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On the Frontier of Computers with the Real World

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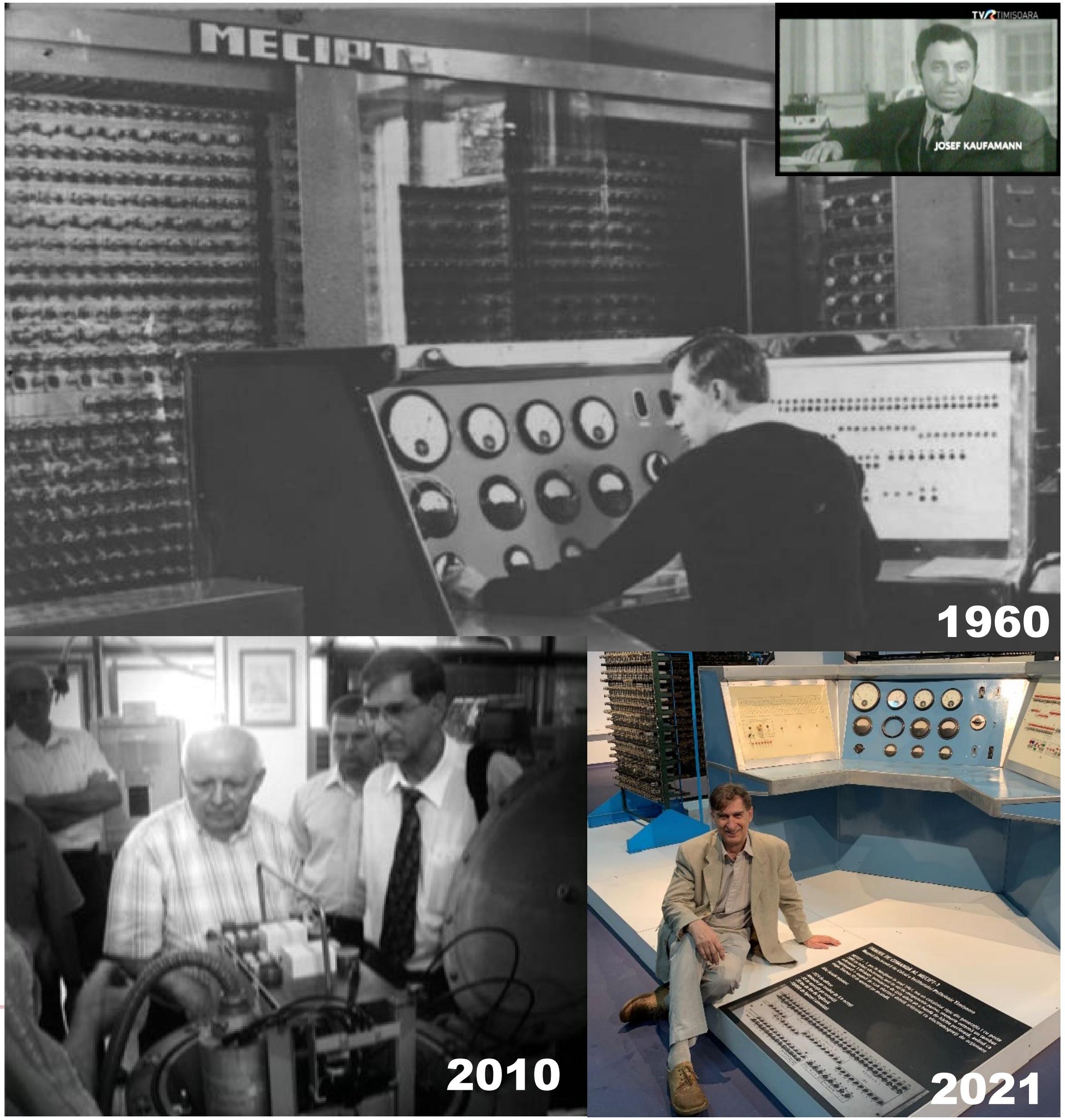
Talk Outline:

- Motivation
- Floating-Point Data Acquisition Systems
- FP-ADC Applications
  - Testing High Power Electric Generators
  - Blood Pressure Measurement
- Conclusions

How did all start?

- **Built** a *Galena Crystal Radio…* more like “Assembled a Galena Crystal Radio Detector Kit.”
- **Read** “La Radio? Mais c’est très simple!” by Eugène Aisberg (the 1st edition was in Esperanto!)
- **Met** MECIPT 1 in its first years of operation, a Generation 1 computer conceived by Dr. Iosif Kaufmann with important contribution from Prof. Győző Kovács.



In 2010 @ Szeged: The Museum of the History of Informatics Foundation

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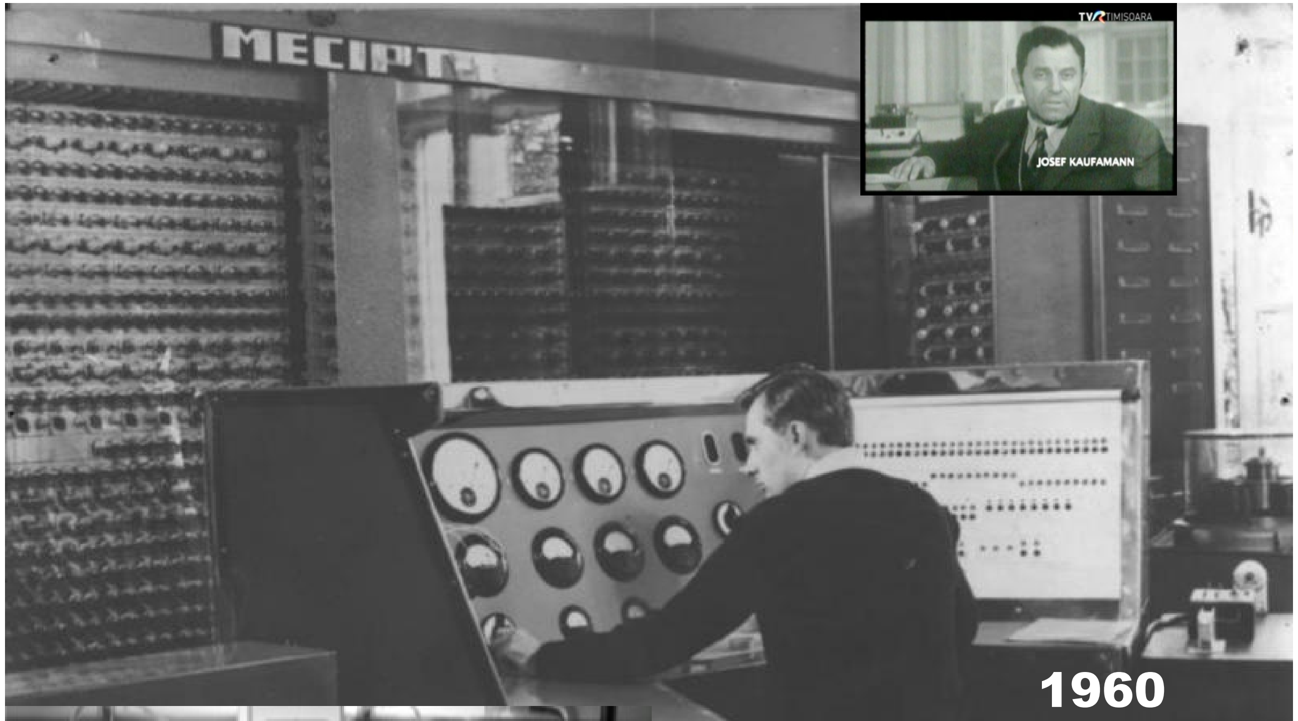
  - magnetic drum memory

- & the rest is history…



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Computers

General Purpose Computers:

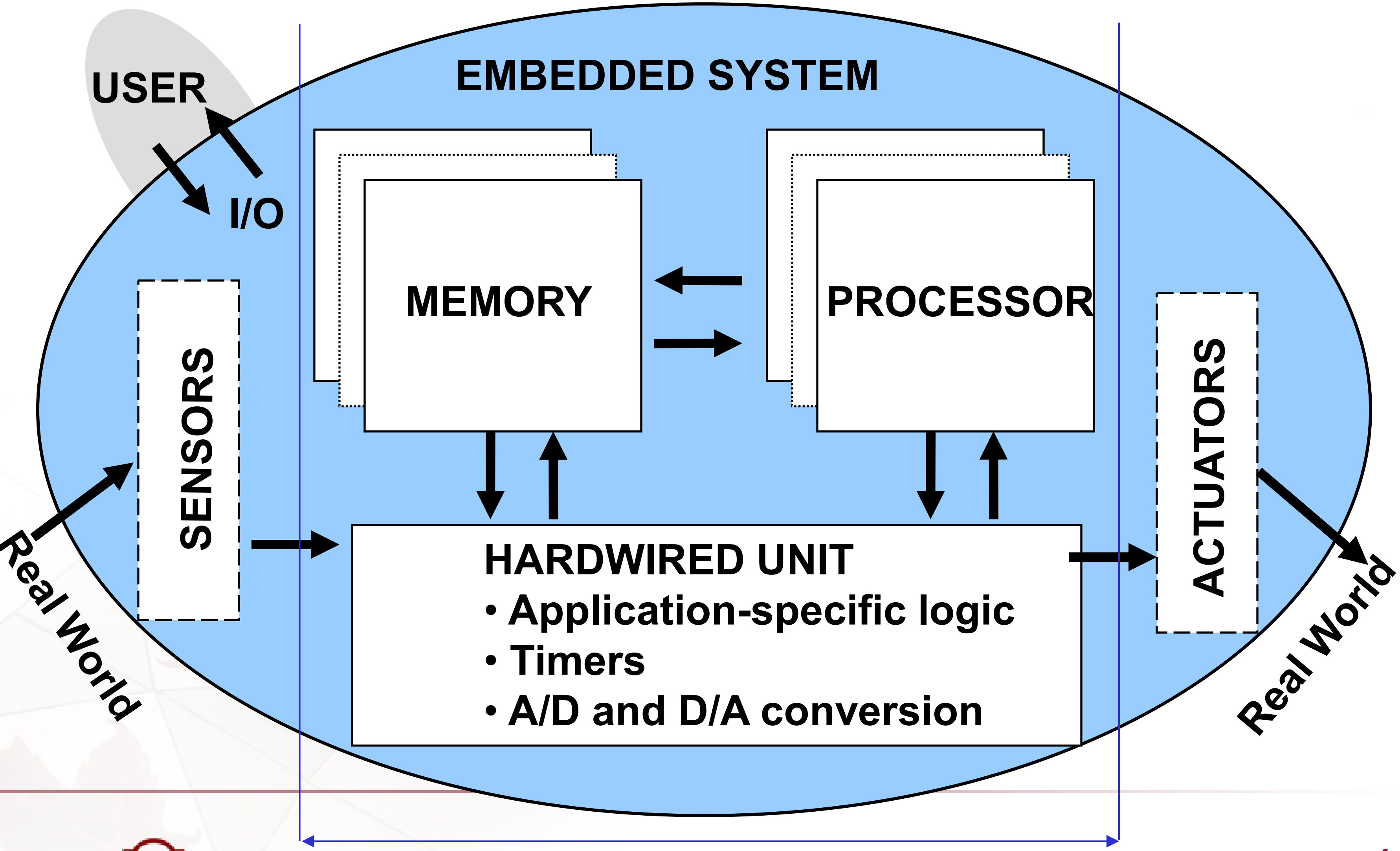
- PC's
- Laptops
- Mainframes
- Servers

Embedded Systems

- part of a larger unit
- provides dedicated service to that real world unit
- billions of units produced yearly, versus millions of desktop units

Air Purifier
Anti-lock brakes
Auto-focus cameras
Automatic teller machines
Automatic toll systems
Automatic transmission
Avionic systems
Battery chargers
Camcorders
Cell phones
Cell-phone base stations
Cordless phones
Cruise control
Curbside check-in systems
Digital cameras
Disk drives
Electronic card readers
Electronic instruments
Electronic toys/games
Environment monitor
Factory control
Fax machines
Fingerprint identifiers
Home security systems
Life-support systems
Medical testing systems
Modems
MPEG decoders
Network cards
Network switches/routers
On-board navigation
Pagers
Photocopiers
Point-of-sale systems
Portable video games
Printers
Satellite phones
Scanners
Smart phones
Smart ovens/dishwashers
Smart TV's
Speech recognizers
Stereo systems
Teleconferencing systems
Temperature controllers
Theft tracking systems
TV set-top boxes
VCR's, DVD players
Video game consoles
Washers and dryers

Embedded System Architecture



Single-functioned
- Executes a single program, repeatedly
- Ideally never terminate

Non-User-Programmable

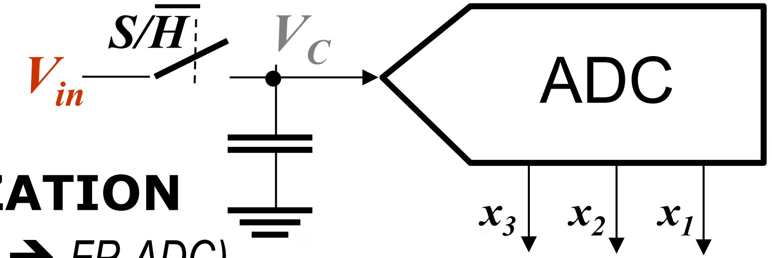
Based on programmable components (e.g. micro-controllers, DSPs, SoC ….)

