- Ambient Intelligence - Industrial Research on a Visionary Concept

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ABSTRACT
In this presentation applications are discussed that describe achievements along the road towards 'Ambient Intelligence'. Appliances and devices disappear into the environment of the individual; instead services come into focus. Key to this development are systems solutions that lead to a significant improvement of the human-machine interface. Along this line, we present important technologies and key system components. They range from technologies for packaging and gathering of ambient energy, to system demonstrators such as low-cost electronic systems, ubiquitous sensor networks and electronics in smart textiles. The prime importance of the supply with electric power and of low-power consumption especially in the peripheral devices are emphasized.

Categories and Subject Descriptors
B.m [**Hardware**]: Miscellaneous.

D.m [**Software**]: Miscellaneous.

H4.2 [**Information Systems Applications**]: Types of Systems – *Logistics*.

H4.m [**Information Systems Applications**]: Miscellaneous.

General Terms
Algorithms, Measurement, Documentation, Performance, Design, Reliability, Experimentation, Security, Human Factors, Verification.

Keywords
ambient intelligence, ubiquitous computing, wearable electronics, sensor networks, RF-ID tags, smart textiles, distributed networks.

1. INTRODUCTION
Ambient Intelligence [1] is the vision that technology will become invisible, embedded in our natural surroundings, present whenever we need it, enabled by simple and effortless interactions, attuned to all our senses, adaptive to users and context and autonomously acting. High quality information and content must be available to any user, anywhere, at any time, and on any device.

Some believe ambient intelligence is a vision for the far future: we may be surrounded by various fantastic features such as intelligent electronic wall papers or 'smart dust' forming distributed intelligence with spectacular features. Indeed, *such* visions lie at least 20 years ahead of us. They will require major progress of alternative technologies that have presently not even shown basic feasibility, such as large-size paper-like display technologies or printable, ultra low-cost, ultra-low power, ultra-high performance, electronics. Experience tells that the introduction to the market of new basic hardware technologies takes a long time even after functionality-proof is accomplished.

On the other side, already today indications of a trend towards ambient intelligence are evident. While in the 1970s one computer served many users, and in the 1990s the personal computer served humans on a one-to-one basis, today more than one computing device serves each user. Peripheral devices which were rather dependent on central computing power a few years ago now contain powerful own computing devices. This trend towards distributed electronic intelligence will likely prevail in the near future. Many interesting aspects of ambient intelligence are relevant in this context. They are feasible by today's technologies or need only limited innovation in sub-fields such as packaging or chip placement. They are based on existing hardware technology and may be products in 5-10 years. This is exactly the timeframe relevant for our research where today, those topics are indeed investigated.

In addition, other preconditions for the relevance of industrial research are kept in mind. We head for applications that make sense to the customer and fulfill real needs. If there is no market with a sufficient size the development does not make sense. Based on those criteria our research is divided into various projects discussed in the following chapters.

2. ELECTRONICS IN THE VICINITY OF HUMANS

One project in this context heads for electronics integrated into clothing. This represents nothing but another step towards portability which is envisioned after the successful introduction of notepads and mobile phones. We follow the idea of seamless integration of electronics into clothing. The electronics is left inside the clothing for cleaning processes. Furthermore, we aim for simple operation. A first demonstrator (Fig. 1) [2,3] was presented recently. This demonstrator is an MP3 player integrated with key pad, ear phones, microphone, and a module that contains the multimedia card and the battery to power the complete system. Low power consumption plays an important role. The lower the total power consumption the higher is the operating time of the rechargeable battery.

Moreover, ambient energy supply is addressed: thermoelectric converters produce energy from body heat (Fig. 2) [4-6]. We chose a device architecture based on a silicon process which leads to low cost. The power produced by this device is relatively small. It is sufficient to power a wrist watch or a heart pulse sensor. For a hearing aid major progress in both the power produced by the device and the power consumed by the electronics of the hearing aid will be required.

In another project, the concept of technical textiles is investigated containing active electronic systems spatially distributed over the fabric [6]. The variety of applications for such a system is huge: pressure sensors and display units in floor cloths for surveillance or guidance systems in public buildings, intelligent sheets for monitoring vital signals of patients in hospitals, defect detection for condition monitoring in textile concrete constructions, and many more. Each of these applications poses high technical requirements regarding functionality, reliability, and ease and cost-efficiency of manufacturing (Fig. 3) [7].

