TS9326 - Live Classroom Measurements of Characteristic Curves and Frequency Responses Using myDAQ

Georg Eggers - Professor, Munich University of Applied Sciences

georg.eggers@hm.edu

Compact, versatile, USB-powered: myDAQ is the perfect ADC/DAC platform to turn theoretical classes into practical lab sessions. At this presentation, explore live measurements of characteristic curves that provide hands-on experience in standard industrial procedures to students but can be realized with minimum cost and effort using myDAQ and LabVIEW.

The determination of a **solar cell's output power curve** delivers insight into I(U) characteristics and demonstrates the easy integration of op-amp circuits into myDAQ setups.

Recording **frequency response characteristics for loudspeakers and mechanical vibrations** then shows myDAQ's potential for dynamic measurements with very simple external circuits.

Department of
Applied Sciences and
Mechatronics

UNIVERSITY
OF APPLIED SCIENCES
MUNICH

Georg Eggers

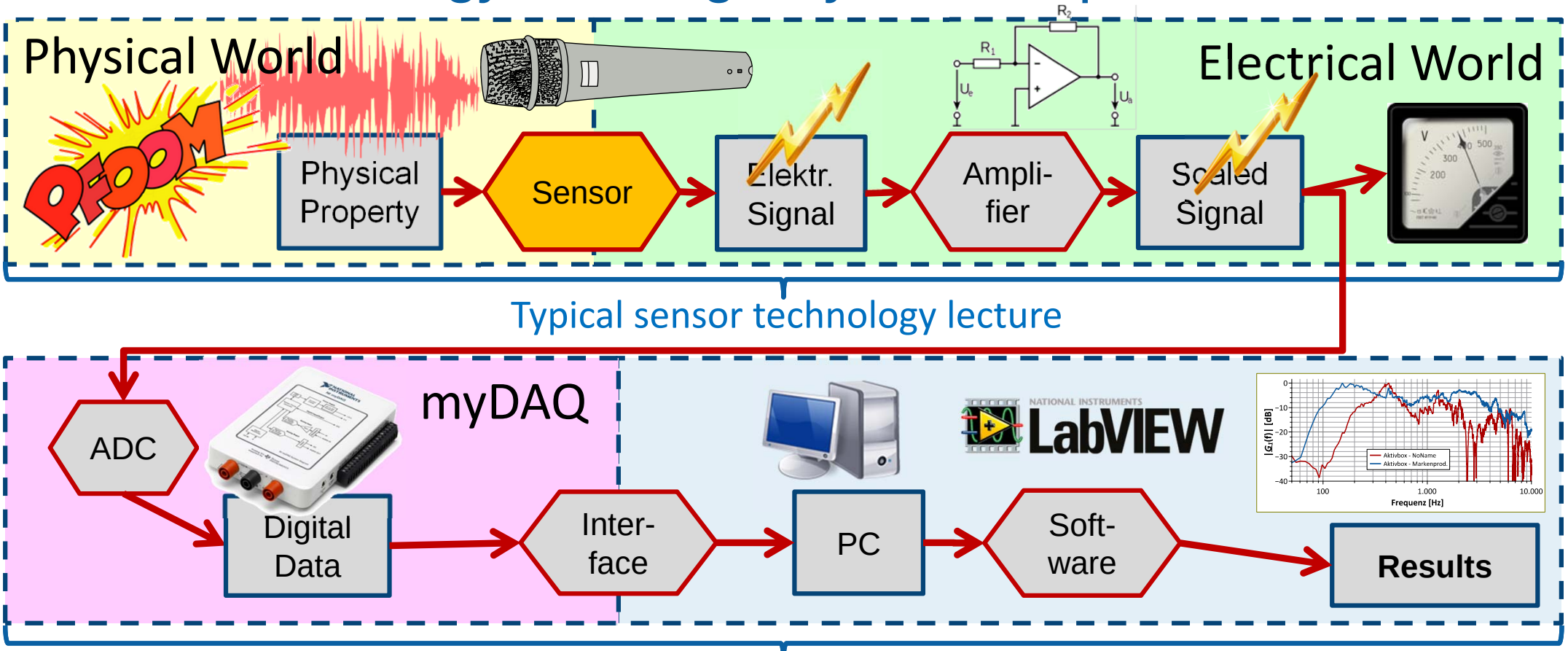
Live Classroom Measurements of Characteristic Curves and Frequency Responses Using the NI myDAQ

georg.eggers@hm.edu

This presentation and all LabVIEW code is available for download

NATIONAL INSTRUMENTS

Sensor Technology: Turning Physical Properties into Data

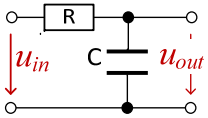


HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN MÜNCHEN
Georg Eggers
fk06.hm.edu

NATIONAL INSTRUMENTS

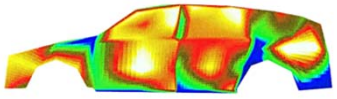
Live Classroom Measurements of Characteristic Curves and Frequency Responses Using the NI myDAQ

1. *Harvesting the Sun:*
   Solar Cell Output Power Curve



2. *System Analysis for Beginners:*
   Bode Plots of Simple Circuits

3. *95-cent Acoustics:*
   Frequency Responses of Loudspeakers

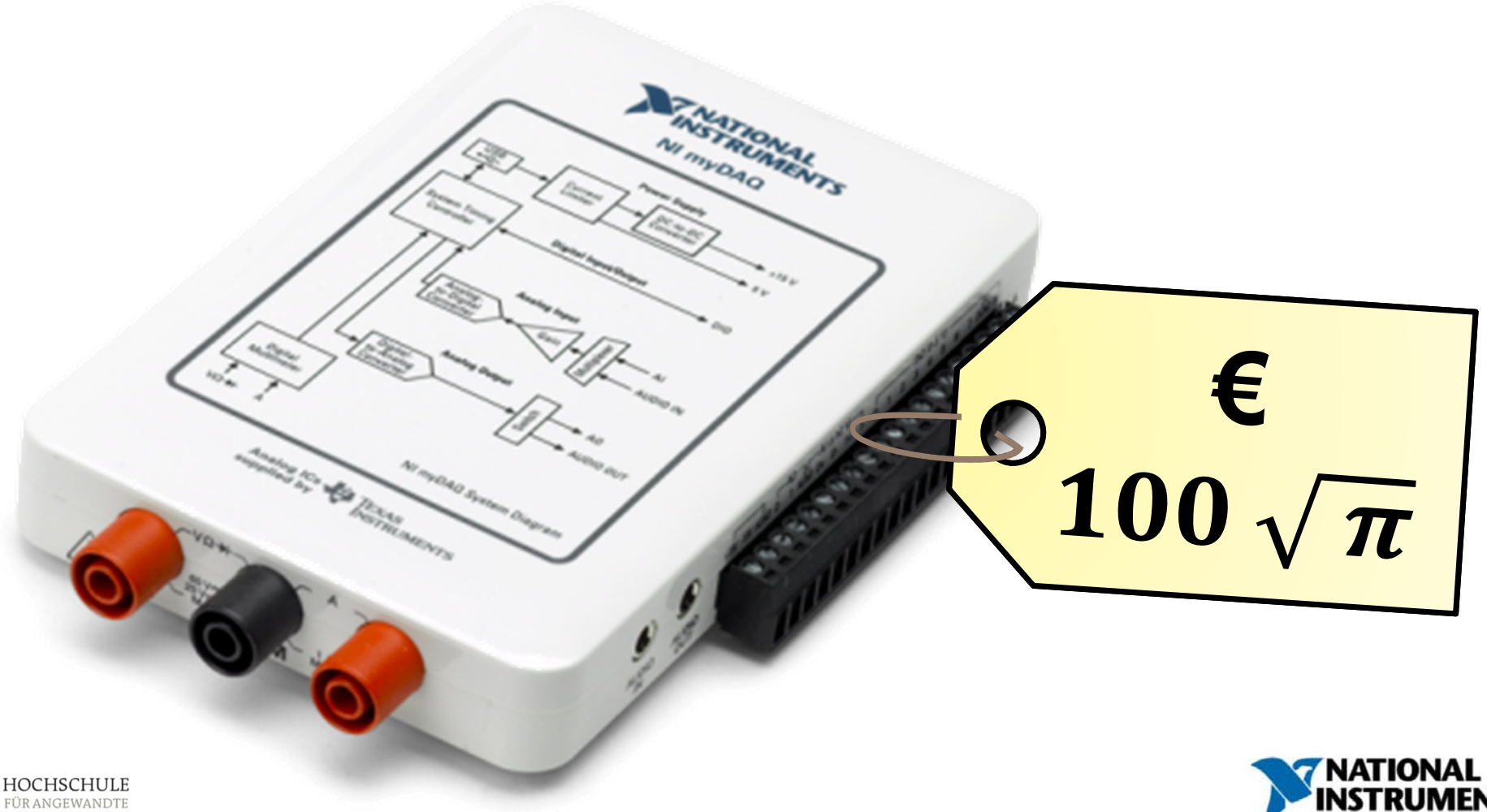


4. *Poor Man's Modal Analysis:*
   Monitoring Mechanical Vibrations

HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN MÜNCHEN
Georg Eggers
fk06.hm.edu

NATIONAL INSTRUMENTS

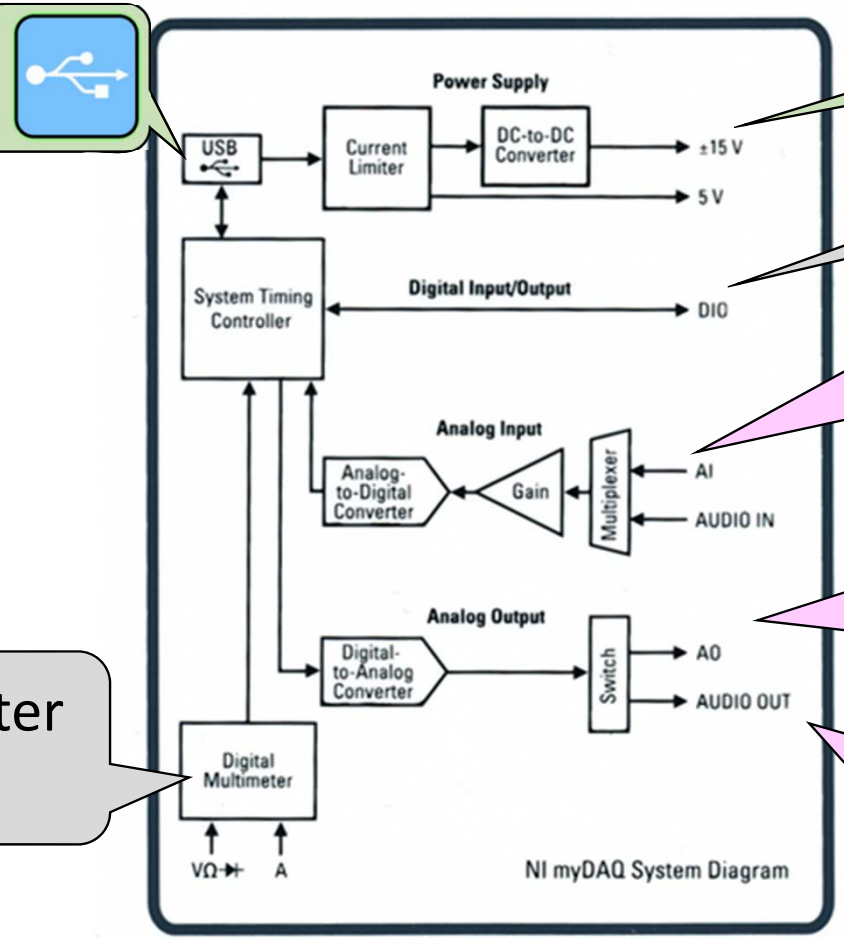
Up to date ADC Hardware



Pictures: National Instruments Corporation

myDAQ: Overview

USB
(bus powered)