Tightly-constrained

Low cost, low power, small, fast…

Reactive and real-time
- Continually reacts to changes in the system's environment
- Maintain permanent interaction
- Are subject to external timing constraints (real-time)

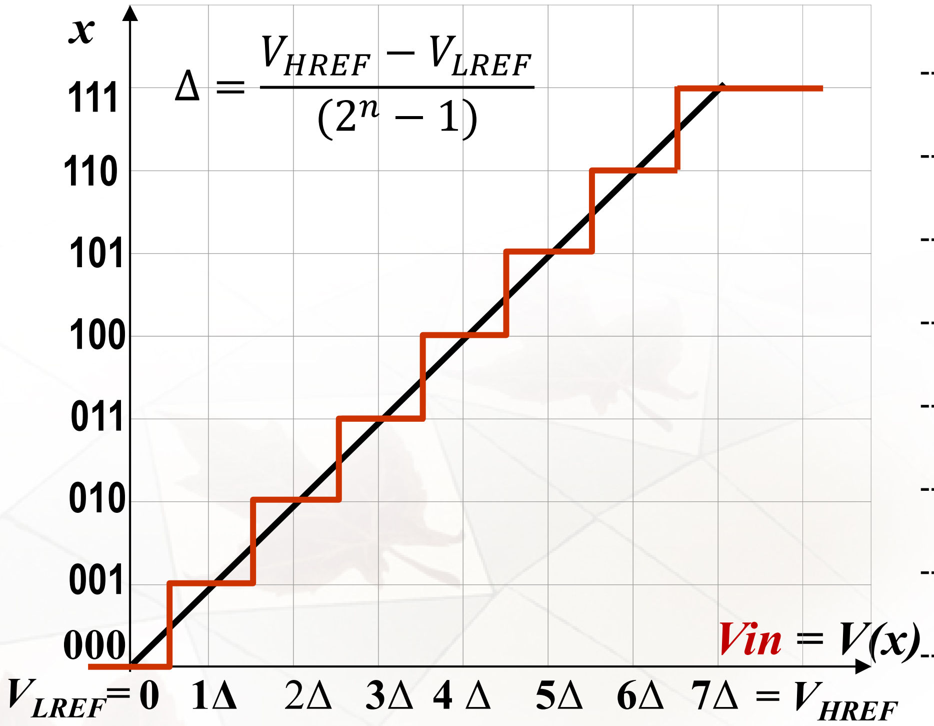
Signal Digitization



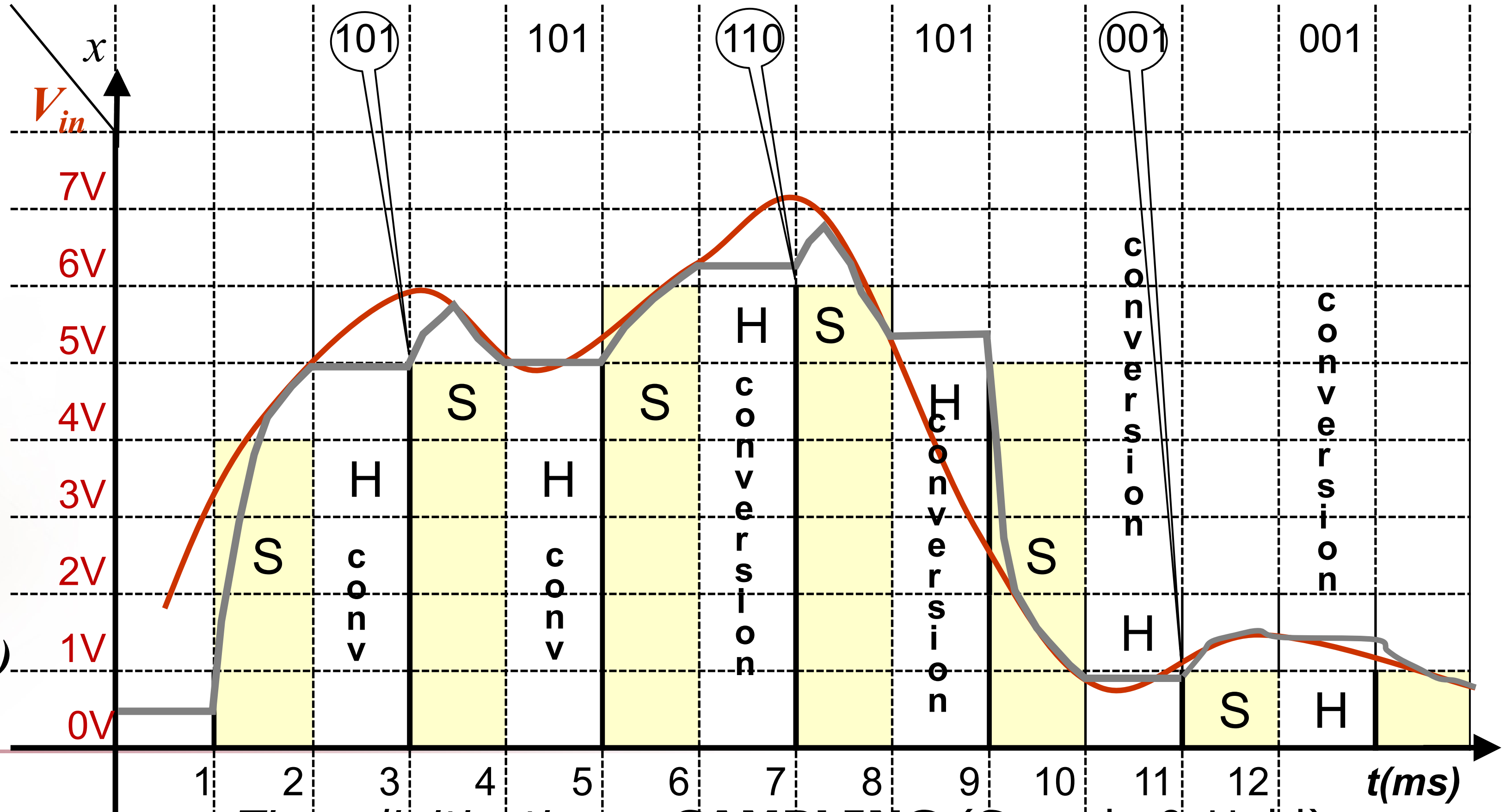
Magnitude digitization = **QUANTIZATION**

(A/D Conversion → COMPRESSIVE SENSING ➔ *FP-ADC*)

$$x = \frac{V_{in} - V_{LREF}}{\Delta}$$



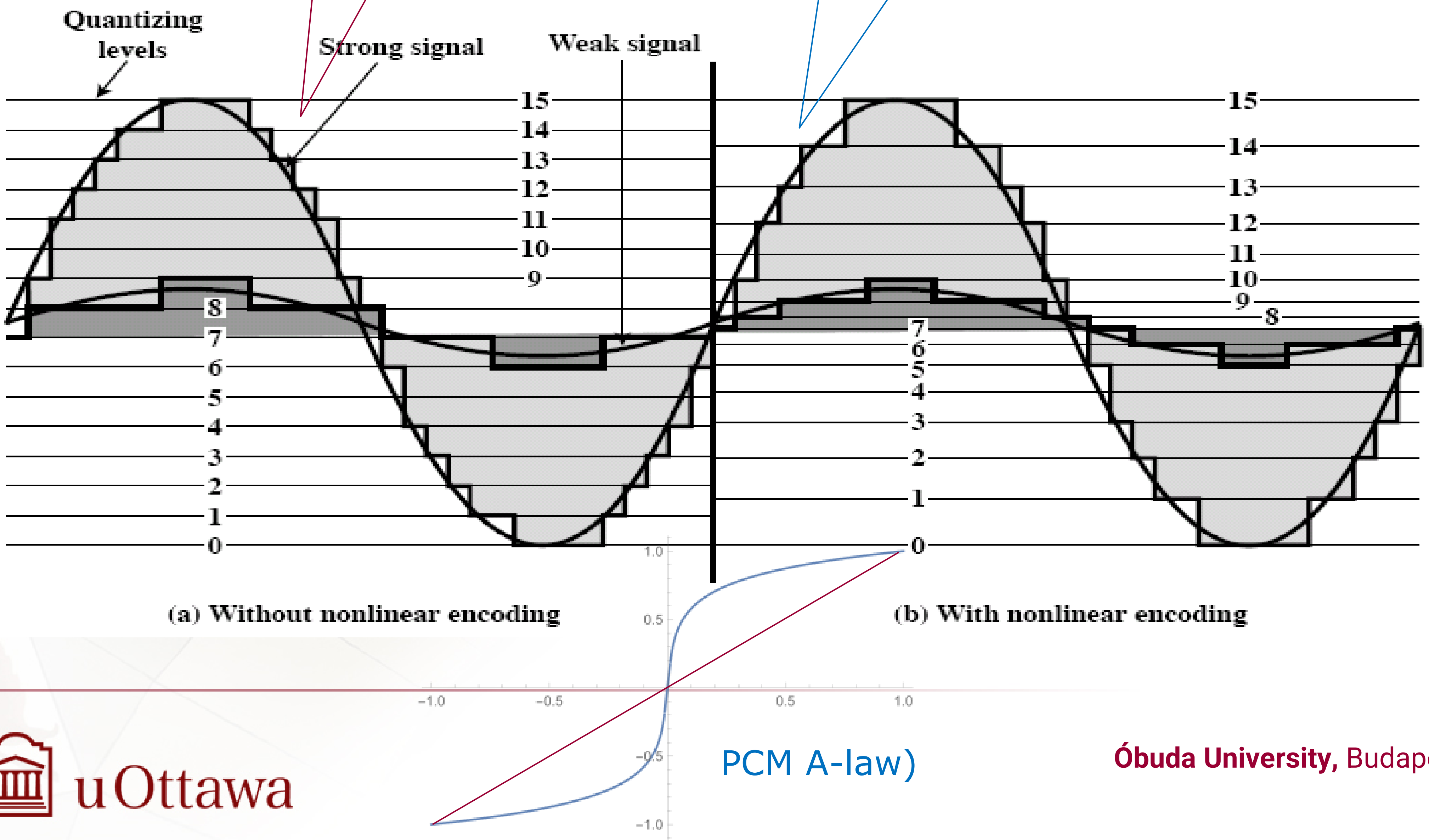
Linear ADC Transfer Function



Time digitization = **SAMPLING** (Sample & Hold)

(COMPRESSIVE SENSING ➔ *Adaptive sampling frequency*) **Óbuda University,** Budapest 2024

