Data acquisition and Noise in Solar Cells

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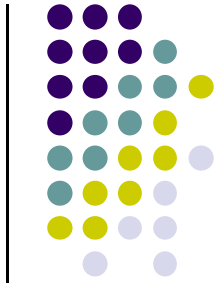
Center for Valorization and Transfer of Competence CVTC

Prezentation structure



- Why this subjects
  - Data Acquisition and Noise in Solar Cells
- DAQ
- Education and Research
- The new WI-TAG >> Tag4M
- New DAQ systems
- Noise
- 1/f Noise
- Noise in Solar cells
- Conclusions
- Some ideas about the Future

Why: Data acquisition and Noise in Solar Cells

- Data acquisition start to be a common technologie (in general) in science and in R&D
- Now we combine **"Virtual Instrumentation"** with the real PC-controlled devices
- Solar panels (plants) on the land – we need flexible and portable solutions (customized) for measurements
- Rapid development – we think the solution can be:
  - **LabVIEW from National Instruments**
  - **VEE-Pro from Agilent Technologies**
- Do not forget the new and powerful
  - **WIRELESS systems**

DATA ACQUISITION and VIRTUAL INSTRUMENTS

- We need to measure Solar Cells and/or Solar panels performances and parameters
- What we can to measure:
  - Materials characteristics
  - I-V characteristics
  - Solar cells parameters, etc.
- DAQ system – based on Virtual Instrumentation
  - Complex analyzers
  - Device control
  - Monitoring systems,
  - **EDUCATION**, etc.

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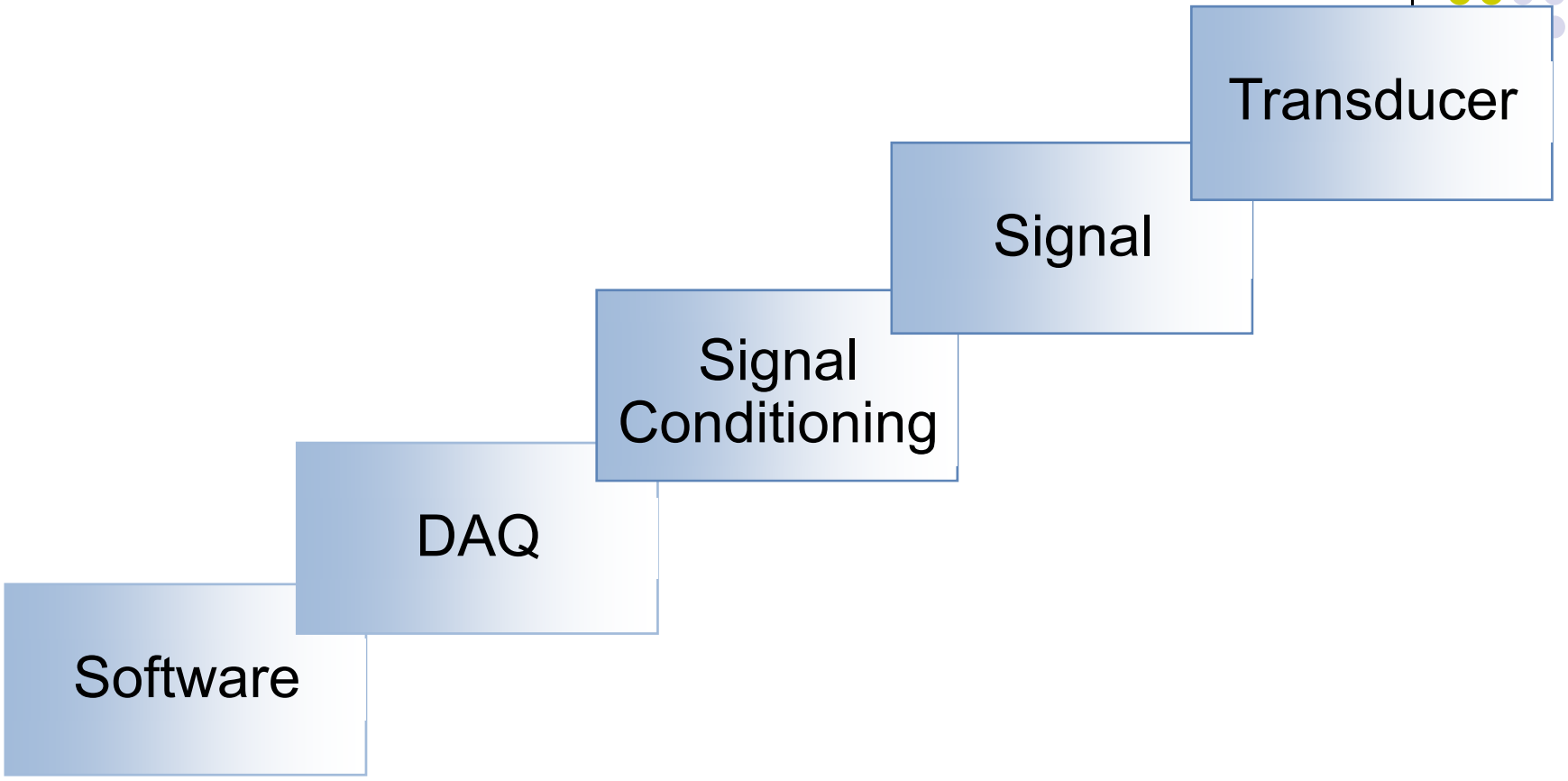
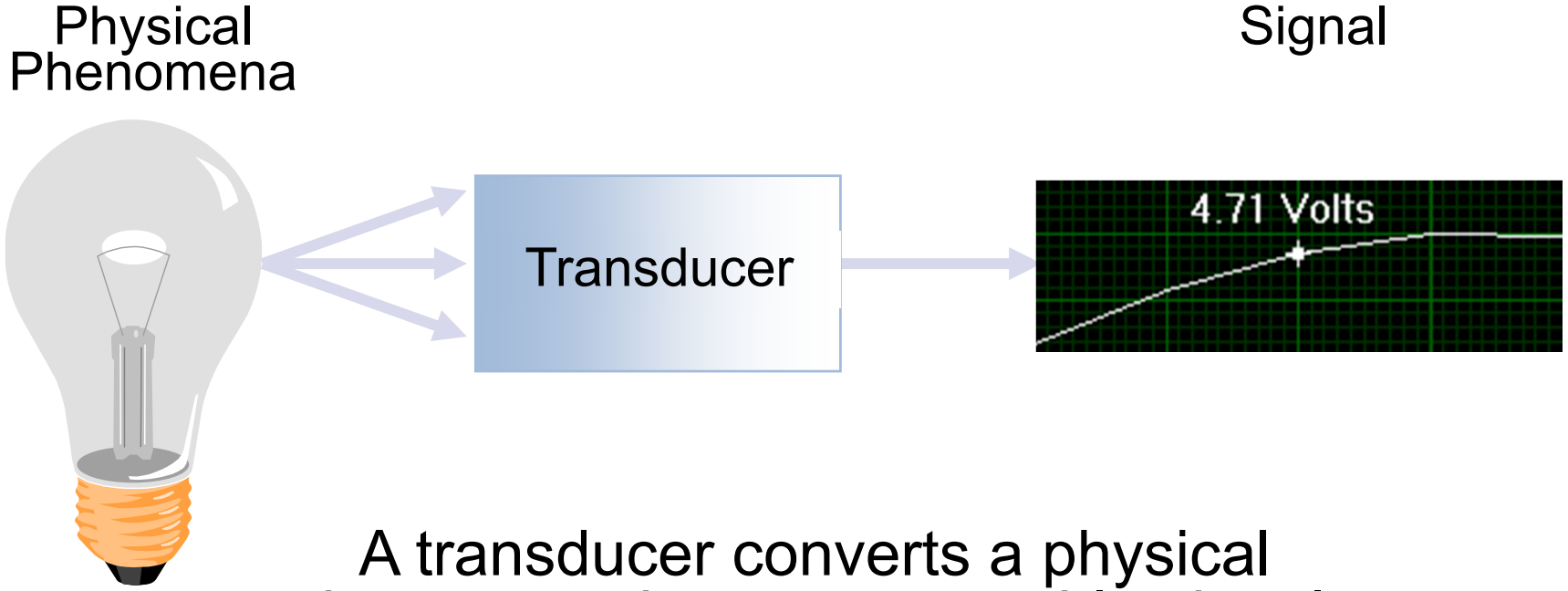
DAQ System Overview



