10TH INTERNATIONAL DESIGN STRUCTURE MATRIX CONFERENCE, DSM'08
11 – 12 NOVEMBER 2008, STOCKHOLM, SWEDEN

WORKING STRUCTURE AND DSM AS INTEGRATION TOOLS IN INTERDISCIPLINARY CONTEXTS

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Keywords: DSM, Working structure, Micro-Electro-Mechanical-Systems, Design for Integration

1 INTRODUCTION

Interdisciplinary product development requires particular attention to the integration of components of diverse disciplines. The domain of MEMS (Micro-Electro-Mechanical-Systems) is a representative example for technologies characterized by a broad variety of different interdisciplinary devices. MEMS mass products are characterised by interaction of diverse disciplines integrated in one product. The diversity of involved technologies, the close integration of components of diverse domains and the simultaneous development of product and manufacturing process influence the development process. The integration of diverse domains and the interrelations between them require the incorporation of skilled specialists from different knowledge fields. Interrelations and interactions in highly complex systems must be considered in an appropriate way [1] and require effective support of designers [6]. The integration can be supported by appropriate methods helping experts of various fields to achieve efficient and effective product development.

This paper suggests methodical support of designers to improve the coherence of MEMS by a new developed integration method based on a working structure and the Design Structure Matrix (DSM).

2 CHALLENGES IN MEMS DEVELOPMENT

MEMS technology originally developed from the technology of integrated circuits in microelectronics. Microelectronics deal with automatically developed two-dimensional structures whereas actual MEMS devices usually include non-electrical subassemblies and usually comprise a three-dimensional design. MEMS are defined as miniaturized discrete objects with integrated sensors, signal or information processing and actuators with characteristic dimensions in the range of few micrometers [1]. Components consist of functional and geometric elements, e. g. beams, diaphragms or bearings. MEMS technology deals with the design, manufacturing and application of such systems [1] and closely integrates diverse disciplines of physics, e. g. micromechanics, microelectronics, microacoustics, microoptics and microfluidics, as well as microbiology and microchemistry.

The miniaturisation of existing or the development of new elements in compact dimensions enables the integration of various elements in a small volume. It also provides new technical principles and properties concerning e. g. inertia or power consumption. Last but not least it serves the demand for continuously decreasing costs that is very important in most of the application fields.

On the other hand the miniaturisation increasingly leads to the limits of manufacturing technology, causes influences between MEMS components and results in physical effects of miniaturisation. A smaller surface-volume-ratio may cause cooling problems and the mechanical properties of a system may change due to the fact that specific mechanical stiffness increases with smaller dimensions [2]. Electromagnetic effects enable electrostatic micromotors but also cause lubrication problems or deflection [3] and undesirable parasitics in small systems. MEMS require not only efficient components but also their correct interaction to fulfil the function of the entire system.

The diversity and the continuous modification of technologies, materials and applications challenge the designer. He must verify assumptions and consider new influences when he designs highly integrated technical systems. A good understanding of physical background, material, manufacturing process, overall concept and desired signal transmission become essential preconditions for a change of dimensions. The complexity caused by number and variety of elements and interactions requires experts of diverse disciplines to solve development tasks.

The reduction of these impacts requires their consideration in the development process by use of adequate methods accepted by designers in practice. Support for interdisciplinary teamwork and the realisation of interfaces is demanded but not sufficiently available.

Required powerful tools and methods for the examination of the entire system beyond single components and domains are missing up to now [4]. Developing a system the conventional way of bottom-up based on a main component lacks the system view, the top-down approach has to deal with missing information about components and their realisation in the beginning. It is advisable to follow a meet-in-the-middle strategy alternating between bottom-up and top-down with increasing maturation of the system [1]. The aspect of integration must be supported by adequate methods in all phases of the development process. Matrices were regarded to be a useful and commonly understandable form of illustration to support communication and collaboration of interdisciplinary teams of MEMS designers.

3 THE WORKING STRUCTURE AS INTEGRATION METHOD

The importance of the geometric and material parameters for the function of mechanical, electronical and optical design was pointed out by Jung [5]. He introduced the “geometry function principle” and constituted the importance of the correlation between geometric and material parameters as well as internal and external influences for the function of a system.