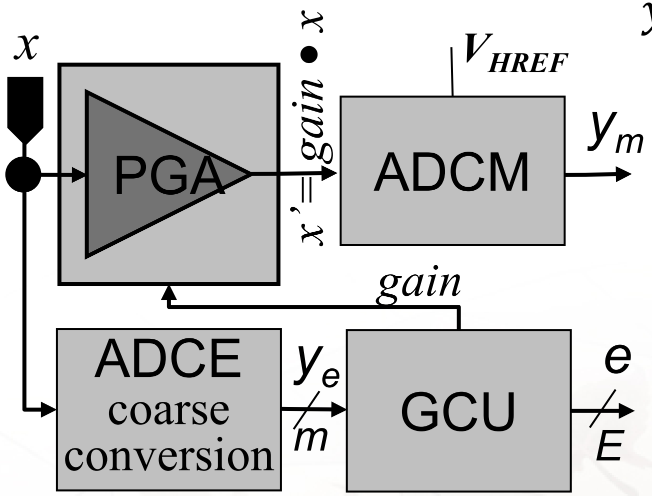
Uniform VS Non-linear Quantization



PCM A-law)

Floating-Point Quantization

$$Q(x) = y_m \cdot 2^e \cdot \left(\frac{1}{2^{2^E-1}}\right)$$



- **ADCM = mantissa** ADC
- **ADCE = exponent** ADC
- **PGA =** Programmable Gain Amplifier
- **GCU =** Gain Control Unit

$$y_e = \begin{cases} -(2^m)\cdot\frac{\Delta}{2} & \text{for } x < -(2^m)\cdot\frac{\Delta}{2} \qquad \text{where} \quad \Delta = \frac{V_{FS}}{2^m} \\ \left\lfloor \frac{x+\frac{\Delta}{2}}{\Delta} \right\rfloor \cdot \Delta & \text{for } x \in \left[-(2^m)\cdot\frac{\Delta}{2}, (2^m-1)\cdot\frac{\Delta}{2}\right] \\ (2^m-1)\cdot\frac{\Delta}{2} & \text{for } x > (2^m-1)\cdot\frac{\Delta}{2} \end{cases}$$

$$e = f(y_e) = \begin{cases} 0 & \text{if } x \in \left[-\frac{\Delta}{2}, \frac{\Delta}{2}\right) \\ \left\lfloor \log_2 \left|\frac{y_e}{\Delta}\right| \right\rfloor + 1 & \text{if } x \notin \left[-\frac{\Delta}{2}, \frac{\Delta}{2}\right) \end{cases}$$

The exponent e performs a partition of the range of the quantized signal in *measurement domains* $\{M_e, e \in [0, 2^E\text{-}1) \cap \mathcal{N}\}$, as given by equation:

$$e = \begin{cases} 0 \quad \text{if} \quad x \in M_0 = \left[-\frac{\Delta}{2}, \frac{\Delta}{2}\right) \\ \left\lfloor \log_2 \left|\frac{y_e}{\Delta}\right| \right\rfloor + 1 \quad \text{if } x \in M_e = \left[-\left(2^{e+1}-1\right)\frac{\Delta}{2}, -\left(2^e-1\right)\frac{\Delta}{2}\right) \cup \left[\left(2^e-1\right)\frac{\Delta}{2}, \left(2^{e+1}-1\right)\frac{\Delta}{2}\right) \\ 2^E - 1 \quad \text{if} \quad x \in M_{2^E-1} = \left(-\infty, -\left(2^{2^E-1}-1\right)\frac{\Delta}{2}\right) \cup \left[\left(2^{2^E-1}-1\right)\frac{\Delta}{2}, \infty\right) \end{cases}$$

Groza V., High-Resolution Floating-Point Analog-to-Digital Converter. IEEE Transactions on Instrumentation and Measurement. ISSN 0018-9456, Vol. 50

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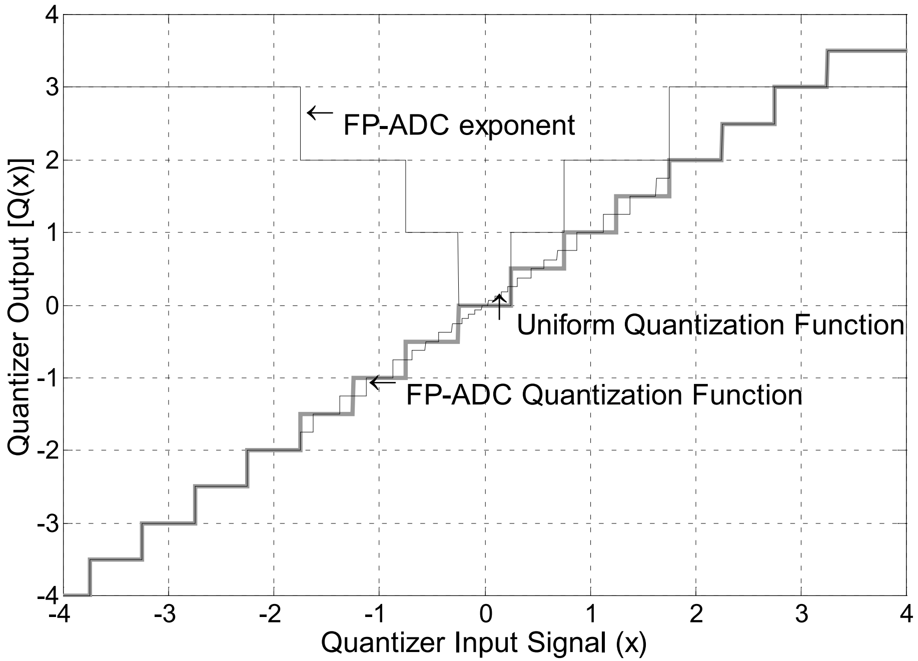
FP-ADC Characteristics



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Transfer Functions

Fig. 6. Normalized Absolute Quantization Error: Uniform ADC (thick line) and FP-ADC (thin line)

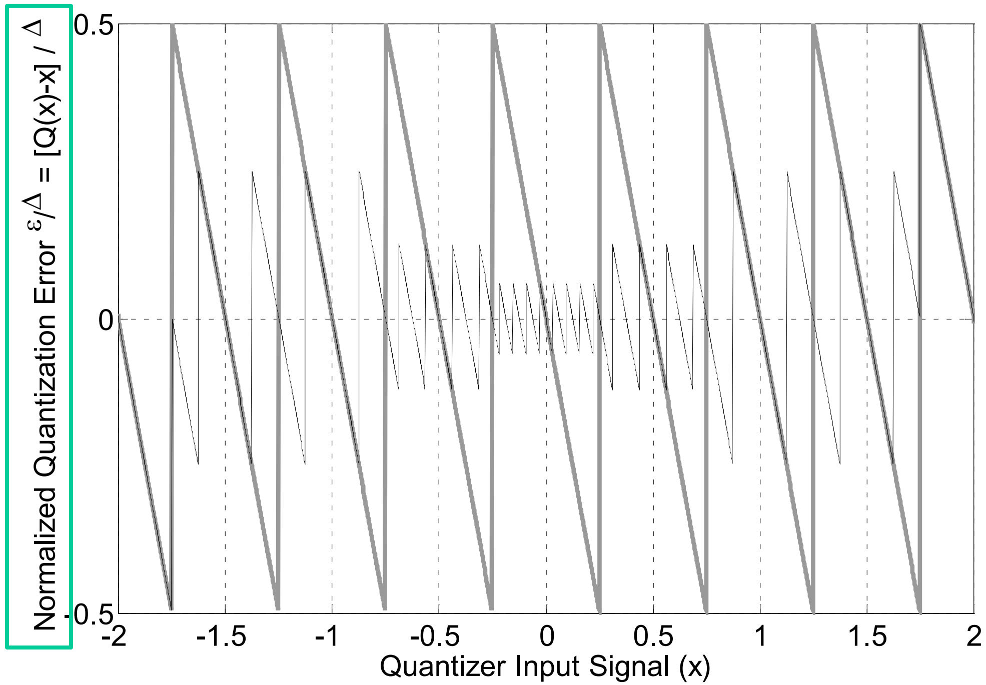

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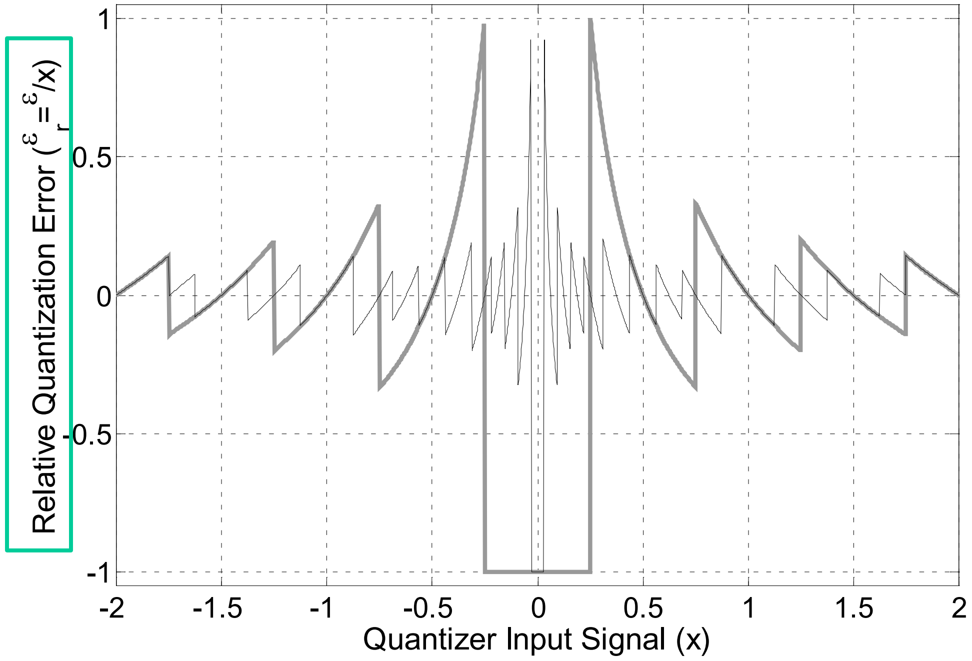
Fig. 7. Relative Quantization Error: Uniform ADC (thick line) and FP-ADC (thin line)



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Dynamics/resolution

$$D_F = 2^{\max E} \cdot 2^{m-1} = 2^{2^E-1} \cdot 2^{m-1} = 2^{2^E-E-1} \cdot D_U$$

Signal-to-Quantization Noise Ratio

$$M\left(\varepsilon^2\right) = \frac{1}{12}\sum_{e=0}^{2^E-1}\left\{\sum_{k=0}^{2^m-1}\left[\Delta_e^3 \cdot p(x_k)\right]\right\}$$

$$\cong \frac{\Delta^2}{12}\left\{\frac{1}{2^{2(2^E-1)}}\sum_{e=0}^{2^E-1}\left[2^{2e} \cdot \int_{M_e} p(x) \cdot dx\right]\right\} = \frac{\Delta^2}{12} \cdot \frac{1}{G(x)}$$

$$x_k = y_k \cdot 2^e \cdot \left(\frac{1}{2^{2^E-1}}\right)$$

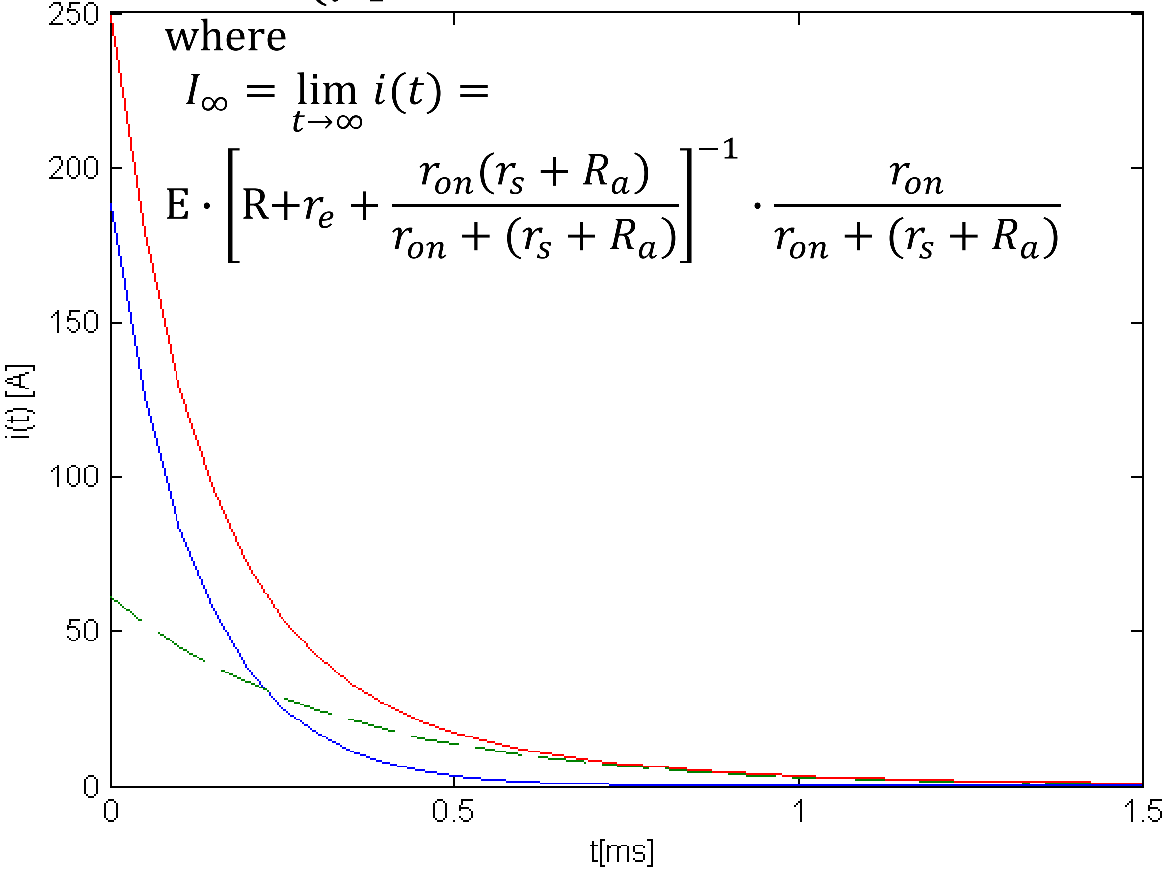
Electrical Machines Testing with DC Decay at Standstill