±15 V for Opamps
+5 V

8 DIO

2 ADC 16 Bit @ 200 kHz
±2 V / ±10 V differential inputs

2 DAC 16 Bit @ 200 kHz
±10 V @ 2mA

Stereo Audio in/out
w supply circuit for electrete mics

Multimeter
I/U/R

Pictures: National Instruments Deutschland AG

HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN MÜNCHEN
Georg Eggers
fk06.hm.edu

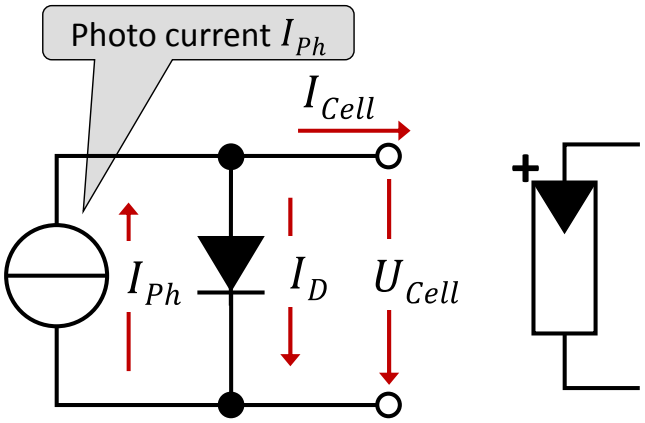
NATIONAL INSTRUMENTS

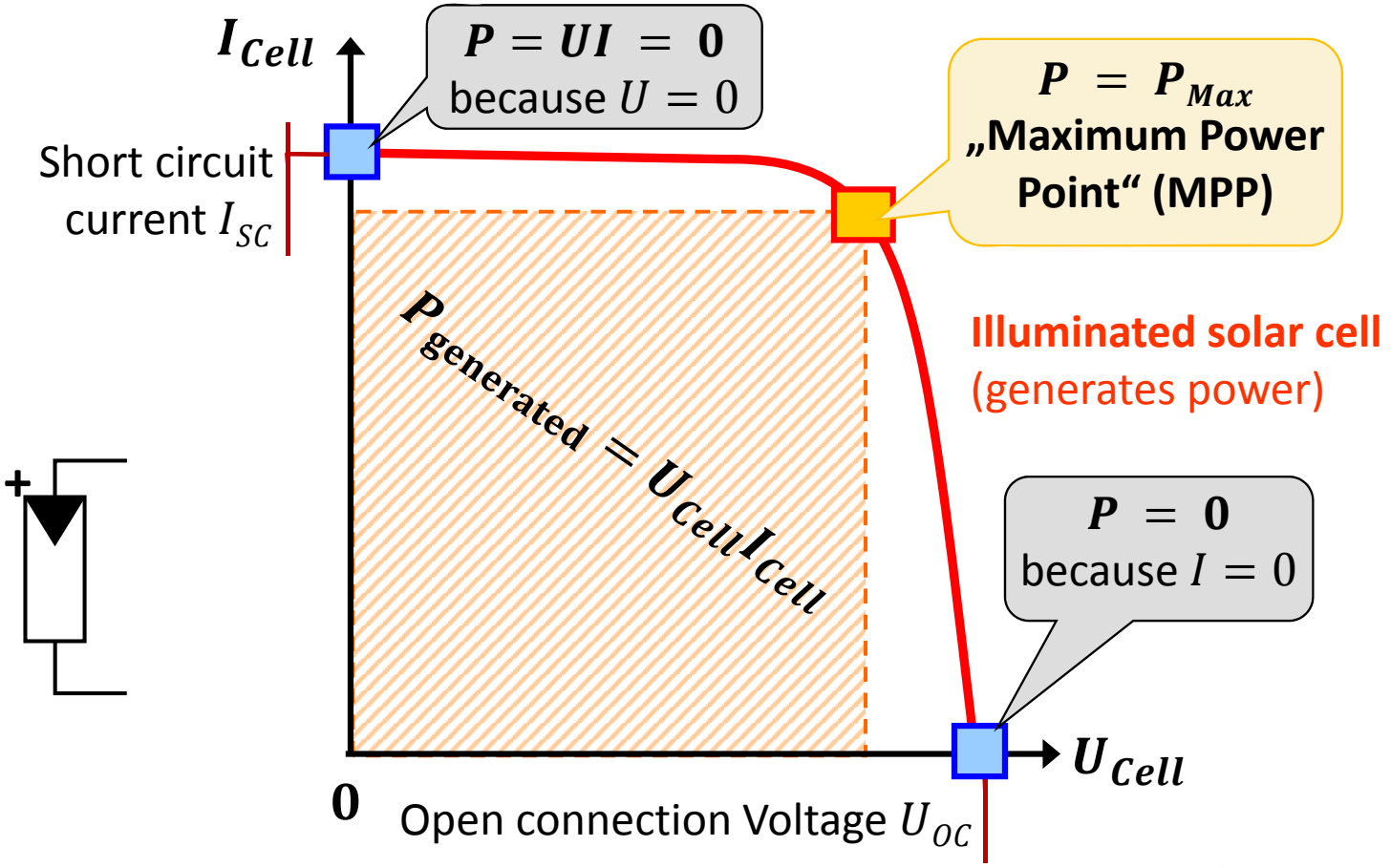
1. Harvesting the Sun:
Solar Cell Output Power Curve

HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN MÜNCHEN
Georg Eggers
fk06.hm.edu

