POLITECNICO
MILANO 1863

Computing Systems

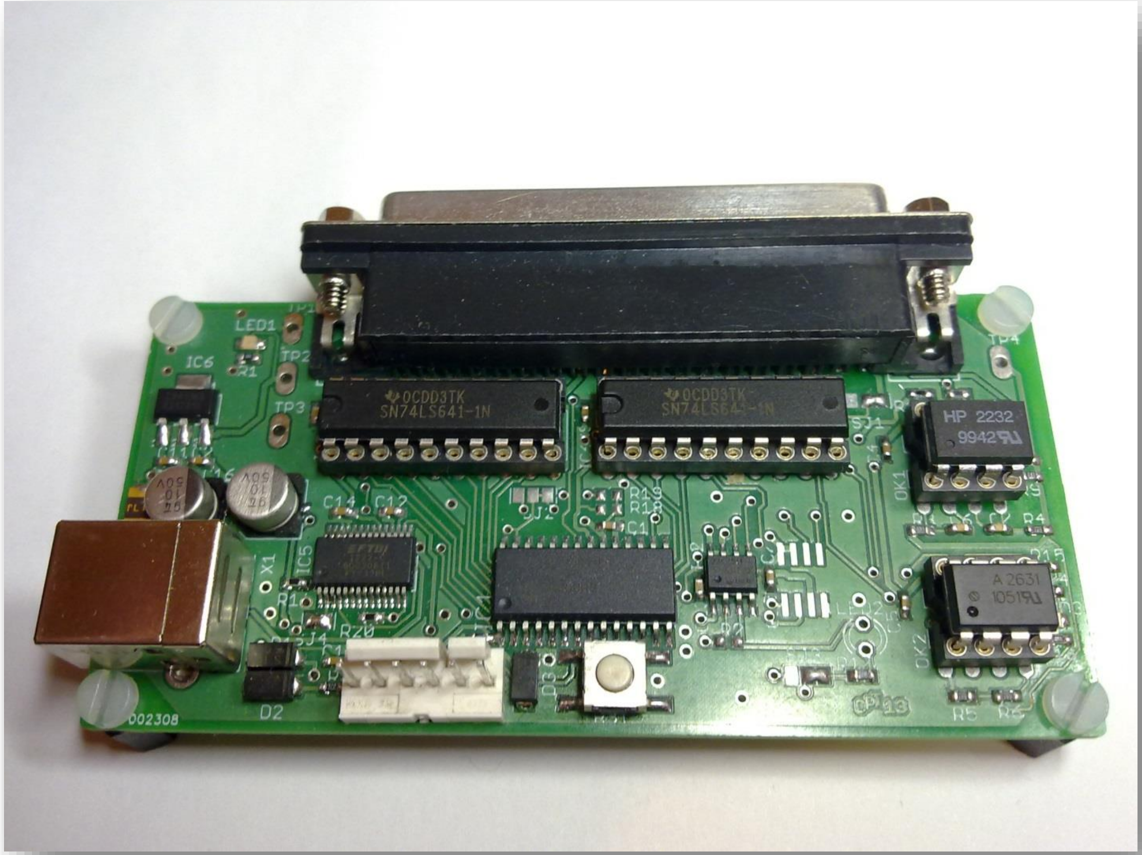
From Specifications to Prototype

Introducition

Goals

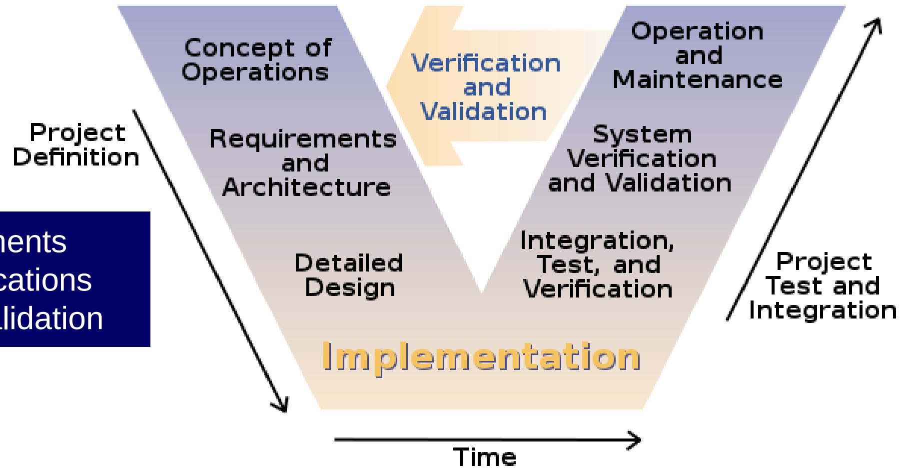
- Small application, to be fulfilled by a single or a small group
- Hardware and Software (split choices)
- Focus on prototype or, at most, pre-series level
- Must be economically viable

Example Application



Systems development life-cycle

- Decomposition of requirements
- Creation of system specifications
- High level requirements validation

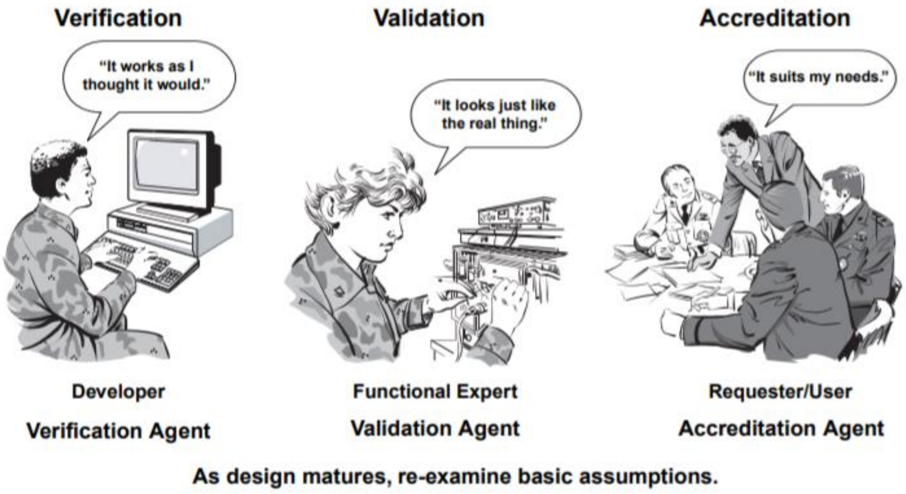


- Integration of parts
- Parts validation

- **Verification**: The evaluation of whether or not a product, service, or system complies with a regulation, requirement, specification, or imposed condition
  - verification is always against the requirements
- **Validation**: the assurance that a product, service, or system meets the needs of the customer
  - validation always against the real world or the user needs

System development

- Specifications
  - Requirements Specifications
    - Functions, performance, qualities, and constraints
  - Design Specifications
    - Architecture
  - Test Specifications
- Architectural selection
- Implementation
  - Buy, build, code
- Verification and test
- Validation



Specification

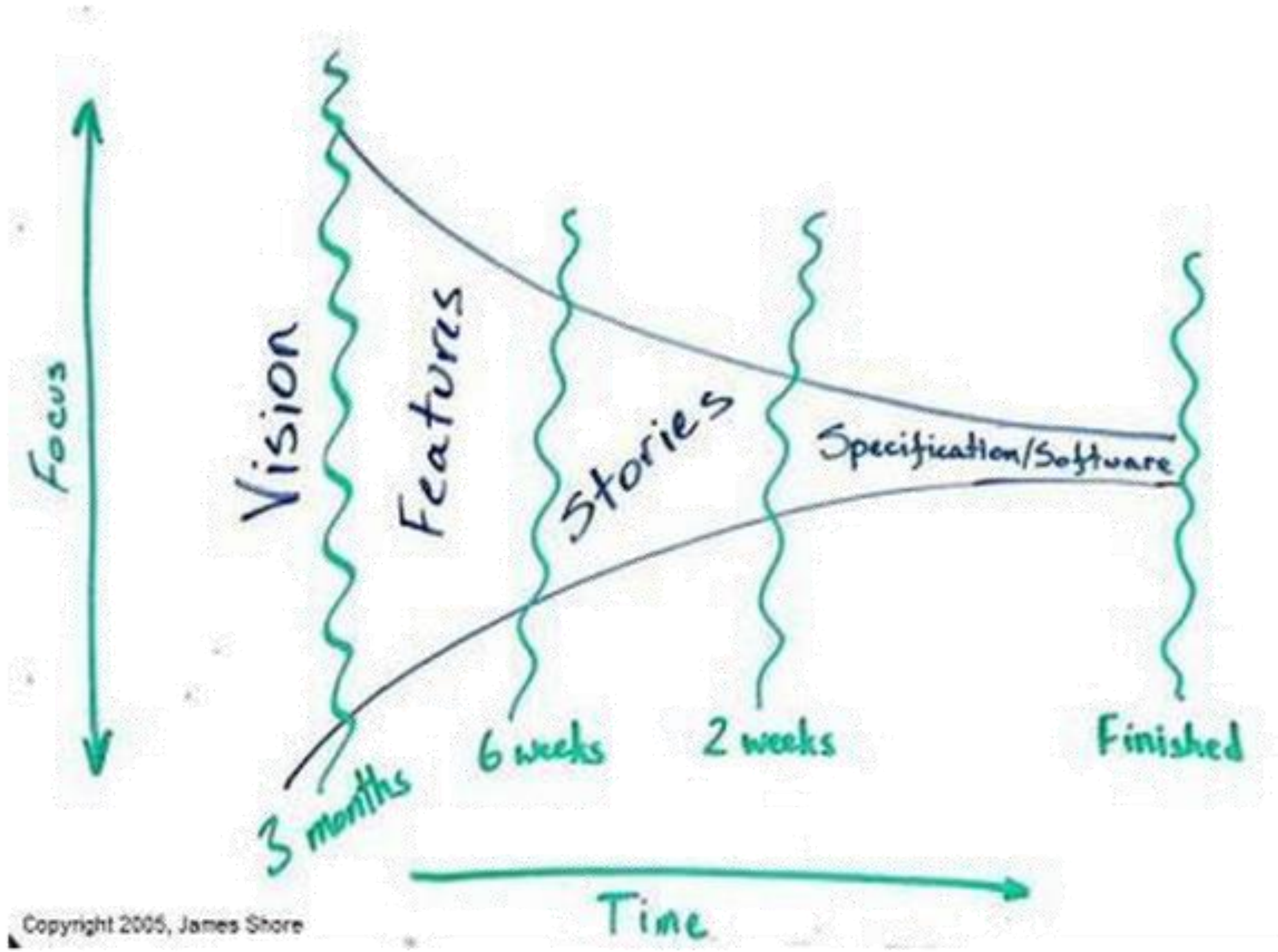
- Specification phase often overlooked.
  - This is the most common cause of delays and failures
- Specification has to include:
  - Functional specifications: **what a system is supposed to do**
    - From scenarios and story cards
  - Non functional specifications: **how a system is supposed to be**
    - Cost, testability, reliability, usability, documentation, …
  - **Customer Acceptance Tests**
- When moving in uncertain ground, sometime is better to make a “Feasibility Study”.
  - Often happens with innovative projects
  - Feasibility study it’s a smaller project on its own.

Specification

- Are specifications overlooked or just postponed?
- A point of view: **Latest Responsible Moment**
  - *"… the idea is that you want to put off decisions as long as you can. But it's the latest responsible moment, not the "last possible" moment; that wouldn't be responsible."*
    - *"… The reason we do this is **because putting off decisions is cheaper and results in better decisions**. Money we spend tomorrow is cheaper than money we spend today, and **between now and tomorrow, we'll learn more things about our environment and the decisions we need to make**. Plus, **things could change** so much that the decision isn't relevant any more. If we've spent the time and effort to make the decision, that money is wasted. So we wait as long as we responsibly can. …"*

http://www.jamesshore.com/Presentations/Beyond%20Story%20Cards.html

Specification



Specification

- It costs much less to invest time in good specifications at first than making mistakes or dealing with the customer after.
- At the end, specifications should to be “complete”
  - **Uncertainty and incompleteness are always present**.
  - Make a look forward if project is in phases: this could preserve a good relation with the customer
    - Typically for non-functional requirements
      - Example: include testing feature (also incomplete but leaving some space for future development) at the beginning could simplify future developments and avoid the reimplementation (cost reduction).
- Standardized procedures/forms help the completeness.
  - This requires experience and some personal and initial cost to learn the procedure.