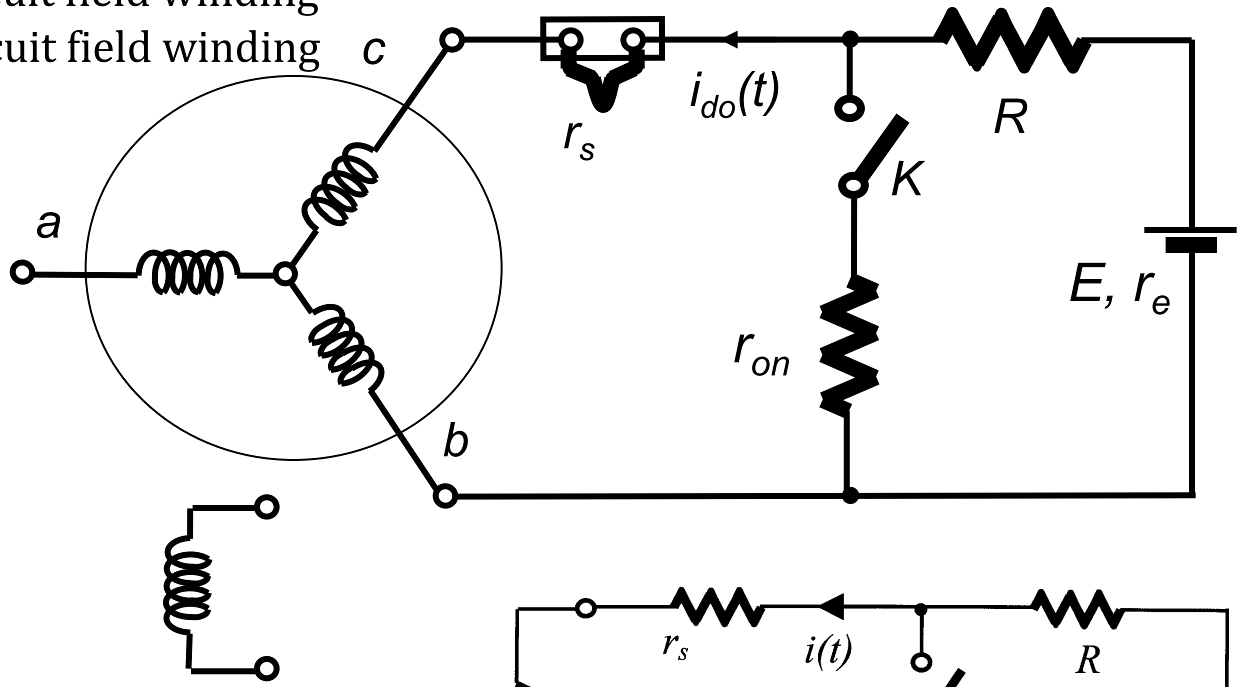
$$i(t) = \begin{cases} I_0 & t < 0 \\ \sum_{i=1}^{n} I_i e^{-\frac{t}{T_i}} + I_\infty & t \geq 0 \end{cases} \qquad n = \begin{cases} 2 & \text{Open-Circuit field winding} \\ 3 & \text{Short-Circuit field winding} \end{cases}$$

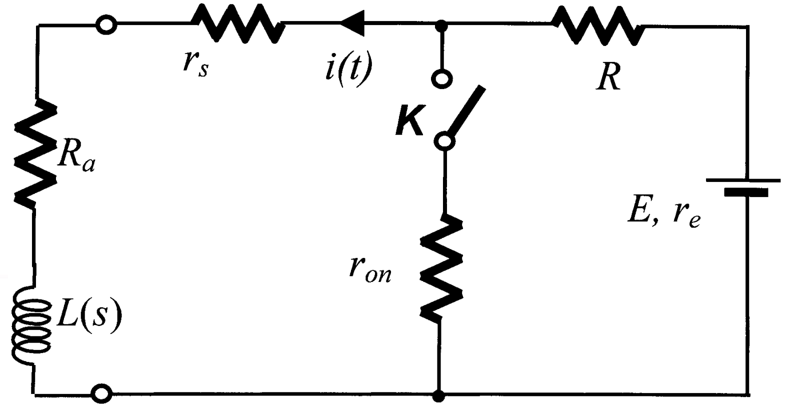
where

$$I_\infty = \lim_{t\to\infty} i(t) =$$

$$\mathrm{E} \cdot \left[\mathrm{R} + r_e + \frac{r_{on}(r_s + R_a)}{r_{on} + (r_s + R_a)}\right]^{-1} \cdot \frac{r_{on}}{r_{on} + (r_s + R_a)}$$







Groza V., Biriescu, M., Liuba, G., Cretu, V., "Experimental Determination of Synchronous Machines Reactances from DC Decay at Standstill." IMTC'2001, IEEE Instrumentation and Measurement Technical Conference, ISBN: 0-7803-6648-8, pp. 1954-1957, Budapest, Hungary, May 2001

DC Decay Testing Method

$$i_{do}(t) = I_{do1} e^{-\frac{t}{T_{do1}}} + I_{do2} e^{-\frac{t}{T_{do2}}}$$

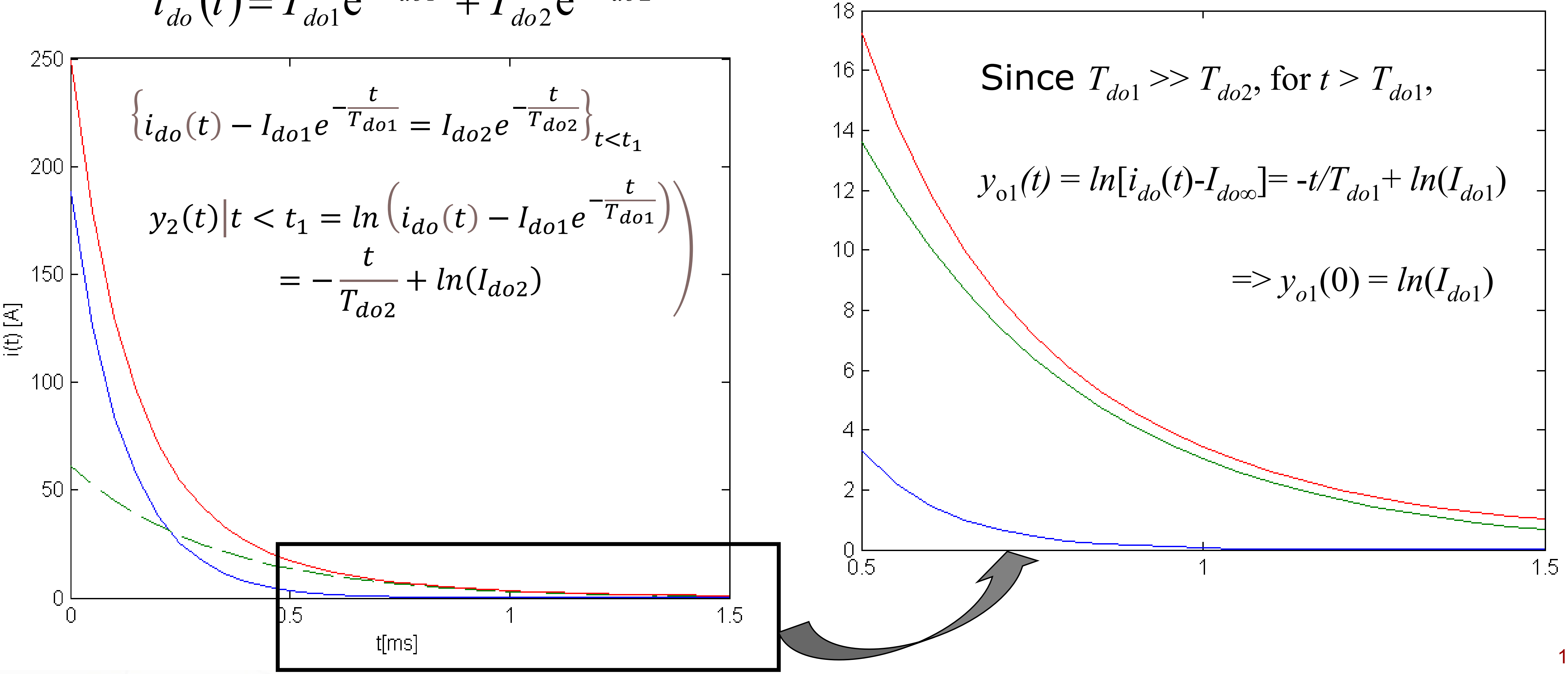
$$\left\{ i_{do}(t) - I_{do1} e^{-\frac{t}{T_{do1}}} = I_{do2} e^{-\frac{t}{T_{do2}}} \right\}_{t<t_1}$$

$$y_2(t)\big|t<t_1 = ln\left(i_{do}(t) - I_{do1} e^{-\frac{t}{T_{do1}}}\right) = -\frac{t}{T_{do2}} + ln(I_{do2})$$

Since $T_{do1} >> T_{do2}$, for $t > T_{do1}$,

$y_{o1}(t) = ln[i_{do}(t) - I_{do\infty}] = -t/T_{do1} + ln(I_{do1})$

$\Rightarrow y_{o1}(0) = ln(I_{do1})$



Method Error Analysis

$$T_1 = \frac{t}{\ln \frac{I_1 - I_\infty}{i(t) - I_\infty}}, \text{ for } t >> T_2 >> T_3 \qquad (7)$$

$$\frac{\Delta T_1}{T_1} = \frac{\left|\left[\Delta_x T_1\right]\right|}{T_1} \cdot D \cdot \left|\Delta x\right| \qquad (8)$$

$$\Delta x = \begin{bmatrix} \frac{\Delta t}{t} \\ \frac{\Delta i}{i} \\ \frac{\Delta I_1}{I_1} \\ \frac{\Delta I_\infty}{I_\infty} \end{bmatrix} \qquad D = \begin{bmatrix} t & 0 & 0 & 0 \\ 0 & i & 0 & 0 \\ 0 & 0 & I_1 & 0 \\ 0 & 0 & 0 & I_\infty \end{bmatrix} \qquad \left[\Delta_x T_1\right] = \begin{bmatrix} \frac{\partial T_1}{\partial t} & \frac{\partial T_1}{\partial i} & \frac{\partial T_1}{\partial I_1} & \frac{\partial T_1}{\partial I_\infty} \end{bmatrix}$$

$$\frac{\Delta T_1}{T_1} = \left|\frac{\Delta t}{t}\right| + \left(\left|\frac{\Delta i}{i}\right| \cdot K_1 + \left|\frac{\Delta I_1}{I_1}\right| \cdot K_2 + \left|\frac{\Delta I_\infty}{I_\infty}\right| \cdot K_3\right) \cdot M \qquad (9)$$

with $K_1 = \frac{a}{a-1}$, $K_2 = \frac{b}{b-1}$, $K_3 = \frac{a-b}{(a-1)\cdot(b-1)}$, $M = \left(\ln \frac{a-1}{b-1}\right)^{-1}$, $a = \frac{I_1}{I_\infty}$ and $b = \frac{i}{I_\infty}$