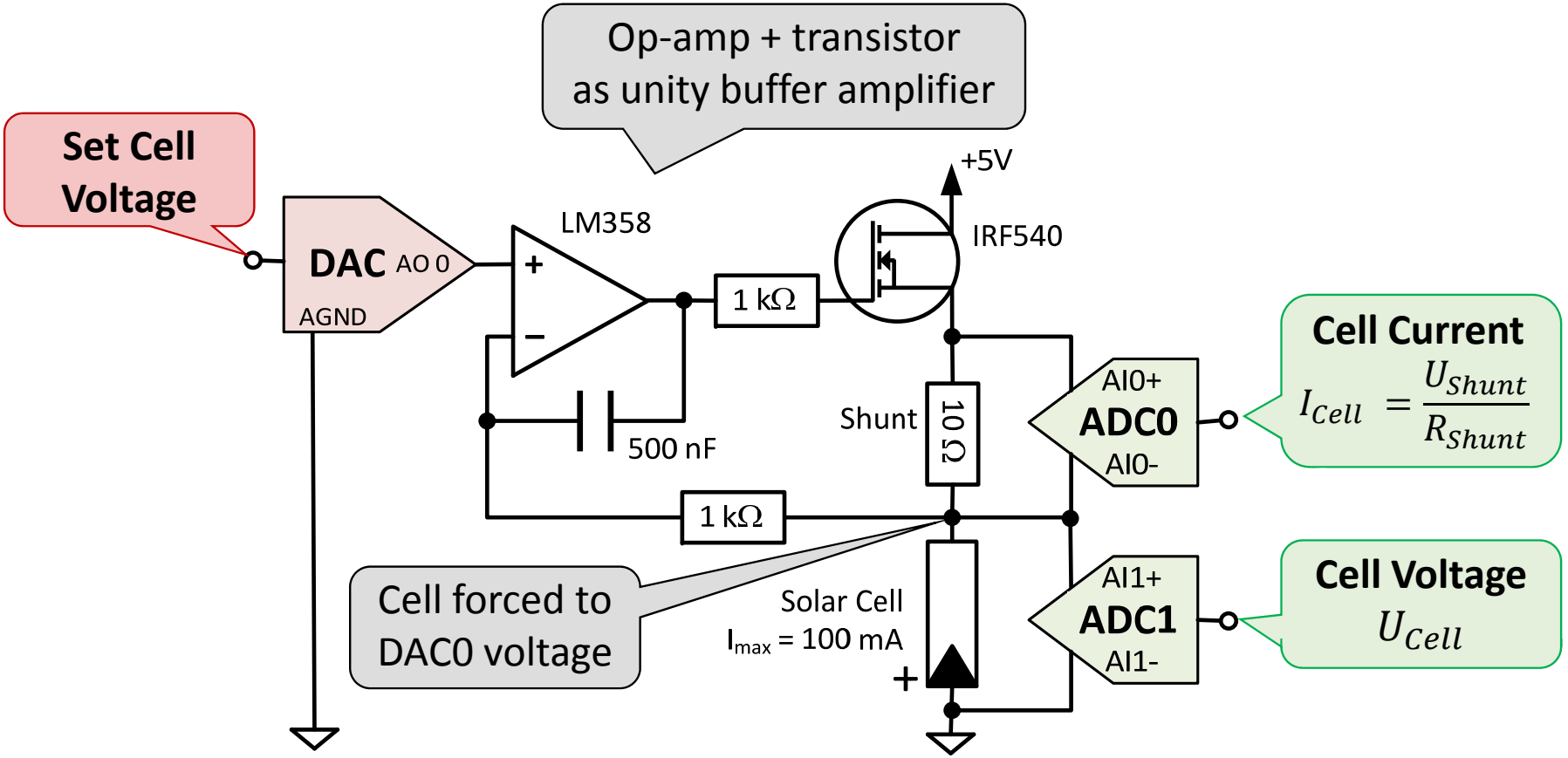
NATIONAL INSTRUMENTS

1. Solar Cell Characteristic Curve



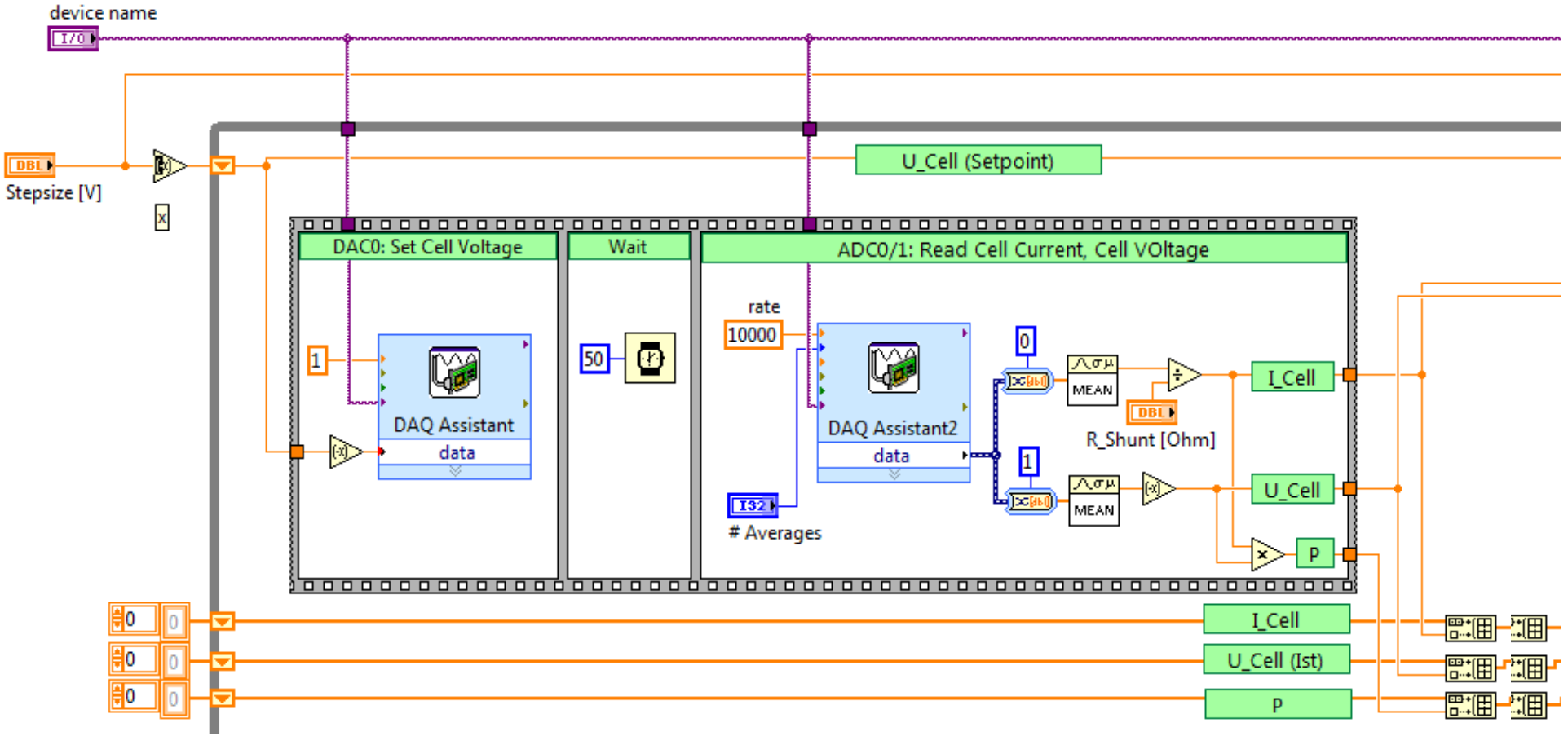


1. Solar Cell Characteristic Curve: Circuit Diagram



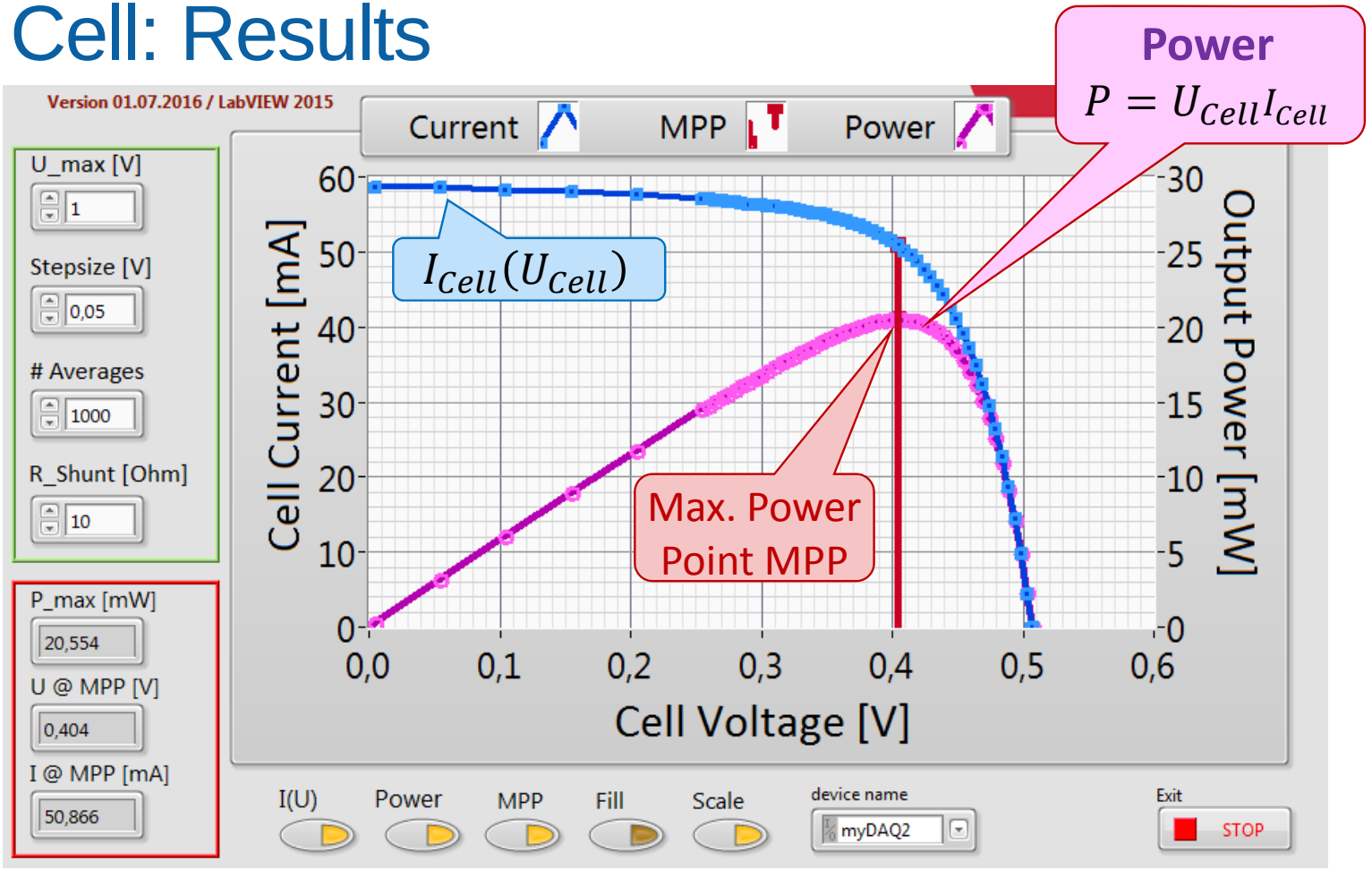
Schaltung nach Wagemann, H.-G.; Eschrich, H.: **Photovoltaik**, Teubner-Verlag, 2007

1. Solar Cell: Block Diagramm



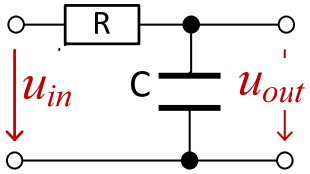
Solar_U-I_NIWeek-myDAQ_07.vi

1. Solar Cell: Results



LabVIEW\SolarCell\Solar_U-I_NIWeek-myDAQ_07.vi

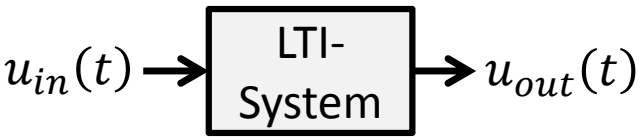
2. System Analysis for Beginners:
Bode Plots of Simple Circuits

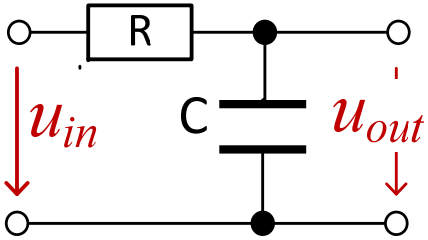


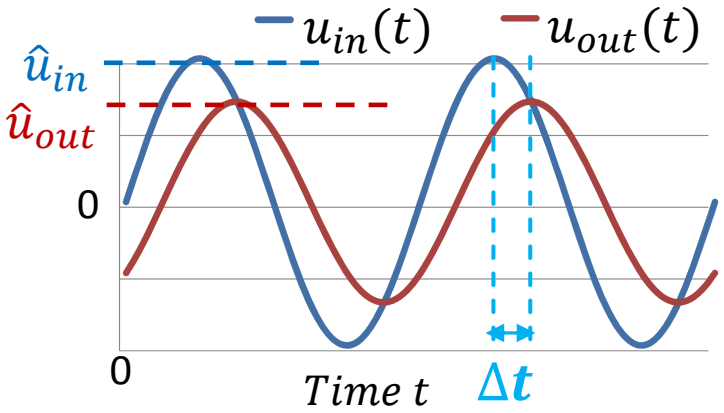
HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN MÜNCHEN
Georg Eggers
fk06.hm.edu

NATIONAL INSTRUMENTS

2. Bode Plot of Low-Pass Filter

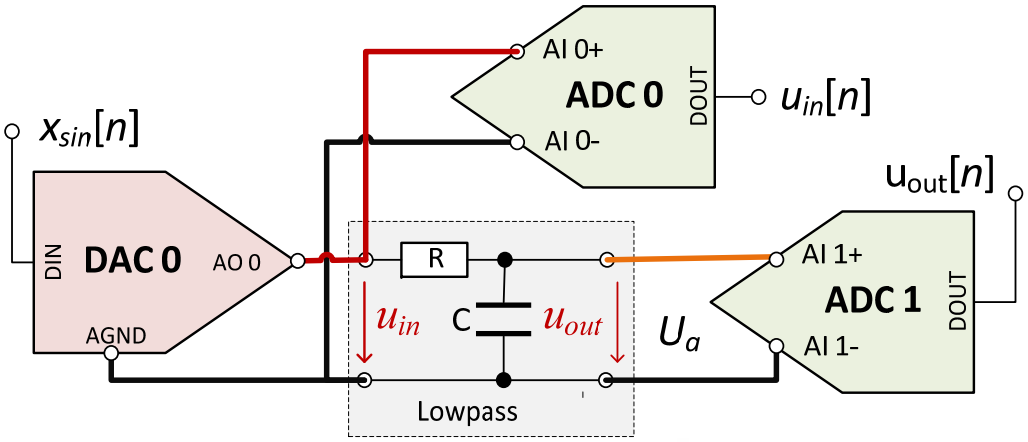




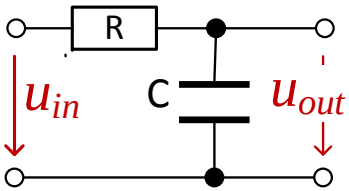


- **Bode Plot** displays:
  - **a.** **Amplitude response** $\frac{\hat{u}_{out}(f_0)}{\hat{u}_{in}}$
  - **b.** **Phase response** $\boldsymbol{\varphi(f)} = 2\pi\ \Delta t\ f_0$