Specification: functions

- Different and cooperative approaches
  - **User story** is one or more sentences in the everyday or business language of the end user or user of a system, that captures what a user does or needs to do as part of his or her job function.
    - it captures the 'who', 'what' and 'why' of a requirement
  - **Scenario analysis** is a process of analyzing possible future events by considering alternative possible outcomes
  - **Use case** is a list of steps, typically defining interactions between a role (in UML the "actor") and a system, to achieve a goal. The actor can be a human or an external system.

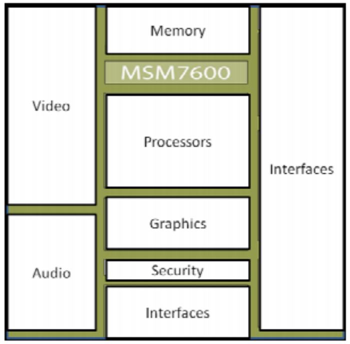
Wikipedia

Architectural selection

- Design space analysis
  - Based on specifications
  - Drivers are performance (first) and cost
- Options
  - Hardware/software partitioning (Performance vs flexibility)
  - Analog and digital
  - FPGA vs Micro
  - Data transfer (Wireless vs wired communications, Bit rate, memory, …)
  - Modularity
- Other
  - Agreements with components providers
  - Designer knowledge (Development tools)

System Design

- “Divide and conquer” philosophy
  - “Divide and conquer” philosophy – 7 blocks
  - **Effective solution**: block that is completely designable or COTS
- Rule of 7
  - At any level of hierarchy, the number of blocks in the design is not arbitrary.
    - In the 1950s, two psychologists published a paper called "*The Magic Number Seven Plus and Minus Two*". In this paper, they demonstrated that the human mind can hold seven objects (plus and minus two) at any one time.



A top down approach

- General Strategy: design around the most complex parts, usually a μC and/or a FPGA.
  - FPGA is a complex block that needs to be partitioned into sub-blocks
    - Clock domains and asynchronous communication channels
    - Functions inside clocks domains,
    - Power islands and power management systems
- Use the one that fits most the application. Some times you have to give up the ones that you know well or have available know-how.
  - This involves the availability of proper IDE tool, compilers, debuggers….

Top Level Choices

- Make Vs Buy
  - Is it the case to design a sub-circuit/interface or to buy a component doing that? Should we do it in software, buy a library or buy/make an HW circuit?
  - “Buy” paradigm needs attention during the functional decomposition: the component has to be an “effective solution”
    - Designer has to know that a component exists.
      - Important: a designer has to be continuously up to date (new component, new feature, bugs, drawbacks and limits, …)
  - Other constraints: special agreements with component providers or the customer.
- In general the driver is the NRE (Non Recurrent Engineering cost) vs number of produced pieces
  - NRE includes tools, learning (components, tools, …),

System Design

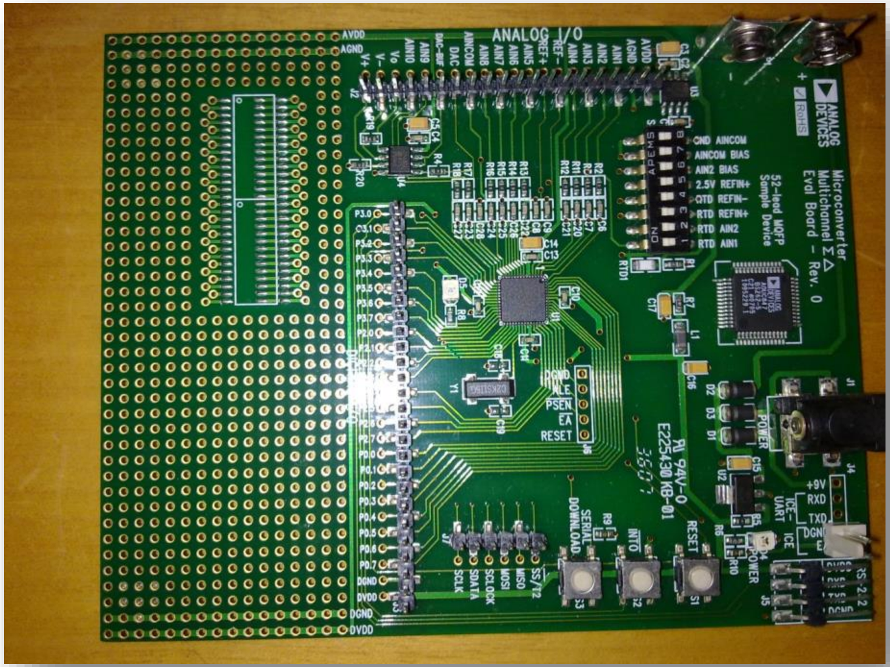
- Interface Design
  - The partitioned system requires to design the interfaces between them
    - **Tightly coupled** systems have interfaces that essentially connect the elements of the system into one single, flat unit
      - More efficient than loosely coupled systems
      - Allow global optimization
      - Local problems can become global problems
    - **Loosely coupled** system, on the other hand, uses interfaces to isolate the different units in the design
      - Isolate the complexity of the sub-systems
      - Local problem remain local
      - More robust

Feasibility

- It can be useful to early prototype most critical parts on a dedicated board
  - A memory, an interface, an analog circuit, ….
- Often Microcontroller manufacturers or their associates sell **development kits** or **evaluation boards** for rapid prototyping.
- In many cases all what you need to do is making a small “daughter card” or “piggy back” for your specific I/O
- This can be done on a **proto board** as well, with wire wrap, etc…
- Proto board keeping standards **can be reused**

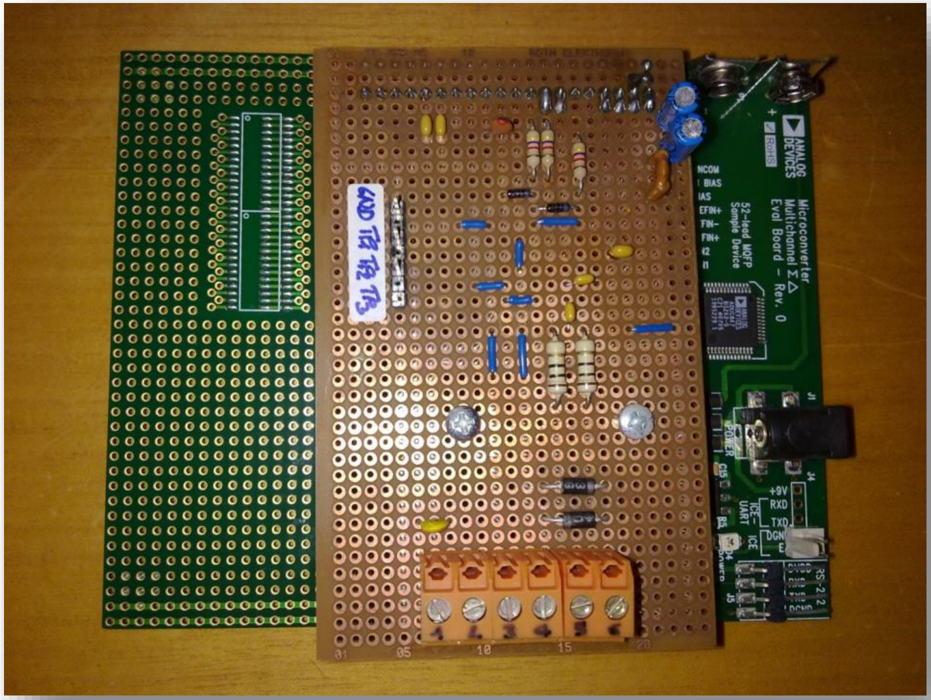
Evaluation Board

- An example of evaulation board
    - Analog Devices



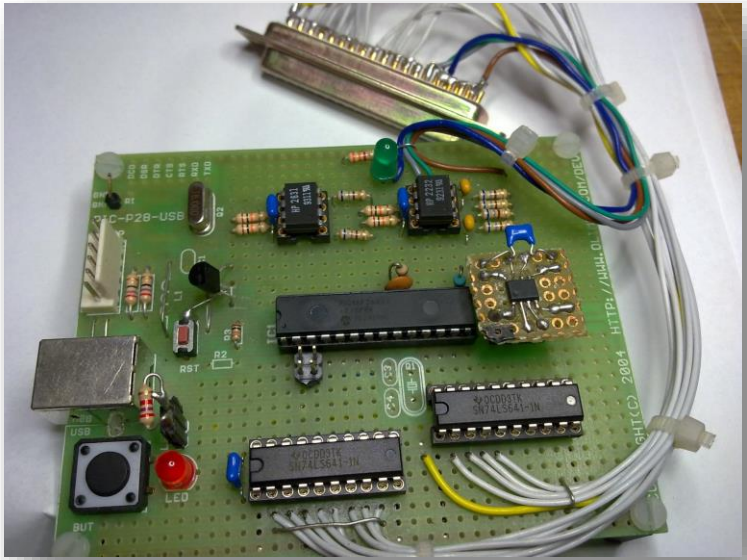
Evaluation Board

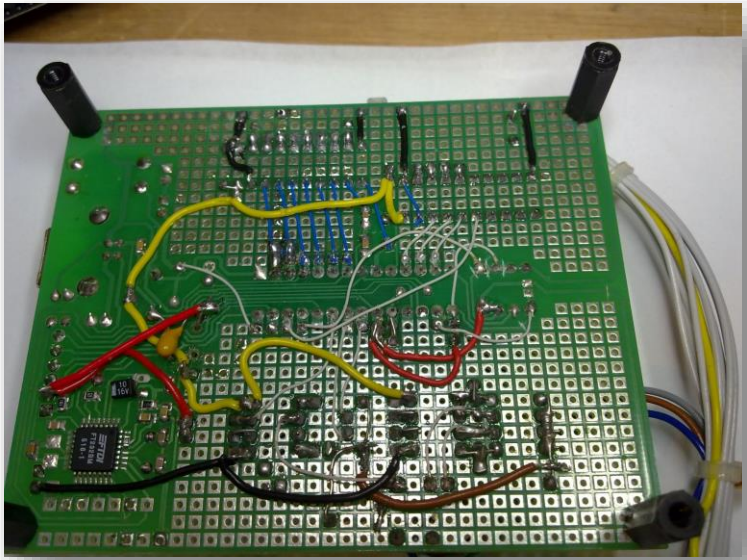
- An example of evaluation board with *piggy back*