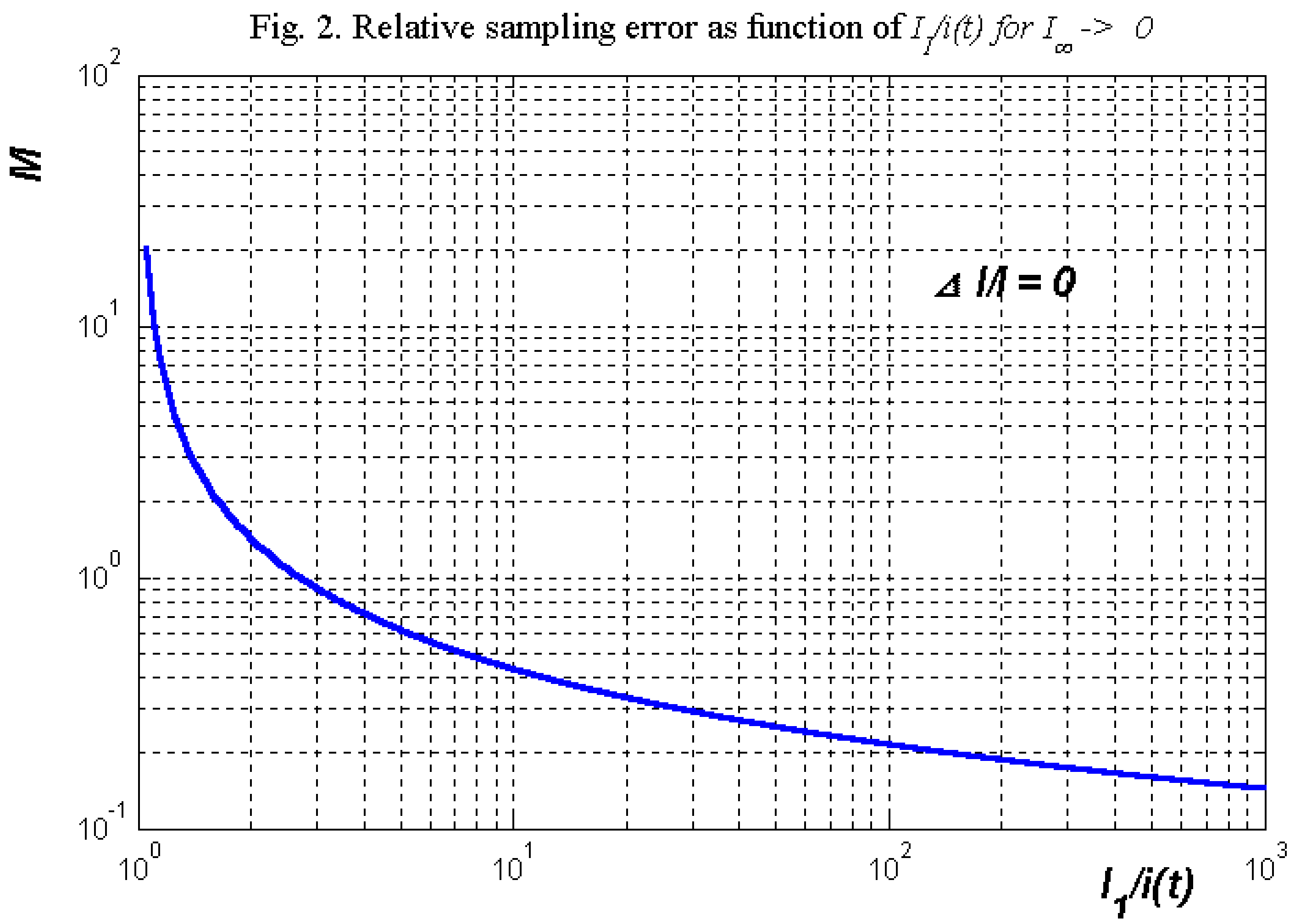
Method Error Analysis

$$\frac{\Delta I}{I} = \frac{\Delta I_\infty}{I_\infty} \Rightarrow \frac{\Delta I_1}{I_1} = \frac{1}{a} \cdot \frac{\Delta I}{I} \text{ and } \frac{\Delta i}{i} = \frac{1}{b} \cdot \frac{\Delta I}{I}$$

$$\frac{\Delta T_1}{T_1} = \left|\frac{\Delta t}{t}\right| + \left|\frac{\Delta I}{I}\right| \cdot K, \text{ where } K = \frac{2}{b-1} \cdot M \qquad (11)$$

- First term = *relative sampling error, introduced by the sampling circuits*
- Second term = *relative quantization error determined by the quantizer's precision*

Relative Sampling Error

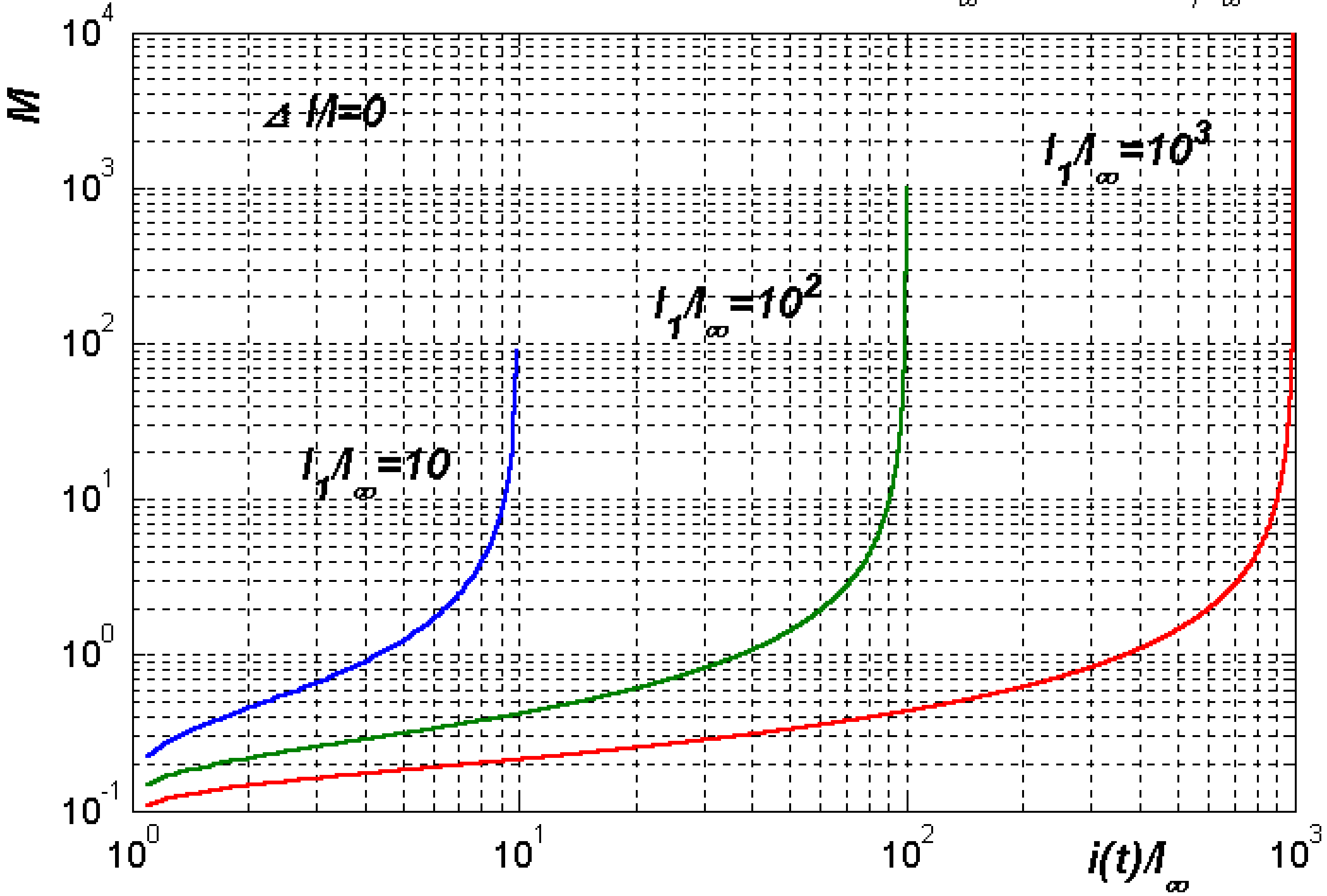


For $\boldsymbol{I_\infty} \approx \mathbf{0}$,
M reduces
relative sampling error for

$$\boldsymbol{i(t) < I_1/3}$$

Relative Sampling Error

Fig. 3. Relative sampling error as function of $i(t)/I_\infty$, for various I_1/I_∞



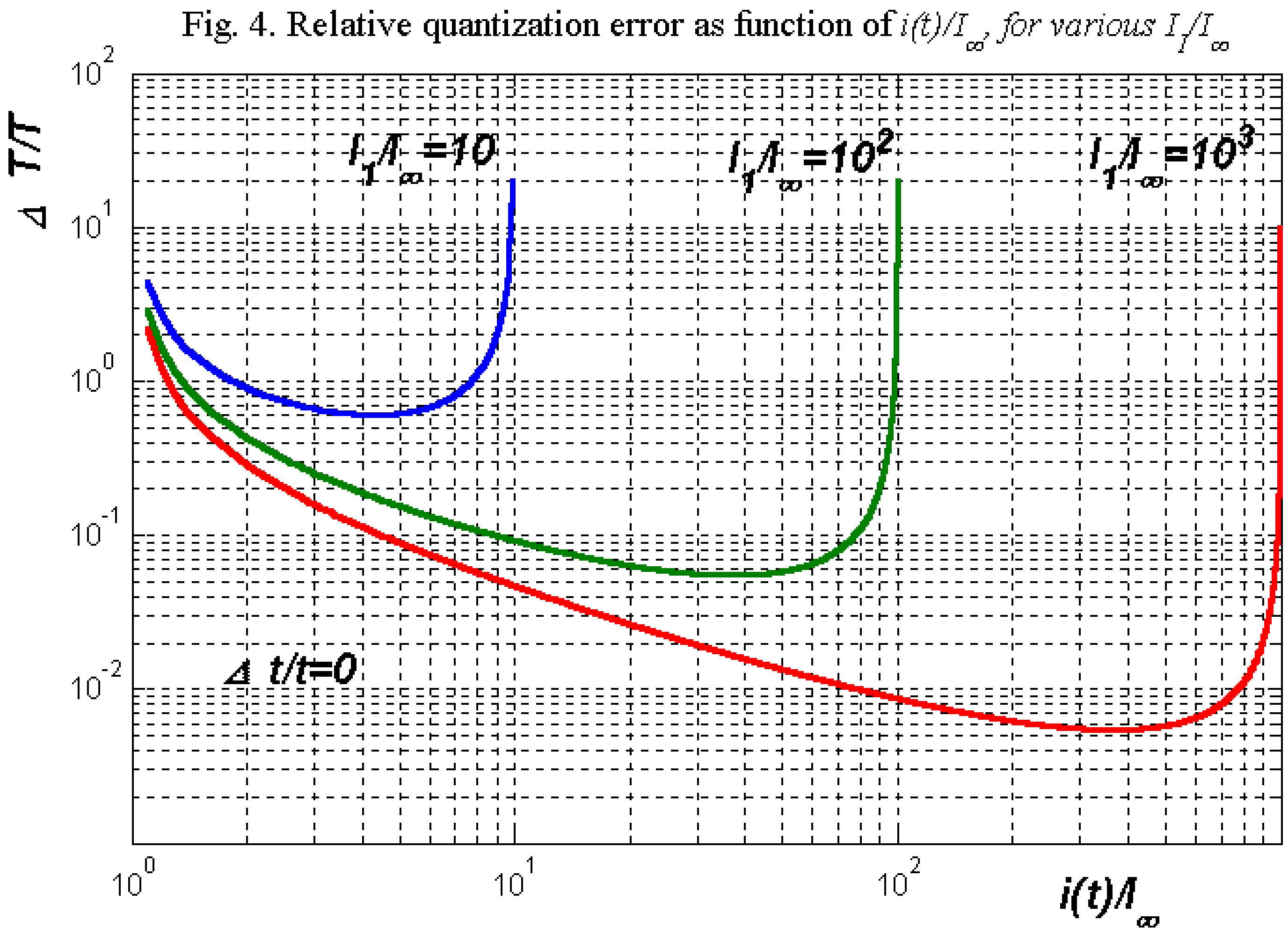
For $\boldsymbol{I_\infty \neq 0}$ M reduces *relative sampling error* for