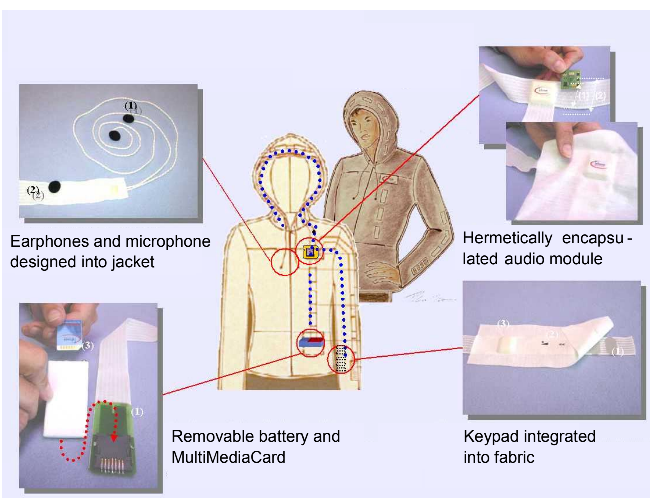

Fig. 1: Sketch of technical details of the MP3 jacket presented as a first technology demonstrator on 'Wearable Electronics'.

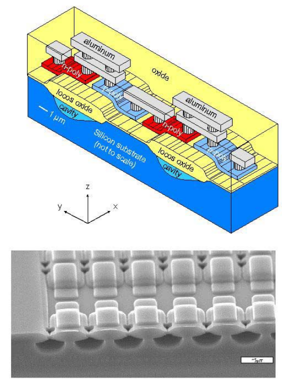

Fig. 2 Schematic sketch and SEM micrograph of a thermogenerator manufactured in a process based on silicon technology.

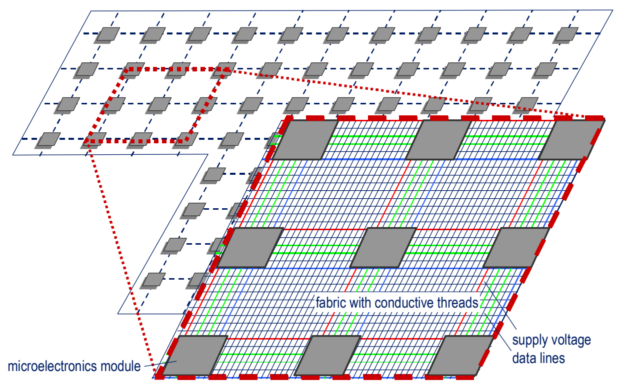

Fig. 3a Schematics of an embedded network of processing elements in a textile fabric

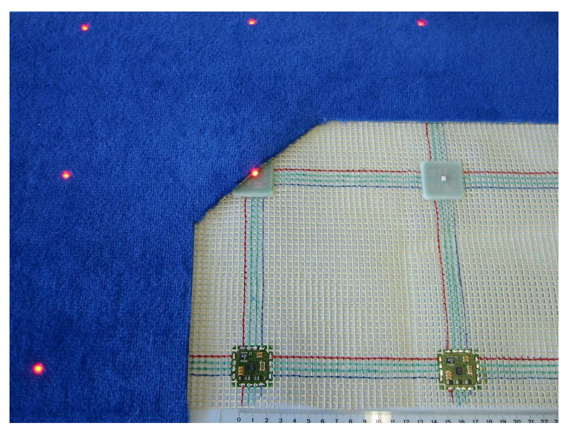

Fig. 3b Concept Demonstrator of a network of electronic units connected via conducting leads in the fabric.

3. HUMAN COMPUTER INTERFACE

An edutainment device for children is developed as an innovation study for a natural and intuitive computer interface (Fig. 4). We intend to use this device as a platform to visualize innovations in this area. In the near future we will demonstrate a solution in the field of 'context to speech'.

This device will obviously not be used with a power cord. Powerful battery technology and low power consumption of the electronics at high computing power are important challenges in this work.

4. UBIQUITOUS SENSOR NETWORK

This project elaborates on a low-cost wireless network for ubiquitous computing environments that creates the necessary link between the user and distributed electronics (Fig. 5). Smart offices and hotel room infrastructures may be among the first examples where this vision will become reality.

Both the peripheral devices and the central terminal are battery powered. The challenges are greatest for the peripherals. 100 µW is the limit in power consumption specified in this project.

