11.6 A 128b Organic RFID Transponder Chip, including Manchester Encoding and ALOHA Anti-Collision Protocol, Operating with a Data Rate of 1529b/s

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Research towards 13.56MHz organic RFID tags is one of the drivers for the field of organic electronics. A capacitively-coupled 64b organic RFID tag operating at 125kHz was demonstrated in [1]. Inductively-coupled 64b organic RFID tag operating at 13.56MHz were reported in [2,3].

A targeted application for plastic HF tags is Electronic Product Coding (EPC) [4,5]. Some EPC specifications have already been met by plastic tags in recent years, namely the transmission of a 64b code [1,2,3] and compatibility with regulations concerning human exposure to electromagnetic fields [2]. Nevertheless, state-of-the-art organic transponder chips fall short of complying with other EPC specs. Significantly higher data rates (26.48kb/s to 52.969kb/s) are needed as compared to the hundreds b/s [1,2,3] shown to date. The clock on the tag should be synchronous with the carrier. Anti-collision protocols should be foreseen. Preferably, the data should be complemented with redundancy check bits and a destroy code. The standards prescribe Manchester encoding. Several types of memory are possible, including write-once-read-many (WORM).

This work presents significant increases in complexity in organic RFID transponder chips compared to earlier reports, which bring the tag closer to EPC. We show a transponder chip with a ROM memory capacity of 128b. Furthermore, it contains a WORM memory in addition to the ROM shown in [1,2,3]. The data rate is doubled, to 2kb/s and is Manchester encoded. Also a basic anti-collision protocol has been added, whereby the readout of multiple organic RFID tags would be possible.

The organic 128b transponder chip is fabricated on a 25μm thin plastic substrate using organic bottom-gate thin-film transistors. The organic electronics technology that is used was developed by Polymer Vision for commercialization in rollable active matrix displays and is described elsewhere [6,7]. The insulator layers and the semiconductor layer are organic materials processed from solution. The transistors, with a typical channel length of 5μm, have an average saturation mobility of 0.15cm^2/Vs.

The design of the organic transponder chip was limited to p-type only logic, since pentacene is a p-type semiconductor. Logic gates, like inverters and NANDs, are designed using zero V_{gs}-logic [1]. The gain of an inverter at the trip point, at a supply voltage of 15V is 1.65. 33-stage ring oscillators are measured, yielding frequencies of around 1.8kHz at 15V supply voltage. Equivalent oscillators are used as clock in our RFID transponder foil.

The schematic overview of the 128b transponder chip can be seen in Fig. 11.6.1. A 33-stage ring oscillator generates the clock signal. This clock signal drives the output register, the 3b binary counter and the 16b line select. The 16b line select selects a row in the code. A bit in this row is selected by the 8:1 multiplexer, driven by the 3b binary counter. This bit is transported to the output register, which sends the bit on the rising edge of the clock to the Manchester encoder. The latter unit encodes the data and sends it to the load modulator of the plastic RFID tag.

The digital logic of the Manchester encoding block is depicted in Fig. 11.6.1. Manchester encoded data, besides the normal bit transitions, requires a transition in the middle of the bit. A transition of 0 to 1 corresponds with a logic 0 and vice-versa. In our design, every transition needs a rising edge of the clock. To include Manchester encoding to this scheme without losing data rate, we generate a clock with double frequency from of the 33-stage ring oscillator. This clock is used to encode the data. The generation of this clock is done by an XNOR behind stage 15 and 25, as depicted in Fig. 11.6.1. The data is encoded by adding another XNOR and NAND gate.

To enable the readout of multiple organic RFID tags at once, a basic anti-collision protocol is added to the plastic RFID transponder chip. The anti-collision protocol used is a basic version of ALOHA, which is a "tag talks first" protocol. A tag sends its code after which a silent period follows. The code is then retransmitted. During the silent period, another tag can be read out. If a tag transmits its code during the transmitting time of another tag, a collision occurs and the code is consequently not valid. A full ALOHA protocol should also allow the reader to acknowledge the successful detection of the code, after which the tag remains silent. This has not been implemented here due to the lack of communication capability from the reader to the tag.

