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A P P U N T I

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MATERIA: Testing. and certifcation - Prof. Carullo

PREATTO STEFANIA - 235695
TESTING AND CERTIFICATION

* TRACEABILITY & COMPATIBILITY
* INTERNATIONAL ORGANISATION OF METROLOGY
* CALIBRATION PROCESS
* QUALITY MANAGEMENT OF MEASURING INSTRUMENTATION
* ANALOG-TO-DIGITAL CONVERSION PROCESS
* DIAGNOSTIC INSTRUMENTATION
  - DIGITAL STORAGE OSCILLOSCOPE
  - DEBUG OF DIGITAL SYSTEMS
* SERIAL INTERFACES
* DATA ACQUISITION BOARDS
* SENSORS
* THERMOCOUPLES
* INDUSTRIAL BUSES
* PHOTOMETRY AND PHOTOSENSORS

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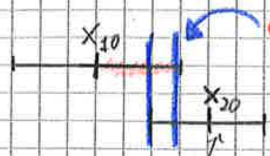
COMPATIBILITY → SINCE THE MEASURE (= RESULT OF A MEASUREMENT) IS AN INTERVAL EQUALITY IS NOT USEFUL IN MEASUREMENT COMPARISON ⇓

- **DETERMINISTIC APPROACH:**

2 MEASUREMENTS OF THE SAME QUANTITY THAT REFER TO THE SAME CONDITIONS ARE COMPATIBLE WHEN THE INTERSECTION BETWEEN THE 2 MEASUREMENT INTERVALS IS NOT AN EMPTY SET

$x_1 = (x_{10} \pm \delta x_1)$

$x_2 = (x_{20} \pm \delta x_2)$



$|x_{10} - x_{20}| < (\delta x_1 + \delta x_2)$

[NOT EMPTY INTERSECTION]

parameter is surely in this interval

DETERMINISTIC MODEL IS WORST CASE MODEL → WORST POSSIBLE COMBINATION CAUSE IT REFERS TO

[ex: I ordered a Resistor of 1 kΩ ; R = 1 kΩ, 1%

[999 ÷ 1001] Ω, 950 Ω is wrong]

- **PROBABILISTIC APPROACH** → WE STATE THAT PARAMETER IS IN THE INTERVAL WITH A PROBABILITY:

- EXPECTED VALUES : x_{10}, x_{20}
- STANDARD UNCERTAINTIES : $u(x_1)$, $u(x_2)$ → REMEMBER THE STANDARD DEVIATION OF A PROBABILITY DENSITY FUNCTION (which)

↓ IT DEPENDS ON THE SHAPE OF THE FUNCTION

COMPATIBILITY IS MET IF : $|x_{10} - x_{20}| < k\, u(x_1 - x_2)$

COVERAGE FACTOR → AFFECTS THE CONFIDENCE LEVEL OF THE COMPARISON

⇓

IF YOU'RE CONFIDENT THAT THERE'S A NORMAL DISTRIBUTION, k CAN BE FOUND IN THE TABLE OF GAUSSIAN DISTRIBUTION

for ex: if we have 2 uncorrelated measurements (STATISTIC INDIPENDENCE)

$$|x_{10} - x_{20}| < k\sqrt{u^2(x_1) + u^2(x_2)}$$

! USUALLY IN A COMPATIBILITY CHECK DETERMINISTIC APPROACH IS PREFERRED

CAUSE YOU HAVE TO BE SURE IF THERE IS OR NOT COMPATIBILITY

⇓

IN DESIGN PROJECT WE HAVE TO WORK IN WORST CASE SO WITH DETERMINISTIC APPROACH

INTERNATIONAL ORGANISATION OF METROLOGY

METROLOGICAL TRACEABILITY CHAIN → STARTS FROM PRIMARY STANDARD DEVICES SO IT'S NECESSARY THAT THESE INSTRUMENTS ARE AVAIABLE

SO MOST COUNTRIES ESTABLISHED **NMIs** (= NATIONAL METROLOGICAL INSTITUTES) [IT: INRIM]

WHICH ARE RESPONSIBLE OF REALISATION / DISSEMINATION (= DISTRIBUTION TO LOWER LEVELS) [2nd LABS] OF MEASURING UNITS

DISSEMINATION PROCESS IN TRACEABILITY CHAIN HAS DIFFERENT LEVELS

PRIMARY STANDARDS ↓ → ARE USED TO DISSEMINATE UNITS TO

SECONDARY LABORATORY → WHICH HAS DIFFERENT LEVEL OF STANDARDS:
- REFERENCE STANDARDS → COMPARED TO PRIMARY STANDARDS
- WORKING STANDARDS → DISSEMINATED TO THE COSTUMERS' LABS

↓

MEASURING INSTRUMENTS

WE HAVE TO ENSURE THE "FREE EXCHANGE" OF THE MEASUREMENTS WHICH REQUIRES A HIGH LEVEL OF CONFIDENCE AMONG THE METROLOGICAL FACILITIES AT DIFFERENT COUNTRIES

ONLY SOLUTION → **INTERNATIONAL AGREEMENTS** AT DIFFERENT LEVELS OF THE METROLOGICAL HIERARCHY

↓ ENSURE

- EQUIVALENCE AMONG THE STANDARDS OF NMIs
- EQUIVALENCE AMONG SECONDARY LABS

INTERNATIONAL AGREEMENTS

PRIMARY STANDARDS:
- **METRE CONVENTION** → ENSURES < PROPAGATION / IMPROVEMENT OF SI (INTERNATIONAL SYSTEM OF UNITS)

  [first convention in 1875, signed in France by different countries]

- **MRA** (= MUTUAL RECOGNITION ARRANGEMENT) → IN ORDER TO ACCESS THE EQUIVALENCE OF A METROLOGICAL INSTRUMENT WITH THE OTHERS

  ↘ SIGNED BY A LOT OF STATES

  FIXED THE EQUIVALENCE OF NATIONAL METROLOGICAL INSTITUTES ALL EQUIVALENT TO ENSURE TRACEABILITY FOR SECONDARY LABS OF OTHER COUNTRIES

  (for example UK NMIs can do references to italian sec. labs)

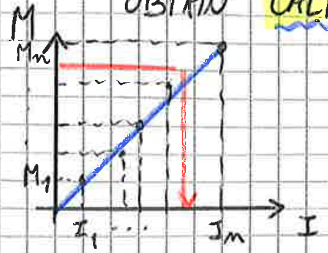
SECONDARY LABS:
- **MLA** (PRINTO WITHIN EA) → GROUPS EUROPEAN **ACCREDITATION BODIES** [IT: ACCREDIA] → SAID THAT A LABORATORY IS ABLE TO DO OPERATIONS
- **MRA** (WITHIN ILAC) → ENSURE EQUIVALENCE AMONG → DIFFERENT ACCR. BODIES [IT: ACCREDIA]

  ↘ CALIBRATION CERTIFICATE ISSUED BY SECONDARY LABORATORIES ← OTHERWISE WE CANNOT ACCEPT RESULTS

TO OBTAIN CALIBRATION:

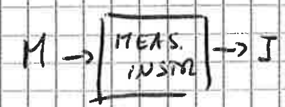
(1) WE APPLY A SET OF VALUES TO THE INSTRUMENT INPUT

OBTAIN CALIBRATION CURVE



we have from the input to the output

we apply M and record results



WHEN YOU FIT EXPERIMENTAL DATAs:

- TRY TO FIND THE MODEL THAT FITS THE EXPERIMENTAL DATAs
- BASED ON PRIMARY KNOWLEDGE OF INSTRUMENTS

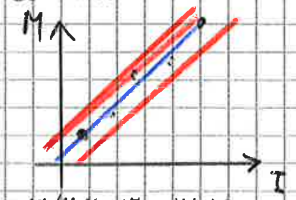
USUALLY THE MOST USED IS LINEAR BEHAVIOR

! IT ISN'T POSSIBLE TO OBTAIN PERFECT LINEAR BEHAVIOR → THE BEST FUNCTION IS A STRAIGHT LINE

ISN'T PERFECTLY REPRESENTATIVE OF LINEAR BEHAVIOR

WE TRY TO MINIMIZE SQUARE

(2) WE DRAW CALIBRATION DIAGRAM TAKING THE MAIN UNCERTAINTY CONTRIBUTIONS INTO ACCOUNT

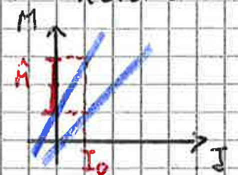


UNCERTAINTY OF INPUT

I → RELATED TO NOISE (NOT DOTS)

- REFERENCE-STANDARD UNCERTAINTY → INPUT AREN'T PERFECT SO INTERVALS AREN'T EXACTED POINTS
  if we repeat the experiment we don't obtain the same results because of noise, environmental conditions and all quantities that affect the behavior of the instrument
- NON LINEARITY OF DEVICE
- TIME DRIFT
- etc...

ONCE THE MANUFACTURER HAS ASSIGNED THE CALIBRATION DIAGRAM



TO OBTAIN AN ESTIMATION OF THE INTERVAL

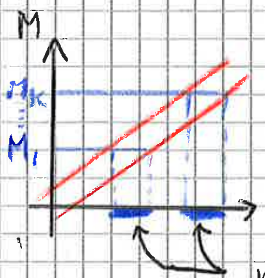
BUT ONE I/O IS NOT REPRESENTATIVE OF THE REAL INSTRUMENT

AFTER CALIBRATION INTERVAL HAS ELAPSED → YOUR MEASUREMENTS AREN'T RELIABLE
↓
SO THEY CAN BE OUT OF TOLERANCE
⇓
THE INSTRUMENT HAS TO BE SUBJECTED TO A VERIFICATION
⬇

2. VERIFICATION

VERIFICATION → IS THE SET OF OPERATIONS INTENDED TO VERIFY THE VALIDITY OF THE CALIBRATION RELATION
↓
(During lab session we have to verify the calibration function of a DMM)

A SET OF KNOWN VALUES ARE APPLIED AT THE INSTRUMENT INPUT
(We move from In to Out but we know calibration function)
↓
ERRORS BETWEEN < APPLIED VALUES / INDICATIONS ARE COMPARED TO MAXIMUM ADMITTED ERRORS (=INSTRUMENT TOLERANCE)



WE APPLY KNOWN INPUT VALUES AND WE RECORD THE OUTPUT

IF WE OBTAIN A MEASURE IN THIS INTERVAL THAT'S OK
IF JUST ONE ISN'T IN THE INTERVAL → FAIL

(INPUT AS SINGLE POINTS)
IN IDEAL SITUATION → VERIFICATION HAS 2 POSSIBLE RESULTS
$\delta M_i = \emptyset$

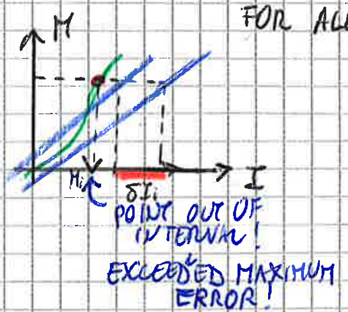
PASS
↓
FOR ALL VERIFICATION POINTS

$$S_i = |M_i - I_i| < \delta I_i, \ \forall i$$

⇓
YOU CAN CONTINUE USING THE INSTRUMENT

FAIL
↓
$\exists i \ | \ S_i > \delta I_i$

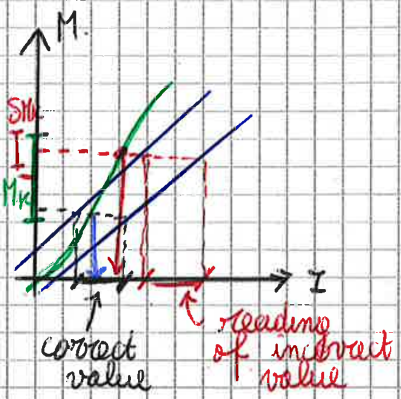
EXISTS AT LEAST 1 VERIFICATION POINT WHERE THE ERROR EXCEED δI_i



BUT IN REAL SITUATION → WE HAVE A MEASUREMENT INTERVAL $\delta M > 0$
↓
WE HAVE TO CONSIDER FALSE RESULTS

FALSE FAIL
↓
EVEN IF THE INSTRUMENT IS CONFORM TO ITS CALIBRATION RELATION ONE VALUE IS OUT OF δI
↓
SO IT DOESN'T PASS VERIFICATION

FALSE PASS
↓
THE INSTRUMENT PASSES VERIFICATION, SO WE USE IT EVEN THOUGH IT ISN'T CONFORM TO CALIBRATION
⇓
! VERY DANGEROUS! SITUATION SHOULD BE AVOIDED! (but it isn't always possible)



PROBABILISTIC APPROACH → PROVIDES A MORE REALISTIC ESTIMATION OF THE FALSE-EVENT PROBABILITIES

STANDARD UNCERTAINTIES (DEVIATION) → CHARACTERIZE < INSTRUMENT / STANDARD (INSTRUMENT)

MAIN DIFFERENCES

DETERMINISTIC	PROBABILISTIC
USES UNIFORM DISTRIBUTION	UNCERTAINTY = RANDOM VARIABLE DESCRIBED WITH A PROBABILITY DISTRIBUTION

PROBABILITY OF FALSE EVENTS DECREASES → AS THE UNCERTAINTY OF THE INPUT VALUES M_i DECREASES

TUR (= TEST UNCERTAINTY RATIO)

→ IS USED TO EXPRESS THE SUITABILITY OF A DEVICE TO ACT AS A REFERENCE STANDARD

= RATIO OF < INSTRUMENT UNDER VERIFICATION I_i / INPUT VALUE M_i

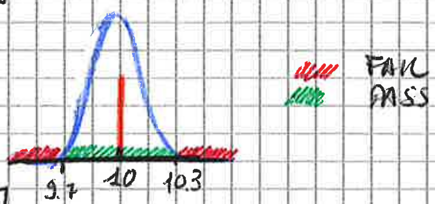
$$TUR_i = \frac{u(I_i)}{u(M_i)}$$

THE HIGHEST THE TUR IS → THE LOWEST IS THE PROBABILITY OF FALSE EVENTS

(2.1) PROBABILISTIC APPROACH

IDEAL SITUATION - $u(M_0) = 0$

$M_0 = 10$ $\quad u(I_0) = 0.1$



[DISTRIBUTION ACCORDED TO NORMAL FUNCTION]

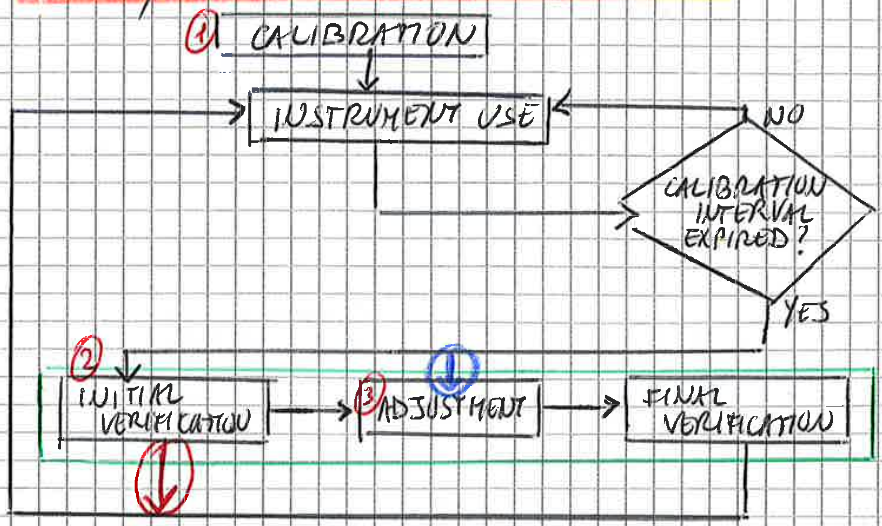
$$U(x) = k_p \cdot u(x)$$ EXTENDED UNCERTAINTY

p → CONFIDENCE LEVEL

$[x_0 \pm 3u(x)]$ → $k = 3$, $p = 99.7\%$

$[x_0 \pm 2u(x)]$ → $k = 2$, $p = 95\%$

LIFE-CYCLE OF A MEASURING INSTRUMENT



OPERATIONS PERFORMED IN A SECONDARY LABORATORY

ADJUSTMENT = OPERATION THAT HAS TO BE DONE WITH REFERENCE STANDARDS : 10 kΩ , 10 V

10 kΩ → STANDARD RESISTOR; 10 V → REFERENCE VOLTAGE → ADJUSTMENT POINTS

INITIAL VERIFICATION → PRE-ADJUSTMENT

→ BEFORE THE ADJUSTMENT AND AT THE END OF CALIBRATION INTERVAL

IT'S VERY IMPORTANT CAUSE YOU DISCOVER YOU DIDN'T MAKE WRONG MEASUREMENTS (HOPE SO!)