In order to consider all influences and interrelations, it is necessary to get a clear view of the geometric combination of fundamental elements as well as the effects of used materials and influencing operation parameters. The relation between geometry and function is essential for the interdisciplinary development of MEMS, but different from other technical areas [6]. The function structure established in mechanical engineering enriched by geometrical, material and operation characteristics of the solution enables a comprehensive view on MEMS and their internal and external functional interrelations. The new developed working structure for MEMS supplies a system view beyond the functional aspects covered by the function structure [7]. It illustrates geometric and material parameters of the components of a system and their mechanical connection.

The illustration by the working structure supplies a holistic view on complex systems and can be completed by more precise descriptions of elements during the development process. This complete overview of all components of a MEMS enables the review of system elements and their interrelations during the development process. Thus the enriched working structure contains far more information than the function structure and allows an intensive observation of the total system during the entire development process.

4 REVIEW OF SYSTEM INTERRELATIONS BY USE OF THE DSM

The analysis of e. g. physical, geometrical or functional interactions between components of the system and its environment is supported by a Design Structure Matrix (DSM) matrix based on the working structure. The DSM represents the system structure and helps to get a clear view of its configuration. Figure 1 illustrates the DSM for the working structure of a rotary incremental encoder.

All parts, connections, flows and external or internal influences are documented in the rows and columns of the matrix. The nature or material of one of these parameters can be added in the beginning or during the structure identification process. Influences and interactions are documented by arrows pointing to the parameter in the column. Thus all influences on e. g. a system component become quite obvious by considering the corresponding row. On the other hand all influences coming from e. g. an external influence like thermal energy are centralized in one column. The matrix also shows components and their direct connections by shaded fields.

The evaluation showed that team structures and collaboration were significantly improved and the number of loops in the development process was reduced in the evaluation projects. Designers in industry stated an improvement of system interrelationship and less failures during the development process. On the other hand the amount of work for the preparation of the DSM matrix was assessed high.

An advanced step to be realised incorporates a computer-aided optimisation by identifying dependencies not only qualitatively but also quantitatively. The separated view on the system from different physical impacts must be separated in the DSM in a first step, resulting in a 3-dimensional matrix. The matrices contain e. g. only thermal or electromagnetical aspects to support specific simulations and to point out relations between the different views.

The development sequence of the different domains is a further aspect that will be considered in future projects in order to accelerate the development process by use of the DSM.

Design **S**tructure **M**atrix	Nature / material	Photo receiver	Bar coding	Photo emitter	Coding disk	Analysis IC	Shaft	Bearing	Housing	Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6	Joint 7	El. Current	Light current	Light / signal	El. signal	Thermal energy	Electromag.energy	External light
Photo receiver				←												←		←	←			←	←
Bar coding		←		←	←	←					←										←		
Photo emitter		←												←			←						
Coding disk			←							←	←												
Analysis IC		←	←												←					←	←	←	
Shaft					←				←		←	←											
Bearing	radial						←		←			←	←								←		
Housing	plastic	←		←	←	←		←					←	←	←	←		←	←		←	←	←
Joint 1	lasered		←		←																		
Joint 2	adhesive				←		←														←		
Joint 3							←	←															
Joint 4								←	←														
Joint 5				←					←														
Joint 6	adhesive					←			←														
Joint 7		←							←														
Light current				←					←														
Light / signal		←	←	←	←				←														
El. signal		←				←																←	
Thermal energy								←	←														
Electromag.energy		←		←	←																		
External light																							

structure

thermal view

electromagnetic view

Figure 1. Design Structure Matrix of a rotary incremental encoder

5. CONCLUSION

MEMS development differs significantly from development in other domains. It requires not only adapted development processes but also appropriate methods to enable the development of products with high quality at reasonable prices. The high grade of integration requires further support of the development process by appropriate methods. The working structure and the corresponding DSM were successfully introduced for this purpose in MEMS development and transferred to other interdisciplinary projects as well. The integration of interdisciplinary systems should be enriched by use of computers to gain a deeper understanding of the systems interrelations and to store and provide this knowledge for further projects.

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Working Structure and DSM as Integration Tools in Interdisciplinary Contexts

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Outline

1 Introduction
2 MEMS Technology and Products
3 Particularities of MEMS Development
4 Working Structure and Design Structure Matrix
5 Evaluation
6 Summary

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Introduction

Micro-Electro-Mechanical-Systems (MEMS) technology is:

- a recently emerging discipline
- with high rates of growth
- a key technology for the 21th century

Source: Texas Instruments

Source: FhG ISIT

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What is a Microsystem?