5. LARGELY DISTRIBUTED ELECTRONICS

We investigate chances for applications of smart RF ID tags that represent possible solutions for peripheral intelligence. The prime challenge for those devices is the demand for an extremely low cost level which will demand innovation not only on the chip level but along the complete value chain.

The operation is as follows: a reader device emits electromagnetic waves that are received by the antenna of the tag to power the tag chip and receive data. The tag modulates the received power according to a specific protocol and thus sends back data since the reader can detect the change in electromagnetic power (Fig. 6). The power received by the tag can be very small depending on the distance from the reader. The higher the distance possible for proper operation the more applications become feasible. Thus low power consumption is of prime importance for the tag chip which has only a few thousand transistors.

Besides Si-based solution that may reach product status in a few years polymer electronics is researched that has the potential to reach cost levels of 1 cent for the complete RF ID tag including the antenna.

In Fig. 7 a 5-stage ring oscillator based on pentacene thin film transistors is presented with a channel length of 5 µm on a flexible substrate. The design has integrated level-shifting and output buffer and achieves a frequency of 4.5 kHz that correspond to a stage delay of 22 µs. This result is only a factor of 3 away from a value of 8 µs required for an RF ID tag that operates at a frequency of 125 kHz. This is the lowest frequency used as a standard in modern tag applications.

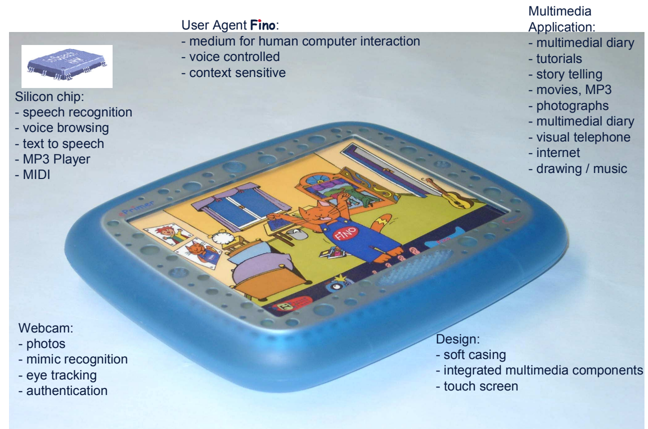

Fig. 4 System demonstrator for an improved human computer interface

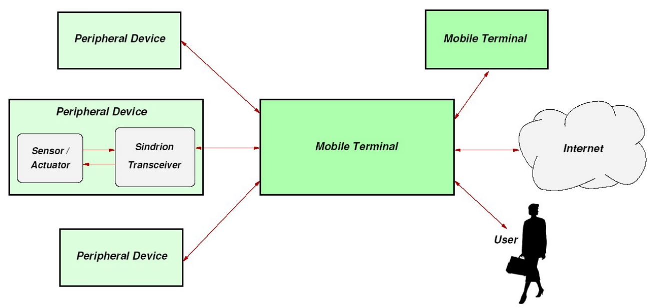

Fig. 5: Low-priced sensors (left) communicate through a wireless interface with a mobile terminal (center), that provides computing power and connections to the world of electronic appliances and the user.

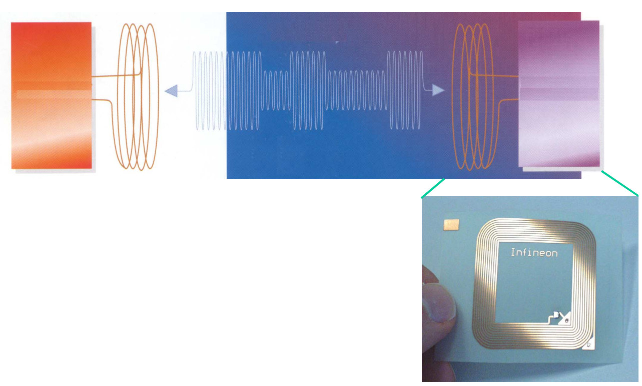

Fig. 6 Schematic representation of a transponder system using a reader (left) that emits electromagnetic waves to power the passive transponder (right bottom), send and receive data to and from the transponder by modulation of the electromagnetic field.