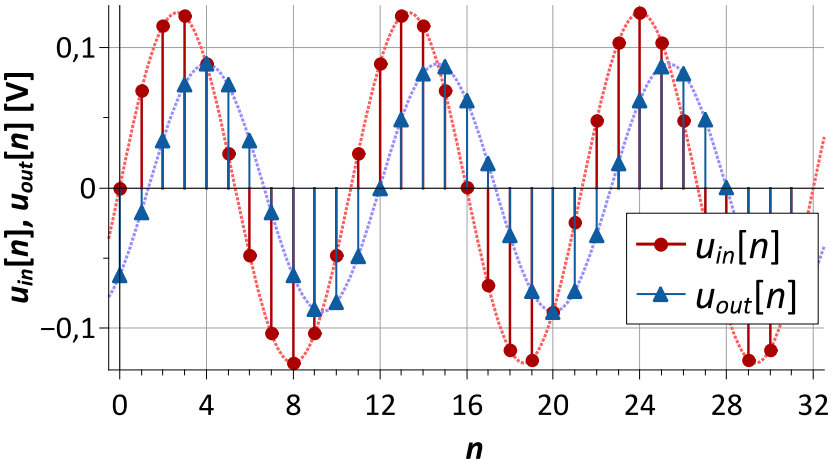
- **Frequency Response Function** $\underline{\boldsymbol{G}}(\boldsymbol{f}) \in \mathbb{C}$
  - $\left|\underline{G}(f)\right| = \frac{\hat{u}_{out}(f)}{\hat{u}_{in}}$
  - $\arg\left(\underline{G}(f)\right) = \varphi(f)$

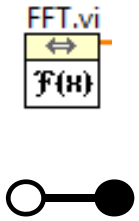


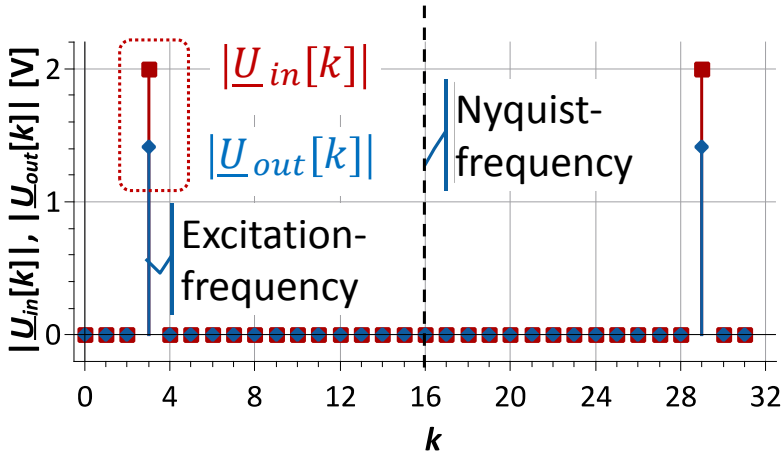
2. Bode Plots: Mathematics



- Record $u_{in}[n], u_{out}[n]$ → Calculate Spectra $\underline{U}_{in}[k], \underline{U}_{out}[k]$ via discrete Fourier transform



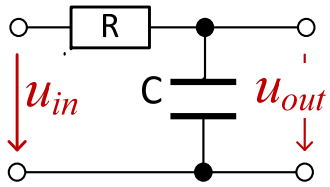


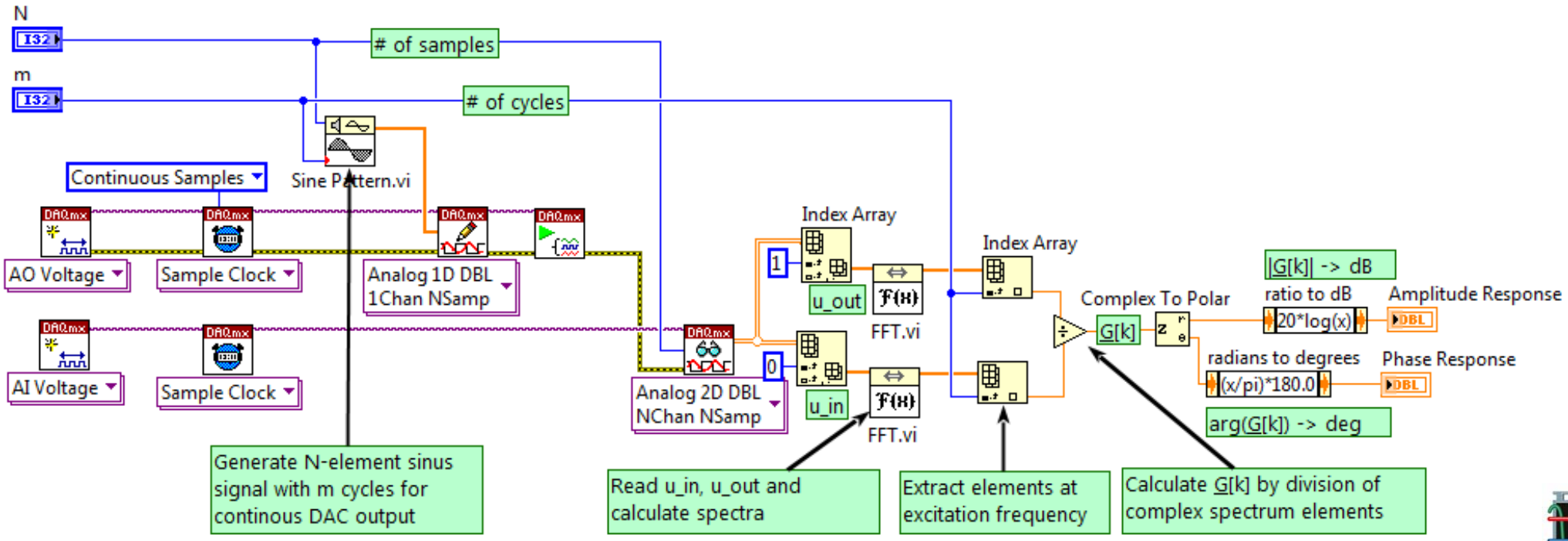


- Amplitude Response: $\left|\underline{G}[k]\right| = \frac{\left|\underline{U}_{out}[k]\right|}{\left|\underline{U}_{in}[k]\right|}$
- Phase Response: $\varphi[k] = \arg\left(\underline{G}[k]\right) = \arg\left(\frac{\underline{U}_{out}[k]}{\underline{U}_{in}[k]}\right)$