„Creating a microsystem means configuring minimised sensors, signal processing and actuators in a way that enables the system to „sense", „decide" und „react“. A crucial factor is that the operation works independently.

Source: Program "Mikrosystemtechnik 1994 – 1999" , German Ministry for Education, Sciences, Research and Technology

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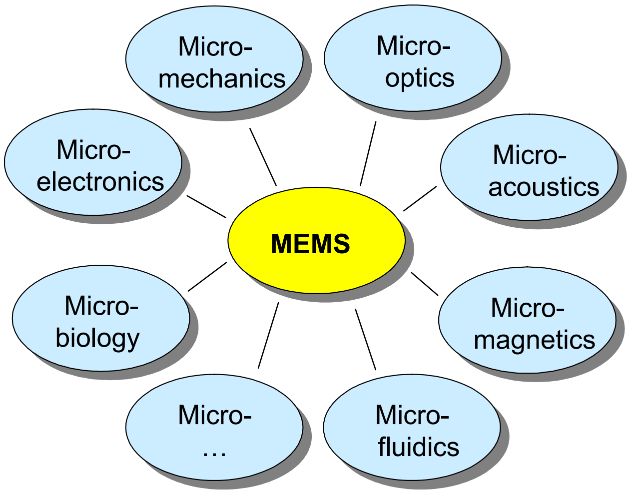
MEMS Disciplines



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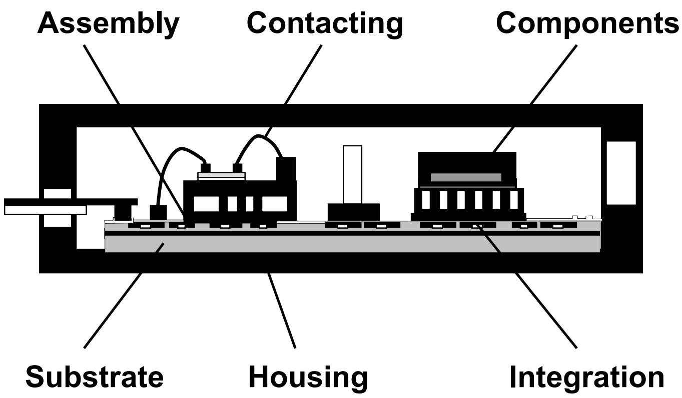
Fundamental Structure of MEMS



Source: Reichl

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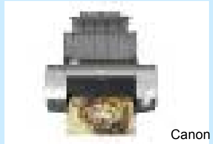
MEMS Products

Automotive Engineering

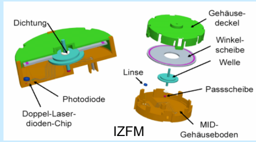
Medical & Biotechnology



Information Technology

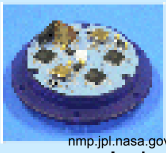
Environment Engineering

MEMS Technology

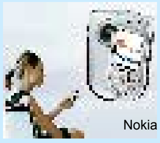


Automation

Intelligent Homes



Aerospace Industry



Telekommunication

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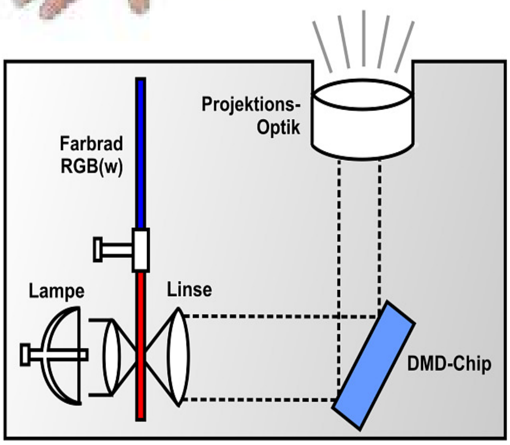
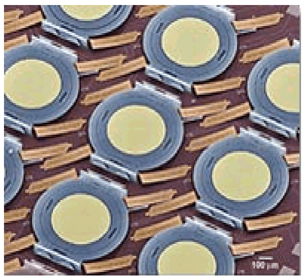
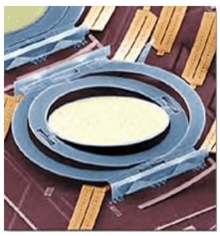
Example: Video Projector







Source: Chip.de; itwissen.info

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Particularities of MEMS Development

- Variety of technologies, materials and applications
- High complexity, continuous advancements
- Operation of the system requires operation of components and their proper interaction.
- Effects of miniaturisation as well as internal and external disturbing effects must be considered.