In Fig. 8 a complete ring oscillator on aluminized plastic foil is shown to operate at a stage delay of 650 µs. This substrate is used for food packages such as chips bags, tetra packs etc and provides an opportunity to realize a low-cost antenna by simply removing material from the aluminum layer [8].

The power problem poses a major hurdle to the realization of such a system. Polymer devices are usually operated at voltages in the tens of volts, the reason being the relatively poor performance of the devices and the wide and thick dimensions of structures and layers used in a process which will ultimately be printed. The challenges for the circuits to produce the dc power from the antenna signal are thus very high. A possible solution to the problem is sketched in Fig. 9. Here a monomolecular layer of 2.5 nm has been applied to form the dielectric layer. The lateral dimensions are kept high in this experiment, suitable for printing processes. This measure allows a major reduction of the operating voltage to a value of about 1.5 V. As a consequence the overall power consumed is largely reduced.

These examples demonstrate that quite a few achievements are already accomplished on our way to a low-cost RF ID tag. Presently, those results are achieved only separately but need to be combined in one single system. This clearly shows that our way to go is still long and challenging.

6. CONCLUSION

This research work strives for application demonstrators and technologies that enable semiconductor solutions for the technology lifestyle of the individual in the 21st century. Here, the individual is the subject whereas electronics is object. In some sense this represents a concept opposite to the one of 'Virtual Reality' where the individual becomes object. The users of the targeted applications want to be served by an environment with an excellent interface between technology and the human. The application must be controllable without specific knowledge. Furthermore, power consumption of electronic devices must be low enough to allow long operation times with a given set of batteries. It is our vision to provide human individuals with means to enable the control of their surrounding, being assisted by highly-functional electronic appliances in the background.

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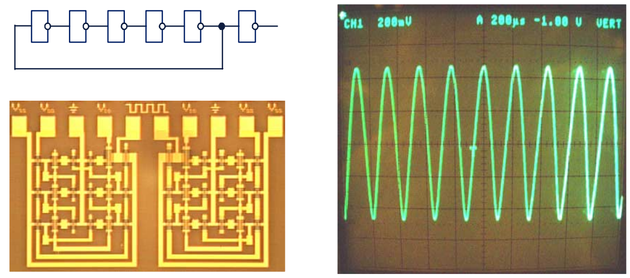

Fig. 7 Pentacene TFTs and circuits on flexible substrates: results of a 5-stage ring oscillator are presented with integrated level-shifting and output buffer and a channel length of 5 µm. The frequency measured is 4.5 kHz which leads to a propagation delay of 22 µsec per stage.

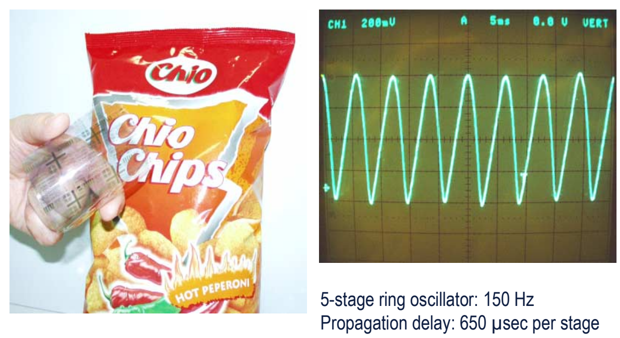

Fig. 8: Vision of a plastic electronic transponder integrated into the plastic bag of a low-priced consumer good. To the right the operation of a ring oscillator is shown realized on an aluminized plastic foil.

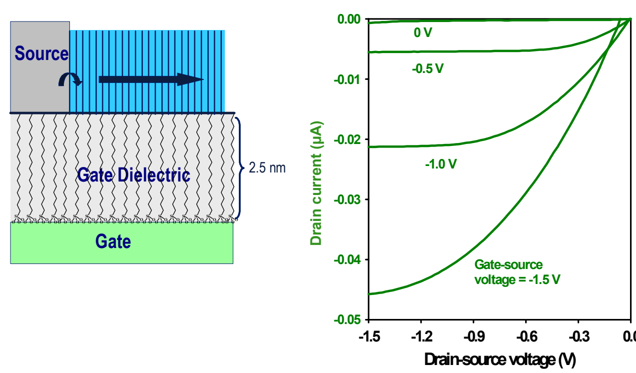

Fig. 9 Organic devices manufactured with a 2.5 nm thick gate dielectric based on self-assembled monolayers of organic molecules.

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