$\boldsymbol{i(t) < I_1/3}$

and better off if

$\boldsymbol{i(t)/I_\infty \rightarrow 1}$, i.e., $\boldsymbol{t \rightarrow \infty}$

Relative Quantization Error



There is a minimum for ***i*(*t*) ≈ 0.4·*I*$_1$** acquired for ***t* → 0**

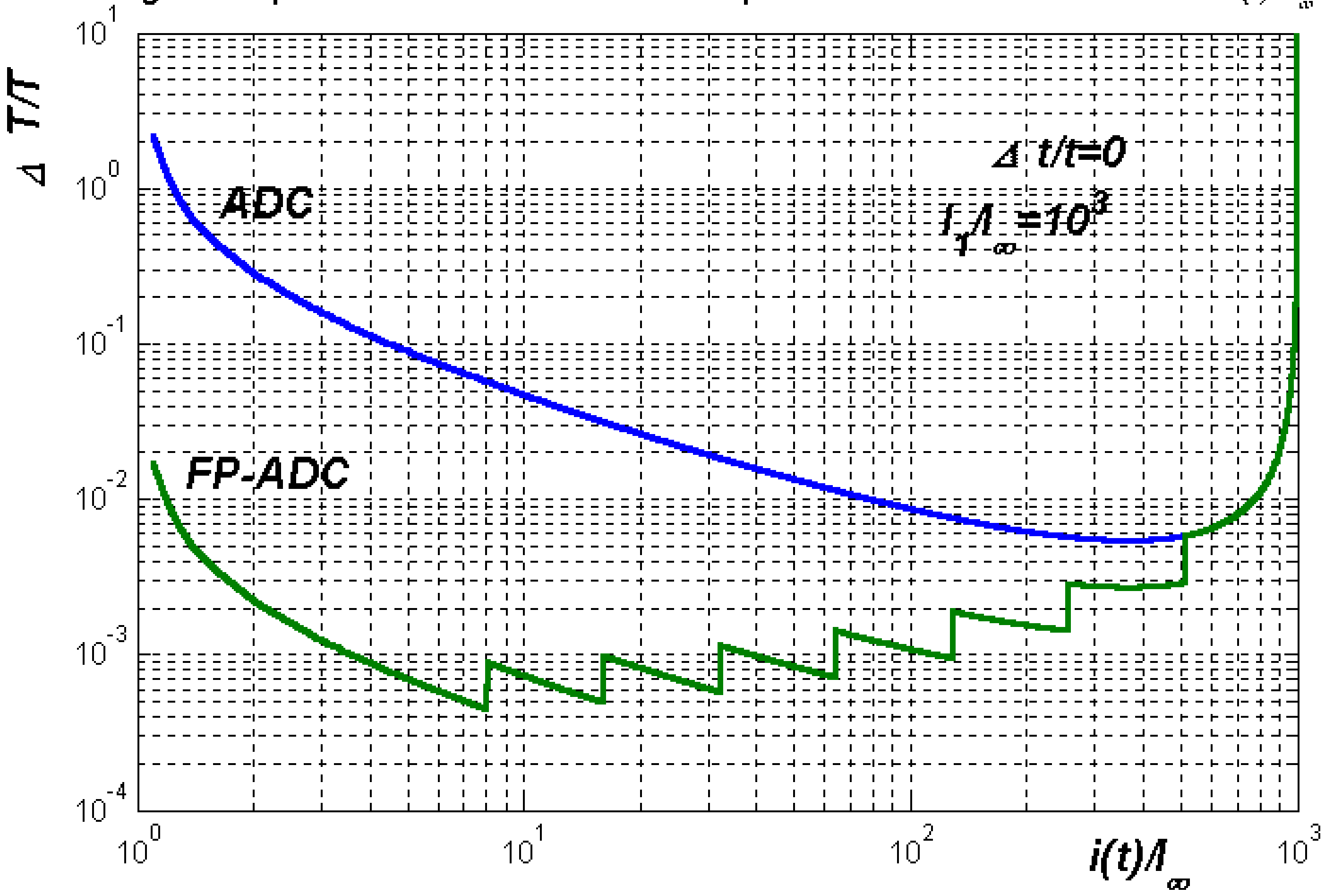
=> flagrantly contradicts with the condition for minimizing the *relative sampling error*

i.e., ***t*→∞**

Relative Quantization Error

Floating Point ADC vs Fix Point ADC

Fig. 5. Fix-point ADC vs FP-ADC relative quantization error as functions of $i(t)/I_\infty$



The highest precision is achieved if T_1 is found from samples of

$\boldsymbol{I} = \{i(t) \mid i < I_1/3\}$ where

- *sampling errors* are intrinsically minimized,
- FP-ADC reduces *relative quantization error*

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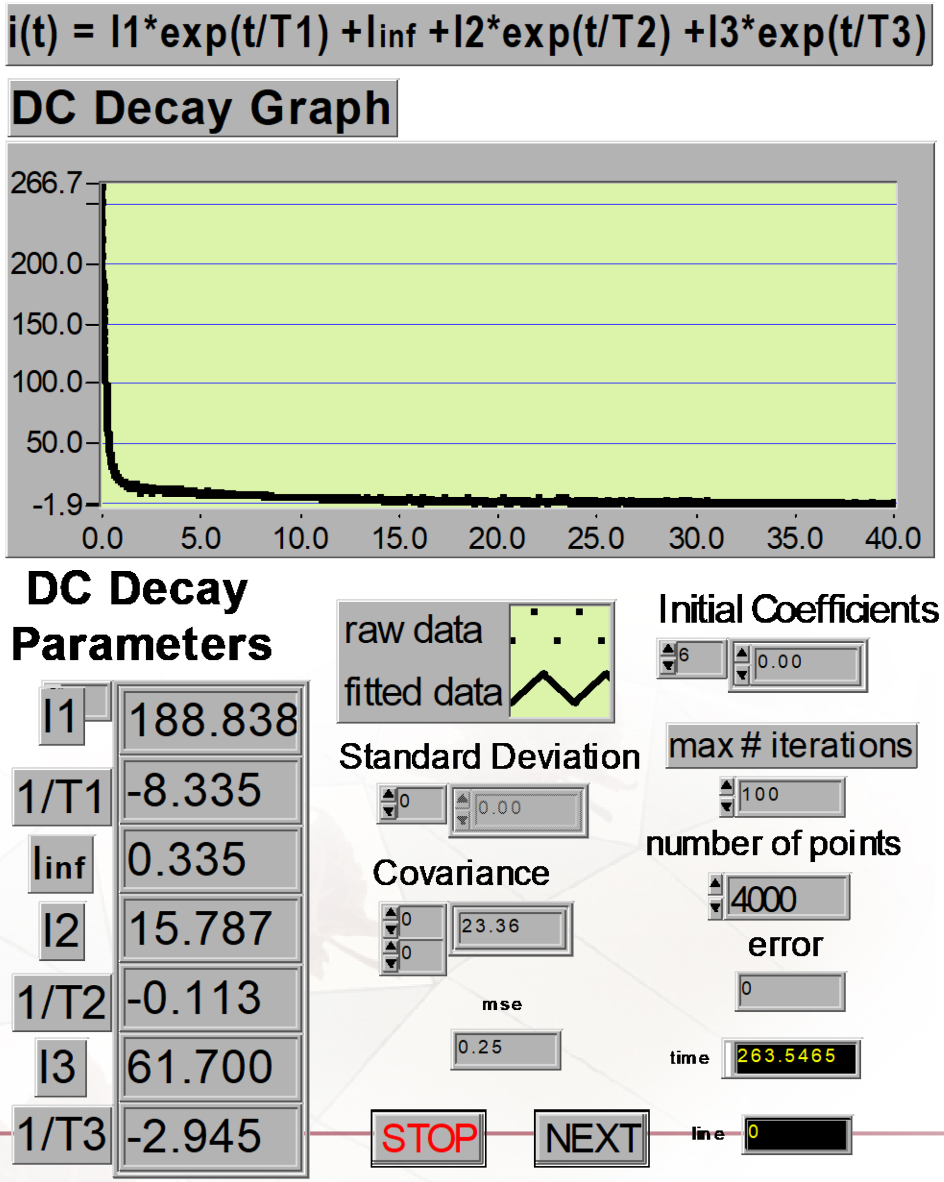
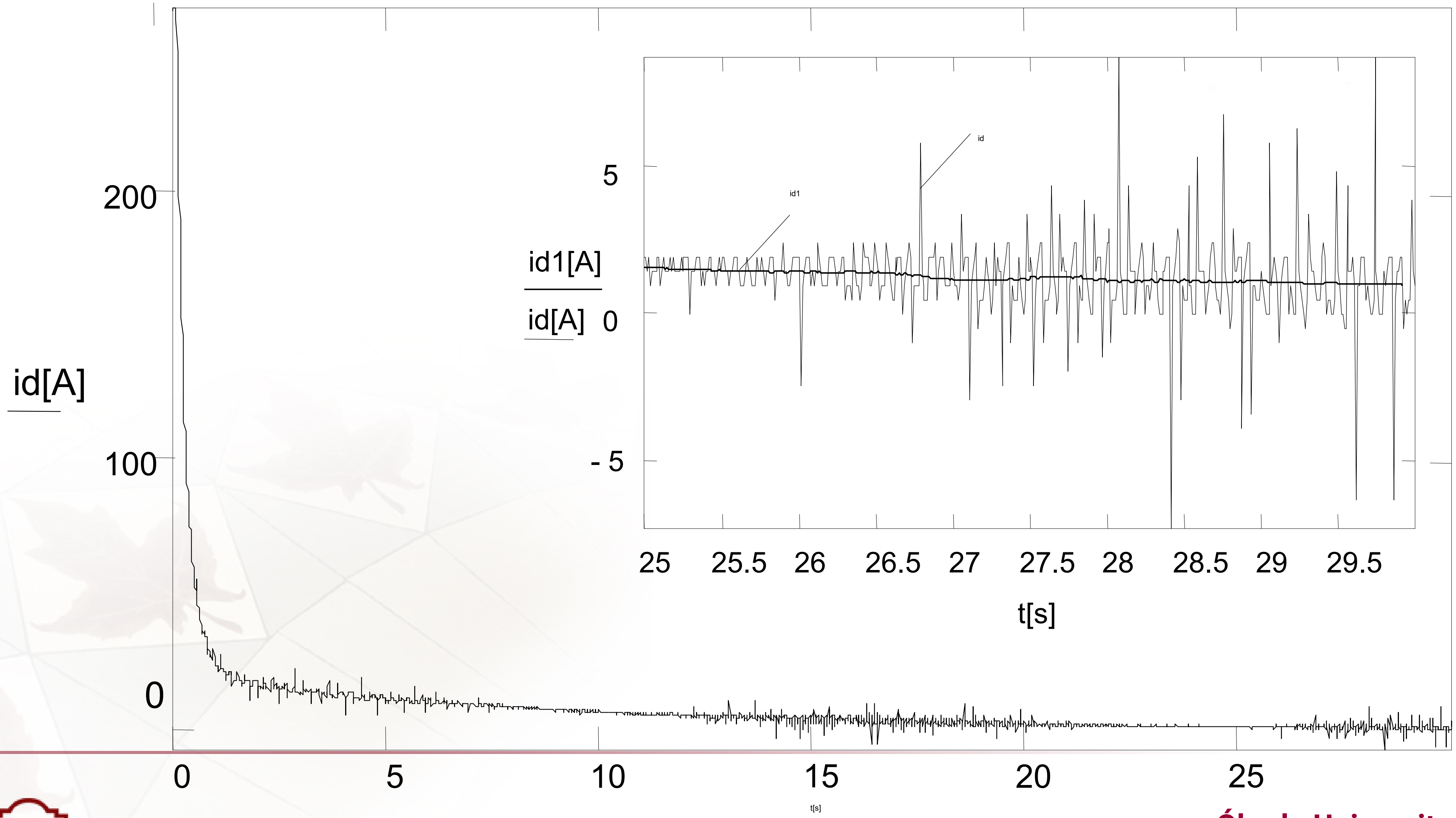