$$\underline{G}[k] = \frac{\underline{U}_{out}[k]}{\underline{U}_{in}[k]}$$

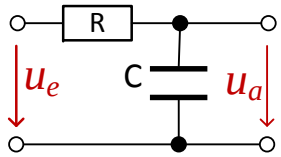
2. Bode Plot: LabVIEW Implementation

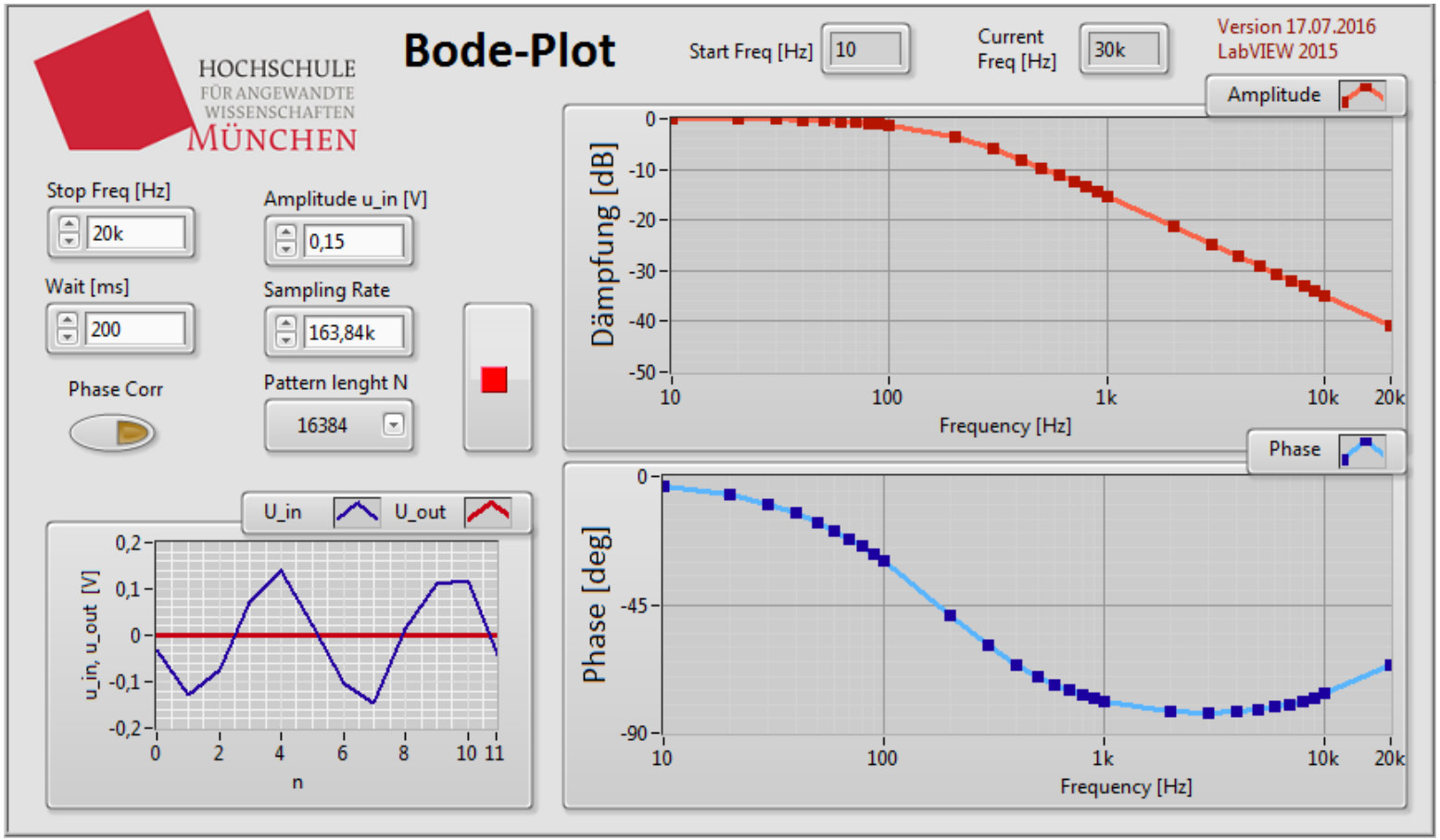




BodePlot-NIWeek_08.vi

2. Bode Plot: LabVIEW Implementation





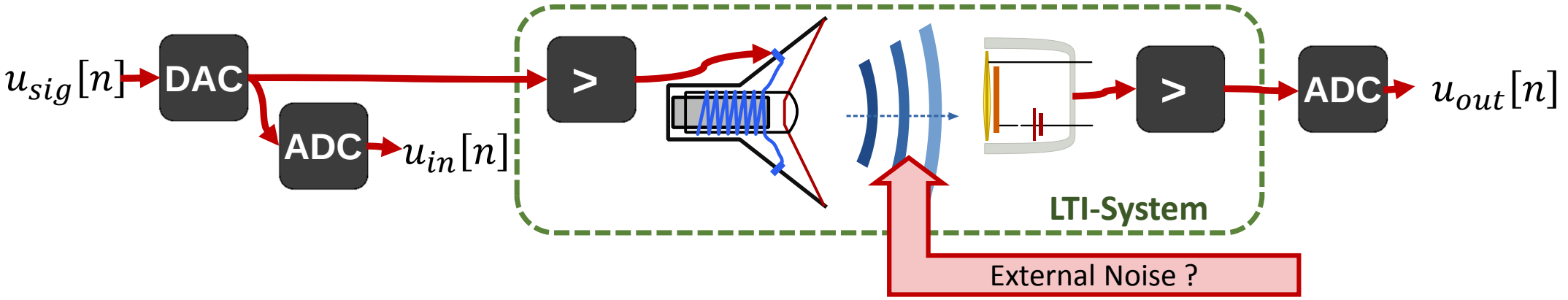
LabVIEW\BodePlot\BodePlot-NIWeek_08.vi

3. *95-cent Acoustics:*
Frequency Responses of Loudspeakers

HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN MÜNCHEN
Georg Eggers
fk06.hm.edu

NATIONAL INSTRUMENTS

3. Loudspeaker Response Curves: General

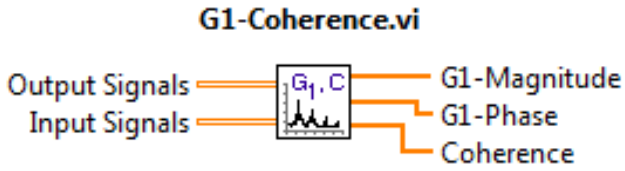


- **LTI-System:** Amplifier – Speaker – Soundwave – Microphone - Amplifier
  - $\underline{G}[k] = \frac{\mathcal{F}\{u_{in}[n]\}}{\mathcal{F}\{u_{out}[n]\}} = \frac{\underline{U}_{out}[k]}{\underline{U}_{in}[k]}$ … only defined for frequencies with $\underline{U}_{in}[k] \neq 0$
    → broadband excitation signal needed
  - $u_{in}[n]$**: White noise** (statistical mix of all Frequencies)
  - **External Noise might interfere with measurement**
    →Validity criterion needed for $\underline{G}[k]$

3. Coherence as Validity Check

- **Coherence** means **constant phase shift** between input and output signal at certain frequency for repeated measurements
- **Coherence as validity check:**
  - **Constant Phase Shift** → Output signal is reaction to input signal
  - **Random phase shift** → Output signal caused by external noise
- **Application:**
  - Repeat Measurement M times; calculate spectra $\underline{U}_{in}[k]_m$, $\underline{U}_{out}[k]_m$
  - Calculate **Coherence-corrected Frequency Response $\underline{G}_1[k]$:**

$$\underline{G}[k] = \frac{\underline{U}_{out}[k]}{\underline{U}_{in}[k]} \quad \Rightarrow \underline{G}_1[k] = \frac{\sum_{m=0}^{M-1}\left(\underline{U}_{out}[k]_m \cdot \underline{U}^*_{in}[k]_m\right)}{\sum_{m=0}^{M-1}\left(\underline{U}_{in}[k]_m \cdot \underline{U}^*_{in}[k]_m\right)}$$



- **Coherence Function $\gamma^2[k]$** mit $0 \leq \gamma^2[k] \leq 1$:

$$\gamma^2[k] = \frac{\left|\sum_{m=0}^{M-1}\left(\underline{U}_{out}[k]_m \cdot \underline{U}^*_{in}[k]_m\right)\right|^2}{\sum_{m=0}^{M-1}\left(\underline{U}_{in}[k]_m \cdot \underline{U}^*_{in}[k]_m\right) \cdot \sum_{m=0}^{M-1}\left(\underline{U}_{out}[k]_m \cdot \underline{U}^*_{out}[k]_m\right)}$$

3. Microphones

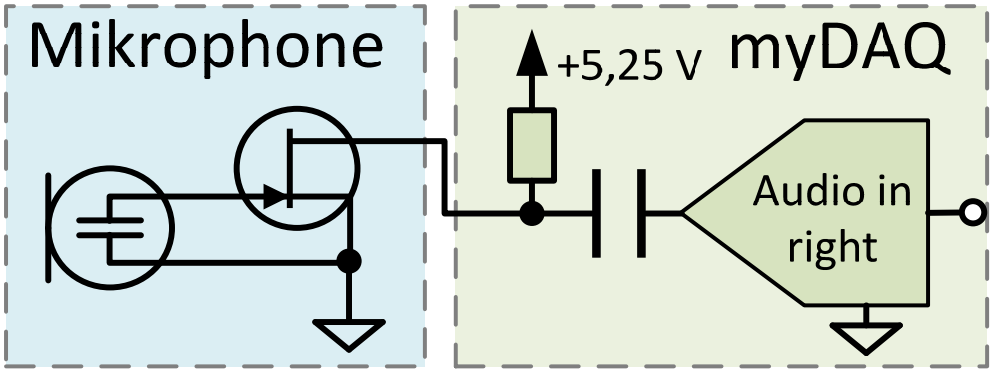
Electret Microphones

- Built-in FET preamp
- Require 5V DC phantom voltage
- Signal level in mV range

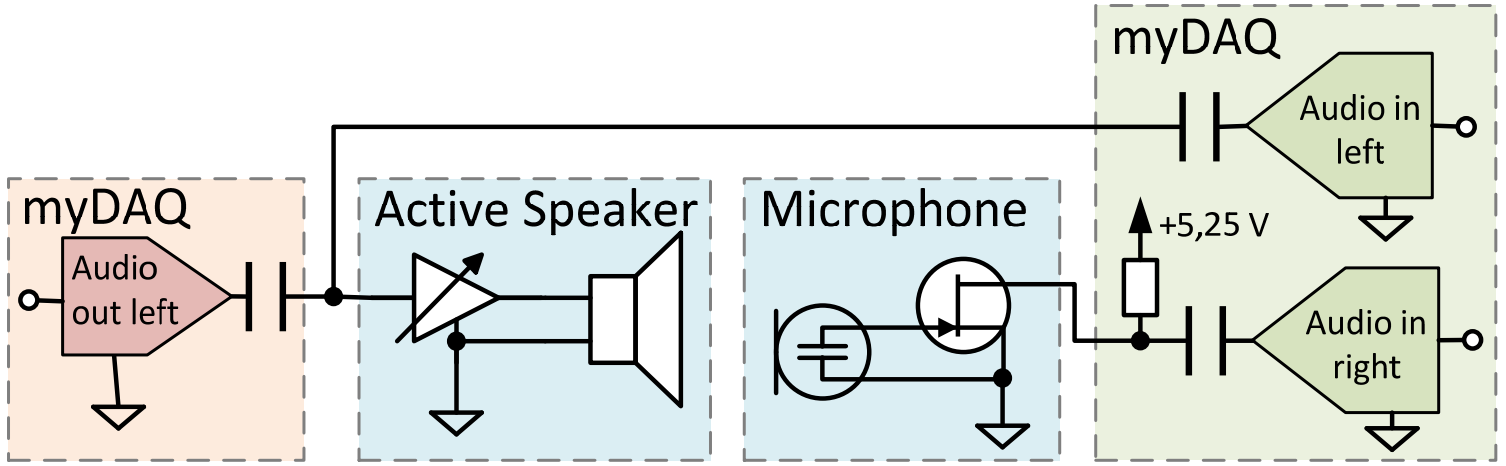
http://https://www.sparkfun.com/products/8635