→ Consequences for the Development Process:

- Development of MEMS always means development of complex systems.
- Support for the handling with interfaces and disturbances is essential for the development of an operable system.
- Designers require tools to support the consideration of the system interrelationship.

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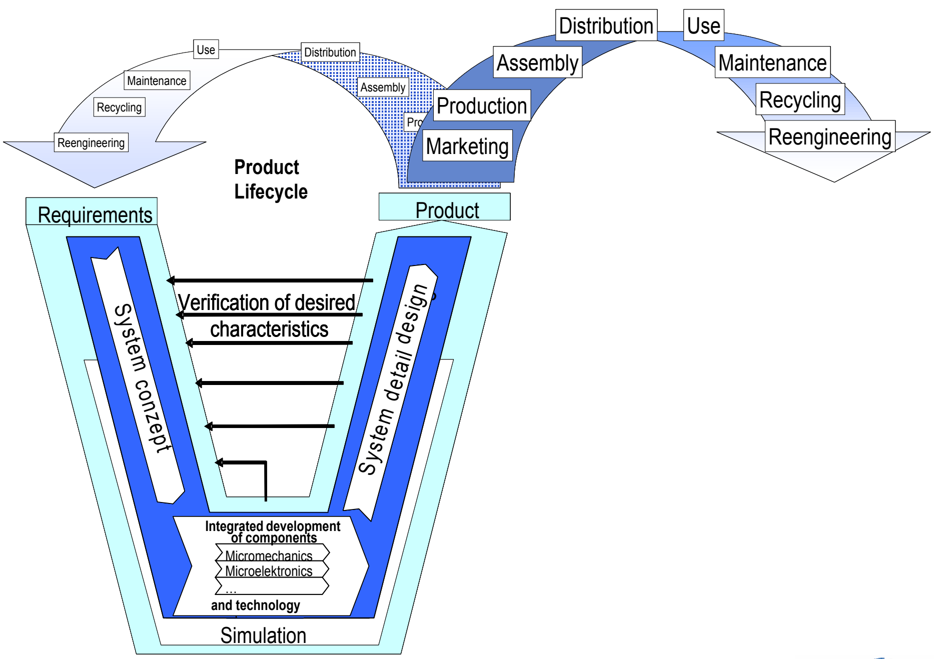
Design Process for MEMS



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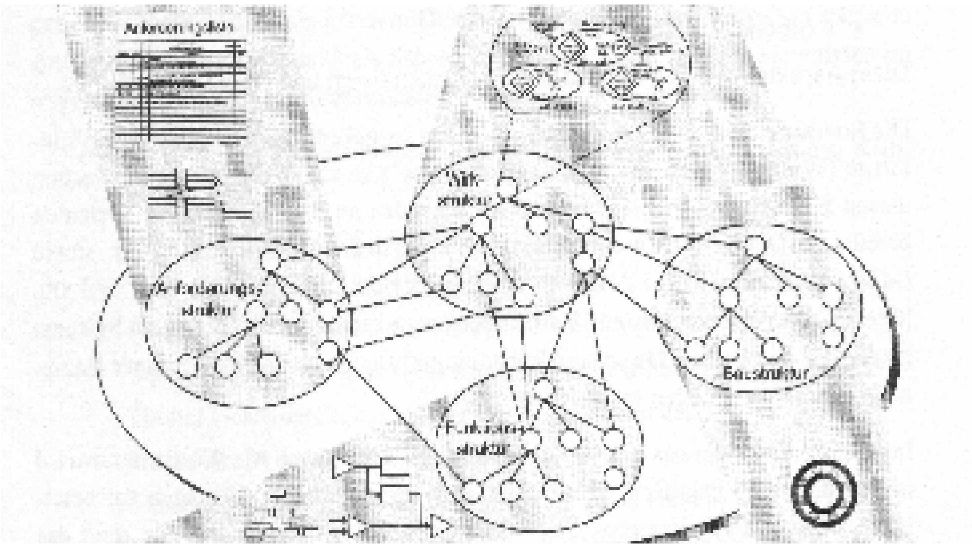
Models in the Development Process

Requirements **Principal solutions**



Working Principles **Construction structure**

Quelle: Köckerling

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Principle of Effect

Operation = f (geometry, material, operating parameters)

↓

Which **Principle of Effect** for a solution?