FINAL VERIFICATION → POST-ADJUSTMENT

→ AFTER THIS THE INSTRUMENT RETURNS TO USER; ALLOWS TO GIVE YOU THE SITUATION OF INITIAL USE

ALTERNATIVE PATHS:

(1) BECAUSE OF COSTS → IF VERIFICATION PASSES $S_i < \delta I_i$ $\forall i$

IT'S SUGGESTED TO TEST BETTER THIS CONDITION (eg $S_k = 0.99\,\delta I_k$ DANGEROUS!)

RISK: WITHOUT COMPENSATING THE DRIFT DURING THE 2nd YEAR THERE COULD BE SOME ERRORS

IF $S_i < 0.15\,\delta I_i$ → OK! YOU CAN DO IT

(↓) PAY MANY ATTENTION! DANGEROUS!

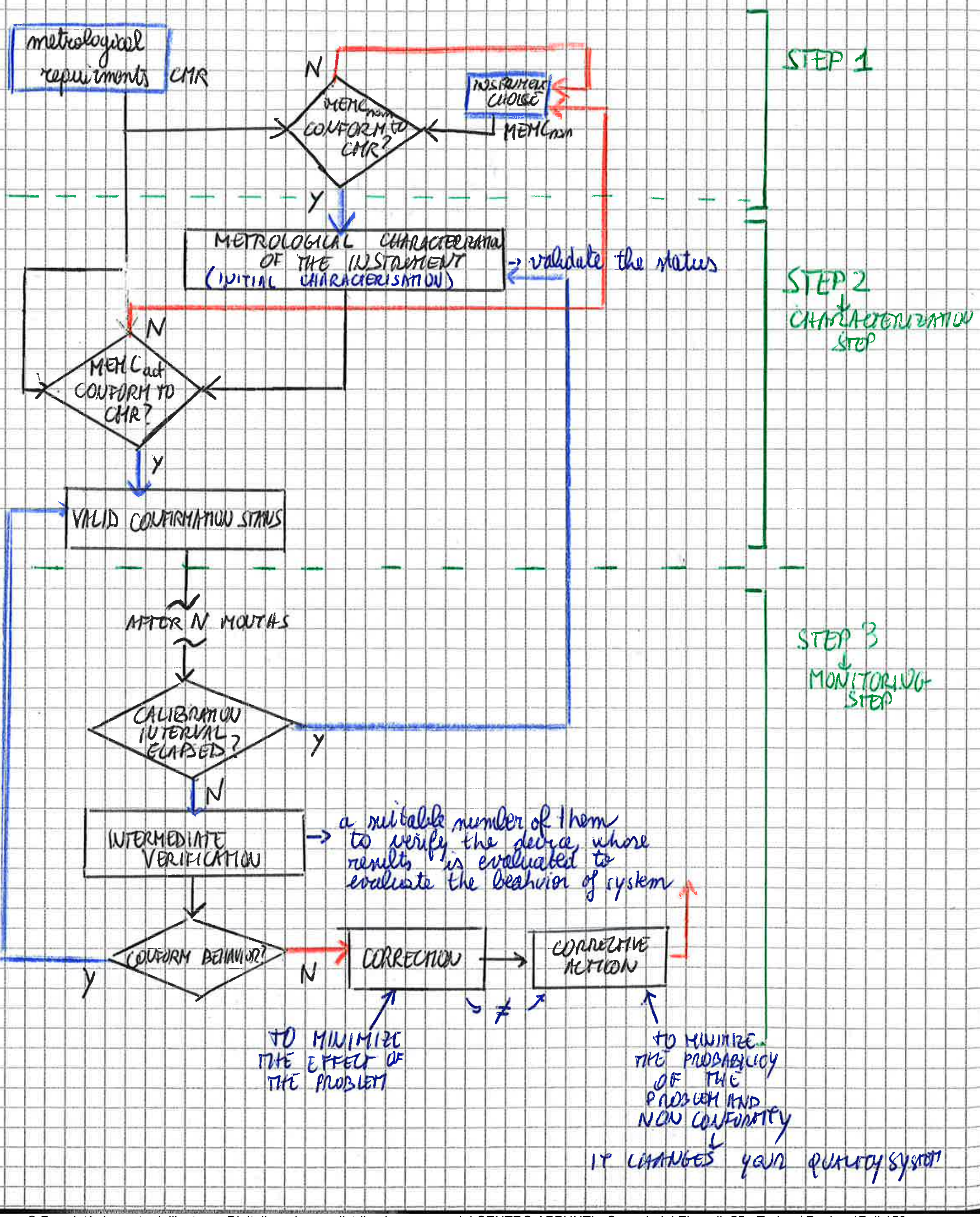
YOU DON'T KNOW THE EFFECT OF YOUR DECISIONS BEFORE SO YOU DELETE INSTRUMENT HISTORY!

↓

IF AN INSTRUMENT CERTIFIED BY A COUNTRY WHICH ISN'T IN THE AGREEMENTS I CAN FOLLOW IT CAUSE I'M NOT INTERESTED IN PASS HISTORY OF THE INSTRUMENT

LIFE-CYCLE OF A MEASURING EQUIPMENT → 3 MAIN STEPS:

1. CHOICE OF INSTRUMENT MODEL THAT POTENTIALLY MEETS THE METROLOGICAL REQUIREMENTS → INPUT: CMR
2. EVALUATION OF INSTRUMENT CONFIRMATION-STATUS (BEFORE ITS USE)
3. MONITORING OF INSTRUMENT CONFIRMATION-STATUS (DURING ITS USE)



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MANAGEMENT OF INSTRUMENTATION

1) CHOICE OF MEASURING INSTRUMENT → RELATED TO CMR

(related to the field where measurement is implemented)

- 1st INFORMATION → KIND OF QUANTITY UNDER MEASUREMENT
  WHEN YOU'VE TO MEASURE MORE THAN 1 QUANTITY: V, R, I, f
  INSTEAD OF USING A VOLTMETER, OHMETER, AMPEROMETER, ETC...
  I USE A DMM
  ⇓
  SELECT A FEW SET OF INSTRUMENT
  (IF I HAVE TO CONFIRM VALIDATION STATUS → IT'S CONVENIENT TO WORK WITH ONE INSTRUMENT)
- EXPECTED RANGE OF VARIATION QUANTITIES → THAT ALLOWS A SUBSET OF THE INITIALLY SELECTED DEVICES TO BE IDENTIFIED

Examples: 1a) quantity: Voltage
waveform: sinusoid
V_{RMS} 230 V @ f = 50 Hz] → average responding / peak responding

1b) if same voltage and arbitrary waveform → true RMS voltmeter

1c) if V_{RMS}: 30 kV → arrange a measurement chain
No direct connection
voltage transformer → puts 30 kV to a lower value
+
average / pick / true RMS voltmeter

2) quantity: Temperature inside an oven
use of memory chain which starts from a sensor
can be
- resistive temperature sensors
- termo-couple devices
- termoresistors
- termopile

cause of range: (1000 ÷ 1500) °C → termocouples, termo-pile

- RESOLUTION
- MAXIMUM ADMITED ERROR (MAE) } IN CMRs AFFECT CHOICE OF EQUIPMENT!

MAE: maximum difference between actual value and nominal value

↓

HAVE TO BE BOTH LOWER THAN THE CORRESPONDING REQUIREMENTS

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2) EVALUATION OF THE INSTRUMENT CONFIRMATION STATUS (BEFORE ITS FIRST USE)

ONCE WE SELECT AN INSTRUMENT WE KNOW $MEMC_{nom}$
BUT WE HAVE TO EXTIMATE $MEMC_{act}$ → IN ORDER TO COMPARE THEM

THIS DOESN'T MEAN WE HAVE TO REPEAT CALIBRATION! NO!

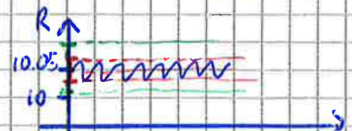
|| NOT ALL THE CHARACTERISTICS OF MANUFACTURER HAVE TO BE VERIFIED BUT ONLY THE CHARACTERISTICS OF CMR

THEREFORE THE EFFECT OF u_q IS VERY CONSIDERED

ex1) 10 kΩ resistor → MAE: 0,001 %
I_{test} affects T_{range} (20 ÷ 80) °C

We select a standard resistor → but we don't use it immediately!
we have to → initially characterize it
→ fix uncertainty that has to be < MAE
(eg 0.00001 %)

We need to know time drift



10.05 nominal value

10.05 enlarges uncertainty interval

ex2) DMM → employed as a DC voltmeter
quantity: DC Voltage
Range: 1 mV ÷ 1 V
T = 23 °C HR % = 50%
MAE: 0.01 % Range

⇒ we have to extimate $MEMC_{act}$
the calibration function for: DC voltage
we have to verify only the ranges wich are specified (eg: 200 mV, 2 V)

VALID CONFIRMATION STATUS OF AN INSTRUMENT → MANTAIN ALL REGISTRATIONS RELATED TO THIS OPERATION IN DEFINED TIME INTERVAL

LABORATORY CAN PROVIDE CALIBRATION CONFORMITY WHICH REFERS TO CALIBRATION CERTIFICATES THAT STATE THE CONFORMITY OF THE INSTRUMENT

PAY ATTENTION TO AVOID AMBIGUOUS INDICATIONS OF THE CONFIRMATION STATUS

LABEL
- GREEN → INSTRUMENT VALID CONFIRMATION STATUS IN ALL RANGES
- RED → DO NOT USE THIS INSTRUMENT
- YELLOW → INSTRUMENT CONFIRMED ONLY FOR PARTICULAR FUNCTIONS IN PARTICULAR CONDITIONS

INTERMEDIATE VERIFICATION → VERY IMPORTANT
→ ALLOWS TO MONITORRE THE RISK OF NON CONFORMITY
⇓
A POSSIBLE WAY TO REDUCE THE PROBABILITY OF NON CONFORMITY CONSISTS IN REDUCING THE INSTRUMENT CALIBRATION INTERVAL (DURING WHICH WE HAVE TO MONITOR THE BEHAVIOR)
(execution of intermediate verification during calibration interval)

IT'S A COMPARISON BETWEEN < GENERATORS / MEASURING DEVICES

IT REQUIRES AVAILABILITY OF GENERATORS
if I have < Power supply / DMM } I can compare these 2 devices

IN CALIBRATION LABORATORIES → YOU HAVE TO OBTAIN CONFORM RESULTS
↓
TAKING CONSIDERATION OF THE TIME DRIFT OF 2 INSTRUMENTS
A FAIL RESULT PROVIDES A DANGEROUS SITUATION SO YOU ACTIVATE FURTHER PROCEDURES

PERIODICAL / NON-PERIODICAL } VERIFICATIONS → PERFORMED APPLYING KNOWN VALUES
↘ RELATED TO COSTS

2 STEPS:
1) FURTHER MEASUREMENTS REQUIRED TO BE CARRIED OUT WITH MORE ACCURATE DEVICES
2) SAME OPERATIONS OF A NOT CONFORM SITUATION AT THE END OF CALIBRATION INTERVAL

⇓

CORRECTION → ANALISYS OF EFFECT OF NON CONFORMITY
≠
CORRECTIVE ACTION → PURPOSE: MINIMIZE PROBABILITY OF OCCURRENCE OF NON-CONFORMITY
↓
IDENTIFICATION OF NON-CONFORMITY CAUSES AND THEN THEIR REMOVAL

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QUANTIZATION → DESCRIBES A QUANTITY BY MEANS OF FINITE NUMBER OF VALUES

⇓

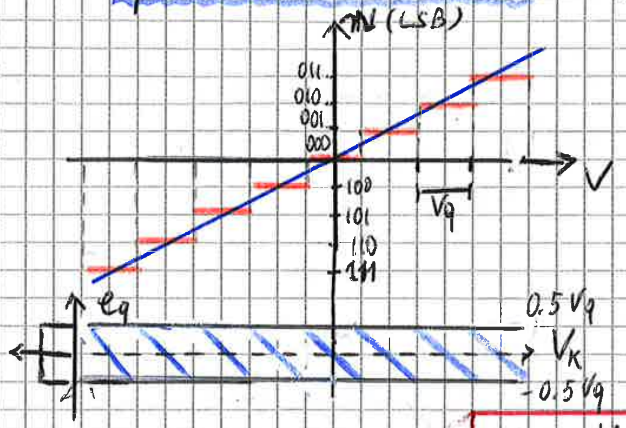
ADC ⇒ DEVICE ACCEPTING AS INPUT: ANALOG SIGNAL
PROVIDING AS OUTPUT: DIGITAL CODE

→ INTRODUCES AMBIGUITY IN THE INTERPRETATION OF DIGITAL CODES

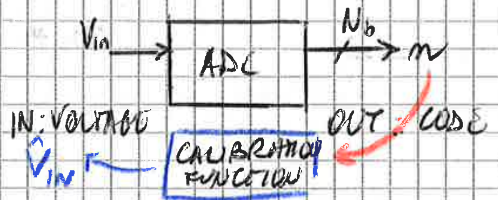
MEASUREMENT RANGE → SUBDIVIDED INTO A FINITE NUMBER OF INTERVALS ALL WITH THE SAME WIDTH.

TYPICAL CHARACTERISTIC IN/OUT OF 3 BIT BIPOLAR ADC

↳ NOT SYMMETRIC (one has to be spent for ∅ calcenal)



ADC → CAN BE CONSIDERED AS A VOLTMETER



QUANTIZATION VOLTAGE: $V_q = \frac{V_{FR}}{2^{N_b}}$ → REPRESENTS **RESOLUTION**: MINIMUM CHANGE OF IN THAT CAN BE OBSERVED AT THE OUTPUT

! SAME DIGITAL CODE IS ASSIGNED TO THE VALUES WITHIN THE SAME QUANTIZATION INTERVAL

FOR FINAL USER IT'S IMPORTANT OUT/IN CHARACTERISTIC ($\hat{V}_{in}$)

↓

IT'S NOT POSSIBLE TO INVERT THE FUNCTION
SO CHARACTERISTIC SHOULD BE APPROXIMATE BY A LINEAR NOMINAL CHARACTERISTIC → THAT ALLOWS TO CONVERT OUT TO IN AND TO ESTIMATE V_{IN} FROM THE CODE n

↓

IT'S ONLY AN APPROXIMATION → SO I CONVERT 111 TO THE CENTRAL VALUE OF THE QUANTIZATION STEP AND IT'S A POSSIBLE SOURCE OF ERROR

QUANTIZATION ERROR: $e_q = \hat{V}_{IN} - V_{IN}$ DIFFERENCE BETWEEN → ESTIMATED V_{IN} / → ACTUAL V_{IN}

$$e_q = \frac{V_q}{2} = \frac{V_{FR}}{2^{N_b+1}}$$

$max(e_q) = 0.5\, V_q$ WHEN V_{IN} IS VERY CLOSE TO THE TRANSITION VOLTAGE

FROM A PROBABILITY POINT OF VIEW → I CAN DRAW THE PROBABILITY DENSITY FUNCTION

↓

WHEN → ANALOG SIGNAL CHANGES IN A CONTINUOUS WAY
→ THERE IS NO CORRELATION BETWEEN V_{in}, N

↓

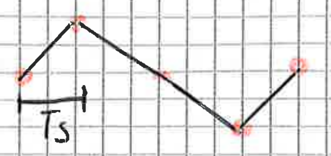
DETERMINISTIC MODEL (WORST CASE MODEL) UNIFORM PROBABILITY DENSITY FUNCTION

SAMPLING → MEANS OBSERVING THE SIGNAL ONLY IN PARTICULAR INSTANTS

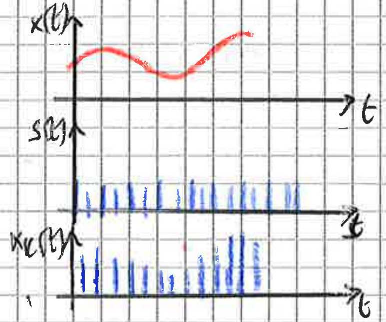
- SAMPLES OBTAINED AT EACH TIME INSTANTS