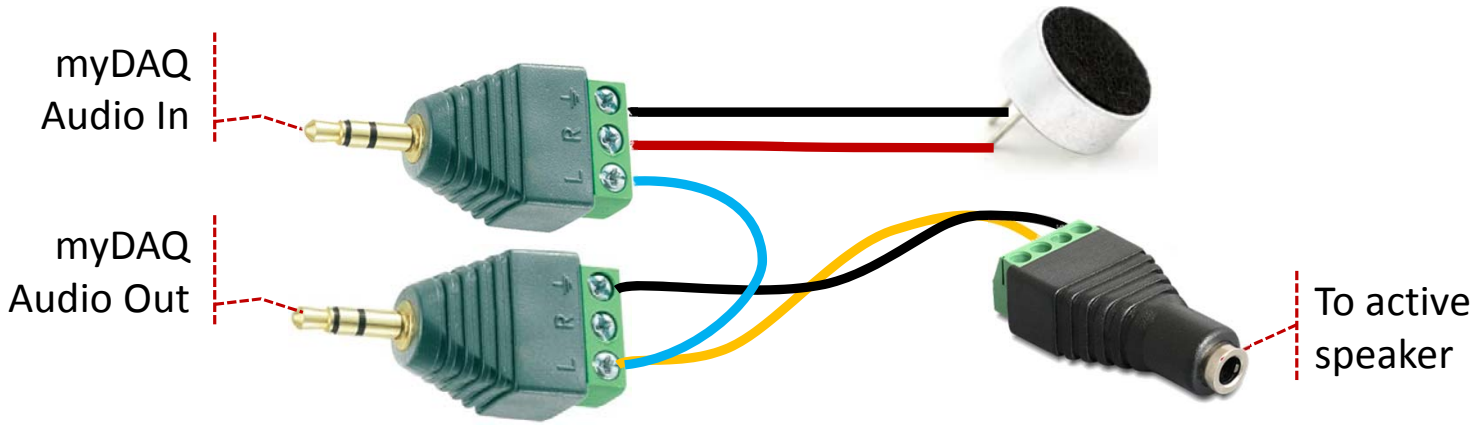
myDAQ Audio In

- Equipped with feeding circuit
- Electret mics can be connected directly

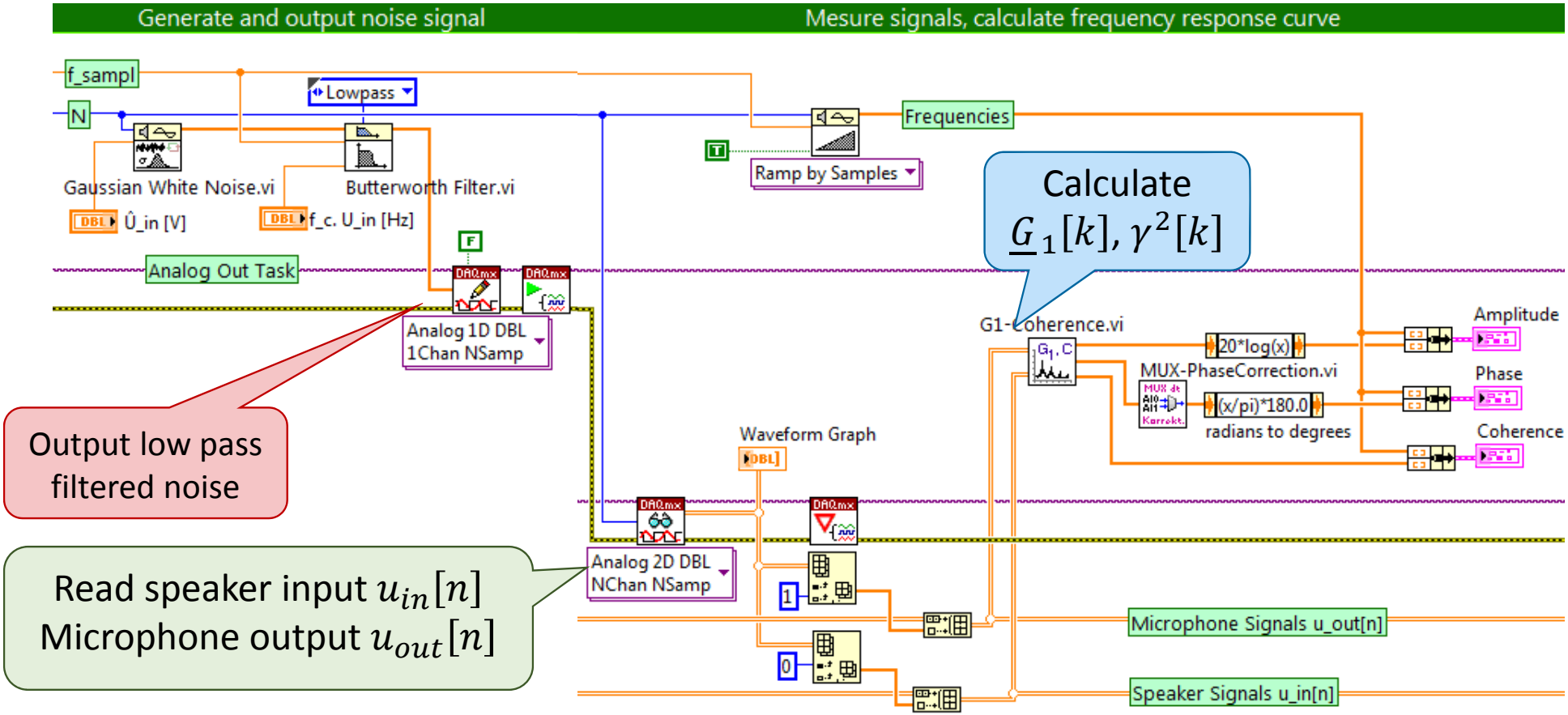


3. Speaker Frequency Response: Setup

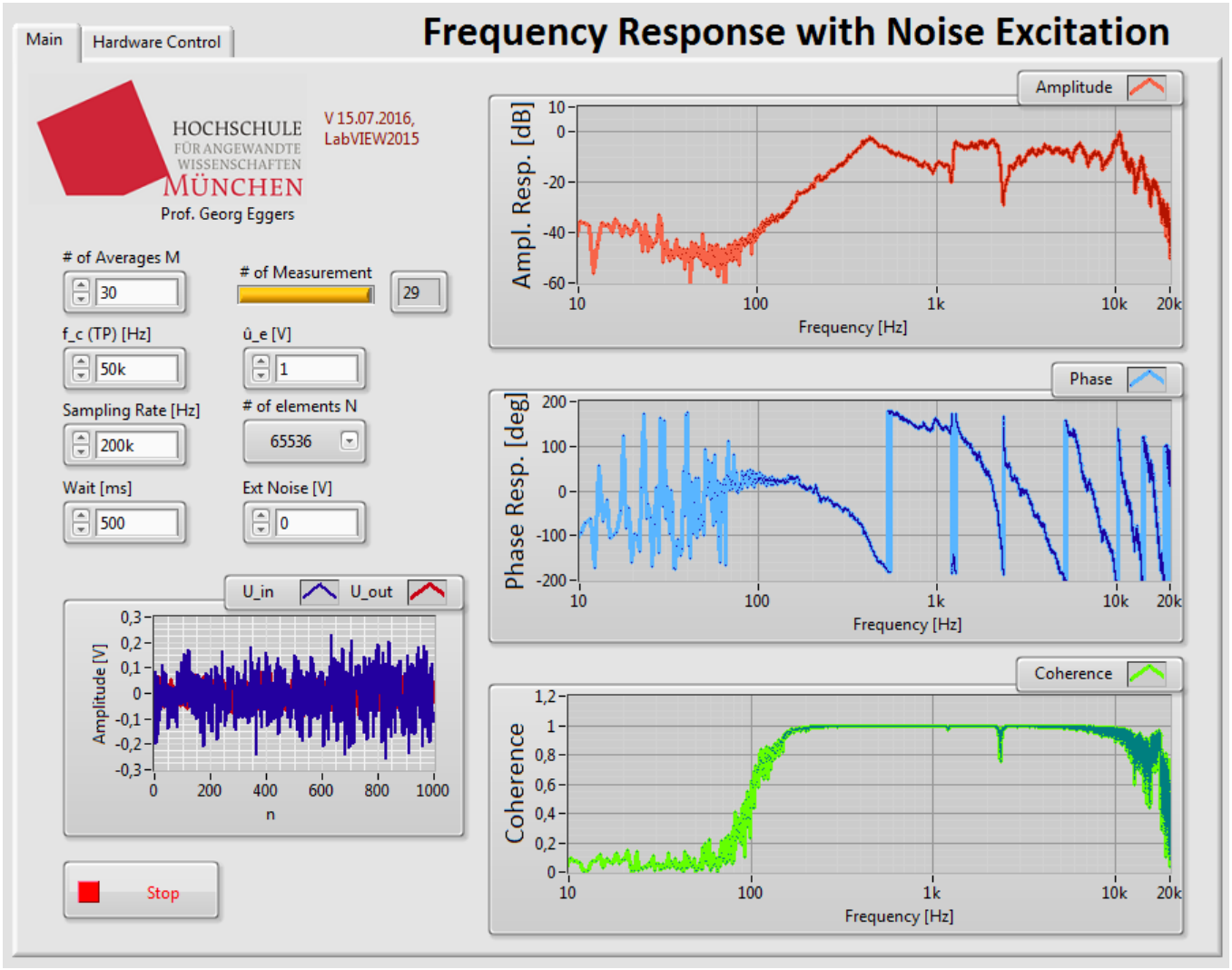




3. LabVIEW Implementation



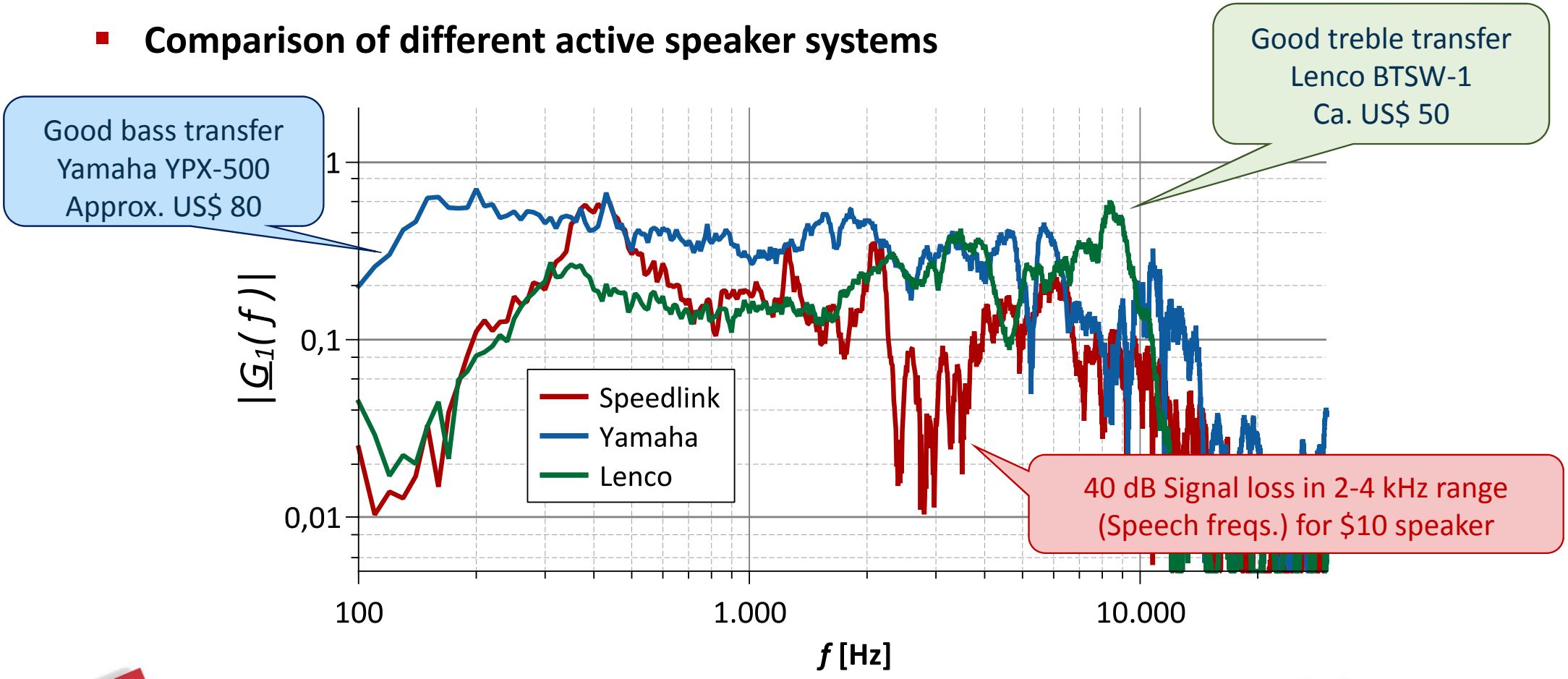
Frequency-Response-Noise-myDAQ_07.vi



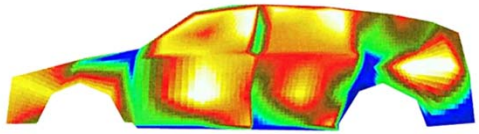
LabVIEW\FrequencyResponse\Frequency-Response-Noise-myDAQ_07.vi

