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**Wireless Personal Area Networks**

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| Abstract | This document presents Samsung Electronics and ETRI’s EFC proposal for consideration as HBC PHY. | |
| Purpose | Discussion | |
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# Introduction

This draft is being submitted to IEEE 802.15 Task Group 6 as a candidate PHY proposal, in response to the Call for Proposal (15-08-0811-02-0006-tg6-call-proposals) issued on 23rd January, 2009. This document will address the modulation schemes, preambles required for the 802.15.6 physical layer. It covers the entire Physical Layer (PHY) protocol for Body Area Networks that is, fully compliant with the approved Project Authorization Request (PAR) and technical requirements document (TRD) that have been developed by the 802.15 TG6.

# PHY Requirements

The requirements that are set forward by the IEEE 802.15.6 (BAN) are

* Scalability of data rates from 10 kbps to 10 Mbps
* Shall support a range of 3 meters at lowest mandatory rate
* 10 piconet co-existence at the lowest mandatory data rate
* Low Power & complexity
* Regulatory Compliance

The comparison criterion relevant to PHY layer is

* Power consumption estimates
* Range for all the data rates
* Co-existence with other networks like ECMA 368

The performance of the proposal with respect to the requirements and comparison criteria is summarized at the end

# Scope of the Proposal

This document proposes Electric-Field Communication (EFC) as the HBC PHY. The proposed EFC has capability to support various BAN applications, such as data exchange for control, personal health care, entertainment, etc. It can handle many types of data (periodical data, random bursts, etc.) in everyday operation environment, e.g., home, office, outdoors, etc.

The proposal is for On-body to On-body (CM3) application where devices are on the body surface or near a person as long as the person can reach and make contact. It supports data rate up to 10 Mbps, and has a very low power consumption requirement.

## Features of HBC

The human body communication (HBC) is a method for data communication using user’s body as a medium, so it does not require any wire or wireless medium. Two devices are connected and data is transmitted between them via user’s body, simply by touch; Touch and Play (TAP) as shown in Figure 1.



Figure 1 – HBC Applications

HBC is very suitable for providing a context awareness service based on TAP. After devices are connected by touch, identification signals are transmitted through user’s body, so the type of devices is recognized by each other. A service to be provided for the pair of devices is determined according to the predefined context table, and then the determined service is provided while data is transmitted through user’s body. Various services which can be provided for various pairs of devices respectively are defined in the context table, so corresponding service between recognized devices can be executed automatically without user’s intervention. For example, when a user touches an advertisement device with one hand while holding a PDA in another hand, the touch is detected by the advertisement device and the device sends information about the advertisement, so the information can be downloaded into the PDA via user’s body. In the context table, each service has execution level respectively which can be set by user previously and the execution of each service is determined according to its execution level, so unwanted service by unintended touch can be prevented. Data communication between multiple devices, such as body sensor network, is possible also using HBC technology while those devices are being in contact with body. One of the devices, master device, controls data transmission between other devices, slave devices, so the user’s body can be shared by multiple devices for data communication.

Human Body Communication has the following features:

* Allows quick and easy connection
* Intuitive Service, Quick Setup, Easy Use
* Afford Privacy & Security

.

HBC provides these features by utilizing Frequency Selective Digital Transmission (FSDT), a type of Direct Digital Signaling. It does not require analog modulation, so the transmitted data can be restored in the receiver using simple signal processing: amplifying, filtering and comparing with a reference signal. Hence, the communication devices with FSDT are easy to implement, has low power consumption, and can be made in small sizes.

## Properties of EFC

In Electric-Field Communication (EFC), data is transmitted by inducing electric-field and capacitive coupling on dielectric material. The fact that, human body has about 300~500 times better permittivity than air and that EFC facilitates FSDT that enables HBC makes EFC a great candidate for HBC PHY. Also, EFC does not need any antenna, just simple electrodes, and has extremely low power consumption. Figure 2 show the basic concept of EFC.

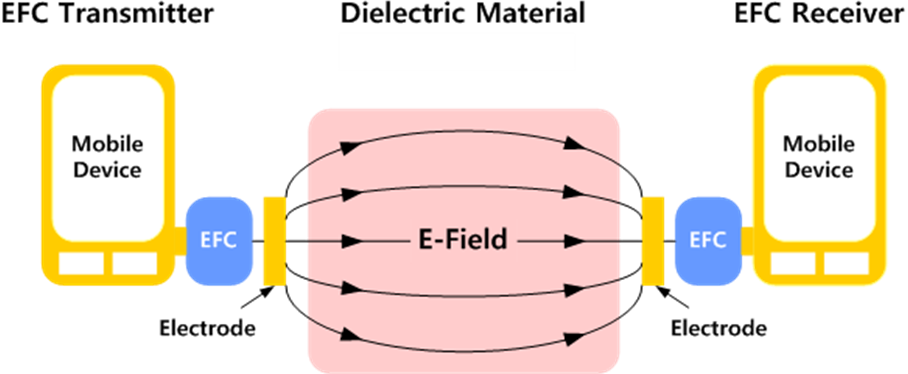


Figure – EFC Concept

# Proposed Specification

This section presents the proposed specification.