→ LINEAR INTERPOLATION
↓
VERY SIMILAR TO THE ORIGINAL ONE

IF WE INCREASE SAMPLE INTERVAL



WAVEFORM ISN'T A GOOD RECONSTRUCTION OF THE ORIGINAL SIGNAL



INFINITE PULSE TRAIN

SAMPLE SIGNAL

$$x_k(t) = x(t) \cdot \sum_{k=-\infty}^{+\infty} \delta(t - kT_s)$$

↑ ANALOG SIGNAL

EVEN IF THE SIGNAL ISN'T A BIG VARIATION
↓
THIS REPRESENTS VERY FAST TRANSIENT

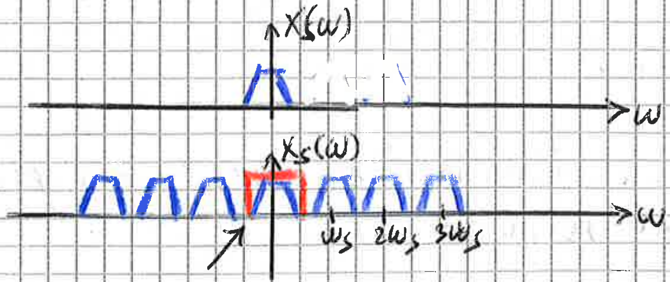
IF WE APPLY THE RULES OF FOURIER TRANSFORM (PRODUCT IN TIME → CONVOLUTION IN FREQUENCY)

$$X_s(\omega) = X(\omega) * S(\omega) = \omega_s \sum_{k=-\infty}^{+\infty} X(\omega - k\omega_s)$$

↑ SPECTRUM

GRAPHICAL REPRESENTATION

ASSUMPTION : BAND LIMITED SIGNAL



SPECTRUM CAN BE REPRESENTED AS AN INFINITE REPETITION

BUT WE'RE INTERESTED IN THE ORIGINAL SIGNAL
SO WE USE ⊓ IDEAL LOW PASS FILTER (CANNOT BE IMPLEMENTED IN REAL SITUATION AS IDEAL)

WE HAVE TO RESPECT SAMPLING THEOREM

$$f_s \geq 2 f_{MAX} \rightarrow f_s > 2 f_{MAX}$$

↑ identified from the characteristics of a sensor

DON'T USE EQUAL CONDITION!

21/10/16

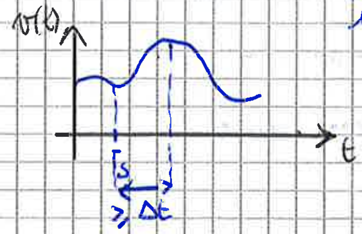
CONVERSION TIME = FINITE TIME NECESSARY FOR ADC TO COMPLETE CONVERSION PROCESS
↓
ANALOG SIGNAL IS CONVERTED IN A CODE

! DURING THE CONVERSION TIME → THE ADC INPUT HAS TO REMAIN STABLE
(cause of resolution of ADC which isn't able to see continuous signals)
↓
SIGNAL SHOULD REMAIN IN THIS RANGE IN ORDER TO BE SEEN: $\pm \frac{1}{2} V_q$

→ IT FIXES A LIMIT TO f_s, REGARDLESS OF THE SAMPLING THEOREM ($f_s > 2 f_{MAX}$)

(according to conversion time, it's a more important limit than f_s)

eg: $\Delta t = 10\ \mu s$ → fixes a limit to f_s
↘ next sample cannot be taken before this interval has elapsed



$$f < \frac{1}{\Delta t} = 100\ kSa/s$$

Applying the Shannon theorem

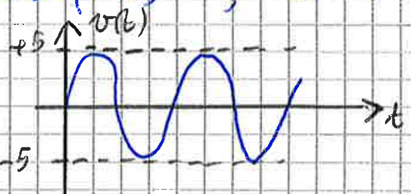
$$f_{MAX} < \frac{f_s}{2}$$

$$f_{MAX} < 50\ kSa/s$$

$N_b = 12$ bit
$V_{FR} = 10\ V$

$\Big\} \ V_q = \frac{V_{FR}}{2^{N_b}} \simeq 2.5\ mV$

our signal: $v(t) = A \sin(\omega t)$, $A = 5\ V = V_{pk}$
Bipolar ADC



$V_{FR} = 10\ V$
$V_{FS} = \frac{1}{2} V_{FR} = 5\ V$

($\omega = 2\pi f$ angular frequence)

What is f_{MAX} that could be correctly converted?

$\Delta V_{MAX} \leq \frac{1}{2} V_q$ during Δt → in order to have a correct conversion

SENSITIVITY RESPECT TO TIME

$$\Delta V_{MAX} = \left.\frac{\partial v(t)}{\partial t}\right|_{MAX} \Delta t = \left.\omega A \cos(\omega t)\right|_{MAX} \cdot \Delta t = \omega A \Delta t$$

$$\omega A \Delta t = 2\pi f A \Delta t \leq \frac{1}{2} V_q$$

$$f_{MAX} \leq \frac{V_q}{4\pi A \Delta t} = \frac{2.5\ mV}{4\pi\, 5\ V \cdot 10\ \mu s} \simeq 4\ Hz$$

↗ SURPRISING RESULT! WE HAVE TO LIMIT f_{MAX} TO 4 Hz!

[WHEN YOU HAVE A SYSTEMATIC EFFECT → TRADITIONAL METHODS.
- RECOGNISE IT
- ESTIMATE THE EFFECT, ITS VALUE
- COMPARE WITH UNCERTAINTY CONTRIBUTION
IF HIGHER TRY TO COMPENSATE]

Example of ADC specifications

- $f_{SMAX} = 40$ MSa/s (it's better to distinguish by using Sa)
  Not fixed, you decide it → important for design issue

  eg: you have to develop a certain product and you have to use this ADC, but the $f_{MAX} = 1$ MHz you need
  so we can set ADC $f_S > 2$ MSa/s
  We have $f_{INST} = 40$ MSa/s
  if we use it NO aliasing but there's a drawback (disadvantage) for this: large amount of sample means high transmission rate!

So use f_S suitable for your application! (In this case 2 MSa/s)

- $N_b = 14$
- Unipolar $[0 \div 2]$ V Bipolar $[-1 \div 1]$ V → same resolution $V_q \cong 120 \mu V$
- One chip S&H
- $E_{TOT} = E_q + E_I + E_O + E_g$ (NON LINEARITY, OFFSET, GAIN) → you can estimate uncertainty as V or LSB

$V_{FR} = 2V$

$FR = 2^{14}$ LSB $\quad FS = 2^{13}$ LSB

$\delta V_{IN} = E_{TOT} \cdot V_q \quad \rightarrow N_B^E = N_b - \log_2(2 \cdot E_{TOT})$ effective number of bits

! IT IS POSSIBLE TO COMPENSATE OFFSET AND GAIN ERROR:

- GAIN ERROR: known input V, obtain $\frac{V_{out}}{V_{in}}$ = slope
- OFFSET → V_{OFF} → set $V_{IN} = \emptyset V$ → OUT = OFFSET ⇒ compensate in software

IN THIS WAY $< E_{TOT} \Rightarrow > N_b^E$

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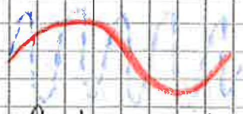
DSO → DOESN'T INCLUDE ANTI-ALIASING FILTERS
↓
IT'S POSSIBLE TO SEE A WAVEFORM WHICH IS WRONG RESPECT TO THE INPUT SIGNAL
↓
ALIASING PHENOMENA IS POSSIBLE!



- - - real signal
—— signal seen
] → DUE TO LOW SAMPLE RATE!
↓
YOU CAN HAVE AN ERROR OF < F / AMPLITUDE

you only know that input signal is a sinusoid

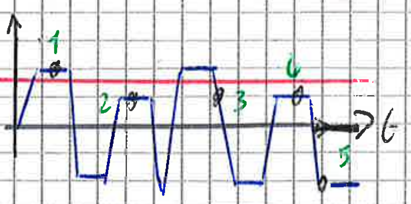
⇓

IN DSO ALIASING CAN BE HIGHLIGHTED
↓
IF YOU CHANGE TIME-BASE CONFIGURATION YOU SEE NON COHERENT WAVEFORMS
(because you sub-sampled signal in a different way)

! SUGGESTION : TO SEE A RIGHT RECONSTRUCTION ⇒ CHANGE TIME BASE
↓
IF NON COHERENT WAVEFORMS, CHANGE f_s

SAMPLING THEOREM REQUIREMENT
↓
HAS TO BE MET WHEN TRANSIENT SIGNALS ARE ACQUIRED (NO REPETITION/NOT PERIODIC SIGNALS)
↓
ONE SHOT (real time) MODE OF DSO
[one possibility to acquire the sample]

CAN BE OVERCOME WITH REPETITIVE SIGNALS (PERIODIC SIGNALS ⊂ REPETITIVE SIGNALS — SUBSET)
↓
EQUIVALENT-TIME SAMPLING



YOU CAN OBTAIN SAMPLES FROM DIFFERENT REPETITIONS
↓
RANDOM SAMPLING REFERS THAT THERE IS NO CORRELATION BETWEEN < SAMPLES (ASYNCHRONOUS TO IT) / TRIGGER EVENT

TRIGGER EVENT → ACTS LIKE A RESET FOR A COUNTER
↓
WE OBTAIN SAMPLES AND REORDER THEM REFERRING TO TRIGGER EVENT WHICH PROVIDES Δt_i WHEN EACH SAMPLE ARRIVES (such that we assign a correct time slot to each sample)

f_{seq} → EQUIVALENT SAMPLING FREQUENCE → DEPENDS ON DSO CAPABILITY TO MEASURE THE DELAY BETWEEN < TRIGGER EVENT / SAMPLING PULSES

$$f_{seq} = \frac{1}{\Delta t}$$

with Δt = resolution that allows to distinguish the position

$$f_{seq} > f_s$$ ← REAL f_s OF DSO

1) SAMPLE MODE → DEFAULT MODE

USES: $T_S = \frac{(time/div) \cdot 10}{N_W}$

(time/div) → DEPENDS ON YOUR TIME BASE CONFIGURATION → FIXES AN f_s

N_W → NUMBER OF WAVEFORMS POINT ON THE DISPLAY FIXED BY THE MANUFACTURER

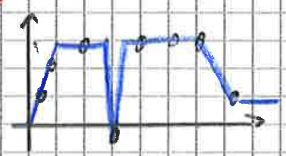
2) AVERAGE MODE → OPERATOR FIXES TIME/DIVISIONS

→ AVERAGE OF THE WAVEFORM POINTS OF SUBSEQUENT ACQUISITIONS

USEFUL IF YOU HAVE REPETITIVE SIGNALS IN ORDER TO REDUCE NOISE (even if noise has the same f of the signal)

[IN DSO < BAND LIMITATION → NOT USEFUL, REDUCES BANDWIDTH ; AVERAGE MODE } TO REDUCE NOISE]

3) PEAK DETECT MODE → DECIMATION TECHNIQUE: WAVEFORM POINTS OBTAINED AS MINIMUM AND MAXIMUM SAMPLE POINTS ACQUIRED DURING 2 WAVEFORM INTERVALS



↓ INCREASES THE PROBABILITY TO CATCH GLITCHES / SHORT PULSES (more than Default mode)

4) ENVELOP MODE → DECIMATION TECHNIQUE: MINIMUM / MAXIMUM } SAMPLE POINTS OF SUBSEQUENT ACQUISITIONS USED TO SHOW MINIMUM AND MAXIMUM ENVELOPE

⇓ YOU BUILD A BAND OF MINIMUM AND MAXIMUM TRANSITIONS

5) HIGH RESOLUTION MODE → DECIMATION TECHNIQUE: WAVEFORM OBTAINED AS MEAN VALUE OF SAMPLE POINTS ACQUIRED DURING A WAVEFORM INTERVAL

→ NOISE REDUCTION

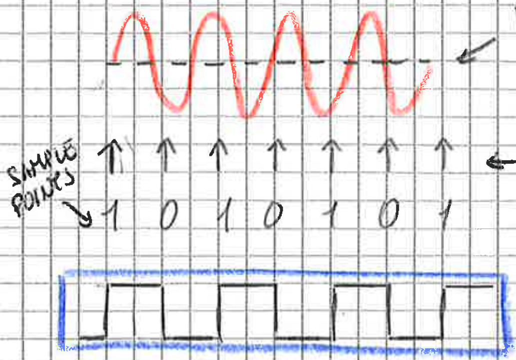
→ RESOLUTION IMPROVEMENTS → WITH SLOW CHANGES WITH RESPECT TO THE f_s / WITHOUT INCREASING THE NUMBER OF BITS

→ AS DITHERING TECHNIQUE IN DAQ BOARD

(1) TIMING MODE → USED WHEN IT'S NOT REQUESTED AN f ~ f OF THE SYSTEM

→ INPUT SIGNALS ASYNCHRONOUSLY SAMPLED

→ SAMPLE POINTS COMPARED TO VOLTAGE THRESHOLD IN ORDER TO OBTAIN A HIGH OR LOW STATES



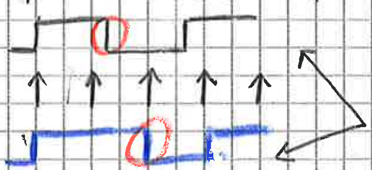
Voltage threshold @ ∅ level

SERIES OF ARROWS REPRESENTING INTERNAL CLOCK OF THE ANALYZER

LOGIC-ANALYZER DISPLAY

→ NO PARAMETRIC INFOS BC'S REPRESENTED AS DIGITAL SIGNAL
⇓
NO CORRELATION BETWEEN < TIME OF THE SIGNAL / TIME OF INSTR.

TIME RESOLUTION (t_{ck}) → INTRODUCES AMBIGUITY IN THE ANALYSIS OF DIGITAL SYSTEMS BECAUSE THE ANALYZER PLACES THE TRANSITION POINTS AT THE NEXT SAMPLE → WORST ERROR: 1 SAMPLE PERIOD



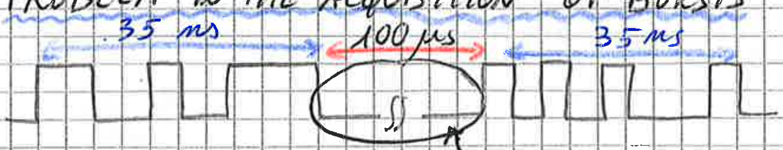
because transition point has a delay

TRADE-OFF BETWEEN < RESOLUTION / ACQUISITION TIME } → RESOLUTION ⇒ LOW VALUE OF ACQUISITION WINDOW
⇓
WE HAVE TO DECREASE ACQ. TIME

(DUE TO LIMITATION OF INTERNAL POINTS)

eg: Memory of 64 kSamples → 4 channels → $t_{ck} = 1\ \mu s$ ⇒ ACQ TIME = 16.8 ms
↘ $t_{ck} = 5\ ns$ ⇒ ACQ T = 81.92 μs

PROBLEM IN THE ACQUISITION OF BURSTS



$t_{ck} = 5\ ns$

LARGE TIME INTERVAL → NUMBER OF MEMORY LOCATIONS

$\frac{100\ \mu s}{5\ ns} \sim 200$ samples!