Proto Board

- An example of proto board

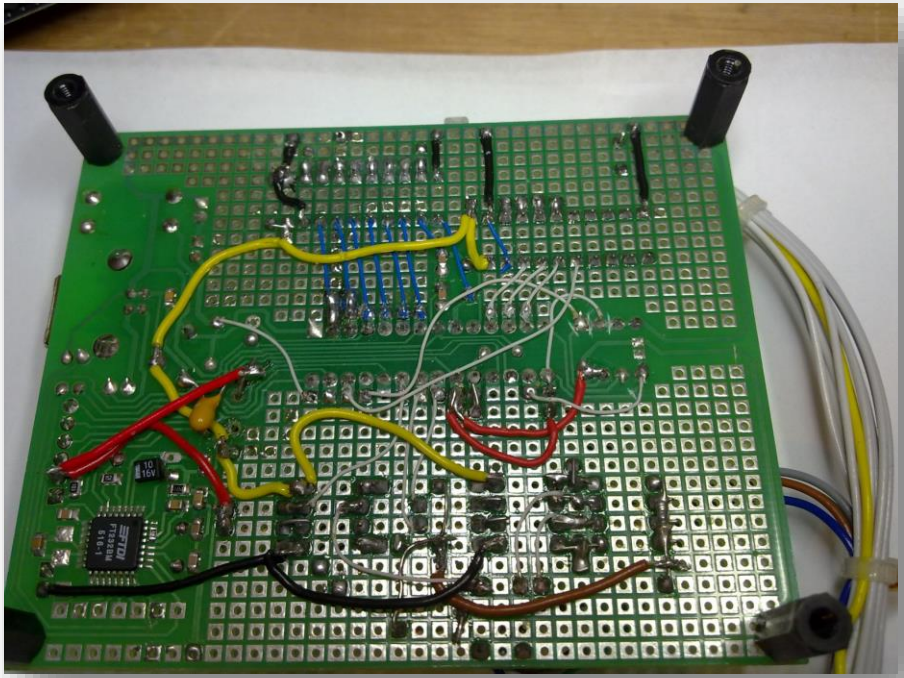




(wired)

Proto Board

- An example of proto board (back)
  - **wired**

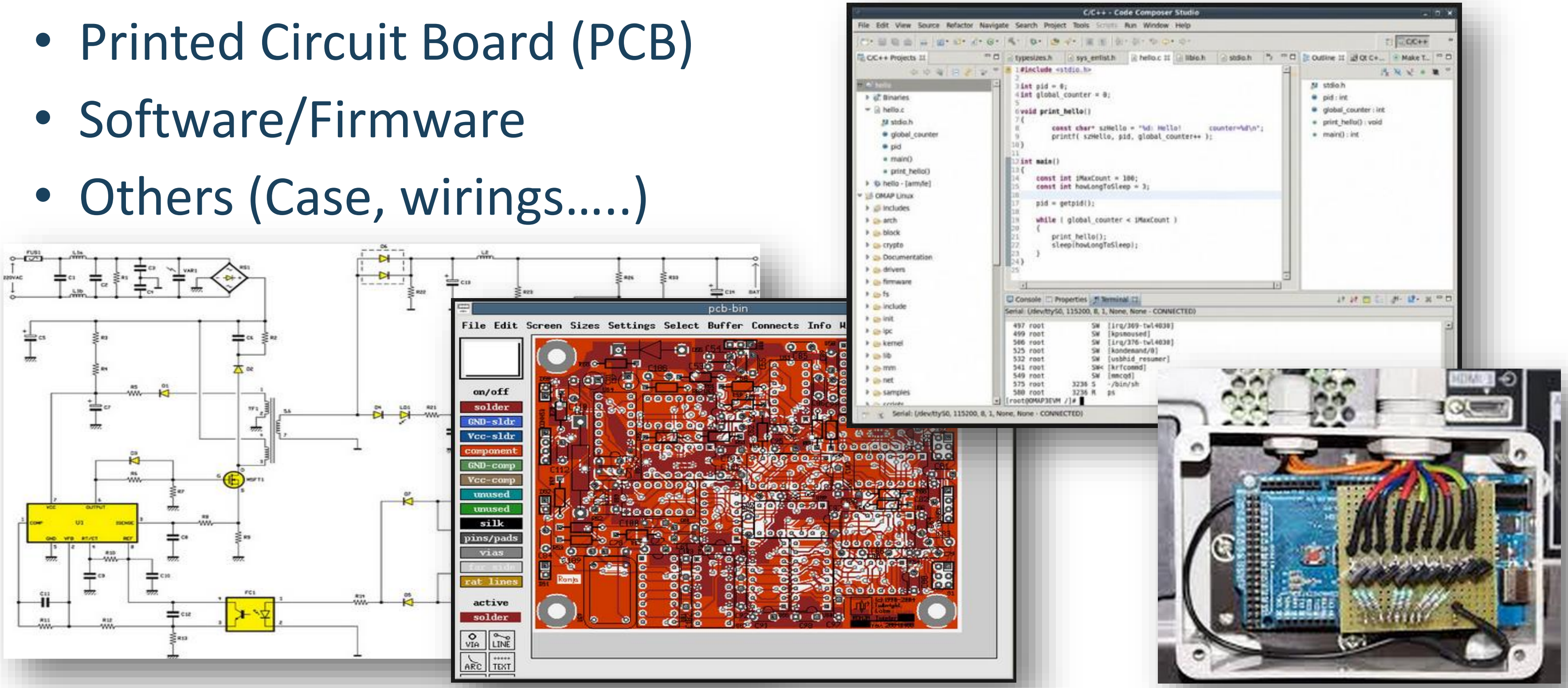


Early Test and Project Planning

- **Developing is an iterative process**.
- Main blocks have to be tested alone as soon as possible, then test sub-assemblies, and so on.
- The later you discover a problem, the more costly will be the solution.
- Sufficient time for testing must be planned in the project budget.
  - An example breakdown can be, very roughly:
    - 20% specification,
    - 30% development,
    - **50% testing**.

Design Break Down

- Electric/Electronic Schematics
- Printed Circuit Board (PCB)
- Software/Firmware
- Others (Case, wirings.....)



Microcontroller Choice

- Manufacturer
  - Overview on their site to drive the component selection; Typically the number of bits bit is the first driver, then others like core, interfaces, frequency, memory, application
- Embedded memory
  - Data RAM, Code Flash/ROM/EPROM, User Flash/E2PROM
- I/O pins and integrated interfaces/features
  - UART, I2C, SPI, USB, IRQ pins, Comparators, ADC converters, PWM, Timer/Counters, RTC, CRC generators …
- Speed, power and energy
  - Clock frequency, energy saving features, heat, power supply
  - Max clock frequency is often Power Supply related
- Other
  - operating temperature (-55 to +125, … -50 to +80), case, compatibility, certifications,…..

Microcontroller choice

- Example TEXAS (www.ti.com/lsds/ti/microcontroller/overview.page)

Microcontrollers (MCU)

Product Tree

- **Microcontrollers** (687)
- **MSP430 Ultra-Low Power 16-bit MCUs** (420)
  - 1 Series (32)
  - 2 Series (57)
  - Value Line (49)
  - 4 Series with LCD (88)
  - 5 Series (92)
  - 6 Series with LCD (59)
  - FRAM Series (21)
  - Low Voltage Series (3)
  - RF SoC Series (18)
  - Fixed Function (1)
  - Extended Temp (47)
- **C2000 32-bit Real-time Control MCUs** (120)
  - C28x Piccolo MCUs (68)
  - C28x Delfino Floating-point MCUs (11)
  - C28x + ARM Cortex-M3 MCUs (12)
  - C28x Fixed-point MCUs (29)
- **Tiva ARM MCUs**
  - C Series for Connected MCUs (70)
    - TM4C123x Series (50)
    - TM4C129x Series (20)
- **Hercules Safety ARM MCUs** (80)
  - RM4 ARM Cortex-R4 (35)
  - TMS570 ARM Cortex-R4 (42)
  - TMS470M ARM Cortex-M3 (3)

Overview | Products | Tools & Software | Technical Documents | Support & Community | Applications | Analog Integration

Overview for Microcontrollers

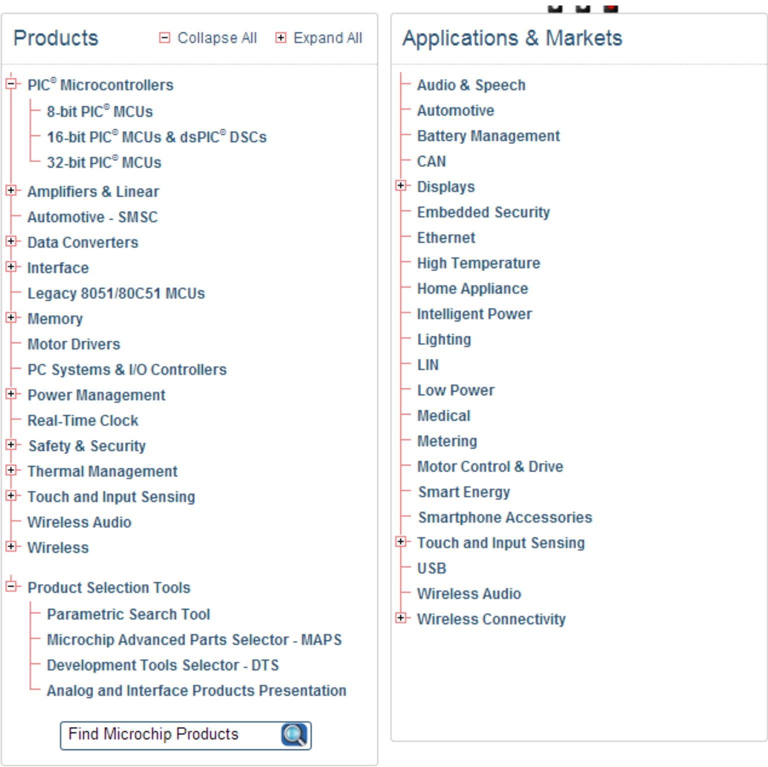
16-bit MCUs	32-bit MCUs	32-bit ARM® MCUs
MSP430™ Ultra-low Power 16-bit Microcontrollers	C2000™ 32-bit Microcontrollers	Tiva™ ARM® Cortex™-M Microcontrollers Hercules™ Safety ARM® Cortex™ MCUs
Core	**Core**	**Core**
MSP430	C28x	ARM Cortex-M3
	C28x + Cortex-M3	ARM Cortex-M4
		ARM Cortex-R4
Frequency	**Frequency**	**Frequency**
Up to 25 MHz	Up to 300 MHz	Up to 220 MHz
Memory (KB)	**Memory (KB)**	**Memory (KB)**
0.5 KB to 512 KB Flash	16 KB to 1 MB Flash	32 KB to 3 MB Flash
FRAM	Up to 512 KB RAM	
Applications	**Applications**	**Applications**
Energy Harvesting	Alternative Energy	Automation & Process Control
Portable Consumer	Digital Power	Automotive & Transportation

Microcontroller choice

- Example TEXAS
  - Products – Parameter selection

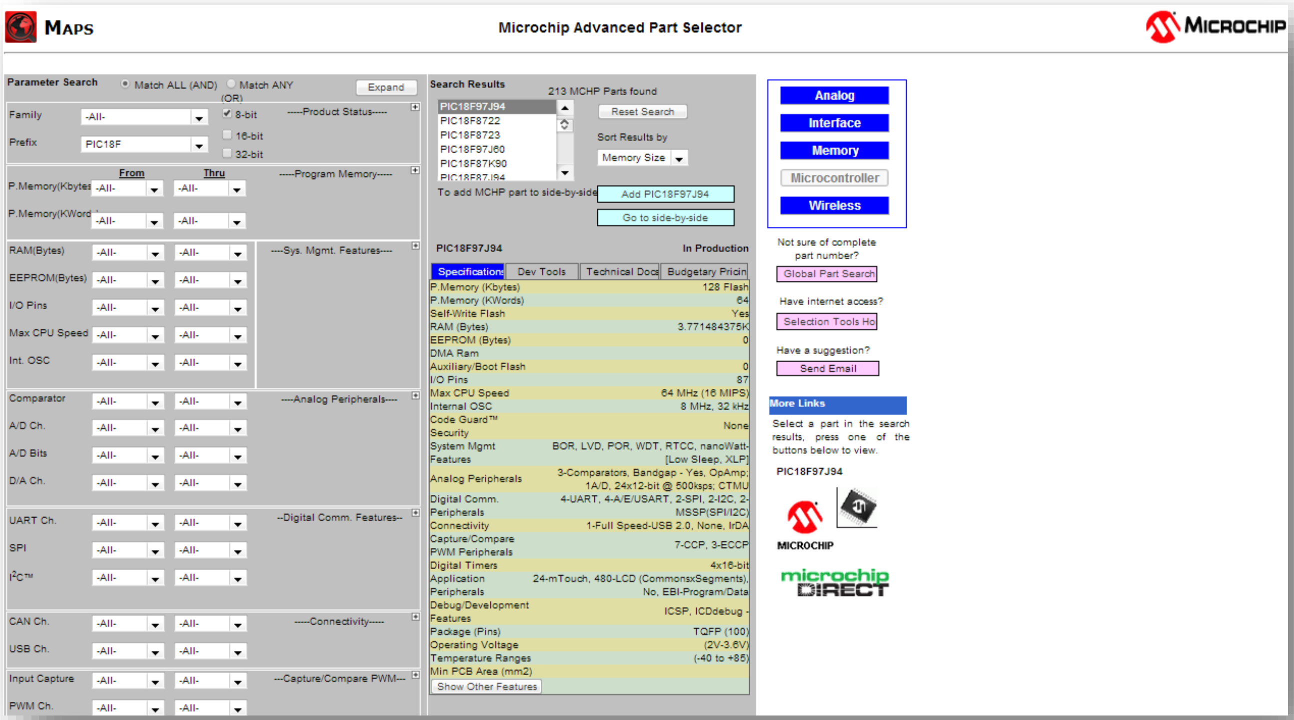
Microcontroller choice

- Example MICROCHIP (www.microchip.com)



