A 110W 10Mb/s eTextiles transceiver for body area networks with remote battery power

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medium with supply-rail-coupled (SRC) differential transmitters (Fig. 27.6.3).
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communication. To save the energy otherwise required to fully charge and dis-
charge DC voltages on $v_+$ and $v_-$ to be at opposite rails at the beginning of packet com-
munication. To save the energy otherwise required to completely charge and dis-
charge the primarily capacitive medium, the DC voltages are held constant by high
impedance resistors, and transmitted signals are AC coupled onto the medium with supply-rail-coupled (SRC) differential transmitters (Fig. 27.6.3). This approach is advantageous, as capacitive-driving reduces output voltage swing and driver load [6,7], irrespective of the network DC potential. Additionally, by using dual capacitors $C_1$ and $C_2$ that are nominally discharged and charged, respectively, a ternary signaling scheme can be used, simplifying RX synchronization algorithms. To illustrate, asserting $pa(0)$ in $TX^+$ charges $C_1$, producing a negative voltage swing on the output that is proportional to the capacitive divider ratio of $C_1$ and $C_2$. Asserting $pa(2)$ would instead discharge $C_2$, generating a positive voltage swing. The opposite effects are arranged for $TX^-$, making the signaling scheme differential, yet operating at different DC levels. Both $TX^+$ and $TX^-$ consist of 7 pairs of binary-weighted tri-state inverters and capacitive DACs to provide voltage swing configurability.

The RX FE samples and digitizes the SRC differential voltage across $v_+$ and $v_-$ using 4 time-offset acquisition (AQ) blocks (Fig. 27.6.4). An SRC common-mode independent sampling structure is implemented, exploiting the fact that $v_+$ and $v_-$ have DC potentials centered at opposite rails. Before packet reception, the sampling capacitors are purged. During the preset phase, the capacitors are charged to the supply rails; since the top plates are floating, their potentials set to mid-rail. During sampling, the bottom capacitor plates are connected to the $eTextiles$ network. As the inputs are already centered at opposite DC potentials and the top plates remain floating, only differential charge is sampled on top of the existing mid-rail charge residing on each capacitor. As a result, during the hold phase, the inputs to the comparators are differentially centered at mid-rail, requiring no additional biasing and reducing the CMRR requirements of the ensuing comparators.

Samples are converted to ternary digits (trits) by two clocked comparators sized for a $3\sigma$ offset under 250mV. Each comparator has 8 bits of differential pair and current source weighting, providing offsets that vary by $\pm60mV$. The comparators are configured to have equal and opposite non-zero offsets, such that any differential samples above or below the absolute offset level convert to trits ‘$+$’ or ‘$-$’, respectively; samples residing between the offset levels convert to ‘0’. The conversion is performed by an offset orientation-independent ternary encoder, permitting the comparator pair to swap roles. After calibration, this form of comparator configuration-redundancy improves the $\sigma$ of offset errors, measured as the difference between the desired and attained offset for each comparator, by 1.5-2.5X.

Each sample and conversion operation completes in two clock cycles, requiring two interleaved AQ blocks to demodulate data at full rate. Synchronization is achieved in the RX back-end (BE) by correlating incoming data using two additional AQ blocks to ensure sampling occurs every half clock period (Fig. 27.6.5). A custom multiplier is implemented for the correlator ternary arithmetic, saving 2 bits in eachadder stage over a traditional 2’s complement topology. If a correlator output crosses a programmable threshold, synchronization is achieved, and the two unused AQ blocks are clock gated. Alternatively, the RX BE can be configured in an auto-correlation mode for a CSMA MAC.

The transceiver is fabricated in 0.18µm CMOS, occupies a core area of 0.83mm$^2$, and operates at 0.9V. Although healthcare applications typically only require 10-100kb/s per sensor, the transceiver communicates at a raw data rate of 100Mb/s to accommodate up to 30 time-multiplexed sensor nodes on the shared medium and to provide margin for remote charging duty-cycling and coding overhead. The RX FE consumes 2pJ/bit, which is at least 20X lower than wireless and BCC systems operating at similar distances, and is comparable to wireless $eTextiles$ systems operating over much shorter distances (Fig. 27.6.6). Over 1m, the TX FE consumes 0.7-to-18pJ/bit for output voltage swings from 6-to-290mV. At 100% receive-mode duty cycle, the chip consumes 110µW, including RX, digital baseband, and I/O power. The remote battery scheme achieves 95% power transfer efficiency from BS to sensor node, compared to 54.9% for wire-
less power transfer efficiency [8]. Figure 27.6.6 shows measured transmitted and received waveforms, and summarizes the chip results. A die photo is shown in Fig. 27.6.7.

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References:
Shared eTextiles communication and power delivery medium

Basestation prototype (eTextiles transceiver & wireless relay)

Figure 27.6.1: Implemented eTextiles system with packet diagram shown.

Packet Diagram:

<table>
<thead>
<tr>
<th>Beacon Req</th>
<th>Payload</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beacon</td>
<td>Node ID</td>
<td></td>
</tr>
<tr>
<td>3-16 bits</td>
<td>5</td>
<td>BS TX / Node RX</td>
</tr>
<tr>
<td>3-16 bits</td>
<td>5</td>
<td>BS RX / Node TX</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No RX/TX</td>
</tr>
</tbody>
</table>

Payload Charge

eTextile nodes

Figure 27.6.2: eTextiles transceiver block diagram used for sensor nodes. The BS uses the same chip, but replaces the super capacitor with a battery.

TX+ (6:0)

Figure 27.6.3: Supply-rail-coupled (SRC) differential ternary transmitter.

RX FE

Figure 27.6.4: RX front end (FE) consisting of four time-offset acquisition (AQ) blocks.

Figure 27.6.5: RX back end (BE) used for synchronization.

Figure 27.6.6: Measured transient waveforms and table of measured results.

Figure 27.6.7: Implemented eTextiles system with packet diagram shown.
Figure 27.6.7: Die photograph of the eTextiles transceiver.