⇓

IT'S POSSIBLE TO MODIFY THE LOGIC ANALYZER IN ORDER TO HAVE A MORE EFFECTIVE USE OF MEMORY

TRANSITIONAL ANALYZER → HAS THE POSSIBILITY TO DETECT THE TRANSITIONS AND USES A COUNTER ABLE TO MEASURE TIME INTERVAL BETWEEN TRANSITIONS

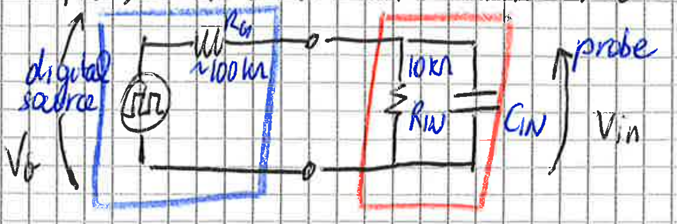
→ STORED DATA → SAMPLES PRECEDED BY A TRANSITION
→ ELAPSED TIME FROM THE LAST TRANSITION (COUNTER STARTS AND IT'S RESET AT EACH TRANSITION)

IN THE PREVIOUS EXAMPLE → WHEN THERE'S A LONG TIME INTERVAL, DURING WHICH COUNTER REACHES THE VALUE 20000 ⇒ STORED IN MEMORY → LESS MEMORY LOCATIONS! SORT OF COMPRESSION TECHNIQUE

- **PROBES** (→ called PODs)
  ↘ A PROBE ALLOWS A LARGE NUMBER OF SIGNALS TO BE EASILY CONNECTED BY MINIMIZING SYSTEMATIC LOAD EFFECT ON TIME BEHAVIOUR
  (WE CAN TOLLERATE THE EFFECT ON AMPLITUDE BUT NOT ON TIME!)

⇓

PROBE → HAS AN INPUT IMPEDANCE → THAT CAUSES SYSTEMATIC EFFECT



$$V_{in} = V_G \frac{R_{IN}}{R_{IN} + R_G} \quad \text{VOLTAGE DIVIDER}$$

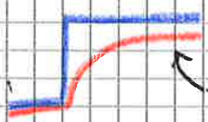
$$\frac{V_{in}}{V_G} = \frac{10^4}{10^4 + 10^2}$$

No strong attenuation in order to not change high level

IF YOU HAVE $C_{IN} = 10\,pF$

$$\tau \cong R_G C_{IN} \rightarrow \tau \cong 10^2 \cdot 10^{-12} = 10^{-1} = 0.1\,ns \Leftarrow \text{CHANGE TIME CONSTANT}$$

($R_G // R_{IN}$)



← SIGNAL RECEIVED BY LOGIC ANALYZER DUE TO EFFECT OF PROBE
↓
AMPLITUDE IS LOWER BUT THERE'S ALSO A DELAY! DANGEROUS (0.1 ns)

DETECTED SIGNAL CAN BE VERY DIFFERENT FROM THE SIGNAL OF THE INSTRUMENT UNDER DEBUG

PROBES
- ACTIVE → INCLUDE VOLTAGE COMPARATORS WITH PROGRAMMABLE THRESHOLD
  → HIGHER CAPACITANCE
  → LARGER
- PASSIVE → SMALLER
  → OFFER HIGHER RELIABILITY
  → C < 10 pF CAUSE THEY CAN BE TERMINATED AT THE CONNECTION POINT OF THE SYSTEM UNDER DEBUG

PROBES
- DESIGNED-IN PROBES → SYSTEM DESIGNED AND DEVELOPED WITH PROBE INCORPORATED IN THE LAYOUT (PROBE EMBEDDED)
  [connectors incorporate into board layout]
- AFTER-THOUGHT PROBES → SOLUTION FOR SYSTEMS WITHOUT INCORPORATED TESTABILITY (for low speed systems)
  [Flying lead probes]

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SERIAL INTERFACE RS-232 (EIA STANDARD INTERFACE)

↳ COMMUNICATION MODE DESIGNED FOR A TELEPHONE LINE

USED TO CONNECT → DTE (Data Terminal Equipment) computer
→ DCE (Data Communication Equipment) modem

} AT LONG DISTANCE → COVERED THANKS TO TELEPHONE LINE

DTE —— DCE

DTE: demodulate the carrier
DCE: used to modulate the carrier

MAIN PARAMETERS:
- MAXIMUM DISTANCE BETWEEN DEVICES → < 15 m - High baud rate; → > distance lower baud rate
- CAPACITIVE LOAD < 2.5 nF
  ↓ AFFECTS THE VALUE OF THE SIGNAL WE TRANSMIT
- VOLTAGE SIGNALS REFERRED TO A COMMON GROUND
- DIGITAL LEVELS:
  - MARK → NEGATIVE VOLTAGE (−25 ÷ −3) V
  - SPACE → POSITIVE VOLTAGE (+3 ÷ +25) V
  - TRANSITION REGION (−3 ÷ +3) V (MONOTONIC BEHAVIOUR)

ELECTRICAL RULES
- TIME TO PASS THROUGH THE TRANSITION REGION:
  - less than 1 ms → for control signals
  - less than 4% T / 1 ms } for data signals
- MAXIMUM SLEW-RATE: 30 V/ms
- IF DEVICE IN IDLE STATE → LINE IS KEPT AT THE MARK LEVEL

DATA PACKET

STOP BIT	ST. BIT	PARITY BIT	D7	D6	D5	D4	D3	D2	D1	D0	START BIT

→ RECEIVER RECEIVES AT FIRST THE START BIT

STOP BIT ↓ MARK
↳ OR: 1 STOP BIT; 2 STOP BIT + PARITY BIT

START BIT ↓ SPACE
↓ MEANS THAT TRANSITION IS SENSED AT RECEIVER

PACKET SIZE: 9 ÷ 12 BITS

⇒ FREQUENCIES OF < TRANSMITTER / RECEIVER ARE DIFFERENT
⇓
EACH ONE HAS A TOLERANCE
AN ERROR HAS A CORRESPONDING SHIFT
> Baud rate → > possibility of error
⇓
IF ERRORS ONE SOLUTION IS TO DECREASE BAUD RATE

ERROR DETECTION

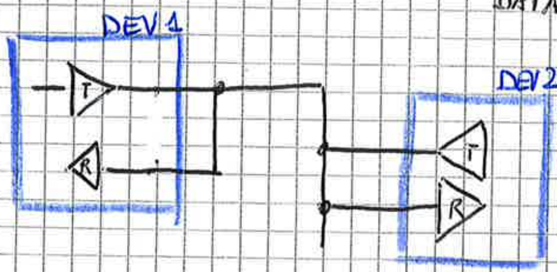
- PARITY ERROR
- FRAMING ERROR → WE EXPECT A PACKET WITH A CERTAIN NUMBER OF BITS → IF STOP BIT ISN'T CORRECTLY IDENTIFIED (SPACE INSTEAD OF MARK)
  ⇓
  ERROR IDENTIFIED
  THE DEVICE TRIES TO RESYNCHRONIZE ON NEW INCOMING PACKETS
  ↳ IF THE SITUATION PERSISTS THE ERROR IS NOTIFIED
  THIS IS DUE TO A WRONG < BAUD RATE / FORMAT SETTING
- OVERRUN → PROBLEM OF MANAGEMENT OF DIGITAL CIRCUIT
  ⇓
  NEW DATA PACKET IS GENERATED IN THE RECEIVER BUT THE PREVIOUS ONE HASN'T BEEN REMOVED YET.
  ⇓
  DUE TO PROTOCOL PROBLEMS

COMMUNICATION MODES:

- DTE1 AND DTE2 CONNECTED THROUGH < MODEM / SWITCHED LINE (DIALING NUMBER IS REQUIRED)
- DTE1 AND DTE2 CONNECTED THROUGH DEDICATED LINE
- DIRECT LINK WITHOUT A MODEM (MOST EMPLOYED)
  WE CONNECT DIRECTLY DEVICES
  SIGNALS RESERVED TO A MODEM ARE < NOT EMPLOYED / EMPLOYED IN A DIFFERENT WAY
  (BASED ON LOCAL CONNECTIONS)

RS - 485

- TRANSMITION ONE-TO-MANY (NO SIMPLEX!) (32 max)
- DIFFERENTIAL SIGNALS
- MAX DISTANCE: 1.2 km
- THREE-STATE DRIVERS → DIFFERENT DRIVERS CAN DRIVE THE DATA LINE → ONLY ONE OF THE DEVICES IS SELECTED
  WHEN A DRIVER ISN'T SELECTED IT GOES IN HIGH IMPEDANCE STATE

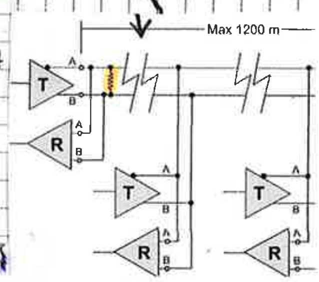


When DEV 1 is selected as Master DEV2 is disabled and put in high impedance state

- 2 DIFFERENT PROTOCOLS:

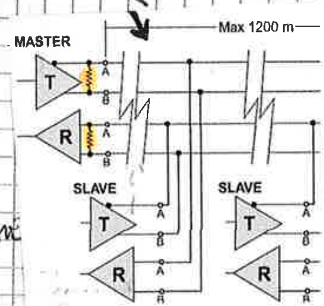
  COMMON TWISTED CABLE CONNECTS ALL DEVICES

- RS-485 2-WIRE
  - TRANSMITTER / RECEIVER } OF EACH DEVICE ARE CONNECTED THROUGH A TWISTED PAIR
  - NODE HAS THE POSSIBILITY TO SEND INFORMATIONS TO AN OTHER NODE (HALF-DUPLEX TRANSMITION POSSIBLE)
  - LOW WIRING COST → DUE TO THE # OF WIRES (LESS WIRES 2<4)



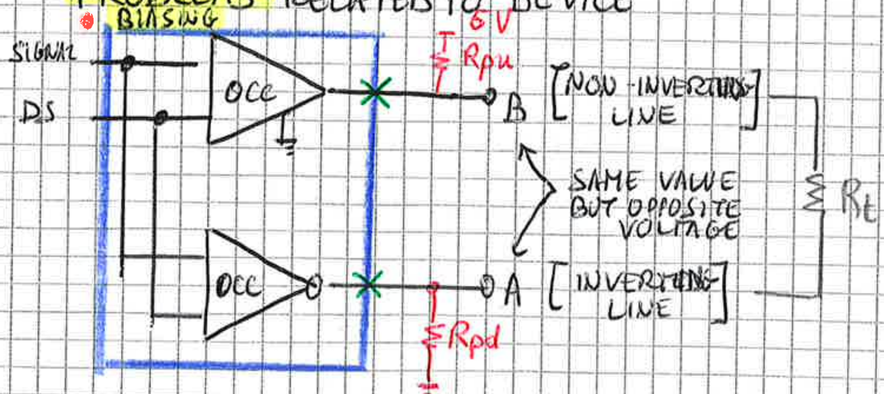
- RS-485 4-WIRE
  - TRANSMITTER OF MASTER —CONNECTED TO→ ALL RECEIVERS OF SLAVE NODES
  - RECEIVER OF MASTER → ALL TRASMITTERS OF SLAVE NODES

  DIFFERENT CABLING



FULL-DUPLEX → POSSIBLE BUT LIMITED TO MASTER-SLAVE, NO COMMUNICATION AMONG SLAVES

- PROBLEMS RELATED TO DEVICE
  - BIASING



IT'S POSSIBLE THAT ALL THE TRANSMITTERS ARE DISABLED (OR OPEN CABLE)
↓
✕ OPEN CIRCUIT
↓
WE CAN HAVE UNDEFINED LEVELS
IN ORDER TO AVOID THIS SITUATION
↓
2 BIAS RESISTORS ARE EMPLOYED TO KEEP THE LINE IN A DEFINED STATE

(OCC = OPEN COLLECTOR CIRCUIT
↓
STANDS FOR 3-STATE)

USB = UNIVERSAL SERIAL BUS → SHORT RANGE DISTANCE BUS

→ SET OF SPECIFICATION FOR COMMUNICATION BETWEEN ELECTRONIC SYSTEMS

→ THANKS TO ITS HIGH SPEED, IT HAS REPLACED RS-232 AND ALL OTHER PARALLEL INTERFACES

→ IT'S NOT ONLY A COMMUNICATION CHANNEL → ACTS AS AN EXTERNAL EXPANSION BUS TO CONNECT PERIPHERALS TO A PC IN A SIMPLE WAY (mouse, keyboards, joysticks, ...)

- ALLOWS HOT-SWAPPING → YOU CAN INSERT AND REMOVE USB WITHOUT TURNING OFF THE SYSTEM
- PROVIDES POWER TO THE BUS !
- BAUD RATE → DEPENDS ON THE VERSION

28/10/16

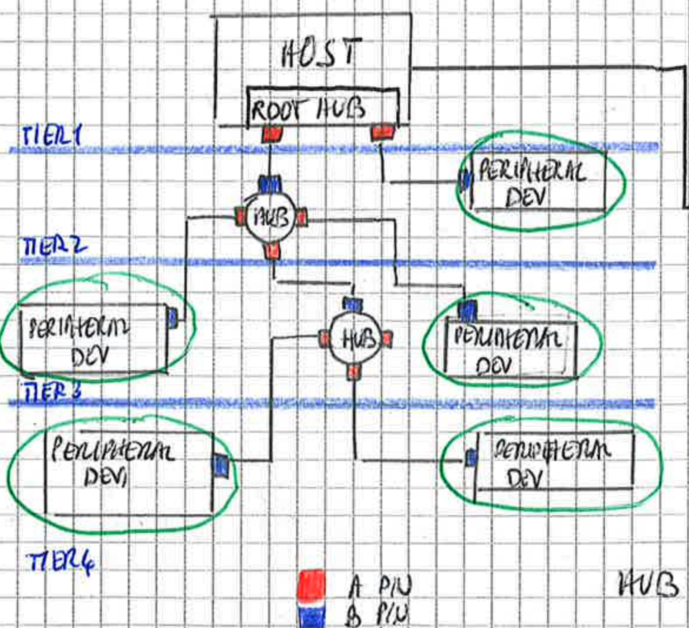
(ARDUINO → CONNECTED TO PC THROUGH A USB INTERFACE)

DEVICES INCLUDED IN USB BUS

- A HOST-DEVICE WHICH MANAGES THE PROTOCOL
- 1 OR MORE USB PORTS
- PERIPHERAL DEVICES CONNECTED IN TIERED-STAR TOPOLOGY
  IN TIERS ⇓ THERE ARE HUBS WHICH EXPAND THE NUMBER OF AVAIABLE PORTS

(DIFFERENT LEVELS OF TIERS, UP TO 6 IN ORDER TO SUPPORT UP TO 127 DEVICES)

USB RECOGNIZES 2 KINDS OF PERIPHERALS
- → STAND-ALONE DEVICES [→ SINGLE FUNCTION] USUALLY EMPLOY ONE COMMUNICATION CHANNEL (mouse, flash drive..)
- → COMPOUND DEVICES [→ MULTI FUNCTIONS] MANAGED USING SEPARATED CHANNELS (videocamera...) ↳ video/audio ch.