Microcontroller choice

- Example MICROCHIP
  - Product selection tool



Microcontroller choice

- Other considerations:
  - Previous successful designs
    - Building Blocks
  - Maturity/Obsolescence/Availability
- Price
  - Depends of volumes

PIC18F8723T-I/PT — View Datasheet

Lead Count: 80 | Package Type: TQFP | Temp Range: -40C to +85C | Packing Media: Tape and reel

Standard Pricing:

Quantity	USD per Unit
1-25	11.68
26-99	10.71
100+	9.69

Estimated Volume Pricing:

Quantity	USD per Unit
1000-4999	8.91
5000+	8.48

Request Quote for High Volume Pricing

In stock (ships immediately): 6,000
When can I get more?
Available in Multiples of 1200
Quantity: ADD TO CART

  - Note: be careful of initial repository cost.
- Hint: Read carefully the *data sheets* … **and ERRATA CORRIGE!!!**

Top level choices-hints

- At early stages **overdesign**
  - Keep some clock speed, I/O, memory and interfaces as spare (i.e. 30%)
- Point to a family of µC or FPGA where you can easily downsize when design is firm.
- Build-in test features from the beginning
  - Electrical: test points
  - Supports: serial interface for debug messages, power and status LEDs and/or a simple Hex Display.
  - Functional: Software routines to tests the system

Design Break Down

- Component selection
  - BOM (Bill of Material) optimization; the part list has to as uniform as possible
    - E.g. one resistor per type is **too** inefficient.
  - Obsolescence Analysis
  - Choose a part that shows a large inventory and optimally is available from multiple vendors and distributors
  - Component family and pin to pin compatibility
    - Q: *I'm currently using EP3C16F484 in my project, and now I want to upgrade to EP3C40F484, need I design again the schematics and relay out the PCB? or I can directly use a EP3C40F484 to solder on the die of EP3C16F484 on the board.*
    - A: *You can use the EP3C40 in place of EP3C16* ***if migration compatibility has been bared in mind during pin placement.*** *See the Migration Devices setting in Quartus assignments. …* ***Select the device you want migrate*** *to in Quartus device settings. Then go to pin planner and select "Pin migration view" in the view menu. Here you will see the pinout of the FPGA devices and you can highlight the differences.*

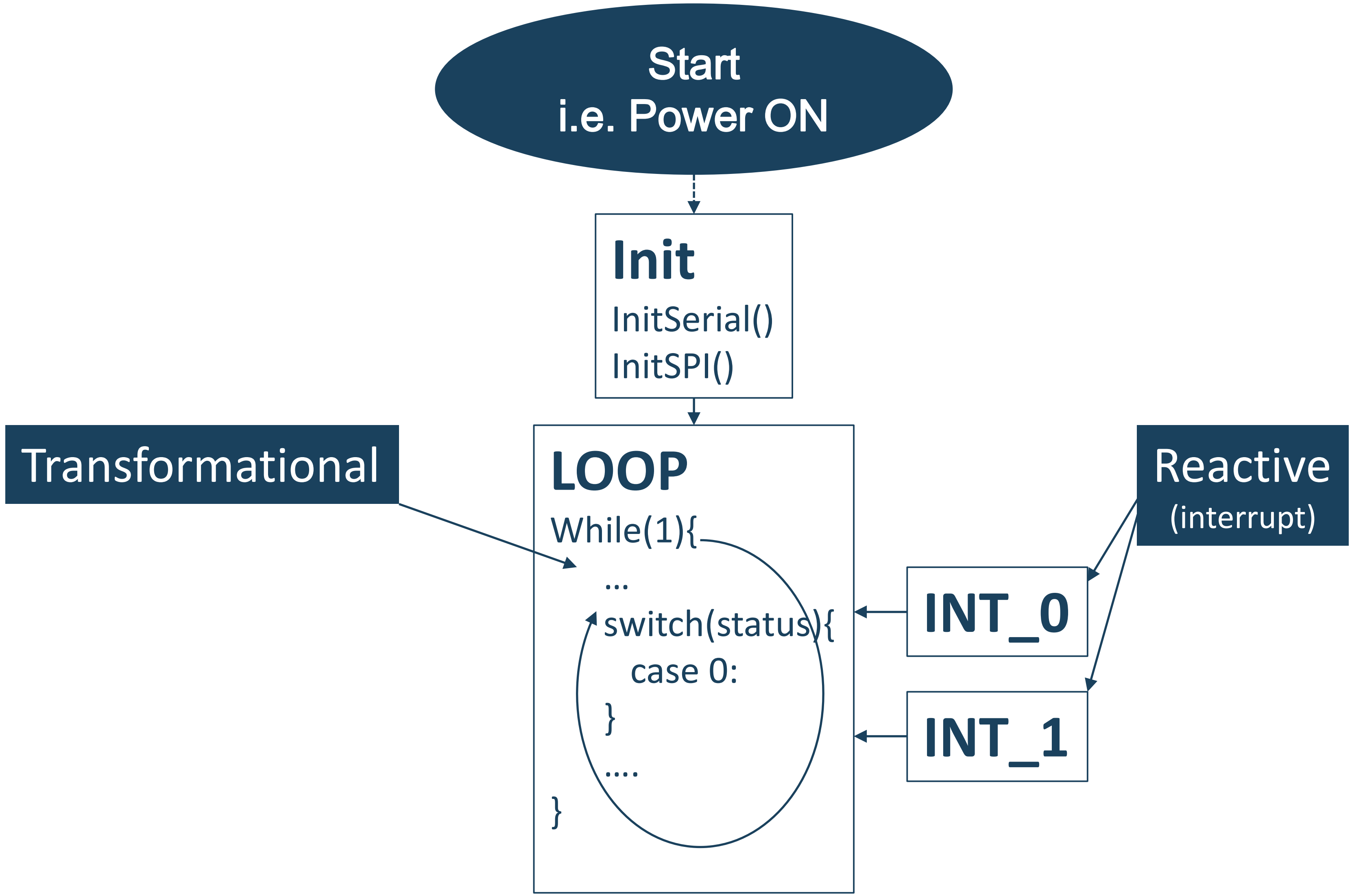
Hardware Design steps

- Schematic
  - Design the circuits according to function, datasheets, rules, environment. Remember: real components not their ideal model!
- Simulation (whenever is possible)
  - Simulate part of the analog circuit is sometime necessary, especially when is the first time. use "reference design" is a good starting point but simulation is a good design practice.
- PCB (printed circuit board)
  - Library creation/update (when necessary)
  - Place (mostly manual; it needs a lot of experience)
  - Route (manual and/or auto)
  - Output in standard format (Gerber…)

Schematics

- In-Board bus:
  - Parallel : Fast, but getting complicated with speed (crosstalk, skew,..), resources hungry (PCB space), old fashion.
  - Serial: Now very simple and powerful, i.e. **SPI, I2C** . Lots of new devices (memories, displays, amplifiers, converters, transceivers, sensors) available that can be easily connected together on a single bus.
- Off-board bus:
  - Mostly serial, with one or more “twisted pair” of conductors : CAN (Open), RS485/422, Profibus, IEEE 802.3x (also on Fiber)
  - Increasing use of wireless technologies: IEEE 802.11(WLAN), IEEE 802.15 (WPAN,BT, ZigBee.).
  - In both cases dedicated interface chips are available off-the-shelf (COTS), often integrating more layers of the protocol besides the physical one.

Software - Loop



SW - Loop

- After initialization (set up of μC core and peripherals) the SW enters an infinite loop.
- From this point it is deterministically event driven by a State Machine.
- Scheduling problem: loop cycle timing must be verified. Often this is very complex, but at least a worst case analysis can be done.
  - Hint : use a short output signal to mark the start /end of a task, so you can easily measure it i.e. with an oscilloscope. A “blink” of a LED can serve this scope.
- Beware of traps and deadlocks if the machine is complex.
  - Hint: use a mnemonic to identify the state (i.e. an enum type) in place of numbers

SW - Interrupts

- Most common way to control real time events in embedded design.
- Usually every peripherial can generate an interrupt when an event occours.
- Interrupts can have priority and be multi-level.
- The way that the specific µC (and the compiler) handles them must be fully understood. Usual good practices should also be used when writing interrupt routines or very unstable behaviour can result.

SW - Interrupts

- Often the source of the interrupt is an hardware timer that has expired.
  - This is the way that events are regularly paced at precise intervals (clock interrupt) and how scheduling is timed in OS.
- So all our system can be syncronized around such a timer, if we need.
- Many µC provide special timers to do so with precision or even have an integrated RTC

SW - Debugging

- Conditional compilation can be used to build special “debug” versions at later stages. So error messages or special output can be sent when a particular event occours.
- As mentioned before is very helpful to have a serial interface and / or a display for debug purposes built into the design. A 2 digit Hex display takes only 8 bits of I/O. With that you can i.e. show 256 different statuses / errors.
- Even a few LEDs can be incredibly meaningful, do not forget them! If you have leftover I/O pins, that is a great way to make good use of them.

Full System Testing

- Once HW and SW are reasonably developed, the full system must be tested.
- This assumes that the system is connected in the environment where it will operate.
- In any case, the real working environment must be simulated as finely as possible and and lot of time must be allowed (and calculated in the development budget) for test. Some bugs will emerge only after long count values accumulate in μC registers or in memory, or when particular environmental (temperature, pressure, EMI, network traffic) conditions are reached.