↓

Geometry-Function dependency	Material-Function dependency	Operating parameter dependency

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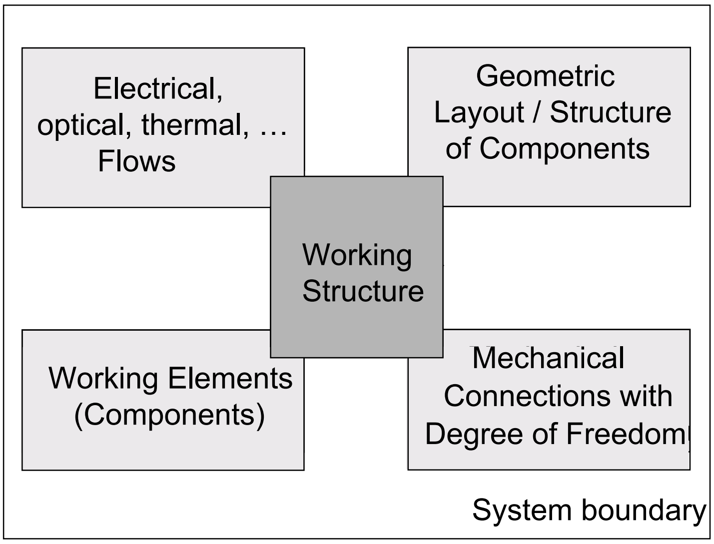
Working Structure



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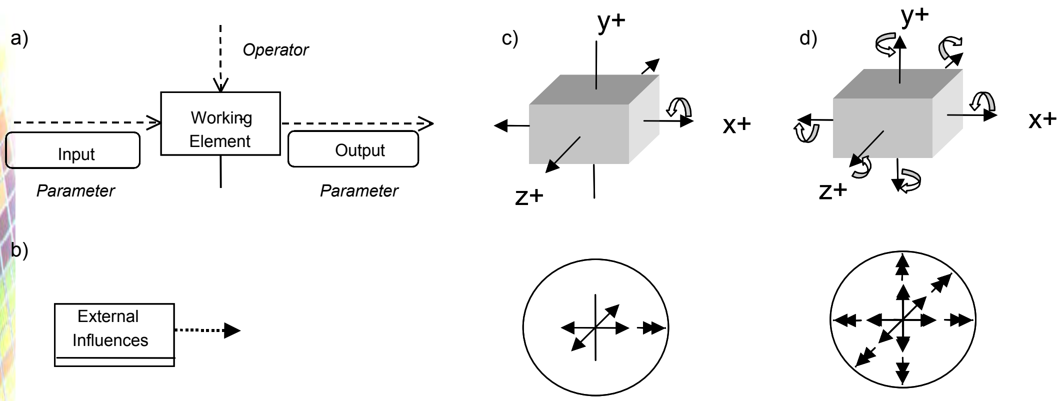
Elements of the Working Structure



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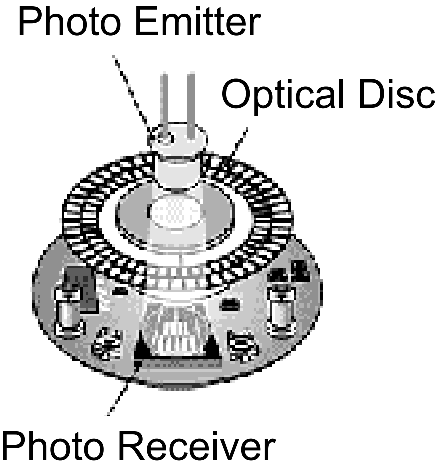
Example Rotary Encoder