## EFC Packet Structure

The EFC packet is composed of Preamble, SFD(Start Frame Delimiter), Header,and PHY Payload(PSDU). And PHY Payload is composed of MAC Header, MAC Payload, and FCS(Frame Check Sequence).

The packet structure and PHY Header fields are shown in Figure 3 and Figure 4, respectively. The description of each header field is given in Table 7 of Section 4.2.3.



Figure – EFC Packet Structure



Figure – PHY Header Fields

## EFC Transmitter

EFC transmitter uses FSDT (Frequency Selective Digital Transmission) scheme; data is spread in frequency domain using frequency selective spread codes and transmitted in digital form. The dominant frequency where most of transmitting signal is distributed can be selected by using specific frequency selective spread code. The EFC transmitter is composed of following blocks as shown in Figure 5:

* Preamble Generator
* SFD/RI Generator
* Header Generator
* Serial-to-Parallel (S2P)
* FS-Spreader [FS = Frequency Selective]
* Pilot Generator
* MUX

The generated Preamble, SFD/RI, Header, PSDU, and Pilot signals are sent to an electrode via a MUX. Since preamble and SFD are fixed data patterns, they are pre-generated and sent ahead of the packet header and payload. These different signals are transmitted in sequence via a MUX and the electrode. The frequency band for EFC is from 10 MHz to 50 MHz.



Figure – EFC Transmitter Block Diagram

### Preamble Generation

A preamble sequence is transmitted four times (PR1 to PR4) to ensure packet synchronization by the receiver. Each preamble sequence is created by spreading a 128-bit gold code sequence via Frequency Shift Code (FSC). FSC uses a repeated [0, 1] code, and the spreading factor (SF) is decided by the number of time FSC is repeated. If the FSC used is [0, 1], the SF is 2, and if the FSC used is [0, 1, 0, 1], the SF is 4. For EFC packet preamble, a SF of 4 is used. In other words, [0, 1, 0, 1] is used for FSC operation. The operating clock frequency is *fCK*. Figure 6 show the preamble generation block diagram, and Figure 7 shows the preamble field.



Figure – Preamble Generation Block Diagram



Figure – Preamble Field

Table 1 shows the Gold Code Generation Polynomials for Preamble, and Table 2 shows the FSC bit mapping used for preamble sequence generation.

Table – Gold Code Generation Polynomials for Preamble

|  |  |  |
| --- | --- | --- |
|  | **Polynomial1** | **Polynomial2** |
| **Polynomial** | **x10 + x3 + 1** | **x10 + x8 + x3 + x2 +1** |
| **Initial value** | **[1:10] (0010010001)** | **[1:10] (0011111010)** |

Table – FSC Bit Mapping for Preamble (@16MHz)

|  |  |  |
| --- | --- | --- |
| **16MHz channel** | **0** | **[1, 0, 1, 0]** |
| **1** | **[0, 1, 0, 1]** |

### SFD and RI Signal Generation

#### Start Frame Delimiter (SFD)

During packet reception, the receiver finds the start of the packet by detecting preamble sequence, and then it finds the starting point of the frame by detecting Start Frame Delimiter (SFD). Unlike preamble sequence, SFD sequence is sent only once. The SFD sequence is generated by applying FSC with SF of 4 to a 128-bit gold code sequence. shows the SFD signal generation block.

By using “time offset,” the SFD field can also indicate the transmitted packets data rate. With this “Rate Indicator” (RI), the receiver does not need to refer to the PHY header to detect the incoming packet’s data rate. This allows the header along with the payload be transmitted at the same high data rate increasing transmission efficiency. More about Rate Indicator is given in Section .



Figure – SFD/RI Signal Generation Block Diagram

Table 3 shows the Gold Code Generation Polynomials for SFD, and shows the FSC bit mapping used for SFD sequence generation.

Table – Gold Code Generation Polynomials for SFD

|  |  |  |
| --- | --- | --- |
|  | **Polynomial1** | **Polynomial2** |
| **Polynomial** | **x10 + x3 + 1** | **x10 + x8 + x3 + x2 +1** |
| **Initial Values** | **[1:10] (0101100000)** | **[1:10] (0000100010)** |

Table – FSC Bit Mapping for SFD (@16MHz)

|  |  |  |
| --- | --- | --- |
| **16MHz channel** | **0** | **[1, 0, 1, 0]** |
| **1** | **[0, 1, 0, 1]** |

#### Rate Indicator using SFD

As mentioned in the previous section, the SFD sequence is used to indicate the data rate of the whole incoming packet, header and payload. This concept is called “Rate Indicator” (RI). The traditional method of indicating data rate in the PHY header may also be used.