In the implementation of this ALOHA protocol, a 4-bit modulo 12 up-counter is used to select whether the data, coming from the Manchester encoder, should be sent out (value of the counter is 0000) or the supply voltage should be connected to the load modulator (all other values of the counter). The clock for this counter is generated by the 3b binary counter and the 16b line select. In this way, the silent period takes 12× the time necessary to stream out all data bits. Figs. 11.6.2 and 11.6.3 depict the measurement results of the 128b transponder chip, including Manchester encoding and the ALOHA protocol. This chip was powered with a supply voltage of 24V and employs 1286 transistors. The 128 bits can be read out in 83.7ms, i.e. a bit rate of 1529Hz. The 8b transponder chip, including Manchester encoding and ALOHA protocol is fully operational at a supply voltage of 22V with a data rate of 2022Hz. A photograph of the 128b plastic transponder chip can be seen in Fig. 11.6.6. The core of the 128b transponder die comprising the ALOHA protocol measures 10.6×9.5mm^2. The data rates and supply voltages of the 8b and 128b transponder chips are plotted in Fig. 11.6.4, together with earlier organic transponder chips.

Monte-Carlo simulations were used to analyze the robustness of building blocks in the above-described chips with 1286 transistors. The critical path is the timing of the signals at the multiplexer.

Supply voltages of 20 to 24V are used for these transponder chips. We calculate that this voltage can be generated on a tag equipped with a plastic double half-wave rectifier [8] and an antenna of 6 to 7 windings on the area of a smart card.

In our transponder chips, the ROM memory has also been partially replaced with WORM memory. In the 8b RFID transponder chip, we exchanged 4 ROM bits with WORM memory. One bit of the latter memory is a zero V_{gs}-inverter, whereby the pull-up transistor is connected to the ground and whereby the connection between the pull-up transistor and the VDD is a metal line, which can be interrupted by means of mechanical breakage (cutting) or thermal ablation (e.g. by means of a laser pulse), as can be seen in Fig. 11.6.5. When this line is not interrupted, this inverter yields a logic 1, and after cutting this line, the bit changes to 0. Figure 11.6.5 shows the measurement results of the 8b transponder chip, including Manchester encoding and ALOHA protocol, when no bits are fused and when bit 5 is fused. This transponder chip is fully operational at a supply voltage of 27V with a bit rate of 1583Hz.

Acknowledgements:
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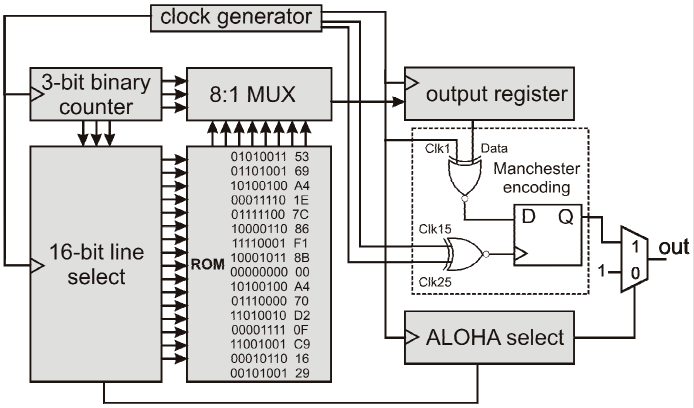

Figure 11.6.1: Schematic overview of the digital logic portion of the 128b transponder chip. It has been implemented on foil in a p-type TFT only logic configuration.

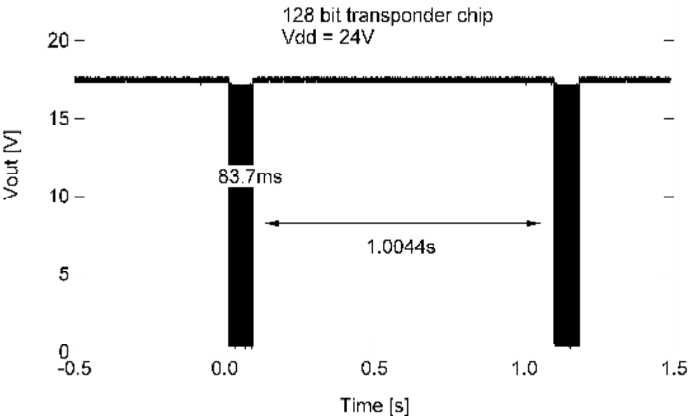

Figure 11.6.2: Measured signal of the 128b organic transponder chip with a power supply of 24V.

