Electronics based on organic transistors is suited to the manufacture of RFID tags for retail applications [1] because of its low-cost, mechanical flexibility and the possibility it offers to integrate circuits with antennas on packaged items. Organic electronics [2] and antennas can be manufactured using low-cost high-volume technologies like printing. Still a convincing demonstration of the technical feasibility of organic RFID transponders is missing.

The RFID tags presented here are manufactured using a photolithographic bottom gate technology [3] on a 25µm thick plastic substrate. The p-type semiconductor is pentacene, deposited from a precursor solution. Transistors consistently provide field-effect mobilities in the saturation region of 0.01cm²/Vs and on/off current ratios of 10⁶.

A crucial element in any DC-powered tag (Fig. 15.2.1) is the rectifier, the only device that must work at the RF carrier frequency. In our technology the organic semiconductor is the top layer in the stack. Integration of a vertical diode [4] would require additional masks and process steps; therefore we chose to implement the integrated rectifier using diode-connected transistors.

The channel length of the transistors is typically 4µm. As the mobility is 0.01cm²/Vs, one would expect a time of flight between source and drain of 160ns at a Vdd of 100V. Based on this simplification of the radio frequency the antenna must have large inductance and a low capacitive and inductive antenna coupling (Fig. 15.2.1). At low frequencies the antenna and the tag, showing a code B on the oscilloscope, is presented in Fig. 15.2.2. The carrier on the reader antenna has a peak-to-peak value of 110V, generating a tag supply of Vdd = –25V.

The 64b code generator proved fully functional. The correct output code was measured at a Vdd of –30V (Fig. 15.2.4). The data rate is 150b/s. A chip micrograph is shown in Fig. 15.2.7; the chip contains 1938 transistors. The 64b code generators were also measured with the integrated rectifier-modulator; the tags work in air with a VACpp voltage of 180V at 125kHz generating the Manchester code.

In summary, a complete RFID system has been presented working at 13.56MHz, the current standard for item level identification. A DC output voltage Vdd as a function of the input peak-to-peak AC voltage VACpp is shown in Fig. 15.2.5. The rectifier works at frequencies beyond 20MHz, far above the limits expected from the simplistic time of flight estimation. The reason for this excellent behavior is attributed to the fact that mobility in organic semiconductors is a power function of the applied gate-source voltage [6] and the rectifiers are operated at large Vgs.

A system capable of generating the 13.56MHz carrier and to read-out the tags via the capacitive antenna was built. This system could successfully energize and readout code A and code B tags at 13.56MHz. The measured output codes are shown in Fig. 15.2.6; the bit rate is 1kb/s for code A and 700b/s for code B. At this carrier frequency an inductive RF link could be advantageously used to increase the range of the RFID system.

Repeated exposure, in air, of the tags to the AC voltage needed to generate sufficient DC supply did not result in measurable performance degradation.

In summary, a complete RFID system has been presented working at 13.56MHz, the current standard for item level RF identification, which is able to distinguish between two tags manufactured with organic transistors. Also reported are functional 64b transponders. All measurements presented have been obtained in air. These results demonstrate the technical feasibility of commercially relevant RF identification systems based on organic tags.

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References:

Figure 15.2.1: Capacitively and inductively coupled organic tags with integrated rectifiers.

Figure 15.2.2: A code B tag is energized and readout at 125kHz using a base station and an oscilloscope.

Figure 15.2.3: The 64b code generator architecture (reset state).

Figure 15.2.4: Signals measured on the 64b code generator at $V_{dd} = 30V$. The programmed code is shown in hexadecimal together with the generated code signal.

Figure 15.2.5: DC output voltage $-V_{dd}$ of the integrated organic rectifier as a function of the input peak-to-peak AC voltage $V_{ACpp}$ at different frequencies.

Figure 15.2.6: Output codes of a code A and a code B tag readout using a 13.56MHz carrier through a capacitive antenna.
Figure 15.2.7: Micrograph of the reticle containing all organic tags.
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