3. Speaker response: Results

- **Comparison of different active speaker systems**



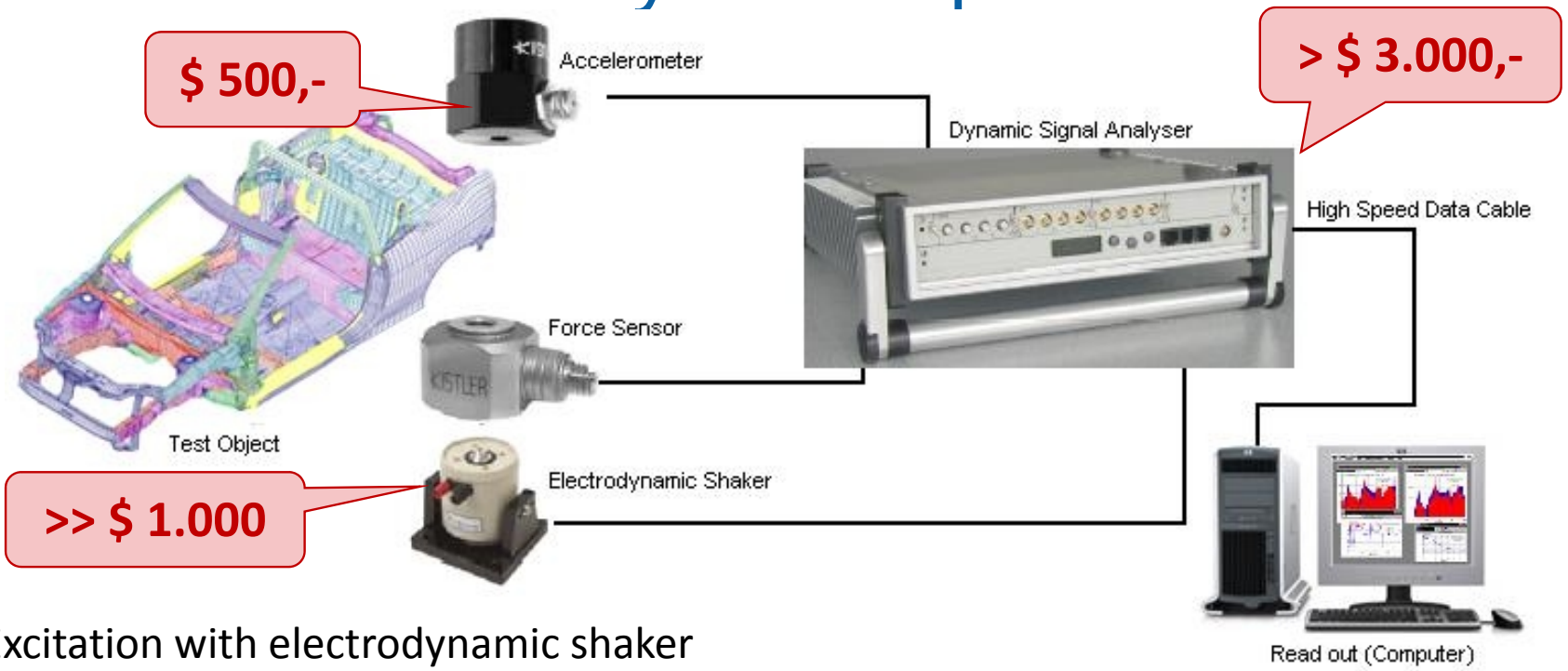
4. Poor Man's Modal Analysis:
Monitoring Mechanical Vibrations



HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN MÜNCHEN
Georg Eggers
fk06.hm.edu

NATIONAL INSTRUMENTS

4. Industrial Modal Analysis Setup



- Excitation with electrodynamic shaker
- Local vibration measurement with piezo accelerometers
- Charge amplifier with ADC required for signal readout

… expensive

https://en.wikipedia.org/wiki/Modal_testing

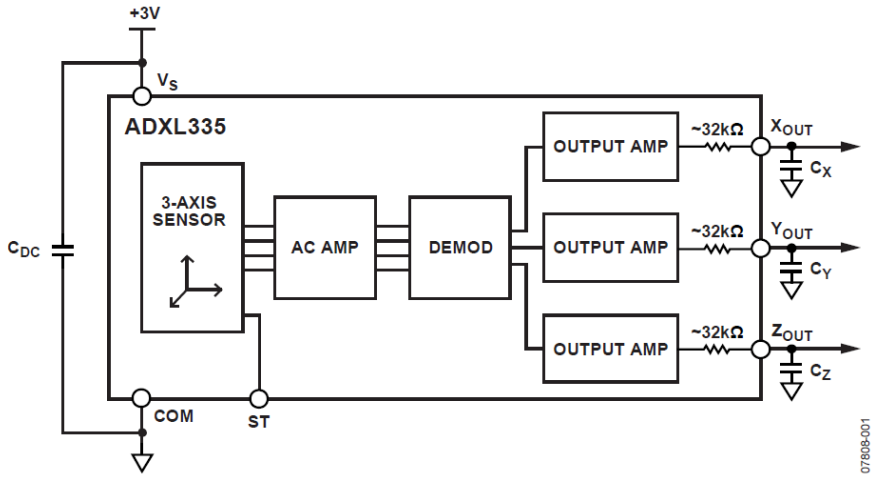
4. Low-Cost Shaker System

Fotos: Franckh-Kosmos Verlags-GmbH & Co. KG

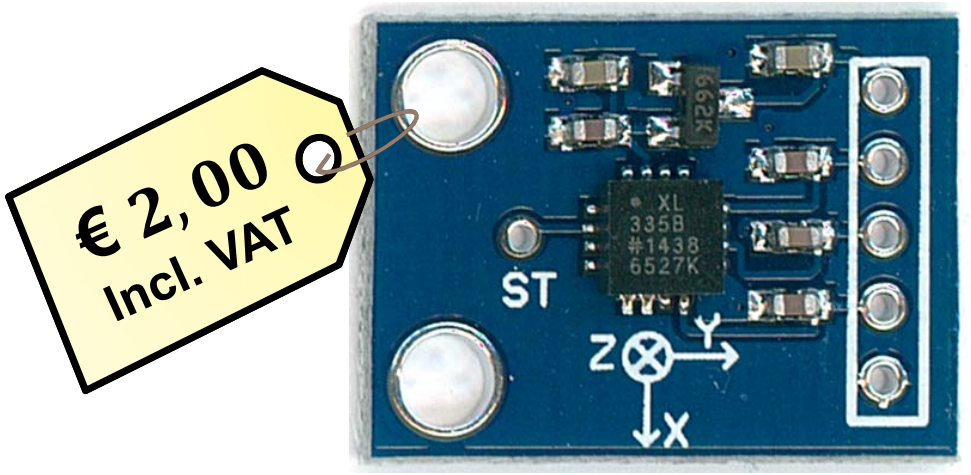
Science toy: Kosmos „Sound Booster“ – *“Turn everything into a loudspeaker”*

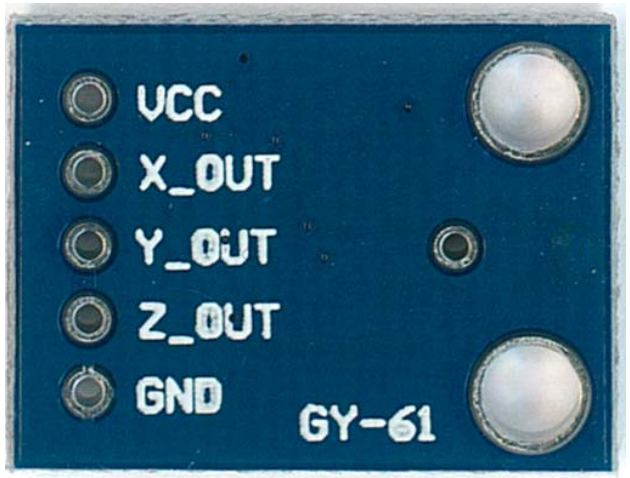
- Self-adhesive impact sound generator
- Battery-powered amplifier module, 3,5 mm audio plug
- Intended use: Construction of improvised speakers

4. Cheap Accelerometers



Picture: Analog Devices Inc.