Bibliography

- [1]J. Catsoulis, Designing Embedded Hardware, 2° Ed. O'Reilly, CA, USA 2005
- [2]W. Stallings, Data and computer communications, 9° Ed, Prentice Hall, NJ, USA 2010
- [3]J. Corbet, A. Rubini, Linux Device Drivers 2° Ed., O'Reilly, CA, USA 2001
- [4]C. A. Shaffer, A Practical Introduction to Data Structures and Algorithm Analysis, 2° Ed. Prentice Hall, NJ, USA 2001
- [5]B. Kernighan, D. Ritchie The C Programming Language 2°Ed. Prentice Hall, NJ, USA 1988

POLITECNICO MILANO 1863

Computing Systems

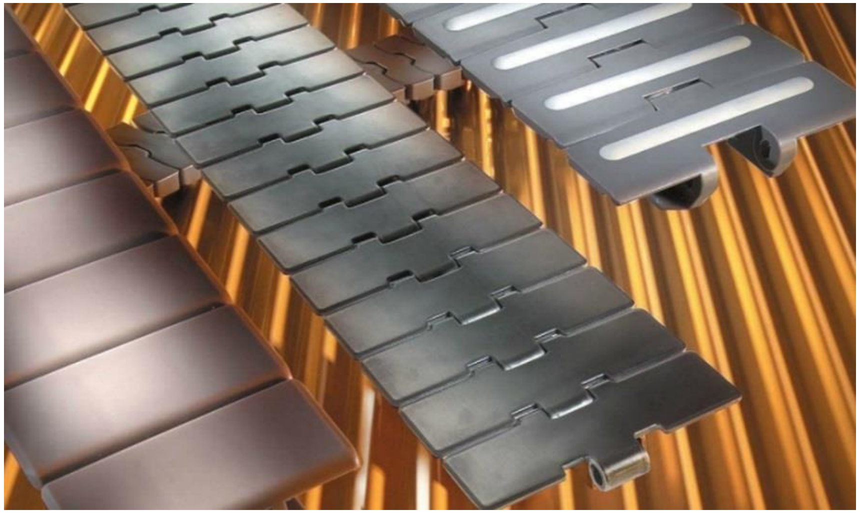
Chains Elongation
an example of project

Part 1: Problem Definition

Ver. Sep 20

Product

- MatTop & TableTop Chain
  - https://www.youtube.com/watch?v=du3PG4trb_s&list=PL9DDEB04D87D2A5BF
- Measure Chain Elongation:
  - https://www.youtube.com/watch?v=W5eo9hmZPJs
  - Plastic and Metal

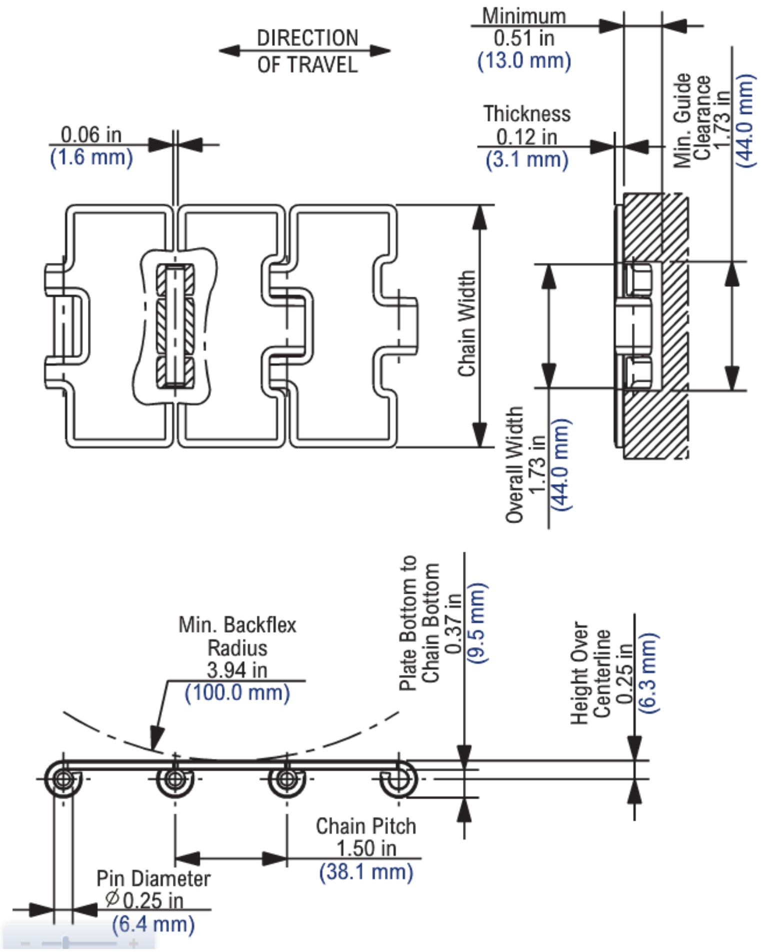


Product

Photo shows 60S31XM TableTop® Chain in 60 Series Stainless Steel material

Chain Information

Chain Width			Min. Side-flex Radius		Approximate Weight	
desc	in	mm	in	mm	lbs/ft	kg/m
3 1/4	3.25	82.6	-	-	1.84	2.74



Requirements

- Requirements
  - Possibly wireless
  - Possibly energetically autonomous
  - Maximum cost of the solution: 20€ per “sensor”
    - industrialized product – 100.000 sensors/year
  - Maintenance:
    - Self-calibration
    - Fault-detection capability
    - Single wing elimination

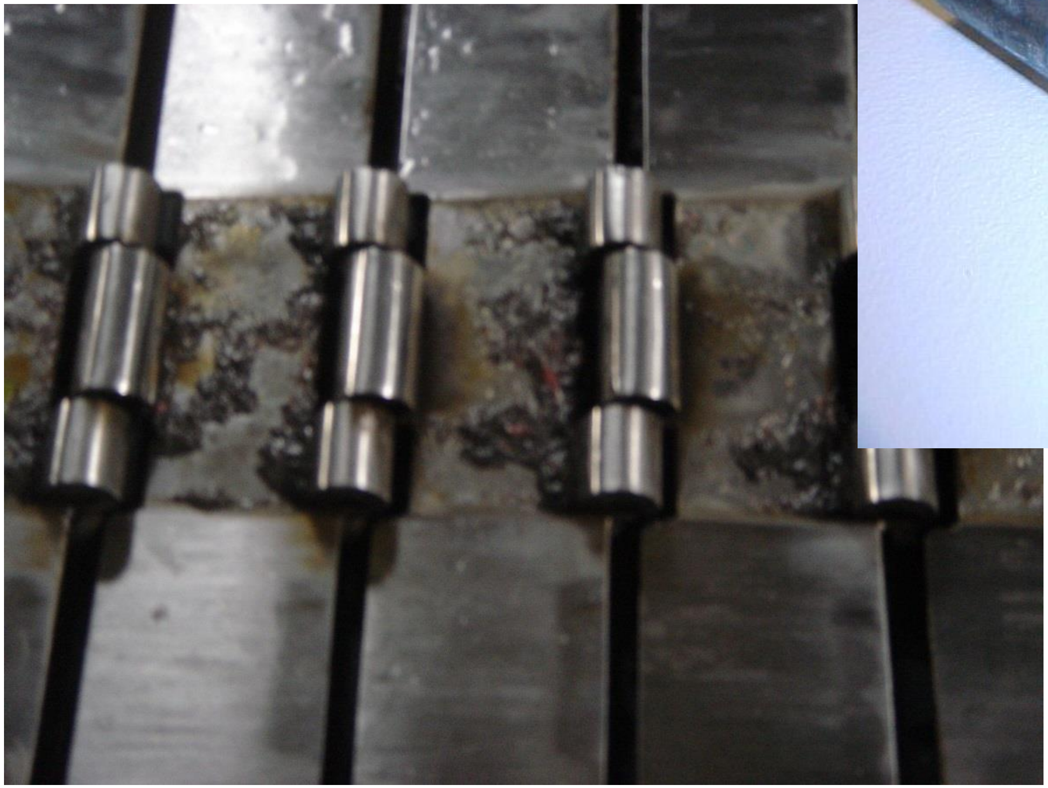
Specifications

- Specifications
  - Life time: from 1 year to 10 years
  - Dragging feature:
    - Angular speed:
      - Constant in the steady state, but it could change in time
      - Transitory time unknown
      - The angular speed is controlled by a gear-motor
    - Plastic elongation of the chain (variable and unknown)
  - Environmental conditions:
    - Water based and/or silicon based lubricant;
    - Presence of broken glasses;
    - Powders from glass, plastic, paper, metal;
      - The silicon land the powder of other products make an abrasive mix.
    - residues of bottled products (beer, soft drinks, sugar)

Specifications

- Specifications
  - Chain sanitization with strong acids or bases
    - impact on plastic chains;
    - intermittent and for short times;
  - Cleaning at high pressure water
  - Typical temperatures of the environment: + 25 ° - + 40 ° C
  - Typical speeds: from 5 m/min (0,83 m/sec) to 120 m/min (2 m/sec)
  - Flow of production: from 5000 to 100,000 products/hour
  - Top surface in contact and friction with bottles; Bottom surface in contact and friction with PE guides (generally)
  - Maximum Elongation (recommended) 3%
    - typically due to pin wearing

Wearing Effect



Computing Systems

Chains Elongation
an example of project

Part 2: Detection system - Sensors Identification

Sensor Analysis

Sensor Analysis

3. Acoustic Solutions

Abstract

This section explores the solution space related with "sound and waves"; in particular, the analysis will cover sensing unit like accelerometers, microphones and ultrasounds.

Sensor: Accelerometer (estimation through vibration measurement)

Accelerometers are a sensor that can be used to reveal the vibration of an objects surface; contrarily to microphones, accelerometers are more tolerant to environmental noise. Accelerometers mainly work on the measurement of an accelerated-mass inertia; the mass is connected with an elastic element and a sensor (e.g. piezoelectric or resistive) measures the relative movement of the mass with respect to fixed structure of the accelerometer. Due to the intrinsic inertia of the mass, when an acceleration occurs the mass moves by a quantity proportional to the acceleration; this movement is measured and transduced into an electrical signal.

- **Operating Principle**: this approach interprets the vibration induced by the chain on a mechanical part of the system (where the sensor is allocated) as a specific physical variable to be measure. An alteration of the characteristic vibration of the chain, during its life, could be to recognize as both a links mass modification (a change of thickness) and a chain peripheral speed.
- **Market Availability**: accelerometers are widely diffused and used in many different environments.
- **Technical features**: accelerometers works in a wide range of temperatures. Accelerometers are extremely robust, they have a wide dynamic range and they are available in many configurations; due to these features, they are suited for various level of environment criticalities: oils, dirt, extreme temperature, immersion and electromagnetic noise. It is worth noting that sensors choice has to be tailored to the specific application domain since its life-time depends on it:
  - Vibration amplitude
  - Frequency range: upper limit is dependent from mechanical rigidity and seismic mass of the accelerometer, lower limit is dependent from the electric features (cutoff frequency and discharge time constant) of the internal sensor of the accelerometer (the one that measures the movement of the mass).
  - Environmental conditions

Most of this type of sensors works with currents range from 0.1mA to 10mA and a power supply of less than 10V.

Accelerations are popularly measured in terms of g-force where g is the acceleration due to gravity at the Earth's surface; in term of SI (International Systems of Units) 1g = 9,80665 m/s^2.

- **Notes**:
  - Extra mechanical contact could be required.
  - Not influenced by environmental noise, or at least less influenced than microphones.

Elongation Measurement

Elongation, in this case, could be measured using an **Anomalous Element and 2 sensors**: the anomalous element, in this case a link (or more depending on the measure method adopted), should be produced using a different material, or a slightly different shape (maybe drilled) so that the vibration produced when it hits mechanical support has different acoustic characteristics. The bigger the difference, the easier the recognition.

- A different material could be subject to a different wearing than the rest of the chain.
- The more the difference between the materials the higher the possibility to identify the link.

Another possibility is to use just **1 sensors**: in this case, the method consists in analyzing the spectrum property produced by the vibration induced on the mechanical support. Since the number of link per time unit depends only on the angular speed, spectrum differences depends only on the space between two adjacent links.

- Spectrum analysis is required.
- Spectrum characterizations have to be identified.
- Spectrum could depends on both elongation and thickness.

Sensor: Ultrasound

Ultrasound wave is a sound wave at the frequency greater than the upper limit of human hearing (approximately grater then 20 KHz). Ultrasound sensors could be used for distance and proximity; although the functional principle is the same, these two classes differs in term of sensor characteristic (sensibility,). **Do note that the analysis, and in general all the considered approaches, excludes any mechanical contact; although this excludes some possibilities, the interaction between chain wear and measurement system wear could make the measure method inefficient and unreliable**.