As shown in , the transmitter can introduce varying time offset when sending the SFD sequence to indicate a fixed set of information. By detecting this time offset, the receiver can figure out what particular information is being sent. For RI, the information delivered is the whole packet’s data rate.

For RI, a total of 24 garbage bits (all 1’s) are introduced to allow time offset in addition to 128 bit Gold code for SFD. This sums to a total of 152 bits. FSC with SF of 4 is applied to give the final SFD field length of 608 bits.

SFD Length = (128-bit gold code + 24 bits for time offset) × 4 = 608 bits (1)



Figure – Rate Indicator using SFD

RI can indicate 7 different data rates as shown in . Using RI allows both PHY header and PDSU transmitted at the same data rate which provides throughput efficiency, especially for high data rates.

Table – SFD Time Offset and Data Rate Mapping for RI

|  |  |
| --- | --- |
| **RI** | **Data Rate** |
| Toffset1 | 125kbps |
| Toffset2 | 250kbps |
| Toffset3 | 500kbps |
| Toffset4 | 1Mbps |
| Toffset5 | 2Mbps |
| Toffset6 | Reserved |
| Toffset7 | Reserved |

Besides RI, traditional method using Data Rate Field (DRF) in PHY header may be used optionally (). Two devices select one of the two methods during initial connection setup handshaking. During this initial handshaking, DRF is used to indicate the data rate, and master device selects the desired method, and the PHY header is transmitted at 125 kbps.

Table – Data Rate Field Value and Data Rate Mapping

|  |  |
| --- | --- |
| **DRF** | **Data Rate** |
| 000 | 125kbps |
| 001 | 250kbps |
| 010 | 500kbps |
| 011 | 1Mbps |
| 100 | 2Mbps |
| 101 | Reserved |
| 110 | Reserved |
| 111 | Reserved |

### Header Generation

When DRF mode (instead of RI) is used, the Header signal is generated as shown in Figure 10. If RI method is used, the header signal is generated by the block shown in Figure 11. Table 7 shows the description of each PHY header field.



Figure – Header Generation Block Diagram

Table – PHY Header Field Description

|  |  |  |  |
| --- | --- | --- | --- |
| Field | Length (bit) | Values | Description |
| Data Rate | 3 | 000: 125 Kbps  001: 250 Kbps  010: 500 Kbps  011: 1 Mbps  100: 2 Mbps  101: reserved  110: reserved  111: reserved | PSDU data rate  (Section ) |
| Pilot Info | 3 | 000 : 0.125 ms (16 bytes)  001 : 0.25 ms (32 bytes)  010 : 0.5 ms (64 bytes)  011 : 1 ms (128 bytes)  100 : 2 ms (256 bytes)  101 : 4 ms (512 bytes)  110 : no insertion | Pilot Insertion Interval (Section ) |
| Sync | 1 | 0 : no sync  1 : re-sync | Re-sync with current superframe boundary timing information |
| D | 1 | 0 : normal mode  1 : dedicated mode | Dedicated mode  (See below) |
| BAN ID | 3 | 000 ~ 111 | Current BAN ID |
| PSDU Length | 11 | - | PSDU Length in Bytes |
| CRC8 | 8 | - | CRC value of PHY Header |

**D Field:**

Dedicated mode allows 1:1 full bandwidth transmission between the master device and a particular slave device. D field indicates whether the current frame is transmitted in dedicated mode or not. Other slave devices, if any, stop any communication when this field is set to 1. Any new device attempting to join the BAN should wait until dedicated mode ends.

### S2P and FS-Spreader

S2P and FS-Spreader generates PHY Header (for RI method) and PSDU. FS-Spreader is composed of Orthogonal coding and FSC as shown in Figure 11.



Figure – S2P and FS-Spreader Block Diagram

The data to be transmitted is created by mapping 4 bits from FIFO (a symbol) to a 16-bit chip. Table 8 shows the symbol-to-chip mapping used. The 16-bit chip is then spread by applying FSC. The spreading factor of FSC used determines the final data rate. Table 9 shows the number of chips per bit for each possible spreading factor.