→ MASTER → MANAGES AND CONTROLS THE BUS
EMBEDS A ROOT HUB TO HAVE THE CAPABILITY TO CONTROL AND SCHEDULING

SLAVES → ONLY ABLE TO RESPOND TO COMMANDS FROM THE HOST
[Apart from an exception usually controls are sent by master and received by slaves]

HUB = BRIDGES THAT EXPAND THE BUS
THEY CAN HAVE THEIR OWN POWER SUPPLY AND MAY INCORPORATE SOME AMOUNT OF INTELLIGENCE

ELECTRICAL CIRCUITS → HOST USES 15 kΩ PULL-DOWN RESISTOR ON < D+ / D−

EACH DATA LINE CAN BE DRIVEN LOW INDIVIDUALLY OR A DIFFERENTIAL DATA SIGNAL CAN BE APPLIED

DATA LINES BOTH LOW INDICATE A SINGLE-HANDED ZERO STATE (SE0) → RECEIVER HAS TO SENSE THE SIGNAL WITH RESPECT TO GROUND

YOU NEED → NO DEVICES CONNECTED TO THE BUS

WHEN IT'S MANTAINED 10-20 ms IN THIS CONDITION IT'S USED TO RESET THE BUS

USB PERIPHERAL → USES 1.5 kΩ R_{pu}

IT PULLS UP → D+ IF FULL-SPEED PERIPHERAL
→ D− IF LOW-SPEED PERIPHERAL
→ HIGH-SPEED MODE NEGOTIATED DURING RESET

⇓

DUE TO POSSIBLE COMBINATIONS OF DATA LINES THERE ARE 2 STATES

J-STATE → D+ HIGH, D− LOW

K-STATE → D+ LOW, D− HIGH

THERE ARE 4 DATA TRANSFER MODES:

1) CONTROL → CONFIGURATION / SETUP / COMMAND INFOS } CAN BE TRANSFERRED BETWEEN < HOST / PERIPHERALS

2) ISOCHRONOUS → USED BY TIME CRITICAL STREAMING DEVICES (eg videocamera)
↘ REAL-TIME DATA TRANSFER BETWEEN < HOST / PERIPHERAL

⇓

SO THAT NO ERROR CORRECTION IS IMPLEMENTED

3) BULK → USED WHEN BIG AMOUNT OF DATA HAS TO BE TRANSFERRED (eg: printer)
↘ ERROR CHECK IS IMPLEMENTED

4) INTERRUPT → USED WITH SMALL AMOUNT OF DATA THAT NEED IMMEDIATE ATTENTION (eg mouse, keyboard)
↓ ERROR CHECK IS IMPLEMENTED

ISOCHRONOUS / INTERRUPT } PERIPHERALS → CAN CONSUME UP TO 90% OF AVAILABLE BANDWIDTH

AFTER 90%, HOST DENIES ACCESS TO THEM

CONTROL / BULK } TRANSFERS USE BANDWIDTH LEFT OVER

DATA ACQUISITION BOARD

04/11/16

DAQ BOARD = ELECTRONIC DEVICE
↳ THERE ARE DIFFERENT VERSIONS:

1) INTERNAL TO THE PC (you have to open PC, restart it in order to restart DAQ)

2) EXTERNAL DAQ → RELATED TO DIFFERENT CONNECTIONS ON THE PC
(once you've installed the driver you can connect the board according to specifications of USB peripheral)

IT'S A DEVICE THAT ALLOWS A CHEAP MULTI-CHANNEL SYSTEM TO BE ARRANGED.
↳ OFFERS LIMITED PERFORMANCES (DAQ COMPARED TO DMM)
UNCERTAINTY IS AFFECTED BY PC INTERNAL NOISE (or due to power supply) → IMPROVEMENTS ARE OBTAINED WITH DAQ BOARDS FOR EXTERNAL BUSES

IT'S NOT A STAND-ALONE DEVICE (≠ DMM)

- IT HAS TO BE CONNECTED TO THE PC IN ORDER TO OBTAIN VOLTAGE SUPPLY
- IT HAS TO BE MANAGED THROUGH SW PROGRAMS
- IT DOESN'T EMBED A DISPLAY (NO BUTTONS ...) DATA ARE STORED AND CAN BE SEEN ON THE DISPLAY OF THE PC

THE MAIN MEASUREMENT FUNCTIONS ARE

- ACQUISITION (SAMPLING AND A/D CONVERSION) OF ANALOG SIGNALS (VOLTAGE, CURRENT, RESISTANCE ...)
  ↓
  EVEN THOUGH THE ADC IS A VOLTMETER YOU CAN HAVE PARTICULAR CONFIGURATIONS IN ORDER TO MEASURE CURRENT, RESISTANCE, ETC.
- GENERATION OF ANALOG SIGNALS (VOLTAGE)
- DIGITAL I/O → IT HAS EXTRA FUNCTIONS BECAUSE IT'S USED TO CONTROL THE SYSTEM USING OUTPUT CHANNELS.

  COUNTERS → IN ORDER TO MEASURE TIME INTERVALS

  TIMERS

TYPICAL PERFORMANCES:

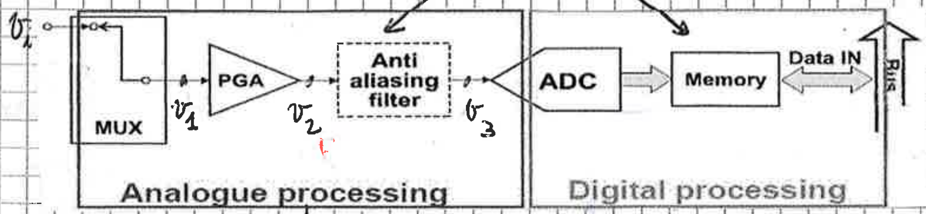
- 16/32 SINGLE ENDED; 8/16 DIFFERENTIAL } VOLTAGE
- RANGES FROM 0.5 V UP TO 20 V → NO VERY HIGH/LOW VOLTAGE SIGNALS
- RESOLUTION → 8 BIT → UNCERTAINTY 1%; → 16 BIT → UNCERTAINTY 0.1%
- SAMPLING FREQUENCY: 50 kSa/s – 50 MSa/s

  } USES HIGHER RESOLUTION BUT LOWER f_s THAN A DSO
- VOLTAGE OUTPUT CHANNELS: (-10 ÷ 10) V

MAIN UNCERTAINTY CONTRIBUTIONS → IMPORTANT FOR DESIGN

ASSUMPTION : FIXED POSITION OF MUX (TO SIMPLIFY SITUATION BUT NOT OFTEN USED)

MEASURING CHAIN → IS DIVIDED IN 2 PARTS



INCLUDES A PART OF ADC ← INPUT ANALOG CIRCUIT, S&H, A PART OF CONVERSION

ANALOG PROCESSING:

EACH PART OF MEASURING ELEMENTS HAS AN UNCERTAINTY CONTRIBUTION:

- **MUX** → UNCERTAINTY CONTRIBUTIONS BASED ON / DUE TO → VOLTAGE OFFSET; RESISTANCE → IMPORTANT IN PARTICULAR OCCASIONS → IF YOU WANT TO MEASURE A RESISTANCE
  CAN BE CONSIDERED NEGLIGIBLE → $v_1 \approx v_i$

- **PGA**
  $V_{FR} = 10\,V$ (BIPOLAR RANGE)
  RANGE = $(-5 \div 5)\,V$ $\quad N_b = 10$
  $V_q = \frac{10\,V}{2^{10}} \simeq 10\,mV \rightarrow e_{q\,MAX} = \frac{V_q}{2} = 5\,mV$
  if $V_{IN} \cong 100\,mV \rightarrow \varepsilon_q = \frac{e_q}{V_{in}} = \frac{5\,mV}{100\,mV} = 0.05 \rightarrow \varepsilon_{q\%} = 5\%$ high value

  PGA → to amplify signal if it's not close to range
  $G = 50 \rightarrow \varepsilon_q = \frac{5\,mV}{5\,V} = 1 \cdot 10^{-3} = 0.001 \rightarrow \varepsilon_{q\%} = 0.1\%$

  PGA → GAIN UNCERTAINTY AND V_{off}, PASS-BAND FLATNESS, TIME AND THERMAL DRIFTS ($\Delta g \rightarrow T$) $\Rightarrow v_2 = [v_1 + V_{off}] \cdot G$

- **ANTIALIASING FILTER** → DEPENDS ON THE CHARACTERISTICS OF THE SYSTEM; → SAME UNCERTAINTY CONTRIBUTIONS $\Rightarrow v_3 = H_0 v_2$

- **SAMPLE & HOLD** CIRCUIT → UNCERTAINTY CONTRIBUTIONS SPECIFIED IN ADC specs included by manufacturer
  $v_S = v_3(t_S)$ (SAMPLE) → CAPACITOR IS CHARGED TO THIS VALUE v_3

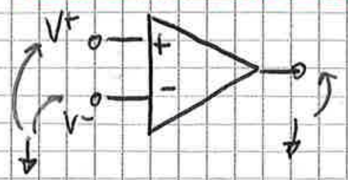
WE OBTAIN

$$\Rightarrow \quad v_S = G H_0 [v_i(t_s) + V_{off}] + n(t_s)$$

→ ELECTRONIC NOISE: DUE TO BOARD COMPONENTS (AMPLIFIERS, TRANSISTORS...); INTRODUCED BY OTHER DEV. USED IN THE ...

[WE DO NOT CONSIDER PROBLEM OF ALIASING]

DIFFERENTIAL AMPLIFIER PERFORMANCE



$V_0 = A_D V_D$ where $V_D = V^+ - V^-$

→ IDEAL BEHAVIOR

≠

REAL BEHAVIOUR

$$V_0 = A_D V_D + A_{CM} V_{CM}$$

where $V_{CM} = \frac{V^+ + V^-}{2}$ ≠ 0 AVERAGE VALUE OF 2 VOLTAGES

A DIFF. AMPL. IS CHARACTERISED BY

$$CMRR = 20 \log_{10}\left(\frac{A_D}{A_{CM}}\right) \quad [dB]$$

↓

EXPRESSES HOW LARGE IS DIFFERENTIAL GAIN RESPECT TO COMMON MODE GAIN

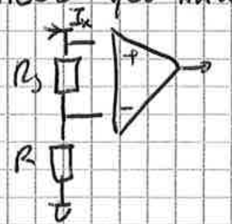
IDEAL CASE: $A_{CM} = 0$ → CMRR → +∞

REAL CASE $A_{CM} \neq 0$ → $V_0 \neq 0$ EVEN THOUGH $V_D = 0$

↓

IT INTRODUCES AN IMPORTANT ERROR CONTRIBUTION 1%

IN MANY SITUATIONS YOU HAVE TO CONSIDER IT



↙ LIKE IN THIS ONE

! V^+ AND V^- LIMITED BY POWER SUPPLY REGARDLESS OF V_D

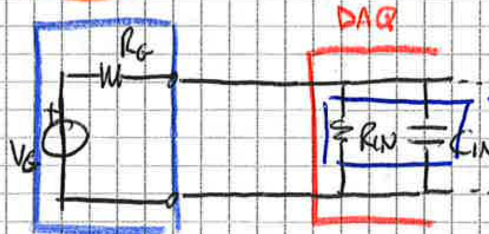
$V_S = 12\,V$

$V_D = 3\,V$ → we cannot apply 10 V, 7 V cause Amplifier input-range: ±5 V → saturation

LOAD EFFECT → INPUT IMPEDANCE → $R \sim G\Omega$, $C \sim pF$ |→ CAUSE NOT NEGLIGIBLE EFFECT FOR AC MEASUREMENT

↓

MAINLY @ H.F WITH A SOURCE WHICH HAS HIGH Z_{out}



$Z_{IN} = R_{IN} // \frac{1}{j\omega C_{IN}} = \frac{R_{IN}}{1 + j\omega R_{IN} C_{IN}}$

as $f \gg$ ⇒ > EFFECT OF CAPACITANCE !

↓

$Z_{IN} \ll$ → NOT NEGLIGIBLE EFFECT AT PASSBAND ($f_{MAX} = \frac{B}{5}$)

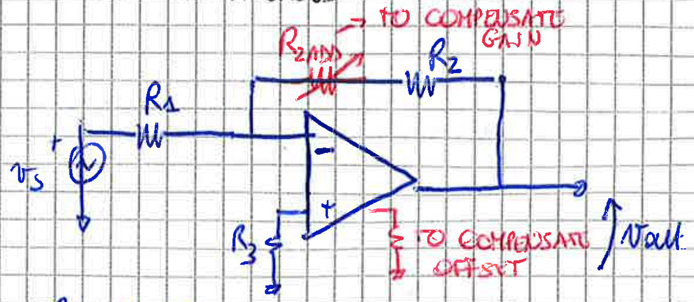
$$V_{IN} = V_G \frac{Z_{IN}}{Z_{IN} + Z_G} = \frac{R_{IN}}{R_G + R_{IN} + j\omega R_G R_{IN} C_{IN}}$$

IDEAL IF $R_G \to \emptyset$, $R_{IN} \to +\infty$ } RATIO = 1 ⇒ DUE TO BOTH SOURCE AND DAQ BOARD

THE COMPENSATION OF DRIFT CAN BE DONE IN 2 WAYS

DIGITAL WAY ↓ CONVENIENT BECAUSE IT ALLOWS THE USE OF VARIABLE COMPONENTS TO BE AVOIDED

ANALOG WAY ↓ BY MEANS OF VARIABLE COMPONENTS WHICH COULD HAVE VERY LARGE DRIFTS



$R_1 = 1\ k\Omega$
$R_2 = 10\ k\Omega$
$G = 10$

$v_{out} = -\frac{R_2}{R_1} v_S$ (G)

$v_{out} = -G v_S$

⇓

but we have offset voltage

$v_{out} = -G(v_S + V_{off})$

$-v_{out} - V_{off} G = +G v_S$

$v_S = \left(-\frac{v_{out}}{G}\right) - V_{off}$ $\Rightarrow$ $v_S = A_1 v_{out} + A_0$

A_0 = constant STORED IN NON-VOLATILE MEMORY

1) we shortcircuit the V_{in} → so find $A_0 = 100\ \mu V$
2) we apply known value $v_{S_{REF}} = 100\ mV$
we obtain $v_{out} = 0.95\ V$
We now find $A_1 = \frac{v_S - A_0}{v_{out}} = \frac{100\ mV - 100\ \mu V}{0.95\ V}$
↳ slightly different from G ($G_{NOW} = 9.95$)

⇓

we store A_0, A_1 in memory of DAQ

But $V_{OFF_{RTI-MAX}} = 1\ mV$

time-drift $= 10\ \mu V/s$ → input offset can become on the order of 10 mV

After 1 year

$V_{OFF_{RTI}} = 5\ mV$

$v_{out_{OFF}} = G V_{off} = 50\ mV$ (scale: 0, 0.05, 1 V)

↓

if we don't compensate with analog circuit it's possible that half of the range can be used

⇒ IN MANY CASES IT'S BETTER TO HAVE VARIABLE COMPONENTS → SO USE ANALOG ADJUSTMENT BUT IT INTRODUCES THE PROBLEM OF DRIFT → TO SOLVE: APPLY FREQUENTLY INTERNAL ADJUSTMENT!
(DMM STORES VALUES IN NON VOLATILE MEMORY → HERE DRIFT IS ACCEPTED)

SPECIFICATIONS OF A COMMERCIAL DAQ BOARD

PCI-6024E → MAIN CHARACTERISTICS:

- DC COUPLED INPUTS
- INPUT CHANNELS: 16 SINGLE-ENDED OR 8 DIFFERENTIAL
- AMPLIFIER CHARACTERISTICS
  - INPUT IMPEDANCE: 100 GΩ // 100 pF { @ LF IS NEGLIGIBLE; @ HF HAS TO BE CONSIDERED }
  - CMRR (DC ÷ 60 Hz): 90 dB
  - GAINS → REFERRED TO EACH VOLTAGE
    1 (±5 V) ← corresponds to the input range of the ADC
    ↘ CHECK IF PROGRAMMABLE FOR EACH CHANNEL WHEN YOU SELECT A BOARD

- ADC → SUCCESSIVE APPROXIMATION
  → $f_{s\,MAX} = 200$ kSa/s → 100 kHz WITHOUT ALIASING
  @ $f = 500$ Hz → PASS-BAND HAS AN EFFECT OF 30%

  → RESOLUTION: 12 BIT

  → OFFSET ERROR → AFTER INTERNAL ADJUSTMENT IS LOWER FOR MORE THAN 3 ORDERS OF MAGNITUDE
  → GAIN ERROR → AFTER INTERNAL ADJ. IS LOWER OF 2 ORDERS OF MAGNITUDE
  } IMPROVEMENTS IN THE PERFORMANCE

→ CROSS TALK → −60 dB → $v_{n\,adj} = \frac{v_{adj}}{1000}$ → THE VOLTAGE ON THE CHANNEL n DUE TO THE VOLTAGE OF ADJACENT CHANNEL HAS AN UNCERTAINTY CONTRIBUTION

⇓

IN ORDER TO HAVE A MINIMUM CROSS-TALK EFFECT (VOLTAGE)

⇓

1. NOT ADJACENT CHANNELS (IF YOU HAVE A SCAN LIST)

ALWAYS USED ⇒ 2. ASCENDING (OR DESCENDING) ORDERING ON THE INPUT SIGNALS!