- **Operating Principle**: The measuring process is the following: ultrasonic waves propagated through a physical mean reflect partially back when mean change (for example when the wave hits and object). A distance between the emitter and the object is measured by coupling a receiver with the emitter and measuring the time spent by the wave to hit the object and to return back.
- **Market availability**: ultrasound sensors (in particular, proximity sensors) are widely used in automation industry; thus, their availability is not an issue. The only concern could be related to difficulties in finding feasible sensors in terms of accuracy, precision, band-width, linearity, …
- **Technical features**: distance measuring via ultrasound is not critically affected by wearing problems since no contact exists between the object and the sensor. However, could be necessary to protect the sensor form contacts with cleaning products, dusts, oils, and dirt in general, without interposing protections between the sensor and the object. Usually, this sensors could operate between 0°C and 65°C, require alimentations between 10V and 30V and have current consumptions of about 10-20mA; for this reason, the system batteries (if any) require to be supported with other power supply sources (cables or some kind of energy scavenging). Accuracy, precision and measure time varies greatly from sensor to sensor. The measure time for sensors that can reach 0.1mm of precision seems to be about 50-60ms.
  - Problem due to chain movement; could be possible that chain movement affects the measurements.
  - Can be used for both plastic and metal chains.
  - Dirt on chain doesn't introduce measurement difficulties.
  - No special links could be required.

Sensor Analysis

Elongation Measurement

Anomalous Element: soundproof link (2 sensors)

The method uses a soundproof material (like paint) or a specific material link to create an anomaly that reacts to ultrasound waves in a different way with respect to the rest of the chain (ultrasound frequency may become an important parameter).

Interesting is the following indication (from www.jiancai365.cn):

> *"..If you live in a noisy city or a loud environment, you may be interested in sound proofing your home or office. There are many different ways of sound proofing your home or office. One inexpensive method of sound proofing is through the use of sound proof paint. If you would like more information about sound proof paint, please read on.*
>
> *An innovative sound proof paint you may be interested in is called acousti-coat. This sound proofing paint was created from technology developed by NASA. It is latex and water based. It contains within it hollow ceramic microspheres, resin, and sound absorbing fillers. The combination of ingredients allows this sound proofing paint to reduce noise by 30 percent.*
>
> *Not only does acousti-coat provide excellent sound proofing, but it also acts as a heat insulator. There are many other benefits as well. For one, the paint has a small textured surface that can help hide any surface defects on your walls such as: dents, dings, abrasions, etc. It is also non toxic and friendly for the environment. If you are clumsy and you spill it, you can clean it up easily with soap and water!*
>
> *Acousti-coat sound proofing paint can be applied directly over your existing paint. It can also be painted over or you can add light pastel colors to the paint. It is very fast drying and it can be applied with roll on brushes or spray guns. The price runs about $31.75 a gallon or $158.75 for a 5 gallon drum. Each gallon will cover about 100 to 150 square feet…."*

- Cost, material properties and compatibility with the chain.
- Generally compatible with the thickness differential measurement, with the exception of the anomalous link which thickness can't be measured (and can be different from the others due to its mechanical characteristics).

Anomalous Element: drilled link (2 sensors, emitter and receiver de-coupled)

The method uses an ultrasound emitter sending a burst of ultrasound impulses to a receiver, placed on the other side of the chain, through a hole drilled an anomalous link. By measuring the time between two measures obtained by two couple of sensors the elongation could be estimated.

- Needs holes, maybe too big. Dirt may be an issue.
- Anomaly sensing needs to be verified.
- Problem with power supply; more than a battery could be required.
- Simple and probably efficient

Sensor: Microphone

Microphones are transducers that turn acoustic energy into electrical one; the most common technologies are the electrostatic and electrodynamics methods. The former is based on a capacitor with moving plate, where acoustic waves change the capacitance, while the latter is based on coil with moving magnetic field, where waves change the magnetic flow.

- **Operating Principle**: the proposed method is based on air viscosity. In particular, the link produces a sound due to both its aerodynamic characteristics and the link speed; different links (i.e. drilled) provide different sounds effect while an acoustic chamber amplifies its effect. Do note that a sound tone, frequency, duration, … could also provide information about the thickness wearing condition, since thicker links could have different aerodynamic characteristics (not only in term of profile but also for some added characteristics embedded in the link).
- **Market availability**: microphones are widely used for many different purposes.
- **Technical Features**: compared to accelerometers, microphones gather acoustic information with more sensibility but also they collect the environmental noise. Among all possible technologies, hypercardioid microphones seem to be the most promising solution due to their high directionality.
  - Mechanical issues regarding the air viscosity.
  - Links with specific profile or modifications in order to provide different acoustic effects
  - Dirt could modify the microphone properties.
  - An acoustic chamber could be necessary

Elongation Measurement

Anomalous Element (2 sensing units):

In this methods, drilled links, or with some concavity, are implemented in order to produce different sound with respect to the normal links.

- Some Link require specific modifications.
- A specific acoustic chamber could be required
- Dirt could be a problem

Thickness Measurement

Variations of "tunnel effect" sound (1 tunnel and air jet, 1 sensor):

An air flow (air jet) is directed inside a custom tunnel where the chain moves. The more the wearing, the higher the air speed; thus the system should produce a different sound.

- Needs Training.
- No needs to modify the chain.

Link modification

This method require to providing some links with some specific infrastructures (i.e. a chamber, a set of hole, fissures, .. in the link): the wearing will break the chamber, enlarge the hole, reduce the fissures, … thus introducing some kind of unexpected acoustic anomaly.

- Some Link require specific modifications.
- Good distinction between new and worn chains.

Sensor Analysis

Elongation measurement table

Fam.	Sensor	Method	Suit.	Cost.	Sens. Cost.	Pow.	Impl.	Acc.	Dep.	Crit.	Ch. Mat.	Sol. Rec.	Sol. Prot.
			0,1	0,1		0	0,2	0,05	0,1	0,15	0,1	0,1	0,1
Acoustic	Accelerometer	*Anomalous Element*	0,75	0,5	0,5	1	0,5	0,75	0,75	0,5***	0,75	1	1
		Spectrum Property Analysis	0,5	0,75	0,75	1	0,75	0,5	1	0,5***	0,75	1	1
	Ultrasound	*Soundproof link*	0,5	0,5	0	1	0,5	0,25	0,5	0,75	0,5	0,5	1
		*Drilled link **	0,25	0,75	0	1	0,5*	0	0,75	0,75	1	0,25	0,5
	Microphone	*Anomalous Element **	0,5	0	0,25	0	0*	0,5	0,5	0,25	0,75	1	1
Capacitive	Cap. Sens.	*Sensing pins*	0,25	0,75	0,5	0,75	0,5	0,75	0,25	0,5	0,25	0,5	0
		Sensing links	0,25	0,75	0,5	0,75	0,5	0,25	0,25	0,5	0	0,5	0,25
Inductive	Ind. Sens.	*Sensing pins – Hall*	1	1	1	1	0,75	0,75	0,5	0,5	0,25	0	0,5
		Sensing pins - Eddy Current	1	1	0	1	0,75	1	0,75	0,75	0,25	0,25	0,25
Mechanic	Rotor	*Speed difference **	0,75	0,5	0,25	0,75	0,75*	1	1	0,5	1	0,5	0,25
		Phase shift	0,75	0,5	0,25	0,5	0,25	1	0,75	0,5	1	0	0,5
	Vibrometer	*Pins (or other)*	0,5	1	1	1	0,75	0,5	0,25	0, 5	1	0	0,25
RF	RFID	*Anomalous link*	0,5	0,75	0,25	0,25	0,75	0,25	0,25-1**	0,5	0	0,75	1
Optic	Camera	*Distance between pixels*	0,5	0,5	0,75	0,75	0,5	0,5	0,25	0,5	1	0,75	0
		Anomalous element	0,5	0,25	0,5	0,5	0,25	0,75	0,25	0,25	0,75	0,75	0,5
	Laser	*Anomalous link*	0,75	0,5	0	0	0,5	0,75	0,5	0,5	1	0,5	0,5
	Photocell (UV)	*Anomalous link (holes) **	1	0,5	0,75	1	0,25*	1	0,5	0,5	0,75	0,5	0,5
		Anomalous link (color)	0,75	0,5	0,75	0,75	0,25	1	0,5	0,75	0,75	0,75	0,75
		*Duty Cycle **	1	0,75	1	1	0,25*	1	0,5	0,5	0,25	0,5	0,25

The higher the value the better the characteristic

Sensor Analysis

- *“In order to select the most promising solution, a cost function needs to be defined using some reasonable weights to be assigned to each parameter:*
  - *Implementability: 0.2*
  - *Criticality: 0.15*
  - *Suitability, Cost (€ - Sensor Cost represents an indicative weight for each solution total cost. Solutions using sensors which cost is greater than 5€ are, a priori, discarded), Dependability, Material of the Chain, Solution Recyclability, and IP Protection: 0.1*
  - *Accuracy: 0.05 (it is considered an indicator)*
  - *Power: 0.0 (it is not considered in this preliminary analysis).”*

Sensor Analysis

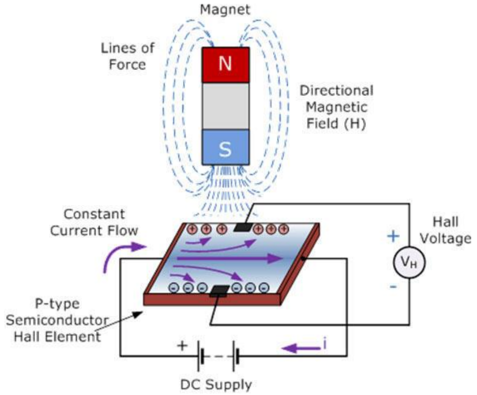
Sensor	Method	Class.	Cost Function	Global Evaluation
Accelerometer	*Audio Features*	2	0,515625	feasible
	*AF - Ac. chamber / holes ***	4	0,496875	low feasibility
	*AF - Feature Sensing ***	6	0,478125	low feasibility
Ultrasound	*Differential measurement*	17	0	unfeasible
	*Feature Sensing (prox.) ***	17	0	unfeasible
Microphone	*Tunnel effect*	14	0,1625	unfeasible
	Hollow link	11	0,18125	unfeasible
Cap. Sensor	*Differential thick. Meas.*	16	0,115625	unfeasible
Ind. Sens.	*Diff. Thick. Meas. (Eddy) **	17	0	unfeasible
	DTM Int. Drop (Hall)	1	0,525	feasible
Dynamometer	*Rollers and spring system*	14	0,1625	unfeasible
RFID Tag	*Tag destruction ***	10	0,375	low feasibility
Camera	*Direct distance measuring*	8	0,45	low feasibility
	Holed anomalous link	9	0,39375	low feasibility
	*FS - Colored An. Link ***	7	0,46875	low feasibility
	FS - Grooves	4	0,496875	low feasibility
Laser	*Conical/oblique holes*	13	0,165625	unfeasible
	Differential measurement	12	0,178125	unfeasible
Photocell (UV)	*Feature sensing ***	3	0,50625	feasible

(*) This solution requires the possibility to control the working frequency of the sensors. Otherwise it must be modified or discarded.

(**) Strongly dependent on the possibility to create an adequate anomalous link.

Hall Effect

- Given a conductor immersed in a magnetic field perpendicular to the direction of the electrons,
  - Electrons are deflected (Lorentz Force)
  - One side of the conductor is negatively charged and the other is positively charged
- The voltage between these planes is called **Hall voltage**



6. Magnetic/Inductive based Solutions

Abstract

In this chapter, solutions based on Magnetic/Inductive properties are analyzed.

Sensors

For this solutions some types of sensor have been considered:

- Hall effect sensors
- Reed Contacts
- Eddy Current sensors

Reed contacts and Hall sensors are used as magnetic field proximity sensors while Eddy current sensors can actually measure a distance. Since Hall effect sensors seems to have better performances and less costs than Reed contacts, the following analysis is based on Hall effect sensors only. So, for now, the analysis if only focused on Hall effect and Eddy current sensors, while the other sensors remains a future possibility. Data sheets for Hall effect sensors considered in this chapter can be found here: http://docs-europe.origin.electrocomponents.com/webdocs/0db7/0900766b80db758b.pdf

Hall Effect

Sensing the pins (2 Hall sensors): two proximity sensors are placed under the chain, on the upper part of the conveyor. If the sensors are placed in a proper and well known distance between each other, it is possible to estimate elongation measurement starting from the displacement of the two sensors output. Since the solution is based on electromagnetic properties, it will work only for chains containing magnetic or magnetizable elements. Do note that for non-magnetizable chains, the possibility of introducing a single magnetic element provide the means for solving material related criticalities using an anomalous element approach with similar parameter values (introducing non-magnetic component into magnetic material is always possible).

