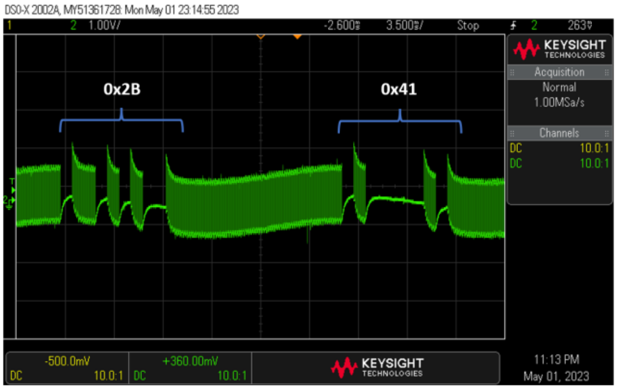
The transmitter shown above is constructed using mainly three components that is Multiplexer, UART and a Bootloadable component. Now, for transmitting an input signal we are using ON-OFF keying technique. In this technique, logic HIGH is indicated by a series of pulses and logic LOW is considered as 0. The 2:1 multiplexer's inputs are one clock and logic zero. When we send logic 1, we receive N number of pulses, and for logic 0, we get zero. Here, N is the ratio of 1-bit time Period of UART and applied clock frequency. We are using an inverter at the output of UART so that the Start and Stop bits could be identified easily. The transmitted wave is observed on CRO (Cathode-ray oscilloscope) as we are transmitting the signal through the medium of air. The transmitting takes place through a copper plate which behaves as a transmitter.

V. RECEIVER

The transmitted signal is received through a copper plate which is connected to the same microcontroller. The receiver has the capacity to receive the input signal at a maximum distance of up to 5cm. The received waveform is viewed on the CRO and later decoded using MATLAB. The waveform to receive the OOK encoded signal, we use a copper electrode on the receiver section which is in close proximity to the transmitter electrode. We can see the data on CRO, and we can extract a CSV file from it. In our case, clock of 12kHz and UART configured at 1200 bps, and one-bit period includes 10 clock pulses. When we extract the data from the CRO, we get approximately 50 sampled signals for one bit of input data. The received data may be slightly distorted, so we can apply a threshold voltage for making it logic 1 or 0. In our case, we use a threshold voltage of 0.25 volts. Finally, we decode the received OOK signal to a simple binary format similar to input data using MATLAB.



The above signal shoes the waveform of data 0x41. The two copper plates connected to each other and the signal is successfully received in the CRO.



We are sending two input data bytes valued 0x2B and 0x41. As it is evident from the above figure that the LSB is received first followed by MSB.

This is the final decoded input signal which is obtained from MATLAB. The received signal is received in the usual form of a low start bit followed by 8 bits of data (LSB-MSB) and a high stop bit. We are sending two bytes of data that is 0x2B and 0x41 having 20 milliseconds of delay between them.

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