$v_1 < v_2 < v_3$ ⇒ THE EFFECT STILL REMAINS BUT WE'VE REDUCED IT

→ SETTLING TIME → 10 µs WITHIN ±0.5 V_p

if 4 ch → we have to wait at least 40 µs

$$f_{si} = \frac{1}{40\,\mu s} = 25 \text{ kSa/s}$$

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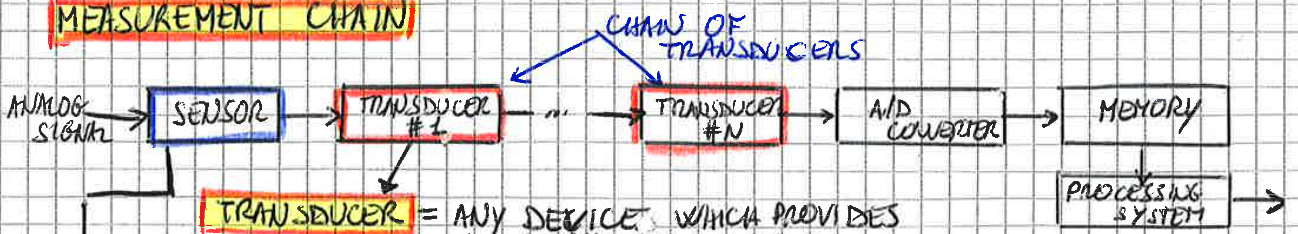
SENSORS

16/11/16

MEASUREMENT CHAIN



TRANSDUCER = ANY DEVICE WHICH PROVIDES AN OUTPUT SIGNAL THAT IS A MODIFIED VERSION OF THE INPUT SIGNAL

SOME EXAMPLES:

- AMPLIFIER/ATTENUATOR → CHANGES THE VOLTAGE
- FILTER → CHANGES THE FREQUENCY COMPONENT
- ADC → COMPLETELY CHANGES THE DOMAIN FROM ANALOG TO NUMERIC
- THERMAL VOLTAGE CONVERTER

SENSOR = THE 1st TRANDUCER WHICH SENSES THE QUANTITY UNDER MEASUREMENT

EXAMPLES →
- THERMOCOUPLE → COUPLE OF 2 DIFFERENT METALS
- STRAIN GAUGE → CONVERTS A DEFORMATION INTO A RESISTANCE CHANGE
- CAPACITIVE HYGROMETER → MATERIAL WHICH SENSES RELATIVE HUMIDITY

SENSOR CLASSIFICATION

→ DIFFERENT CRITERIA ARE USED TO CLASSIFY SENSORS ACCORDING TO THE GOAL

- ACCORDING TO → MEASURED QUANTITY (OR INPUT QUANTITY) [Temperature, humidity, pressure, ...]
- BASIC PHYSICAL PRINCIPLE
  - seebeck effect
  - electromagnetic coupling
  - Hall - effect
  - piezoelectric effect
- OUTPUT SIGNAL → REGARDLESS OTHER CRITERIA → Impedance, Voltage, Current...

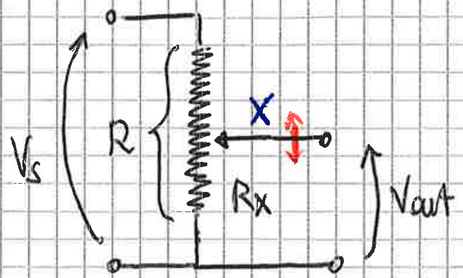
WE ARE INTERESTED IN OUTPUT SIGNAL BECAUSE WE WANT THE DESIGN OF A DATA ACQUISITION SYSTEM

⇓

THERE'S A FURTHER SUBDIVISION

- PASSIVE SENSORS → WE HAVE TO DESIGN A STIMULING CONDITIONING CIRCUIT (eg: Resistance) → BASED ON OUTPUT IMPEDANCE CHANGES
- ACTIVE SENSORS → OUTPUT SIGNALS ARE ACTIVE SIGNALS

A COMMON APPLICATION FOR VOLTAGE DIVIDERS → CAN BE POTENTIOMETER SENSOR (IN AUTOMOTIVE APPLICATIONS → TO MEASURE DISTANCE)



$$R_X = X \cdot R$$ (R ← ALL RESISTANCE)

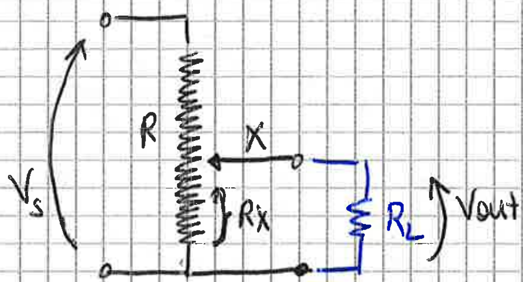
⇓

$$\frac{V_{out}}{V_S} = X$$

IT'S AN IDEAL SITUATION
⇓
WE DON'T CONSIDER THE R OF THE INPUT VOLTMETER

⇓

IN REAL SITUATION → WE HAVE TO CONSIDER THE LOAD EFFECT DUE TO THE PRESENCE OF THE VOLTMETER

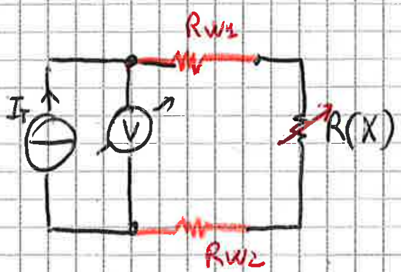


$$\frac{V_{out}}{V_S} = \frac{X}{1 + \frac{R}{R_L} X}$$

IT'S A VERY IMPORTANT SYSTEMATIC EFFECT ⇒ IF WE NEGLECT IT WE MAKE AN ERROR
↓
IT'S BETTER TO HAVE R NEGLIGIBLE WITH RESPECT TO THE INPUT RESISTANCE R_L OF THE VOLTMETER

$$R = \frac{R_L}{10}$$

- VOLT-AMMETER METHOD → MEANS TO SEND A TEST CURRENT I AND TO MEASURE VOLTAGE DROP
⇓
BY MEANS OF OHM LAW



$$R_m = \frac{V_m}{I_T} = R(X) + R_{W1} + R_{W2}$$

($R_{W1} + R_{W2}$ → SYSTEMATIC EFFECT)

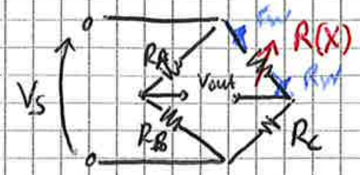
⇓
THE CURRENT SOURCE PROVIDES A TEST CURRENT, MEASURING THE VOLTAGE WE HAVE THE RESISTOR BUT ALSO THE RESISTANCES OF WIRES AND THE CONTACT RESISTANCES
⇓
WE HAVE TO COMPARE THE EXPECTED VALUE OF R_{W1}, R_{W2}

IF NEGLIGIBLE OK

IF NOT, SHORTCIRCUIT R(X) AND STORE IN THE INTERNAL MEMORY SO THAT AUTOMATICALLY SUBTRACTS THE RESULT

BUT CONTACT RESISTANCES DEPEND ON RANDOM VARIABLES.

- **UNBALANCED WHEATSTONE BRIDGE** → IT'S LIKE A DOUBLE VOLTAGE DIVIDER!



R(X) → OUR SENSOR

$$V_{out} = V_S \left[\frac{R_B}{R_B + R_A} - \frac{R_C}{R_C + R(X)} \right]$$

INPUT-OUTPUT RELATIONSHIP

⇓

$$V_{out} = f\left[R(X)\right]$$

Vout IS A FUNCTION OF R THAT IS A FUNCTION OF X

⇓ WE WANT

$$\frac{R_B}{R_A} = \frac{R_C}{R(X_0)}$$

→ s.t. WE OBTAIN $V_{out}(X_0) = \emptyset$

⇓

WE CONVERT A SMALL R CHANGE IN A SMALL V CHANGE BUT AROUND ∅

⇓

s.t. WE HAVE A LIMITED NUMBER OF DIGIT!

! $\frac{R_B}{R_A} = \frac{R_C}{R(X_0)} = 1$ → THE UNITARY RATIO ALLOWS THE MAXIMUM BRIDGE SENSITIVITY (LARGER VOLTAGE SIGNAL) BUT ALSO THE STRONGEST NOT LINEARITY

⇓

WE HAVE TO FIND A TRADE-OFF BETWEEN < NON-LINEARITY / SENSITIVITY

⇓

IF LINEARITY IS A REQUIREMENT → INCREASE THE RATIO!

⇓

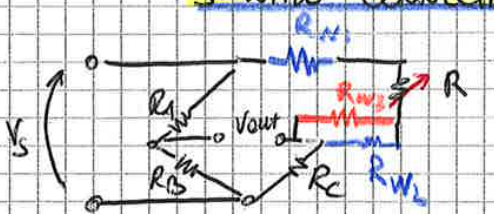
IF WE APPLY AN HIGHER VOLTAGE → > BRIDGE SENSITIVITY BUT PAY ATTENTION TO SELF-HEATING PROBLEMS!

THERE'S AN OTHER PROBLEM → DUE TO THE PRESENCE OF WIRE AND CONTACT RESISTANCES (R_W)

⇓

2 POSSIBLE SOLUTIONS

3-WIRE CONNECTION



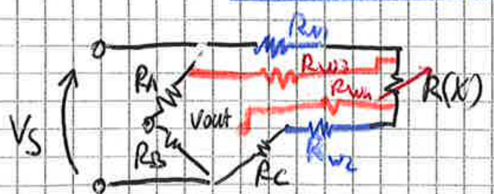
YOU ADD A CONNECTION ($R_{W1}+R(X)$) AN (R_C+R_{W2}) IN OPPOSITE ARMS OF THE BRIDGE

⇓

A POSSIBLE SOLUTION IS $R(X_0) = R_C$

AS A CONSEQUENCE THERE'S NO MORE PERFECT COMPENSATION

4-WIRE CONNECTION



IF $R_A, R_C >> R(X)$

⇓

WE SOLVE THE PROBLEM BY MOVING THE EFFECT FROM R(X) TO R_A, R_C

⇓

WHEN RESISTORS ARE VERY DIFFERENT

PLATINUM RTD (PRTD) → EMPLOYED TO ARRANGE
- HIGH ACCURACY RESISTIVE THERMOMETER
- THERMOMETER FOR INDUSTRIAL APPLICATIONS

INPUT/OUTPUT RELATIONSHIP (CALENDAR-VAN DUSEN) → DEPENDENT ON TEMPERATURE RANGE

- RANGE $(0 \div 850)$ °C $\quad R = R_0 (1 + A\theta + B\theta^2)$
- RANGE $(-200° \div 0)$ °C $\quad R = R_0 [1 + A\theta + B\theta^2 + C(\theta - 100)\theta^3]$

↓

CALIBRATION FUNCTION → USUALLY THIS EXPRESSION IS EXTENDED DOWN TO −40 °C

$$\theta = \frac{-AR_0 + \sqrt{A^2R_0^2 - 4BR_0(R_0 - R)}}{2BR_0}$$

THE VALUE OF CONSTANTS (A, B) DEPENDS ON THE PLATINUM PURITY

R_0 = PRTD RESISTANCE @ 0 °C

- Pt 100 → $R_0 = 100\,\Omega$
- Pt 25 → $R_0 = 25\,\Omega$
- Pt 1000 → $R_0 = 1000\,\Omega$ → TO MINIMIZE THE PROBLEM OF WIRE AND CONT.

↓

UNCERTAINTY CLASSES → INSTRUMENTAL UNCERTAINTY

↓

DEFINED CLASSES
FOR EACH RANGE YOU HAVE A TOLERANCE VALUE WHICH IS A FIXED VALUE

→ SYSTEMATIC EFFECT → DUE TO WIRE AND CONTACT RESISTANCES (LOAD EFFECT)

↓

WIRE EFFECTS HAVE TO BE COMPENSATED OR 4-WIRE CONNECTION HAS TO BE EMPLOYED (BECAUSE CONTACT RESISTANCES AREN'T WELL REPRODUCIBLE)

→ SELF-OVERHEATING → WITH HIGHER I_T IS A BIG PROBLEM (IMPORTANT IN THE DESIGN)

FOR → WIRE WOUND SENSORS → $(0.05 \div 0.3)$ °C/mW
→ THICK-THIN → 0.005 °C/mW

THERMOELECTRIC VOLTAGE → 10 µV CAUSES A TEMPERATURE ERROR $\Delta\theta = 0.25$ °C

↓

USING MATERIALS WITH LOW THERMOELECTRIC COUPLING ETC. IS A GOOD WAY TO MINIMIZE THIS PROBLEM

⇓

! FOR A Pt-100 → THE USE OF $I_T = 1\,mA$ IS A GOOD TRADE-OFF BETWEEN < SELF-OVERHEATING / EFFECTS OF V_T

23/11/16

STRAIN RESISTIVE SENSORS

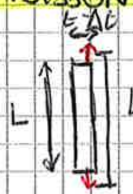
→ THE QUANTITY UNDER MEASUREMENT IS THE STRAIN = CONSEQUENCE OF AN EXTERNAL STIMULA

2 POSSIBLE STRAINS:
- EXPANSION (POSITIVE)
- CONTRACTION (NEGATIVE)

STRAIN ε IS DEFINED AS THE RATIO BETWEEN LENGTH CHANGE ΔL / INITIAL LENGTH L OF AN OBJECT

$$\varepsilon = \frac{\Delta L}{L}$$

POISSON STRAIN → IF WE APPLY A TRACTION FORCE TO A METALLIC ROD THE OBJECT IS SUBJECTED BOTH TO AN EXPANSION ON THE FORCE DIRECTION AND TO A COMPRESSION IN THE TRANSVERSE DIRECTION WITH RESPECT TO THE FORCE



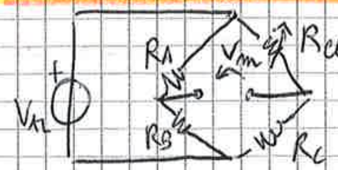
POISSON MODULE

$$\nu = -\frac{\varepsilon_t}{\varepsilon} = \frac{-\Delta t/t}{\Delta L/L}$$

STRAIN → COULD BE THE QUANTITY UNDER MEASUREMENT BECAUSE
- IT GIVES INFORMATIONS ABOUT THE STRESS THE OBJECT IS SUBJECTED AND ABOUT ITS RELIABILITY
- IT ALLOWS OTHER QUANTITIES TO BE OBTAINED (F, P, a, ...)
  - IT NEEDS A DOUBLE STAGE:
  - QTY OF INTEREST: FORCE
  - ↓
  - WE OBTAIN STRAIN FROM R
  - WE OBTAIN FORCE FROM STRAIN

2 CATEGORIES OF STRAINS
- BOUNDED
- UNBOUNDED → METAL WIRES AREN'T FIXED INTO A STRUCTURE

UNBALANCED BRIDGE WITH 1 ACTIVE STRAIN GAUGE



$$\frac{R_A}{R_B} = \frac{R_{C0}}{R_D}$$

$V_m = \emptyset$ WHEN THE SENSOR IS UNLOADED

$$V_m = V_{AL}\left(\frac{R_B}{R_B+R_A} - \frac{R_D}{R_D+R_C}\right)$$

$\varepsilon \ll 1$ LINEAR EXPANSION

$$\Delta V_m = \frac{\partial V_m}{\partial \varepsilon}\varepsilon = V_{AL}\frac{K\varepsilon}{4}\frac{1}{1+\frac{K\varepsilon}{2}} \approx \frac{V_{AL}K\varepsilon}{4}$$

→ PROPORTIONAL TO $\langle {K \atop \varepsilon}$

⇒ SOLUTION NOT COMMONLY EMPLOYED SINCE T EFFECT ISN'T COMPENSATED

⇓

UNBALANCED BRIDGE WITH ONE ACTIVE STRAIN GAUGE AND 1 INACTIVE STR. GAUGE

→ EXACTLY THE SAME CIRCUIT AS BEFORE BUT WITH 2 STRAIN GAUGES

- R_{C0} ACTIVE
  - FIXED IN A WAY TO SENSE DEFORMATION
  - MOUNTED IN THE DIRECTION OF INTEREST
- R_{D0} INACTIVE
  - MOUNTED IN TRANSVERSE DIRECTION
  - USED TO MINIMIZE T EFFECT

BOTH DEPENDENT ON T IN THE SAME FORM

⇓

MINIMIZATION OF TEMPERATURE EFFECTS

$$V_m = V_{AL}\left[\frac{R_B}{R_A+R_B} - \frac{R_D(\vartheta,\nu)}{R_D(\vartheta,\nu)+R_C(\vartheta,\varepsilon)}\right]$$

⇓

BUT R_D INTRODUCES 2 PROBLEMS

- IF IT'S BOUNDED IT SENSES THE POISSON STRAIN $R_D(\vartheta,\nu)$
- IF IT'S UNBOUNDED IT'S NOT MECHANICALLY COUPLED AND IT'S NOT SUBJECTED TO THE SAME T AND ε OF R_C