Hall Effect

Suitability:

- *Physical feasibility/Sensor characteristics*: given a suitable magnetic condition, Hall effect proximity sensors prove more than suitable to sense the pin passage: 1KHz switching frequency is more than enough for sensing a 7mm pin (this is the worst case, related to plastic chains), and the considered sensor can work with a switching frequency of 10KHz. They can work with temperatures ranging from -40° to 85°C. Do note that, although distance Hall sensors exists, they are not widely diffused on the market, and so, for this analysis, only common Hall effect proximity sensors are considered.
- *Confidence*: the solution confidence is mainly related on the possibility to have the correct magnetic conditions. It is already known that in some cases these conditions could not be achieved, but for every other application there should be no criticalities.

Hall Effect

Costs:

- *Sensors costs*: the cost of these sensors is extremely low, 5 sensors cost less than a euro, and costs drop significantly for industrial quantities. Do note that this is the cost of the sensor itself, and that some control circuit is required, thus increasing the costs.
- *Elaboration costs*: the output of the sensors has to be sampled, and basing on phase displacement, elongation can be estimated. It is also possible, knowing the angular speed, to compute peripheral speed measurement and then calculate the elongation. In the case of anomalous element the computational costs may be slightly higher.
- *Storage costs*: low for pins sensing, only a portion of the output signals must be stored before computation; in case of anomalous element these costs increase.
- *Conveyor variations costs*: low, a magnet capable of magnetize chain elements must be installed near the sensors.
- *Other costs* (installation, maintenance, reparation): some kind of protection and maintenance for the sensors is required, but it's not critical as for other applications, since magnetic sensors doesn't suffer dirt as other sensors do. It may be required the insertion (and presence) of an anomalous element into the chain, so maintainers will have to consider its presence.

Hall Effect

Power Needs: quite low, with a supply voltage ranging from 2.2V to 18V and a supply current of 1.5A to 5A. This solution requires two sensors.

Implementability:

- *Structure*: the sensors have to be placed in the upper part of the conveyor, just under the chain and near the driving sprocket. A magnet should be placed near the chain in the closeness of each sensor, in order to polarize magnetic elements so that the sensor could sense the presence of a pin when it passes.
- *Conveyor modification*: none, except for the installation of the magnets and the sensors.
- *Adaptability*: good when the right magnetic conditions can be met, since this solution doesn't require particular modifications on the conveyor.
- *Physical protection*: far less critical than for other methods, but anyway the sensors have to be protected and maintained.

Accuracy: mainly dependent from switching frequency, which is more than enough to provide a good accuracy.

Hall Effect

Dependability:

- *Toughness*: magnetic sensors shouldn't be much affected by dirt, the only problem is related to magnetic dusts that can be attracted by the magnet. In order to avoid that dirt accumulation causes measuring problems, a sort of automatic recalibration may be needed from time to time.
- *Calibration issues*: Hall effect sensors must be calibrated during the installation, since they are able to sense the Earth magnetic field if placed in certain positions. Automatic procedures should be implemented, also to face the possible dirt accumulation mentioned above. However, these are little calibration issues.
- *Self-checking*: possibly obtainable via data processing or by sensors replication, more difficult in case of anomalous element detection.

Hall Effect

Criticisms: none evident, but some tests must be performed and the electronic control must be developed. For the variant based on anomalous element, the anomaly could cause a localized different wearing, which may invalidate the measurement. Magnets transport may generate some problems.

Chain material type: chains containing (or that may contain) magnetizable elements only.

Solution Reusability: very low, for positioning issues, the sensors are not recyclable. Control circuit, on the contrary, could be reused in some way.

Solution protection: low for the case of pin sensing. Also, if the anomaly is purely in magnetic permeability and not visible, this value increases further.

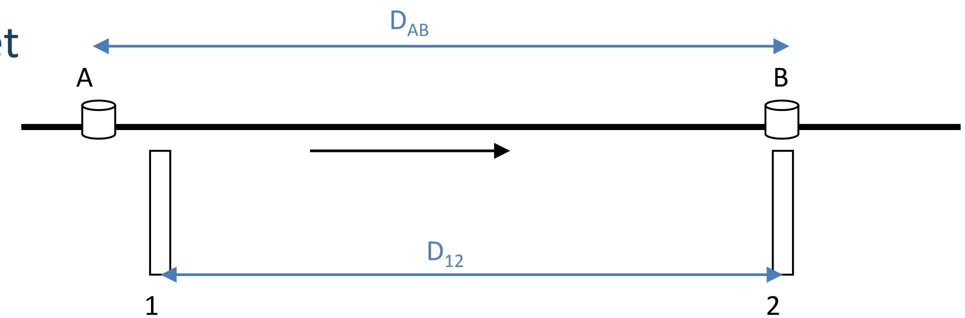
Computing Systems

Chains Elongation
an example of project

Part 3: Identification of the elongation
Theoretical Approach

Model and Parameters

- Two modified links
  - links with magnet



  - Problem: metal links – Solution: a plastic insertion in a special link
- Assumptions:
  - D_{AB} must be multiple (N) of the link length (L): N*L
  - $D_{AB}>D_{12}$
    - Sensors are used to start and stop timers (or models of time)
  - D_{12} is fixed by design

Model and Parameters

- Chain speed: $V_c = D_{12}/(t_{B2} - t_{B1})$
- Distance between magnets: $V_c = D_{AB}/(t_{B1} - t_{A1})$
  - D_{AB} is unknown
- $D_{12}/(t_{B2} - t_{B1}) = D_{AB}/(t_{B1} - t_{A1}) \rightarrow D_{AB} = D_{12} * (t_{B1} - t_{A1})/(t_{B2} - t_{B1})$
- Time model: $(t_{B1} - t_{A1}) \sim C_{BA} * Ts$; $(t_{B2} - t_{B1}) \sim C_{BB} * Ts$;
  - Where Ts is the sampling period
- Finally: $D_{AB} = D_{12} * C_{BA} * Ts / (C_{BB} * Ts) = D_{12} * C_{BA}/C_{BB}$
- Elongation: $El\% = D_{AB}/D_{AB0} - 1$ where D_{AB0} is the reference elongation

Model and Parameters

- The elongation threshold is 3% (Two type of links: 1,5” and 1”)
- Some critical point:
  - N has to be as higher as possible in order to
    - Increase the precision - in order to get 3% (100 times)
    - Face with the upper bound of the sampling rate
      - The system has to use “interrupt”; low sampling rate allows to neglect the context switch time (e.g. with 32MHz, 20KHz could be a correct simple rate)
  - N has to be as lower as possible in order to
    - Consider that the speed of the chain could be not constant (transitory)
    - Counters is limited in Bits (The counter is the model of time)
    - Consider some limitations for PCB production
      - The higher is D12 the higher is the PCB cost
- The chain speed is from 2m/sec to 0,08m/sec

Model and Parameters

	1"	1,5"
N	-	-
2	2,54	3,81
3	5,08	7,62
4	7,62	11,43
5	10,16	15,24
6	12,7	19,05
7	15,24	22,86
8	17,78	26,67
9	20,32	30,48
10	22,86	34,29
11	25,4	38,10
12	27,94	41,91
13	30,48	45,72
14	33,02	49,53
15	35,56	53,34
16	38,10	57,15

- D_{12} Identification ($D_{AB}>D_{12}$)
- D_{AB}

Note:
1) Magnets are in the middle of links
2) Measurements in mm

- Two D_{AB} solutions make the approach uniform: 150mm and 300 mm
- It is worth noting that double is D_{AB}, the half is the sampling rate at the same accuracy

Model and Parameters

- The **minimum resolution** must be get at the highest speed
  - 2 m/sec
  - Minimum distance is covered in
    - 150mm → $75*10^{-3}$ second ; 300mm → $150*10^{-3}$ second
  - To get 0,03% - 0,05% of granularity (at 2 m/sec)
    - 150mm*0,03% = $4,5*10^{-2}$ mm → $22,5*10^{-6}$ second → 44,444 KHz
    - 150mm*0,05% = $7,5*10^{-2}$ mm → $37,5*10^{-6}$ second → 26,667 KHz
    - 300mm*0,03% = $9,0*10^{-2}$ mm → $45,0*10^{-6}$ second → 22,222 KHz
    - 300mm*0,05% = $15,0*10^{-2}$ mm → $75,0*10^{-6}$ second → 13,333 KHz
  - Note: the noise (mechanical and/or electrical – i.e. sensor jitter -) could greatly affect the precision
- A possible solution is 300mm and 20KHz
  - Similar PCB cost but less critical points

Model and Parameters

http://pcbshopper.com/

Dimensions: 30.5 × 1.5 cm

Layers: 2

Company	Color	Qty	Price	Total with shipping*	Total Days†
ITEAD Studio China Read or write reviews	Green	10	€16.15 total €1.62 each	Registered Air Mail: €21.83 DHL: €36.46	21 days 13 days
Use the 2 Layer PCB Larger than 30cm x 30cm Prototyping service. Order 2 times.					
Dirty PCBs China Read or write reviews	Green	10	€20.30 total €2.03 each	Hongkong Airmail: €24.71 DHL Hong Kong: €37.95	48 days 17 days
Accutrace PCB4U USA Read or write reviews	Green	10	€26.48 total €2.65 each	*Contact manufacturer for shipping costs.*	
PCBWay China Read or write reviews	Green	10	€20.68 total €2.07 each	HK Post: €31.02 DHL: €44.18	33 days 10 days
Select the 2-3 days build time. Price includes PayPal fee.					Go to Order Page
Smart Prototyping China Read or write reviews	Green	10	€48.37 total €4.84 each	Deutsch Post: €54.55 HK DHL Express: €62.49 UPS Express: €76.61	14 days 11 days 8 days
Choose 95% E-test.					Go to Order Page

Dimensions: 15.5 × 1.5 cm

Layers: 2

Company	Color	Qty	Price	Total with shipping*	Total Days†
Dirty PCBs China Read or write reviews	Green	10	€15.89 total €1.59 each	Hongkong Airmail: €18.54 DHL Hong Kong: €33.54	48 days 17 days
PCBWay China Read or write reviews	Green	10	€16.92 total €1.69 each	HK Post: €25.38 DHL: €40.42	33 days 10 days
Select the 2-3 days build time. Price includes PayPal fee.					Go to Order Page
Breadboard Killer Australia No reviews yet Read or write reviews	Green	10	€20.54 total €2.05 each	DHL: €29.20	25 days
Smart Prototyping China Read or write reviews	Green	10	€28.60 total €2.86 each	Deutsch Post: €33.01 HK DHL Express: €42.72 UPS Express: €56.84	14 days 11 days 8 days
Choose 95% E-test.					Go to Order Page
ShenZhen2U China Read or write reviews	Green	10	€28.97 total €2.90 each	Registered Air: €35.15 Deutsch Post: €39.56 HK DHL Express: €43.09 UPS Express: €57.21	26 days 16 days 13 days 10 days
Choose 95% E-test.					Go to Order Page

Model and Parameters

- The **counter size** is constrained (upper bound) by the lowest speed of the chain (0,08 m/sec)
  - Maximum distance is covered in
    - 304,8mm → 3,81 second
  - With 20KHz the maximum counted value is
    - 3,81*20000 = 76200
  - This value imposes 32 bit register
    - Higher speeds are tolerable
- Note: at the maximum speed 300mm → $150*10^{-3}$ second. With 20KHz of sampling rate the value in the counter is 0,15*20000 = 3000