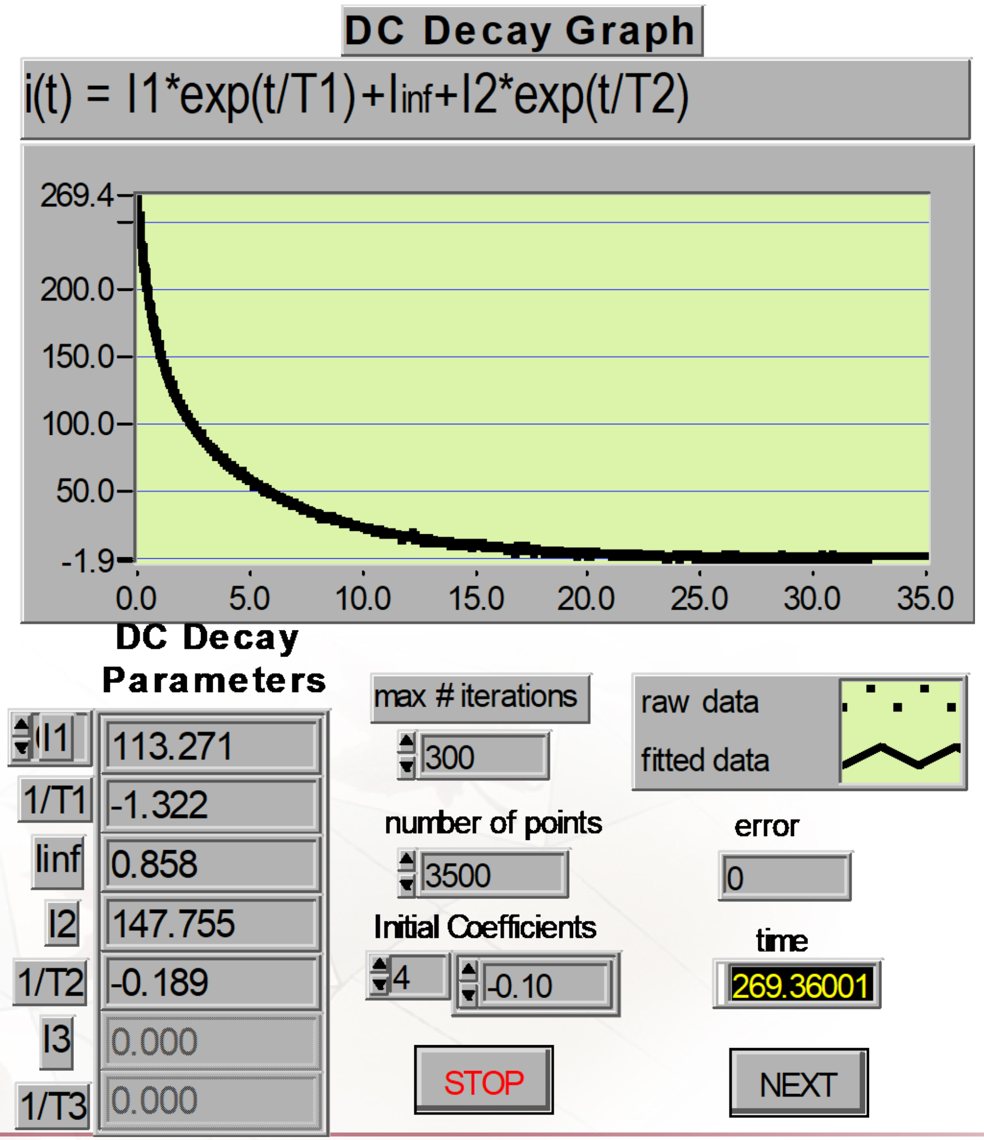
Fig. 8. Snapshot of virtual instrument for processing DC decay of stator transient current in a synchronous machine at standstill with direct-axis rotor position and the field winding short-circuited

d-axis Rotor Position & Short-circuited

- Complex *virtual instrument* (VI) determines the synchronous machine parameters and displays the results
- Snap-shot of results acquired with the testing stand from measurements performed on a *synchronous machine at standstill with* *direct-axis rotor position and the field winding short-circuited*
- The tested machine had 76.5 MW active power and 10.5 kV rated voltage.

d-axis Rotor Position & Short-circuited





q-axis Rotor Position & Open-circuited

Snapshot of results acquired with the testing stand from measurements performed on the 76.5 MW/10.5 kV synchronous machine at standstill with quadrature q-axis rotor position and the field winding short-circuited

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Heisenberg Uncertainty Principle in **Blood Pressure Monitoring**

- S. Tavoularis, Measurement in Fluid Mechanics, New York : Cambridge University Press, 2005
  - One can measure pressure of a fluid inside of a pipe only if a sensor is inserted in it!
- Direct measurement of blood pressure is invasive, and, as such, it has a very limited clinical value.
- Non-invasive blood pressure measurement is the only application where direct measurement methods from other fields could not be applied for practical and ethical reasons.

- BP cannot be **measured** non-invasively but only **estimated** from indirect measurements (Korotkov sounds, cuff pressure oscillations, tonometry, etc.)
- It is the result of internal REGULATION
  - It is an internally measured property
  - Actually, **you measure the measure in which the regulator responds to measurement!**
  - If taken several times, BP will "regress to the mean"

The Measurand = Pulse pressure in arteries

Mean Arterial Pressure (*MAP*):

The average value of the pressure over time

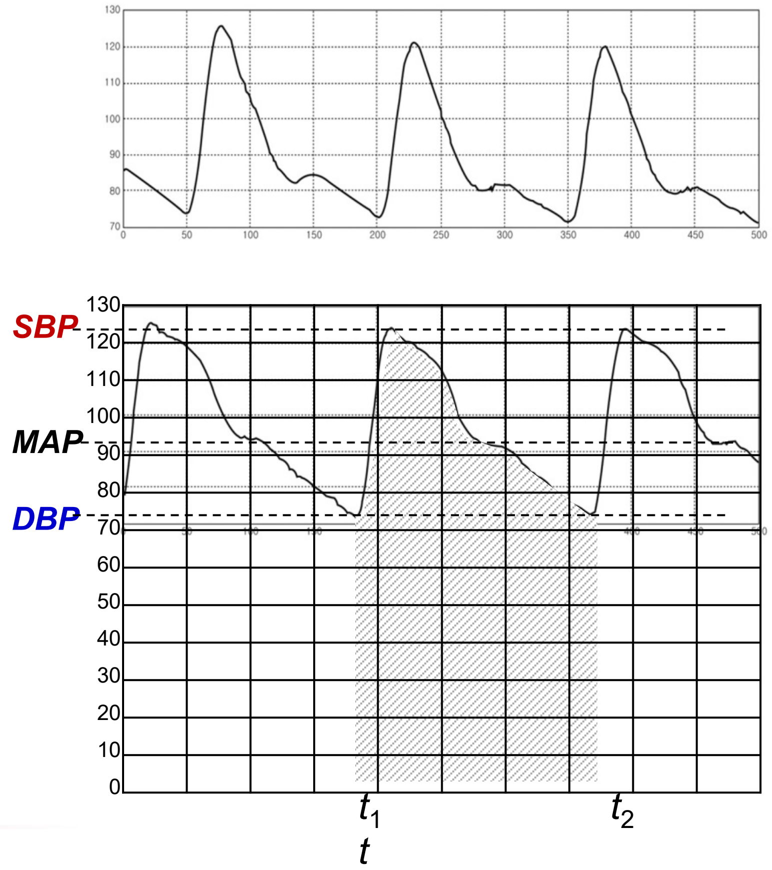
$$MAP = p_{mean} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} p(t)dt$$

The DC Component of the Fourier transform of the pressure waveform

- **Systolic Blood Pressure:** Pressure in the artery as heart contracts (maximum)
- **Diastolic Blood Pressure:** Pressure in the artery as heart relaxes (minimum)

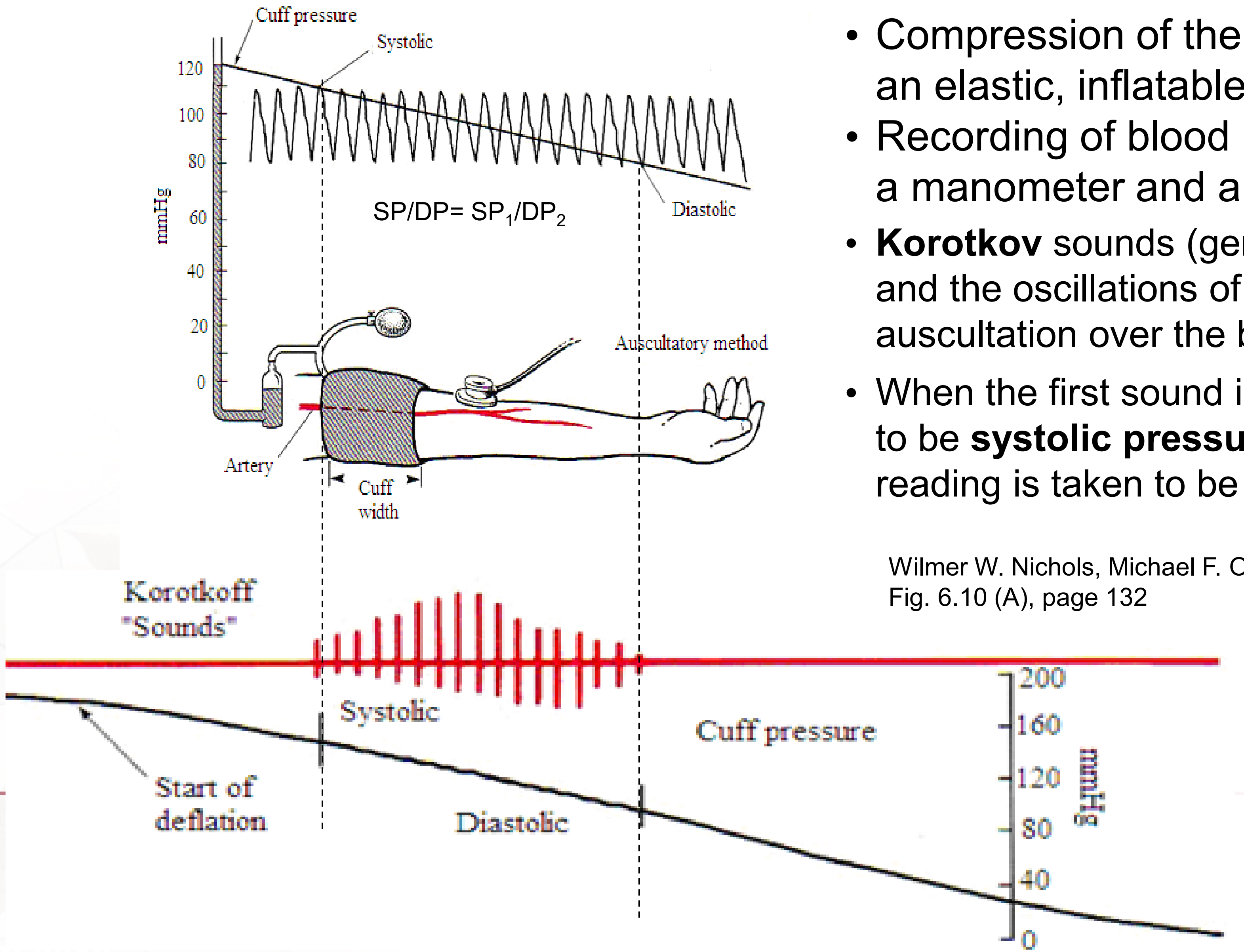
SBP*, *DBP*, and *MAP

- Cannot fully describe the blood pressure waveform (discard information)
- Provide a simple, easy to read glimpse into a patient's condition, while still having some diagnostic value
- More readily obtainable (non-invasively)



Two pressure waveforms recorded from the same patient at different times. SBP and DBP are the same, while MAP and overall shape are not.