25/11/16

STRAIN - GAUGE BASED LOAD CELLS

LOAD CELL = TRANSDUCER THAT CONVERTS A FORCE INTO AN ELECTRICAL SIGNAL

= DOUBLE STAGE DEVICE:

1) THROUGH A MECHANICAL ARRANGEMENT → FORCE —CONVERTED→ STRAIN
2) THROUGH A STRAIN GAUGE → STRAIN → RESISTANCE

(AND THAN A RESISTANCE → VOLTAGE CONVECTED TO THE ACQUISITION SYSTEM)

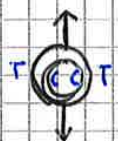
2/4 STRAIN GAUGES IN < HALF-BRIDGE / FULL-BRIDGE } CONFIGURATION EMPLOYED TO → MAXIMIZE SENSITIVITY → MINIMIZE T EFFECT

SEVERAL **MECHANICAL ARRANGEMENTS** HAVE BEEN DESIGNED IN ORDER TO CONVERT A FORCE INTO A STRAIN (IT DEPENDS ON THE QTY OF INTEREST AND ON THE APPLICATION):

- SIMPLE BENDING → 2/4 STRAIN GAUGES IN PUSH-PULL CONFIGURATION

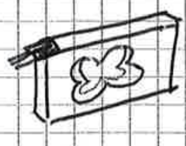
F → APPLIED IN A PARTICULAR POINT
2 STRAIN GAUGES

- NOT SUITABLE IF YOU DON'T HAVE A PRECISE POINT OF APPLICATION
⇓
HIGH SENSITIVITY WITH RESPECT TO THE POINT OF APPLICATION
- SUITABLE FOR LOW RANGE (UP TO 5 kN)



- 4 STRAIN GAUGES
- SUITABLE FOR HIGH RANGE (UP TO 1000 kN)

- DOUBLE BENDING → TENSION AND COMPRESSION ARE ON THE SAME SURFACE BEAM THANKS TO THIS PARTICULAR ARRANGEMENT
⇓
LOW SENSITIVITY WITH RESPECT TO THE POINT OF FORCE APPLICATION

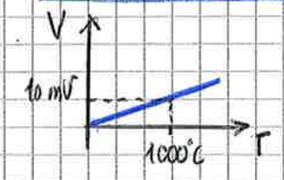


T COMPENSATION DEPENDS ON REPRODUCEABILITY OF STRAIN GAUGES

S-TYPE → S-SHAPE MECHANICAL ARRANGEMENT
⇓
THANKS TO THE INTERNAL HOLE WE HAVE AN AREA SUBJECTED TO COMPRESSION AND ONE OTHER TO EXPANSION

- COMPRESSION/TENSION → COLUMN TYPE → BASED ON THE EFFECT ON BOTH THE DIRECTION OF INTEREST AND ON TRANSVERSE DIRECTION (→ MAX SENSITIVITY)
- SHEAR → STRAIN GAUGE FIXED TO A PARTICULAR ANGLE WITH RESPECT TO THE DIRECTION OF INTEREST (SMALLER AND STRONGLY RESISTANT TO TRANSVERSE LOADING)

COMMERCIAL THERMOCOUPLES → BY CONVENTION, THE COUPLE OF USED METALS ARE INDICATED BY MEANS OF A LETTER



→ EXPECTED VOLTAGES ARE ON THE ORDER OF mV

$$S_R = \frac{10\ mV}{1000\ °C} = 10\ \mu V/°C$$

⇓

α → ISN'T CONSTANT WITH TEMPERATURE

NOT LINEAR BEHAVIOR OF THE THERMOELECTRIC VOLTAGE

$e_{AB} = \sum h_i \Delta\theta^i$ — k_i, h_i FROM INTERNATIONAL STANDARDS

$\Delta\theta = \sum k_i e^i_{AB}$ → FOUND BY MEANS OF HIGH ORDER POLYNOMIAL FACTOR

- **UNCERTAINTY CLASSIFICATION** → DIVIDED IN NORMAL / SPECIAL
  → STANDARDS THAT FIXES THE VALUE OF THE COEFFICIENTS

eg: [1.7°C, 0.5%] ← $\frac{0.5}{100}$ reading

E-type normal thermocouple

$\delta\theta = 0.5\%\ 400° = 2°C$

$\max\{2°C,\ 1.7°C\} = 2°C = \delta\theta$

(IF YOU WANT A BETTER UNCERTAINTY → DO A GOOD CHARACTERIZATION.)

- TEMPERATURE LIMITS → ! MEASUREMENT RANGES REFER TO THERMOCOUPLES METALS, NOT TO THE SHEALTH
  ↓ FOR HIGH T ARE EXPENSIVE
  → USUALLY SPECIAL SHEATHS ARE EMPLOYED ONLY FOR THE THERMOCOUPLE PART EXPOSED TO HIGH TEMPERATURES
  ⇓

VERY THIN TO OBTAIN A LOW TIME CONSTANT (VERY FAST ANSWER WITH RESPECT TO TEMPERATURE TRANSIENT)

θ_1 HAS TO BE KNOWN

θ_0 COULD BE DIFFERENT

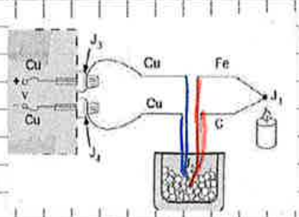
⇓

SO IT'S NECESSARY TO NOT INTRODUCE FURTHER THERMOCOUPLES, SO **EXTERNAL CABLES**

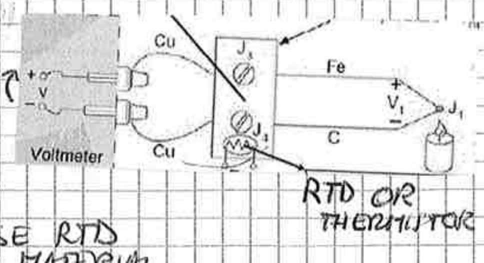
↓

SAME THERMOCOUPLE METALS BUT LARGER DIAMETER AND STANDARD SHEALTH

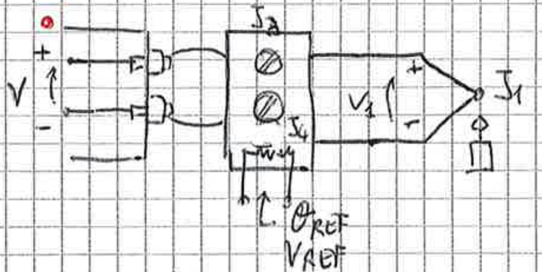
A FURTHER STEP → IS TO USE THE ICE BATH AS THE ISOTHERMAL BLOCK
↓
ICE FROM PURE WATER (BECAUSE OF SALT)
CONTAINER → WELL INSULATED
⇓
! USED FOR VERY PRECISE MEASUREMENTS AT NMIs AND SECONDARY LABS



IN INDUSTRIAL APPLICATIONS → IT'S NOT CONVENIENT TO USE THE ICE-BATH
⇓
THE TEMPERATURE OF THE ISOTHERMAL BLOCK IS MEASURED BECAUSE J3 AND J4 BECOME THE REFERENCE JUNCTION
↓
IN ORDER TO MEASURE T ON THIS BLOCK, I USE RTD OR A THERMISTOR INTEGRATED INTO THE MATERIAL (PASSIVE SENSOR)



A DATA ACQUISITION SYSTEM WORKS IN A PROCEDURE CALLED SOFTWARE COMPENSATION WHICH FOLLOWS THESE STEPS

- RTD/THERMISTOR RESISTANCE IS MEASURED AND T_{REF} IS ESTIMATED
- THE REFERENCE JUNCTION VOLTAGE V_{REF} IS OBTAINED BY MEANS OF T_{REF}
  ⇓
  $$V_{REF} = \sum h_i \, \theta_{REF}^i$$
- 

  V_1 IS THE CORRECTION TO V
  ⇓
  SO THE MEASURED VOLTAGE V IS ADDED TO V_{REF} IN ORDER TO OBTAIN V_1 $(\Delta\theta = \theta_1 - \theta_{REF})$
  (WITH THE LAW OF ADDITIVE VOLTAGES)
- θ_1 IS OBTAINED WITH V_1.

I USE A THERMOCOUPLE INSTEAD OF USING A DEVICE THAT MEASURES THE ABSOLUTE TEMPERATURE BECAUSE:

- MEASUREMENT RANGES WITH THERMOCOUPLES ARE LARGER THAN OTHER TEMPERATURE SENSORS
- THERMOCOUPLES ARE LARGER THAN < THERMISTORS / RTD
- ISOTHERMAL REFERENCE IS USED FOR MANY THERMOCOUPLE ELEMENTS
  ⇓
  SEVERAL CONNECTIONS WITH ONE SOFTWARE PROCEDURE

INDUSTRIAL BUSES

30/11/16

REQUIREMENTS OF A DATA ACQUISITION SYSTEM

MAIN CHARACTERISTICS OF AN INDUSTRIAL BUS

- DESIGNED TO WORK IN INDUSTRIAL ENVIRONMENTS (SENSORS, TRANSDUCERS, ACTUATORS, CONTROLLERS) OVER LONG DISTANCES (NOT IN THE AREA OF A LAB)
- ARRANGED TO BE CHEAP NOT ONLY FROM THE POINT OF VIEW OF THE MATERIAL BUT ALSO FOR COMPLEXITY (FEW WIRES)
- AVAIBLE IN DIFFERENT VERSIONS FOR DIFFERENT REQUIREMENTS EXPRESSED IN TERMS OF
  - SPEED OF PROCESSING
  - EXTENSION (COVERED LENGTH)
  - NUMBER OF NODES (FEW OR HUNDRED DEPENDING ON THE APPLICATION)
- PHYSICAL LAYER ON STANDARD INTERFACES (RS232) OR SPECIFIC STANDARDS (IEC 61158)

FIELDBUS

- NAME USED TO INDICATE ANY INDUSTRIAL BUSES
- ONE OF MOST EMPLOYED
- ALL DIGITAL (NO ANALOG SIGNALS IN COMMUNICATION), SERIAL 2-WAY COMMUNICATION SYSTEM (POSSIBILITY TO TRANSFER DATA IN 2 DIRECTIONS) DEFINED IN STANDARD IEC - 61158
- CHEAP BUS WITH A SIMPLE WIRING
  - BASED ON ONLY 2 WIRES, A SHIELDED (TO MINIMIZE THE EFFECT WITH RESPECT TO NOISE) TWISTED-PAIR CABLE FOR BOTH SUPPLY-VOLTAGE AND SIGNAL
  - SEGMENTS WITH LENGTH UP TO 1 Km AND 10 CONNECTED DEVICES (LONGER DISTANCES BY MEANS OF REPEATERS)
  - FIXED TRANSMISSION SPEED (31,25 kbit/s)
- VOLTAGE SUPPLY (DIRECT COMPONENT) and SIGNAL (ALTERNATE COMPONENT) } DECOUPLED WITH
  - TERMINATORS
  - CONDITIONERS
  - STUBS/"SPURS" (CONNECTED TO BUS WITHOUT OPENING THE SYSTEM)

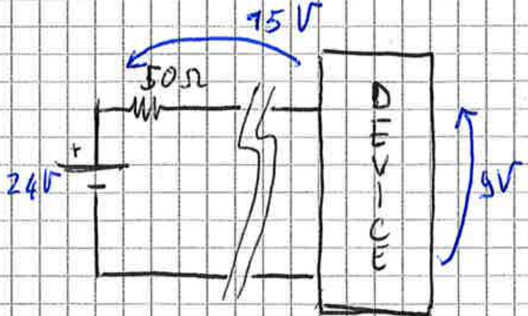
BUS COMPONENTS

- THE CABLE SECTION HAS TO BE SUITABLE FOR THE SUPPLY VOLTAGE THAT HAS TO BE SUBMITTED
- STARTING FROM THE MAIN CHARACTERISTICS WE CAN ESTIMATE
  - THE DISTANCE WITH THE POWER SUPPLY
  - THE NUMBER OF INTERCONNECTED DEVICES

BUS DESIGN → POWER SUPPLY / ATTENUATION CONSTRAINTS } FIX

- THE MAXIMUM LENGTH: $V_s = 24\ V$

$V_{min} = 9\ V$, $I_{min} = 20\ mA$ } BY CONNECTED DEVICES



$$R_{line} = \frac{V_s - V_{min}}{I_{min}} = \frac{24\ V - 9\ V}{20\ mA} = \frac{15\ V}{20\ mA} = 750\ \Omega$$

$$L_{max} = \frac{R_{line} - R_{pow\,supp}}{\text{resist. of line}} = \frac{750\ \Omega - 50\ \Omega}{44\ \Omega/km} \simeq 15.9\ km$$

A SINGLE DEVICE CAN BE CONNECTED AT A DISTANCE OF 15.9 km

- THE NUMBER OF CONNECTED DEVICES

$V_{bus} = 15\ V$, $R_{p.s.} = 50\ \Omega$ } $I_{max} = \frac{15\ V}{50\ \Omega} = 300\ mA$

↑ max current with a certain number of devices at ∅ distance

Max number of devices: $N = \frac{I_{max}}{I_{d\,min}} = \frac{300\ mA}{20\ mA} = 15$

- LENGTH CONSIDERING < TALKER/PUBLISHER → generates a signal with $V_{pp} = 0.75\ V$ min
  RECEIVERS/LISTENERS → each is able to decode a signal with $V_{pp} = 0.15\ V$ min

$$Att_{max} = 20 \log\left(\frac{V_{pub\,min}}{V_{list\,min}}\right) = 20 \log\left(\frac{0.75}{0.15}\right) \sim 14\ dB$$

$$L_{max} = \frac{Att_{max}}{Att_{nom}} = \frac{14\ dB}{3\ dB/km} = 4.7\ km$$

Att_{nom} ↖ nominal attenuation considering the specifications of the bus

4.7 km ↑ Maximum distance for ideal cable ↓

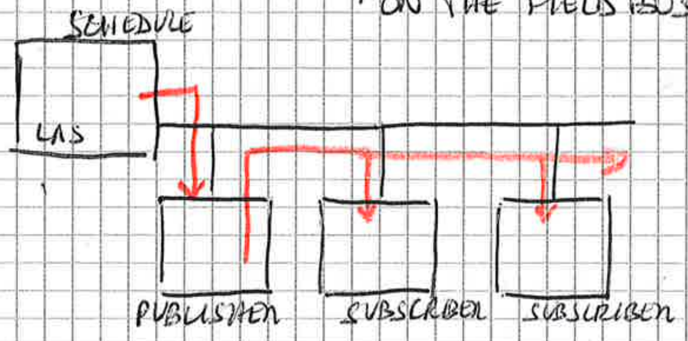
Specification of the protocol: the main run cannot exceed a total length of 1900 m

BUS ACCESS → IS MANAGED WITH 2 LEVELS OF COMMUNICATION:

- **SCHEDULED COMMUNICATION** → MANAGED ACCORDING TO A DETERMINISTIC TABLE CALLED **LAS** (= LINK ACTIVE SCHEDULER)
  ↓
  DEVICES ON A FIELDBUS COULD BE
  - BASIC DEVICES WITHOUT LAS CAPABILITIES
  - LINK MASTER DEVICES THAT ARE CAPABLE OF BECOMING THE LAS
    ↓
    IN THE BUS CONTROLLER

  → DEVICES ARE IDENTIFIED BY MEANS OF AN ADDRESS

  → ONCE YOU'VE IDENTIFIED YOUR BUS AND THE TIME, YOU KNOW THE TRANSMISSION RATE
  ↓
  SO YOU CAN BUILD A DETERMINISTIC TABLE
  ↓
  SCHEDULED COMMUNICATION IS USED FOR THE REGULAR CYCLIC TRANSFER OF DATA AMONG DEVICES ON THE FIELD BUS



ON THE BUS THERE'S A CONTROLLER THAT HAS THE CAPABILITY TO MANAGE THE TRANSMISSION WHICH CAN BE
- SCHEDULED
- UNSCHEDULED

SCHEDULED COMMUNICATION IS THE HIGHEST PRIORITY ACTIVE FOR THE LAS

↓

ONCE THE DEVICE A RECEIVES, IT BECOMES THE PUBLISHER, THE OTHERS ARE SUBSCRIBERS. THE PUBLISHER RECEIVES A DATA MESSAGE AND TRASMITS IT TO OTHERS

- **UNSCHEDULED COMMUNICATION** → CAN BE PERFORMED BETWEEN THE TRANSMISSION OF SCHEDULED MESSAGES
  ↓
  THE LAS SENDS A PASS-TOKEN (PT) MESSAGE TO EACH DEVICE WHICH HAS THE POSSIBILITY TO SEND DATA THAT AREN'T IN SCHEDULING

THE LAS HAS A LIST → LIVE LIST → THAT ALLOWS TO KNOW THE ACTIVE DEVICES

PROFIBUS PA = MODIFIED VERSION OF THE FIELDBUS

→ BUS WITH 2 WIRES (SHIELDED TWISTED PAIR CABLE) FOR BOTH SUPPLY VOLTAGE AND SIGNAL

→ DATA TRANSMISSION:

- DIGITAL, DIFFERENTIAL SIGNALS, BIT-SYNCHRONOUS MANCHESTER ENCODING
- 8-BIT CHARACTER (≠ FROM FIELDBUS)
- DATA PACKET WITH 16-BIT CRC (→ ALLOWS A GOOD PRECISION) (ADDED TO < PREAMBLE, START-STOP)

→ FIXED TRANSMISSION RATE: 31.25 kbit/s

→ LINE AND TREE TOPOLOGY WITH TERMINATION

→ NUMBER OF STATIONS (> THAN FIELDBUS)

↳ UP TO 32 WITHOUT REPEATERS

UP TO 126 (MAX 4 REPEATERS)

↳ WHEN YOU HAVE A LONGER LENGTH OF THE BUS

THE CHOICE OF THE BUS A PART FROM ELECTRICAL CHARACTERISTICS, COULD BE REPRESENTED ACCORDING TO THE MANAGED PROCESS.