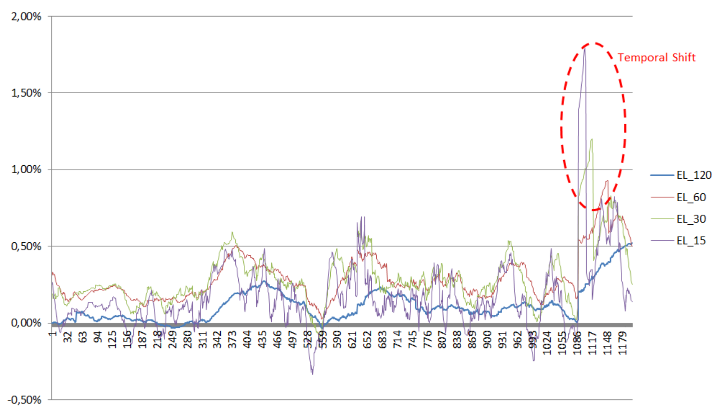
Computing Systems

Chains Elongation
an example of project

Part 4: Calibration, initialization
Architecture, protocol, packets

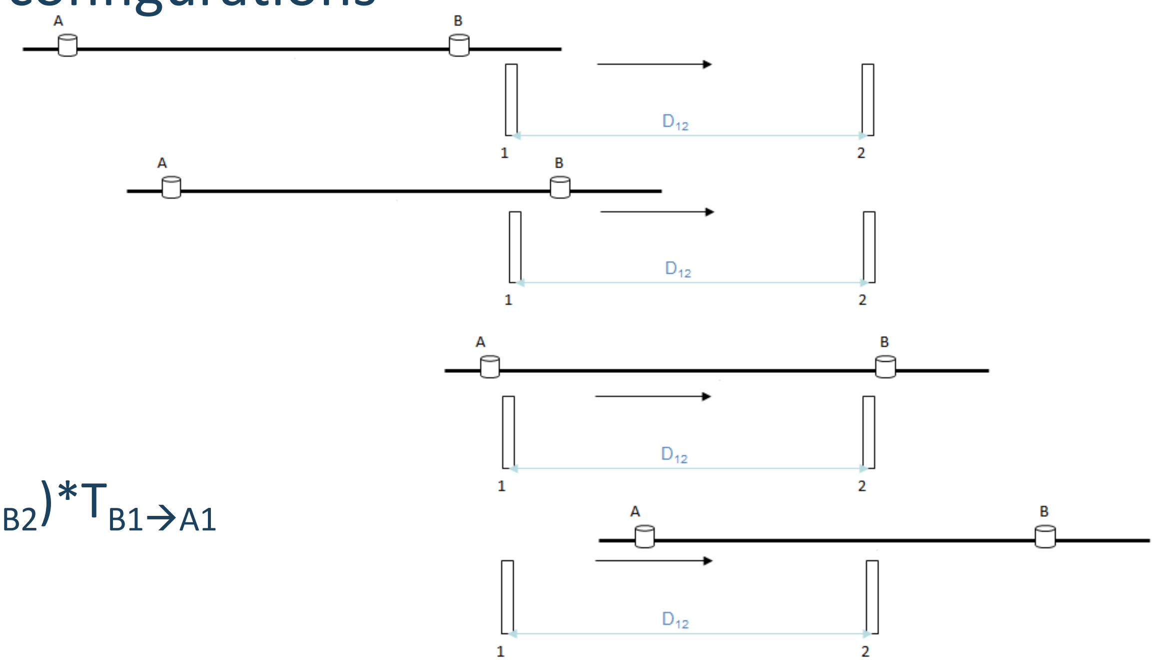
Calibration

- Self calibration
  - Average of the first K samples
    - This is possible due to the dynamic of the system: chain liveness is from 6 month to 10 years with thousand and thousand of “rounds”.
    - K = 120
- Filtering
  - To reduce the noise
  - To increase the readability of data
    - Moving average of M samples
      - Note: A temporal shift is introduced
    - M = 120
  - Note: a small filter also on the “smart sensor”
    - Median 16 values



Initialization

- Possible configurations



D_{12} is known

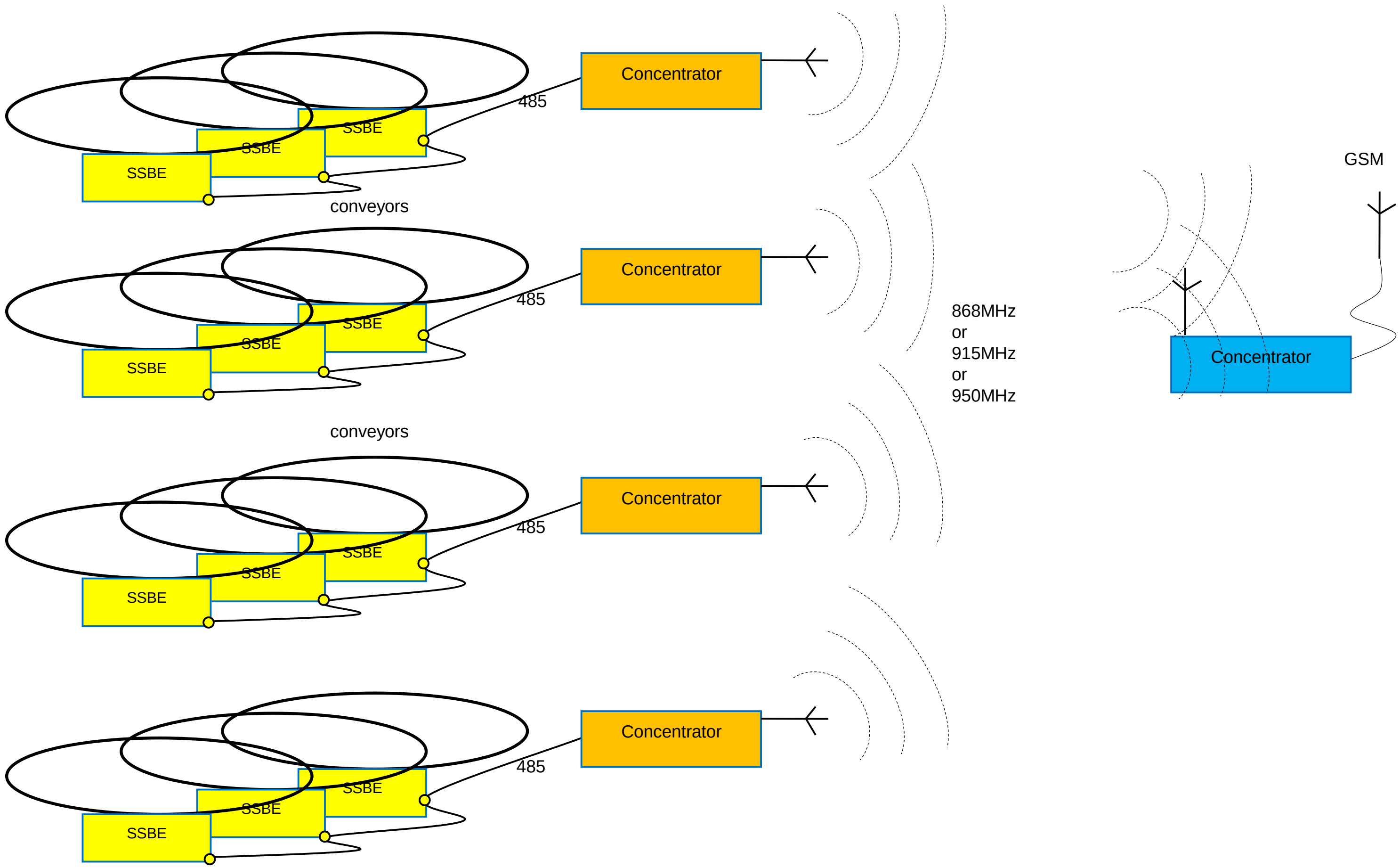
$V=D_{12}/\ T_{B1\rightarrow B2}$
$V=D_{AB}/\ T_{B1\rightarrow A1}$

$D_{AB}=(D_{12}/\ T_{B1\rightarrow B2})*T_{B1\rightarrow A1}$

[Example]

sens 1	sens 2	sens 1	sens 2					Correct	
sen 2	sen 1	sen 2		…	sens 1			Wrong	it starts with S2
sen 1	sen 2			…	sens 1	sens 2		Wrong	Tba too long! (attention to counter overflow)
sen 2				…	sens 1	sens 2	sens 1	Wrong	it starts with S2

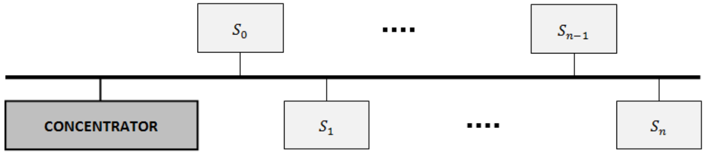
Architecture



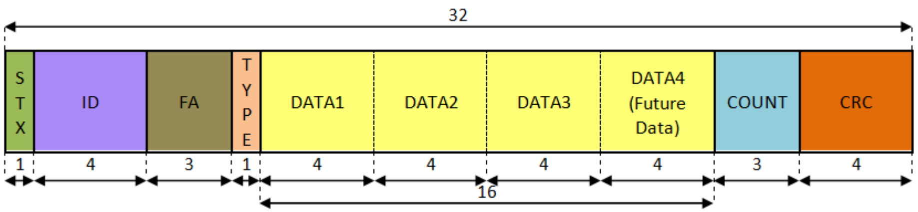
Protocol

- The system has to be «run-time» self-configurable (automatic set-up) : ADD New devices or REMOVE Broken devices
- Peering
  1. concentrator to sensors: broadcast reset (periodic)
     - All sensors are un-paired
  2. Concentrator to sensor: request of “existence in life”
  3. Sensors to concentrator: ID transmission (random)
  - Identified sensors are stored in a “pairing” table in the concentrator
  - IF(at least one sensor is identified)
    GOTO step 2
    ELSE
    All sensors are in the list
  - Note: time is sliced (number of slices…?) and a sensor get one slice randomly. The seed is the 32 bit ID of the sensor

Protocol



- «smart sensors» and concentrator



- *STX*: Start of the frame, it represents the beginning of each packet.
- *ID*: sensor ID referenced by the message (it may refer to a single sensor or to all sensor in the case of a broadcast message).
- *FA* (Future Applications): this field will be used for some future additional information or to store some data as the status or the firmware release operating on the sensor.
- *TYPE*: typology of the datum contained into the packet. For more details, look the *Table of the Values* stated below.
- *DATA*: actual data in the packet. *DATA1*, *DATA2* and *DATA3* are currently used while *DATA4* is ready for future data exchanges (as another datum in addition to those already reported).
- *COUNT*: counter of the measures. The sensor increases this internal counter by one on each new [valid] acquisition accomplished. The reported number can thus be used by the concentrator to detect anomalies (no new acquisition over a sufficiently long time, …) and to choose a viable period for requesting data from each sensor.
- *CRC*: Cyclic Redundancy Check is a non-secure hash function designed to detect accidental changes to raw computer data.

TABLE OF THE VALUES:

ID	FF.FF.FF.FF	Broadcast (a message with this ID is sent to all sensors)
	xx.xx.xx.xx	ID number of the sensor
TYPE	00	Request of the presence
	01	Confirmation of the presence
	02	Acknowledgement provided by the concentrator to the sensors
	10	Request of the data (three time counters)
	11	Data sent by the sensor (with counter)
	ED	Network reset
	FF	Error message sent by the sensor
DATA	yy.yy.yy.yy	Data sent by the sensor
	01.00.00.00	Error message: a magnet is no longer detected
	02.00.00.00	Error message: a sensor is no longer detected
	03.00.00.00	Error message: no magnet is detected or no sensor responds
	04.00.00.00	Error message: counter over-running
	05.00.00.00	Error message: unsubstantial measure
	06.00.00.00	Error message: excessive variability of the data (data must remain within a certain range, if the value exceeds a threshold for k consecutive times, then there is a problem)