Wireless Energy Harvesting Switch

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ZF Friedrichshafen AG, Electronic Systems
Agenda

1. ZF Friedrichshafen AG, Electronic Systems
2. Development of a new product idea
3. Challenges for Energy Management
4. Applications and Products
### The ZF Group – An Overview

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>2013 / 2012*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sales</strong></td>
<td>16,837 Mio. €</td>
<td>+ 8 %</td>
</tr>
<tr>
<td><strong>Employees (end of year)</strong></td>
<td>72,643</td>
<td>+ 6 %</td>
</tr>
<tr>
<td><strong>Capital expenditure</strong></td>
<td>954 Mio. €</td>
<td>- 7 %</td>
</tr>
<tr>
<td><strong>R&amp;D expenditure</strong></td>
<td>836 Mio. €</td>
<td>+ 9 %</td>
</tr>
</tbody>
</table>

122 production companies in 26 countries

8 main development locations in 4 countries

33 service companies and more than 650 service partners

*As of 2012 excluding ZF Lenksysteme.
### Business Unit Electronic Systems

#### Product Lines

<table>
<thead>
<tr>
<th>Human Machine Interface</th>
<th>Body, Chassis, Driveline</th>
<th>Computer Input Devices</th>
<th>Industrial Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic gearshifts</td>
<td>Electronic control units</td>
<td>Keyboards</td>
<td>Standard switches</td>
</tr>
<tr>
<td>Mechanical gearshifts</td>
<td>Sensor assemblies</td>
<td>Key modules</td>
<td>Controls</td>
</tr>
<tr>
<td>Displays</td>
<td>Power electronics</td>
<td>Mice</td>
<td>Sensors</td>
</tr>
<tr>
<td>Knobs</td>
<td>Switch and switch assemblies</td>
<td>Card readers</td>
<td>Power electronics</td>
</tr>
</tbody>
</table>

CHERRY is a registered brand of ZF Friedrichshafen AG for the product lines CID and IS.

Sales 2012:
- Electronic gearshifts: 12%
- Mechanical gearshifts: 11%
- Displays: 26%
- Knobs: 52%
Wireless Energy Harvesting Switch

Development of a new product idea

The Wireless Energy Harvesting Switch is an innovative alternative to Cherry’s wired switches.

The small and compact size with high energy profit is the unique characteristic of the harvester.

RF Technology
- Frequency: 868/915 MHz, 2,4 GHz
- Protocol: ZF proprietary, KNX-RF, ZigBee, BTLE
- Antenna: wire, PCB

Mechanic
- Actuating Force: 6N (designable)
- Actuating Stroke: 4 mm (designable)
- Life time: < 1 mio
- Power: > 330 µJ
Wireless Energy Harvesting Switch

Energy Harvesting System
Wireless Energy Harvesting Switch
Cherry Energy Harvesting System

Sensor
Energy Generator

Energy Management
Level of efficiency ~70%

Rectifier Energy buffer Voltage Converter

Direction detection

RF Chip
μC RF

Wireless Energy Harvesting Switch
Cherry Energy Harvesting System
Different energy harvester provides different output signals

- **Symmetric Pulse**
- **Oscillation**
- **Asymmetric Pulse**
- **Linearity**
Wireless Energy Harvesting Switch
Output Voltage of Cherry Switch

Output voltage of the generator when switch is pressed

\[ E = \int_{t_1}^{t_2} U(t) \cdot I(t) \cdot dt \]

Output voltage of the generator when switch is released

Load resistance 100 Ohm
Wireless Energy Harvesting Switch
Operating Principle

\[ \Phi = \vec{B} \cdot \vec{A}, \quad u_{ind} = -\frac{d\Phi}{dt} \]

\( \Phi \) = magnetic flux  \quad \vec{B} = \text{magnetic flux density}
Wireless Energy Harvesting Switch
Energy Transformation

The generator transforms mechanical energy into electrical energy.

- **Press**
- **Release**

The edge steepness depends on the load of the generator.
Wireless Energy Harvesting Switch

Impedance Matching of the Harvester

The energy of the generator on different ohmic resistance

Energy [mJ] vs Load [Ω]

- Press
- Release

stably between 50 and 200Ω
Wireless Energy Harvesting Switch
Impedance Matching of the Harvester

Ohmic resistance of the generator in idle mode

- High resistance at the borders are uncritical bc. the current is low (=low power).
- The resistance is never lower than 50Ω

\[ R = \frac{U}{I} \]

Voltage measured
Current measured
Resistance calculated
Wireless Energy Harvesting Switch
Energy Management

Energy Management
Level of efficiency ~70%

Rectifier  Energy buffer  Voltage Converter
Using two transistors instead of diodes to avoid losses through diode forward voltage
Wireless Energy Harvesting Switch
Energy Management

The capacity of the energy buffer influences
- the peak,
- the ramp-up time and
- the fall-time of voltage.
Wireless Energy Harvesting Switch
Energy Management

A high input voltage range of the step-down-converter reduces the losses.
Wireless Energy Harvesting Switch
RF Components

The data rate and the telegram length defines the transmission time of one telegram

- **KNX**
  - (16,384 kbit/s, 35 byte)
- **ZigBee GP**
  - (250 kbit/s, 21 byte)
- **Bluetooth LE**
  - (1 Mbit/s, 17 byte)
- **EnOcean**
  - (125 kbit/s, 14 byte)
- **ZF proprietary**
  - (75 kbit/s, 12 byte)
Wireless Energy Harvesting Switch
RF Components

The transmission time of the RF electronic depends on:
- available energy
- supply voltage of RF chip
- current consumption of RF chip

\[ E = U \times I \times t \]
\[ t = \frac{E}{U \times I} \]

The current consumption depends on RF chip and adjusted transmission power:

<table>
<thead>
<tr>
<th>Sample Calculation Platform A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>230 µJ</td>
</tr>
<tr>
<td>230 µJ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Calculation Platform B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>230 µJ</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Calculation Platform C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>230 µJ</td>
</tr>
<tr>
<td>246 µJ</td>
</tr>
</tbody>
</table>
Wireless Energy Harvesting Switch
Products and Applications

Industrial-
sensoric

Home-
Automation
(Surface Switch)
Summary

1. Development of a new product idea: the small and compact size with high energy profit fits to industrial applications

2. Challenges for the Energy Management: the optimized combination of components leads to an optimized level of efficiency

3. Applications and Products: switches for industrial applications and light switch for KNX coming soon
Thank you for your attention