IF θ, THE ORIENTATION ANGLE OF THE CONSIDERED AREA WITH RESPECT TO THE SOURCE,

$$E_e = \frac{I_e \cos\theta}{d^2}$$

IRRADIANCE CHANGES WITH RESPECT TO THE ANGULAR OBSERVATION (COSINE LAW)

SOLID ANGLE → Ω, REPRESENTS A PART OF AN OBSERVER'S VISUAL FIELD

P: OBSERVER (OUR EYE)
r: RADIUS

$$\Omega = \frac{A}{r^2}$$

[sr] → STERADIANT

RATIO BETWEEN < AREA OF OBSERVATION / SQUARE OF RADIUS

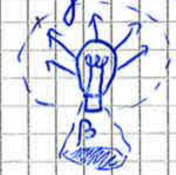
⇓

IT'S INDEPENDENT ON r! VALUE OBTAINED ONCE YOU'VE DEFINED THE AREA YOU WANT TO SEE / TRANSMIT

IF TOTAL VISUAL FIELD IS A SPHERE $\Omega = \frac{4\pi r^2}{r^2} = 12.57$ sr

NO SOLID ANGLE IS GREATHER THAN THIS
IT'S THE MAXIMUM SOLID ANGLE → FOR AN ISOTROPIC SOURCE

if we have an isotropic source except a cone shadow with angle β



$$A = 2\pi\left(1-\cos\left(\frac{\alpha}{2}\right)r^2\right) = 2\pi\left(1-\cos\left(\frac{360-\beta}{2}\right)\right)r^2$$

$$\Omega = 2\pi\left(1-\cos\left(\frac{360-\beta}{2}\right)\right)$$ ← if source is isotropic

PHOTOMETRIC QUANTITIES (PERCEIVED BY HUMAN EYES)

- **LUMINOUS INTENSITY**, I_V [cd] (CANDELA) → REPRESENTS LIGHT INTENSITY OF AN OPTICAL SOURCE AS PERCEIVED BY THE HUMAN EYE

  $1 \frac{W}{sr} = 683$ cd (@ 555 nm)

- **LUMINOUS FLUX**, Φ_V [lm] (LUMEN) → REPRESENTS THE LIGHT POWER OF AN OPTICAL SOURCE AS PERCEIVED BY HUMAN EYE

  1 cd = 1 lm/sr

  $$I_V = \frac{\Phi_V}{\Omega_s}$$

- **ILLUMINANCE**, E_V [lux] → REPRESENTS THE LUMINOUS FLUX INCIDENT PER UNIT AREA

  1 lux = 1 lm/m²

  USED TO CHARACTERIZE ILLUMINATION CONDITIONS (DISTANCE IS AN IMPORTANT CONDITION)

- **SPECTRAL RESPONSE** → DESCRIBES THE PHOTOSENSOR SENSITIVITY TO OPTICAL RADIATION OF DIFFERENT WAVELENGTHS
  - ↓ ONLY A SMALL PART OF THE OPTICAL RADIATION SPECTRUM IS RECEIVED BY THE SENSOR (OUR EYES FOR EXAMPLE)
  - ↘ IT'S A RELATIVE MEASURE
    CALCULATED NORMALIZING THE OUTPUT WITH RESPECT TO THE OUTPUT OF MAXIMUM SENSITIVITY

- **SENSITIVITY** → PROVIDED DEPENDING ON THE OUTPUT TYPE:
  - OUTPUT UNITS PER UNITS OF ILLUMINANCE FOR SENSOR WITH SPECTRAL RESPONSE IN THE VISIBLE RANGE (PHOTODIODE → A/lux, THERMOPILES → V/lux)
  - OUTPUT UNITS PER UNITS OF INCIDENT RADIATION (A/W)

- **NOISE** → EXPRESSED BY MEANS OF NEP (= NOISE EQUIVALENT POWER)
  → USUALLY PROVIDED AS LIGHT LEVEL REQUIRED TO OBTAIN A SNR OF UNITY
  → IS THE RATIO BETWEEN < OUTPUT NOISE CURRENT FOR 1 Hz BANDWIDTH / MAXIMUM ABSOLUTE SENSITIVITY (@ λ_p)

$$NEP = \frac{\text{noise current } [A/\sqrt{Hz}]}{\text{absolute sensitivity } [A/W]} \quad [W/\sqrt{Hz}]$$

↳ EXPRESSES THE MINIMUM DETECTABLE INPUT POWER OF A PHOTODIODE

RELIABILITY BASIC CONCEPTS - PART 1

RELIABILITY = EXPECTED LIFETIME OF A DEVICE IN DEFINED CONDITIONS

WHAT FUNCTIONALITIES IT HAS AND ITS BEHAVIOUR FOR A CERTAIN TIME INTERVAL
↓
IT HAS TO BE AS LONG AS POSSIBLE (IT DEPENDS ON THE SYSTEM)
↓
IT'S EXPECTED THAT DIFFERENT CONDITIONS AFFECT THE LIFETIME

QUANTITATIVE PARAMETERS FOR RELIABILITY ARE RANDOM VARIABLES, BY EMPLOYING THE BASICS OF PROBABILITY THEORY

WE HAVE TO DISTINGUISH BETWEEN
- NON REPAIRABLE
- REPAIRABLE

} SYSTEMS

WE REFER TO PROBABILITY BECAUSE WE HAVE TO REFER TO THE POPULATION OF THE DEVICES AND NOT TO A SINGULAR DEVICE

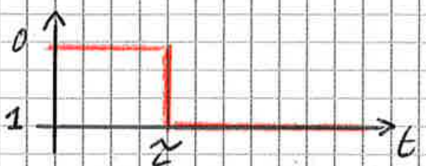
RELIABILITY FOR NOT REPAIRABLE COMPONENTS

NON REPAIRABLE SYSTEMS → SYSTEMS DESIGNED FOR NOT BEING REPAIRABLE
↓
THEIR LIFETIME DEPENDS ON NOT (REPAIRABLE) COMPONENTS.

NOT REPAIRABLE COMPONENTS → HAVE A LIFE CYCLE CALLED **REPAIR-TO-FAILURE PROCESS**

THE DEVICE STARTS IN THE WORKING STATE AND AT A CERTAIN TIME INSTANT A FAILURE OCCURS
↓
WE'VE A FAILURE TRANSITION AND THE COMPONENT GOES TO THE FAILURE STATE.

THE POSSIBLE RANDOM VARIABLE IS THE TIME INSTANT WHEN THE FAILURE OCCURS
↓
τ = TIME TO FAILURE
→ RANDOM VARIABLE → WE'VE TO INVESTIGATE ABOUT THE PROBABILITY DISTRIBUTION



⇓ ACCORDING TO THIS SCHEME

RELIABILITY = THE PROBABILITY THAT A COMPONENT WILL SATISFACTORILY PERFORM ITS INTENDED FUNCTION UNDER GIVEN CIRCUMSTANCES FOR A SPECIFIED PERIOD OF TIME

= PROBABILITY THAT TIME TO FAILURE IS GREATHER THAN t

$$R(t) = P\{\tau > t\} \Rightarrow \begin{cases} R(0) = 1 \\ \lim_{t \to \infty} R(t) = \emptyset \\ R(t) \text{ NOT INCREASING FUNCTION} \end{cases}$$

→ BUT IT CAN BE CONSIDERED CONSTANT AT CERTAIN TIME INSTANTS

UNRELIABILITY = THE PROBABILITY THAT A COMPONENT GOES IN THE FAILURE STATE BEFORE THE TIME t

$$F(t) = P\{\tau < t\}$$

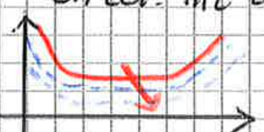
→ CUMULATIVE PROBABILITY DISTRIBUTION OF τ

BATHTUB CURVE OF ELECTRONIC COMPONENTS (SHAPE OF A BATHTUB)

WEAR OUT PERIOD → DUE TO AGING ELECTRICAL PROCESSES BRING IT TO FAILURE

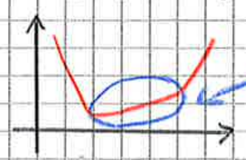
BURN-IN PERIOD → HIGH HAZARD-RATE EVEN IF THE COMPONENT IS NEW IT HAS AN HIGH RATE TO GO TO THE FAILURE STATE (POOR RELIABILITY)
THE FAILURE RATE RAPIDLY DECREASES: THIS PERIOD IS CHARACTERIZED BY INFANT MORTALITY (WEAK PART OF THE POPULATION)
MANUFACTURER PROVIDES WARRANTY
↓
THE MANUFACTURER USUALLY DOES A BURN-IN TEST → PERFORMED IN FINAL DEVICES IN ORDER TO FIND THE WEAK PART OF THE POPULATION AND ELIMINATE IT
⇓
APPLICATION OF STIMULUS THAT BRING THE FAILURE OF WEAK COMPONENTS

USEFUL LIFE PERIOD
THE FAILURE RATE IS ALMOST CONSTANT (FAILURES OCCUR IN A RANDOM WAY)
↓
THERE'S NO A DECREASING WHEN t INCREASES → THERE'S NO MEMORY IN THE DEVICE AND NO DEPENDENCE ON THE TIME IN THE WORKING
↓
ELECTRONICS COMPONENTS DON'T SUFFER FROM WEAR
⇓
RELIABILITY OF THE COMPONENT CAN BE IMPROVED BY USING IT IN LESS SEVERE CONDITION
⇓
DERATING
↓
EFFECT: THE CURVE IS SHIFTED



(OPPOSITE: IN MORE SEVERE CONDITIONS IT RAISES UP)

BATHTUB CURVE OF MECHANICAL COMPONENTS



DURING THE USEFUL TIME THE FAILURE RATE INCREASES, DUE TO WEAR PHENOMENA

THE BATHTUB CURVE → IS A VALID MODEL ONLY IF CERTAIN FAILURES ARE TAKEN INTO ACCOUNT
- EARLY FAILURE
- RANDOM FAILURE (IN USEFUL LIFE)
- WEAR-OUT FAILURE

→ IT'S BEHAVIOUR CAN BE DIFFERENT IF OTHER FAILURES OCCUR
- MISUSE FAILURE
  ↓
  DUE TO UNSUITABLE STIMULI (RESISTOR WHOSE VALUE IS HIGHER THAN MAXIMUM ADMITTED)
- DESIGN FAILURE
  ↓
  DUE TO UNSUITABLE DESIGN (DUE TO INTERACTION WITH OTHER COMPONENTS)

EXPERIMENTAL APPROACH TO RELIABILITY

OFTEN IT'S NOT POSSIBLE TO WAIT FOR RELIABILITY OF A COMPONENT BUT IT'S BETTER TO HAVE AN EXPERIMENTAL APPROACH

N COMPONENTS RANDOMLY SAMPLED ARE SUBJECTED TO A LIFE TEST (STARTING FROM $t=0$)

[IF SAMPLES NOT RANDOM → MEASURE IS BIASED]

τ_i : TIME-TO-FAILURE OF THE i-th COMPONENT

N_w (N_b): # OF WORKING (BROKEN) COMPONENTS AT TIME t

⇓

$$\hat{R}(t) = \frac{N_w(t)}{N}$$

$$\hat{F}(t) = \frac{N_b(t)}{N} = 1 - R(t)$$

EMPIRICAL EXPECTED LIFETIME: $\widehat{MTTF} = \frac{1}{N} \sum_{i=1}^{N} \tau_i$ OBTAINED AT THE END OF THE TEST

⇓

EXPERIMENT CAN ELAPSE IN 2 YEARS
LONG EXPERIMENTAL TIME CANNOT BE ACCEPTED BECAUSE OF THE COST OF THE TEST

⇓

FOR THIS REASON IN PRACTICAL → ACCELERATED LIFE TESTS ARE PERFORMED (ALT)

↓

PARTICULAR MODELS ARE USED TO HAVE ACCELERATION FUNCTIONS

——— T = 30°C

- - - - - T = 25°C

HALT = HIGH ACCELERATED LIFE TESTS
INCLUDE TESTS WITH FAST TRANSITIONS 
APPLIED OR ALSO COMBINED STIMULI (T AND < VIBRATIONS or HUMIDITY)

⇓

IN ORDER TO MINIMIZE EXPERIMENTAL TIME

REPRESENTATION AS AN RBD → **SERIES CONFIGURATION**

E_i = EVENT WHERE i-th COMPONENT IS IN THE WORKING STATE

E = THE WHOLE SYSTEM MUST BE IN THE WORKING STATE

! EVENT E IS TRUE ONLY IF ALL EVENTS E_i ARE SIMULTANEOUSLY TRUE

E_i ARE STATISTICALLY INDIPENDENT

$$P\{E\} = P\{E_1 \cap E_2 \cap \ldots \cap E_N\} = \prod_{i=1}^{N} P\{E_i\}$$

BY DEFINITION $P\{E_i\} = R_i(t)$

$$P\{E\} = R(t) = \prod_{i=1}^{N} R_i(t)$$

SINCE AT t_0 $R_i(t_0) < 1$ $\Rightarrow$ $R(t_0) < R_{i-min}(t)$ — THE RELIABILITY OF THE SYSTEM IS LOWER THAN THE MINIMUM RELIABILITY

↓

THE WEAKEST COMPONENT AFFECTS THE RELIABILITY OF THE WHOLE SYSTEM

FOR EXPONENTIAL RELIABILITY FUNCTIONS (CONNECTED IN SERIES FROM A RBD POINT OF VIEW)

$$R(t) = e^{-(\lambda_1+\lambda_2+\lambda_3)t}$$

→ THE SYSTEM FAILURE RATE IS THE SUM OF THE COMPONENTS FAILURE RATES

$$MTTF = \frac{1}{\lambda} = \frac{1}{\sum \lambda_i}$$

! IN A SERIES CONFIGURATION THE FAILURE RATE INCREASES AS THE NUMBER OF COMPONENTS INCREASES (MAKE WORSE THE RELIABILITY)

RULE: MINIMIZE THE # OF ELEMENTS ⬅

PARTS COUNT METHOD → USEFUL FOR SYSTEMS WITH A SERIES CONFIGURATION THAT HAVE

- A VERY LARGE NUMBER COMPONENTS
- COMPONENTS WITH A CONSTANT FAILURE RATE
- COMPONENTS THAT CAN BE GROUPED INTO FEW FAMILIES

↓

ELECTRONIC BOARD (DAQ BOARD, µC BOARD)

↓

IN THE SYSTEM K DIFFERENT COMPONENT FAMILIES ARE IDENTIFIED, EACH ONE WITH n_i COMPONENTS WITH CONSTANT FAILURE RATE λ_i

$$\lambda_s = \sum_{i=1}^{K} n_i \lambda_i$$

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