Auscultation - Background



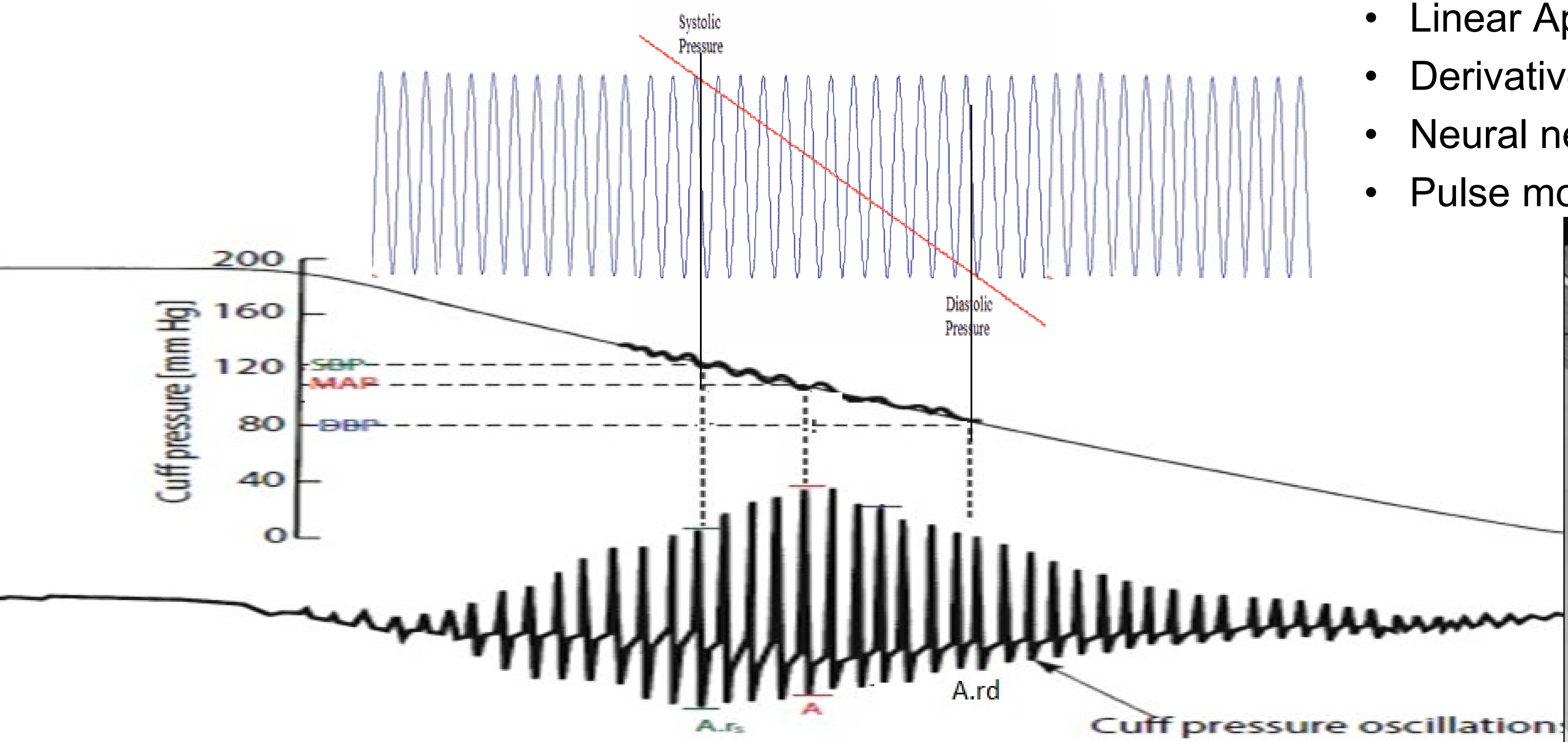
- Compression of the brachial artery using an elastic, inflatable cuff;
- Recording of blood pressure levels using a manometer and a stethoscope
- **Korotkov** sounds (generated by the turbulent flow of blood and the oscillations of the arterial wall) are heard during auscultation over the brachial artery distal to the cuff;
- When the first sound is heard, a reading is recorded and taken to be **systolic pressure** and when the last sound is heard a reading is taken to be **diastolic pressure**.

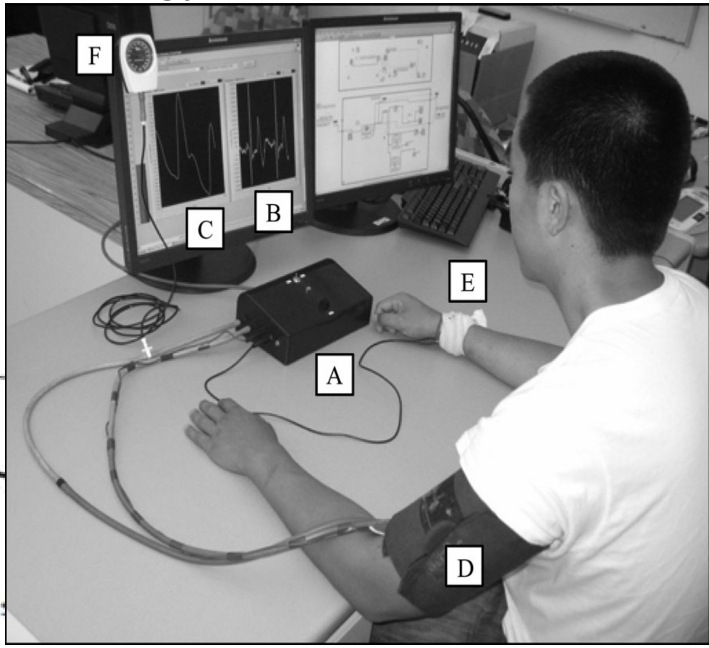
Wilmer W. Nichols, Michael F. O'Rourke: McDonald's Blood Flow in Arteries, 4th Edition – Fig. 6.10 (A), page 132

Model-based Oscillometric BP Estimation

Oscillometric Algorithms:

- **Maximum amplitude algorithm (MAA)**
- Linear Approximation Algorithm
- Derivative Oscillometry
- Neural network method
- Pulse morphology method

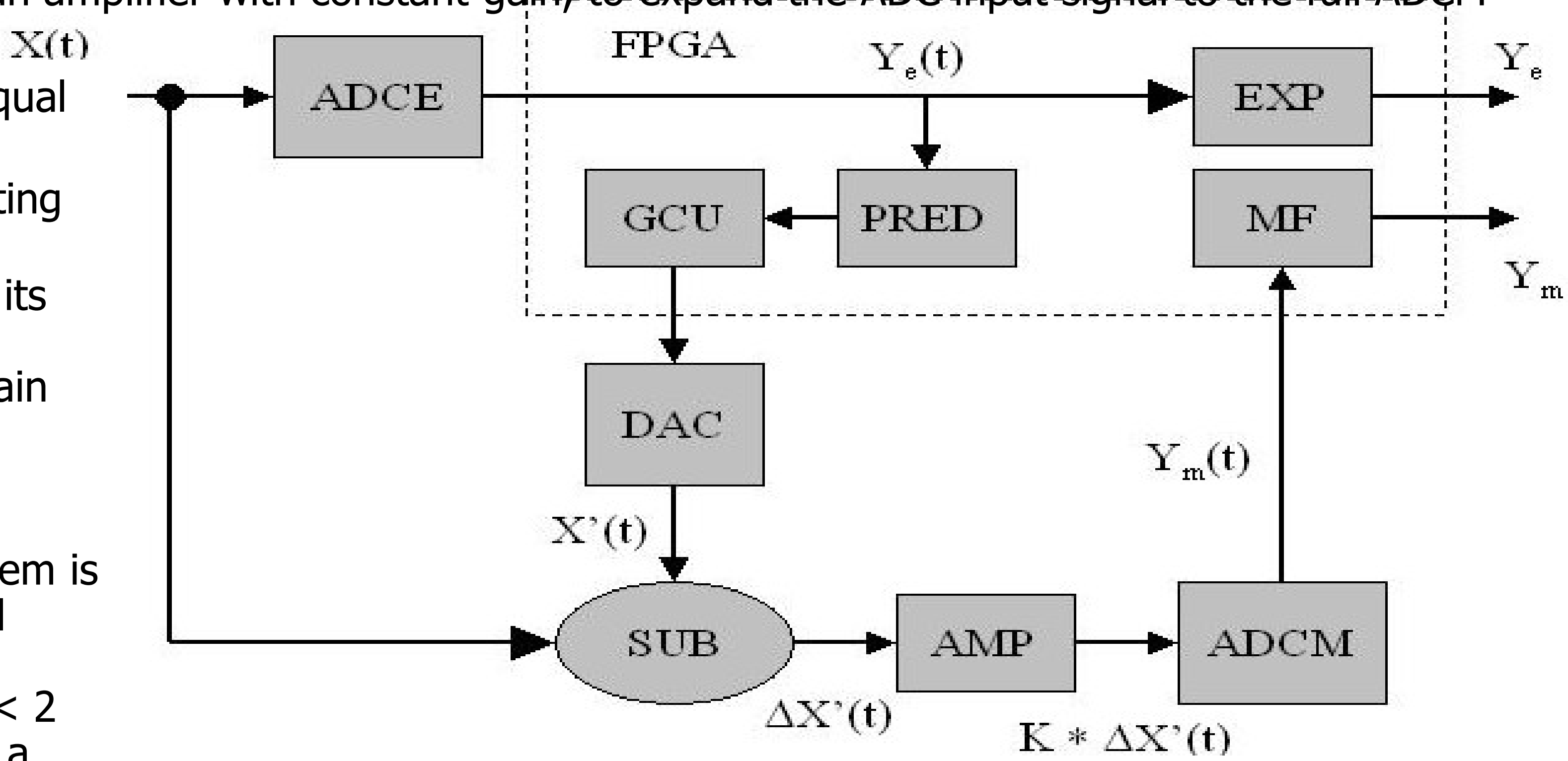




Predictive Differential Floating-Point Analog-to-Digital Converter

- The coarse quantization, accomplished by the ADCE, provides a rough value of the current value of the input signal, which is directly fed to the FPGA for encoding the exponent.
- It is also being inputted to the predictive circuitry (PRED) in the FPGA to forecast the future value of the quantized signal to be applied to the DAC.
- The Gain Control Unit sets the input DAC setting based on the prediction, for the generation of the analog representation of the rounded-off exponent, X′(t).
- After subtraction from the original signal, the difference signal ΔX′(t) will be bound by 0< ΔX′(t)<q, where q is the quantization step.
- The difference signal ΔX′(t) is amplified using an amplifier with constant gain, to expand the ADC input signal to the full ADCM range.

- The gain of the amplifier is thus chosen to be equal to $k = V_{maxin}/q$
- The ADCM output is sent to the FPGA to formatting the mantissa.
- If the acquired signal falls in the same range as its prediction, the conversion result is delivered immediately; if not, the mantissa is acquired again with the DAC input reset to the most recently acquired exponent.
- As long as the input signal fluctuates within one single ADCE quantization step, much of the system is kept in its static state, allowing for the statistical properties of the measured signal to dominate.
- Thus, in general, this system will require 1 < *n* < 2 measurements on average. How close it gets to a single measurement per sample will depend on thestatistical properties of the measured signal itself.



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Thank You !

Conclusions

- Measurements of high-power synchronous machines are inefficient with classic methods
- Solution: standstill time response (SSTR) –

  DC DECAY TESTING METHOD
- Analysis of the relative method error

  => designed and built a microcomputer-based testing stand provided with a **floating-point quantization** sub-system
- Results from test of a synchronous machine of 76.5 MW active power and 10.5 kV rated voltage are presented
- Con: cannot find parameters’ dependency with rotation