Table – Symbol-to-Chip Mapping

|  |  |  |
| --- | --- | --- |
| Symbol | Data Bits | Chip |
| 1 | 0000 | 1111 1111 1111 1111 |
| 2 | 0001 | 1010 1010 1010 1010 |
| 3 | 0010 | 1100 1100 1100 1100 |
| 4 | 0011 | 1001 1001 1001 1001 |
| 5 | 0100 | 1111 0000 1111 0000 |
| 6 | 0101 | 1010 0101 1010 0101 |
| 7 | 0110 | 1100 0011 1100 0011 |
| 8 | 0111 | 1001 0110 1001 0110 |
| 9 | 1000 | 1111 1111 0000 0000 |
| 10 | 1001 | 1010 1010 0101 0101 |
| 11 | 1010 | 1100 1100 0011 0011 |
| 12 | 1011 | 1001 1001 0110 0110 |
| 13 | 1100 | 1111 0000 0000 1111 |
| 14 | 1101 | 1010 0101 0101 1010 |
| 15 | 1110 | 1100 0011 0011 1100 |
| 16 | 1111 | 1001 0110 0110 1001 |

Table – S2P and FS-Spreader Spreading Results

|  |  |  |  |
| --- | --- | --- | --- |
|  | Chip Length | Spreading Factor | Spreading Sequence/Bit |
| 2Mbps | 16 | 4 | 16×4/4 🡒 16 chip/bit |
| 1Mbps | 16 | 8 | 16×8/4 🡒 32 chip/bit |
| 500kbps | 16 | 16 | 16×16/4 🡒 64 chip/bit |
| 250kbps | 16 | 32 | 16×32/4 🡒 128 chip/bit |
| 125kbps | 16 | 64 | 16×64/4 🡒 256 chip/bit |

### Pilot Generation

To prevent loosing synchronization due to clock drift, “Pilot” sequence can be inserted in PSDU as shown in Figure 12. The same sequence used for SFD is used for pilot, and the pilot insertion interval is indicated in the “Pilot Info” field in PHY header. There are six pilot insertion interval is used (Table 10).



Figure – Pilot Insertion in PSDU

Table – Pilot Insertion Periods

|  |  |
| --- | --- |
| **Pilot Info Field** | **Insertion Period** |
| 000 | 16 byte |
| 001 | 32byte |
| 010 | 64 byte |
| 011 | 128 byte |
| 100 | 256 byte |
| 101 | 512 byte |
| 110 | No pilot insertion |

# PER Performance and Link Budget

This section presents the simulated PER performance in AWGN channel and Link Budget.

## Simulated PER Performance

Figure 13 shows the simulated PER performance in AWGN channel for 1 Mbps and 2 Mbps with 1 Koctet payload size. Simulation was done in MATLAB using two samples per chip. Symbol synchronization & frame synchronization operations were considered.



Figure – Simulated PER Performance

## Link Budget

Table 11 and Table 12 show Link Budget for 1 & 2 Mbps cases. Voltage-mode transmission is assumed, and CM3 Path Loss figure is obtained from Sec. 8.2.2 of “Channel Model for Body Area Network (BAN)” [IEEE 802.15-08-0780-09-0006]

Table – Link Budget (1 Mbps)

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Symbol | Value | Unit |
| Data Rate | R | 1 | Mb/s |
| Average Tx Power | PTX | -12 | dBm |
| Path Loss (CM3) | PL | 54 | dB |
| Average Rx Power (PRX=PTX-PL) | PRX | -66 | dBm |
| Rx Noise Figure | NF | 10 | dB |
| Average Noise Power per bit (PN= -174+10log10(R)+NF) | PN | -104 | dBm |
| Minimum required Eb/No for BER=10-6 | Eb/No|req | 4 | dB |
| Implementation Loss | IL | 6 | dB |
| Link Margin (LM=PRX-PN-Eb/No|req-IL) | LM | 28 | dB |
| Minimum Rx Sensitivity Level (SRX=PRX-LM) | SRX | -94 | dBm |

Table – Link Budget (2 Mbps)

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Symbol | Value | Unit |
| Data Rate | R | 2 | Mb/s |
| Average Tx Power | PTX | -12 | dBm |
| Path Loss (CM3) | PL | 54 | dB |
| Average Rx Power (PRX=PTX-PL) | PRX | -66 | dBm |
| Rx Noise Figure | NF | 10 | dB |
| Average Noise Power per bit (PN= -174+10log10(R)+NF) | PN | -101 | dBm |
| Minimum required Eb/No for BER=10-6 | Eb/No|req | 7 | dB |
| Implementation Loss | IL | 6 | dB |
| Link Margin (LM=PRX-PN-Eb/No|req-IL) | LM | 22 | dB |
| Minimum Rx Sensitivity Level (SRX=PRX-LM) | SRX | -88 | dBm |

# Summary

As the PHY for HBC, this document proposed EFC, a simple and low power communication technology. EFC transmitter can be implemented with only digital circuits and share one electrode with the receiver. Also, EFC receiver does not need blocks related to RF carrier signals such as mixer or VCO.