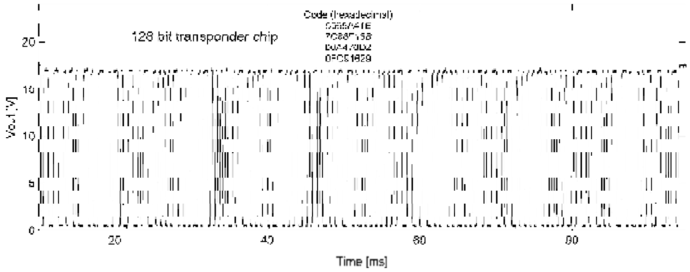

Figure 11.6.3: Zoom of one period of Fig. 11.6.2 with the code of the transponder chip shown.

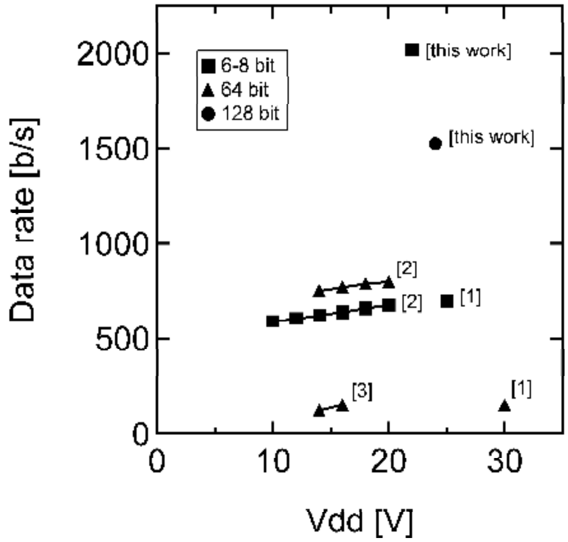

Figure 11.6.4: Comparison of transponder chips described in this work with those reported in literature.

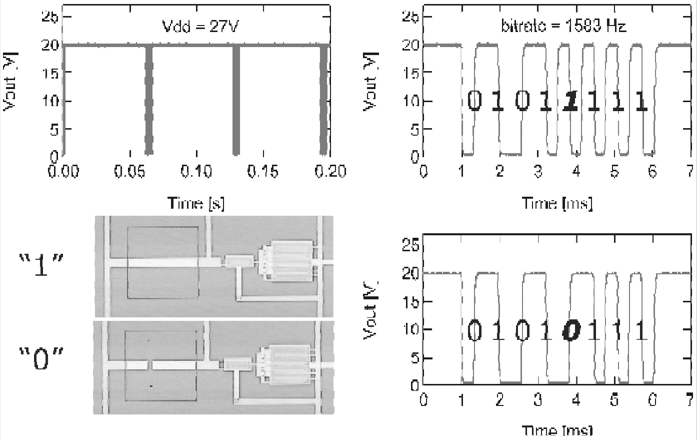

Figure 11.6.5: Signal of the 64b RFID tag measured on the reader (unamplified reader signal). As 0.7V drops over the diode at the reader, a tag-generated signal of about 1.1V is obtained, from which 30mV is load modulation (modulation depth h = 1.4%). The expected code sequences are superimposed.

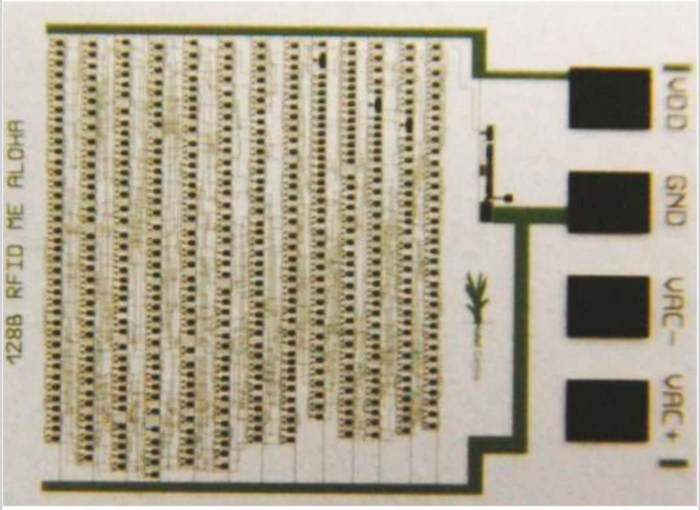

Figure 11.6.6: A photograph of the 128b RFID transponder foil.