Source: www.g-tronic.com

Source: IMAB Uni Braunschweig



Source: Eltra

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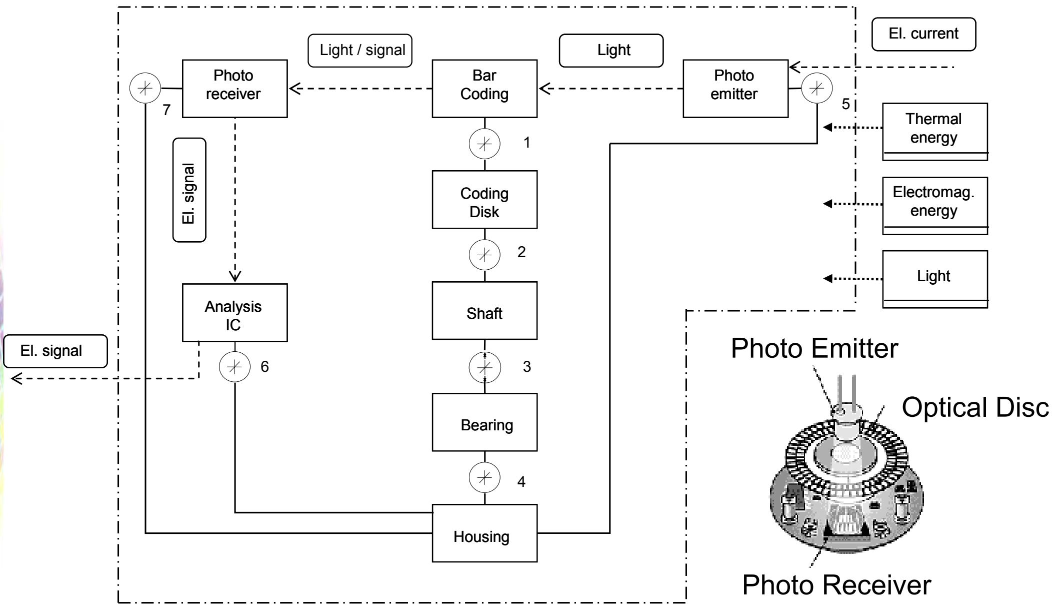
Rotary Encoder: Working Structure



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Design Structure Matrix: Different Views

Design Structure Matrix	Nature / material	Photo receiver	Bar coding	Photo emitter	Coding disk	Analysis IC	Shaft	Bearing	Housing	Connection 1	Connection 2	Connection 3	Connection 4	Connection 5	Connection 6	Connection 7	El. Current	Light current	Light / signal	El. signal	Thermal energy	Electromag.energy	External light
Photo receiver				←												←		←	←			←	←
Bar coding		←		←	←	←					←										←		
Photo emitter		←												←			←						
Coding disk			←							←	←												
Analysis IC		←	←												←					←	←	←	
Shaft					←				←		←	←											
Bearing	radial						←		←			←	←								←		
Housing	plastic	←		←	←	←		←					←	←	←	←		←	←		←	←	←
Connection 1	lasered		←		←																		
Connection 2	adhesive				←		←														←		
Connection 3							←	←															
Connection 4								←	←														
Connection 5				←					←														
Connection 6	adhesive					←			←														
Connection 7		←							←														
Light current				←					←														
Light / signal		←	←	←	←				←														
El. signal		←				←																←	
Thermal energy								←	←														
Electromag.energy		←		←	←																		
External light																							

structure

External light

thermal view

External light

electromagnetic view

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Evaluation

- Three evaluation projects:
  - Development of a inclination sensor
  - Development of a sensor for angel of rotation
  - Development of an air mass sensor

→ Findings:
  - Significant Advancement of communication between involved technical disciplines
  - Improvement of system interrelationship
  - Avoidance of development failures
  - High amount of work for preparation

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Introduction and Summary

Interdisciplinary product development requires particular attention to the integration of components of diverse disciplines. MEMS (Micro-Electro-Mechanical-Systems) technology is a representative example for technologies characterises by a broad variety of different interdisciplinary devices and shows typical problems and solutions of interdisciplinary design:

- MEMS require attention to their specific characteristics during the development process.
- Inadequate integration of MEMS systems causes failures.
- Design should therefor be supported by adequate methods.
- The working structure supports a system view and enables the designer to identify possible weak points.
- The Design Structure Matrix supports an intensive inspection of the system.