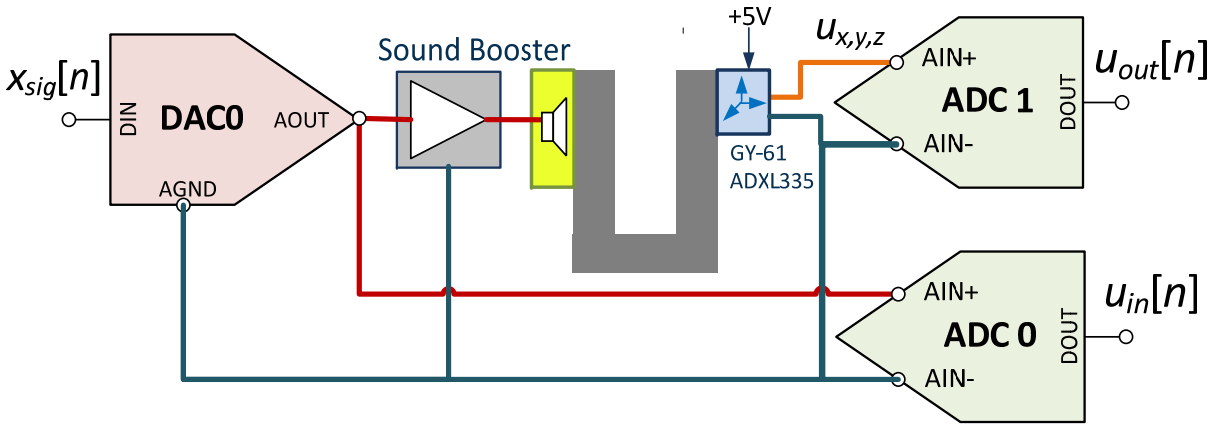
GY-61 ADXL335 3 Axis Accelerometer

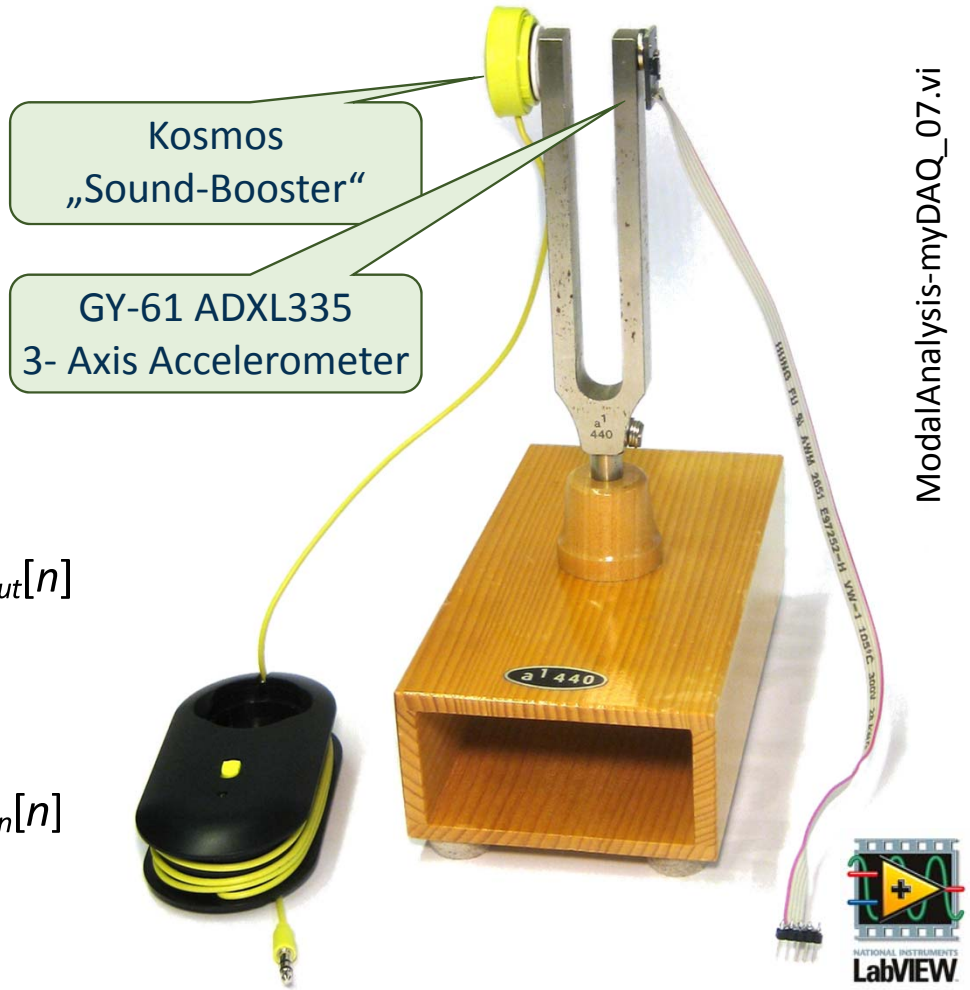
- 3-Axis accelerometer module based on ADXL335 to be uses with „Arduino“ boards
- 3 analog outputs $0{,}6\,..\,2{,}4\ \mathrm{V} \equiv -3g\,..\,+3g$
- Bandwidth up to 1,6 kHz (x,y) / 0,5 kHz (z)

4. Poor Man's Modal Analysis

Same LabVIEW-SW as used in speaker analysis

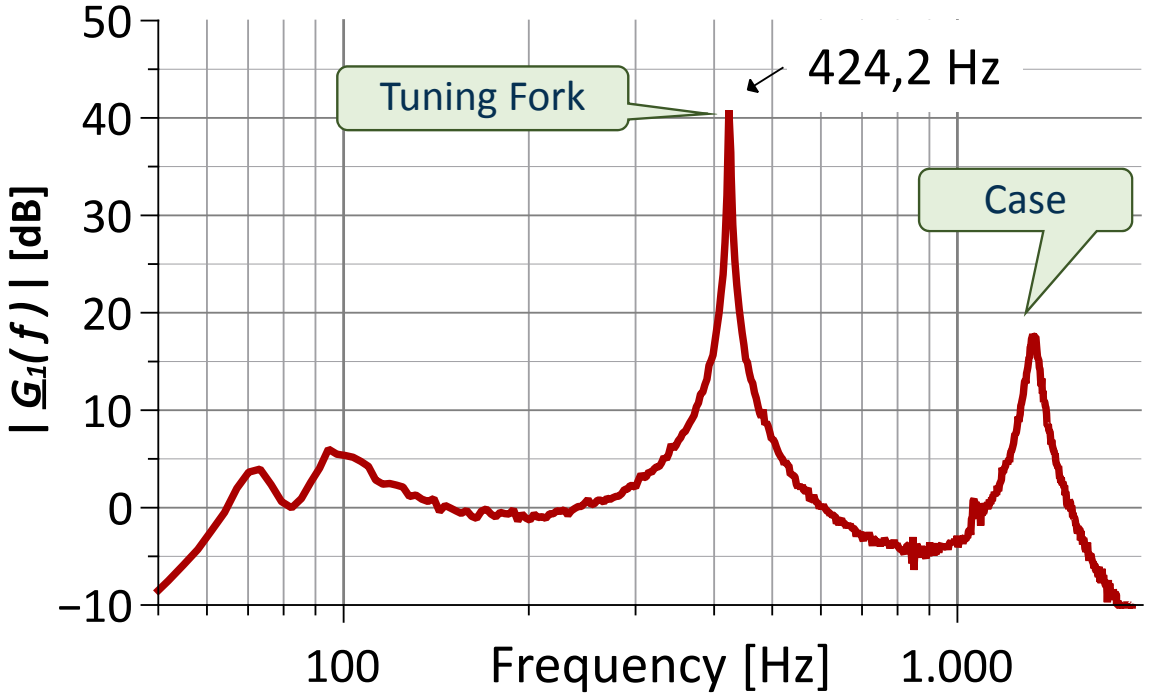
- White noise excitation
- Calculation of coherence-corrected frequency response $\underline{G}_1[k]$





ModalAnalysis-myDAQ_07.vi

4. Modal Analysis: Results

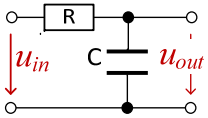


ModalAnalysis-myDAQ_07.vi

- Resonances of tuning fork and wooden resonator box
- Fork resonance shifts from 440 to 424 Hz due to speaker/sensor weight

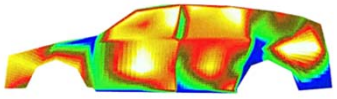
Live Classroom Measurements of Characteristic Curves and Frequency Responses Using the NI myDAQ

1. *Harvesting the Sun:*
   Solar Cell Output Power Curve



2. *System Analysis for Beginners:*
   Bode Plots of Simple Circuits

3. *95-cent Acoustics:*
   Frequency Responses of Loudspeakers



4. *Poor Man's Modal Analysis:*
   Monitoring Mechanical Vibrations

HOCHSCHULE FÜR ANGEWANDTE WISSENSCHAFTEN MÜNCHEN
Georg Eggers
fk06.hm.edu

NATIONAL INSTRUMENTS

References

Big Thanks to:

- HM Mechatronics Students for unrepining beta testing
- Jan Kniewasser (NI Germany Academic Field Sales) for getting me in touch with myDAQ
- Rhonda Keenan, Gretchen Edelmon, Mahmoud Wahby, (National Instruments Corporation) for supporting my NI Week visit

Weblinks

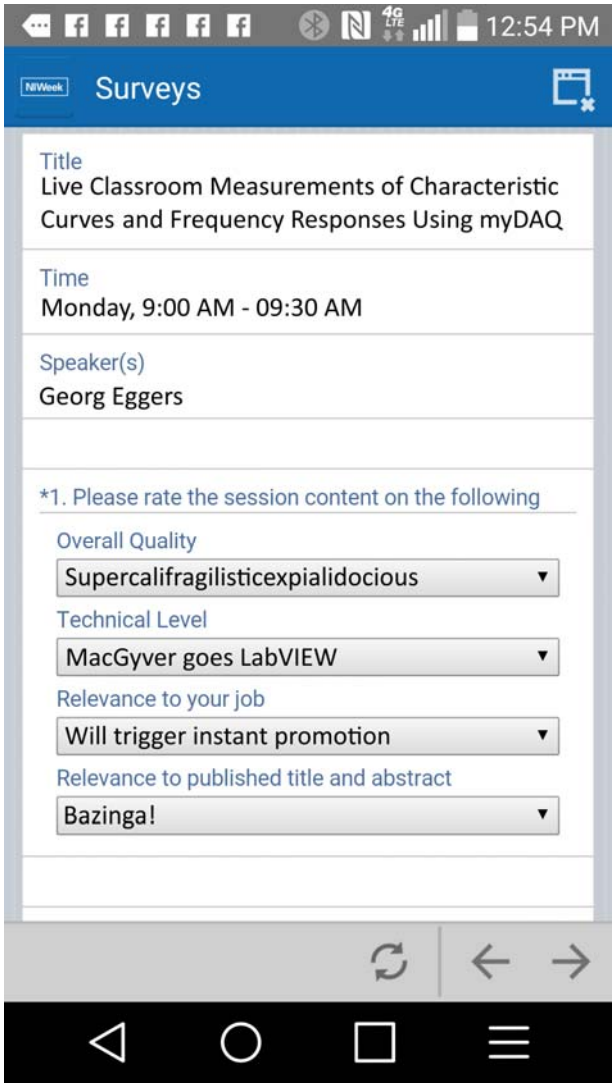
- Presentation and LabVIEW code available from NI Week Website

Literature

- Wagemann, H.-G.; Eschrich, H.: Photovoltaik, Teubner-Verlag, 2007
- Brigham, Elbert Oran (1988): Fast Fourier Transform and Its Applications, Pearson, 1988
- Randall, R. B. (1987): Frequency analysis. Naerum: Brüel & Kjaer.

Pictures and Data Sheets

- NI myDAQ: http://www.ni.com/mydaq/d/
- Kosmos „Sound Booster“: http://www.kosmos.de/produktdetail-1-1/sound_booster-7683/
- ADXL335: http://www.analog.com/en/products/mems/mems-accelerometers/adxl335.html
- CEM-C9745JAD462P2.54R Microphone: http://www.challengeelectronics.com/microphones/omni_directional/



Before you go, take the survey.

Thank You!