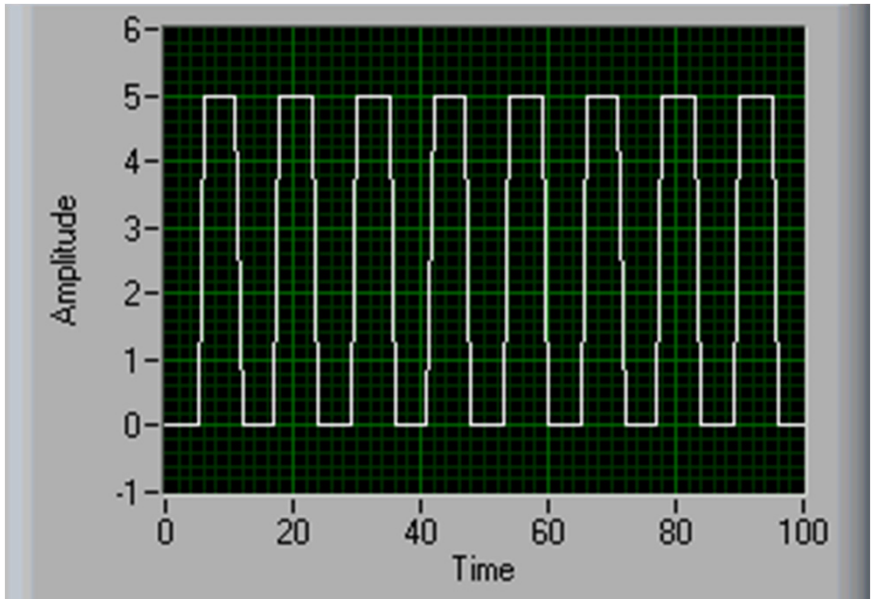
What is a Transducer?



A transducer converts a physical phenomena into a measurable signal.

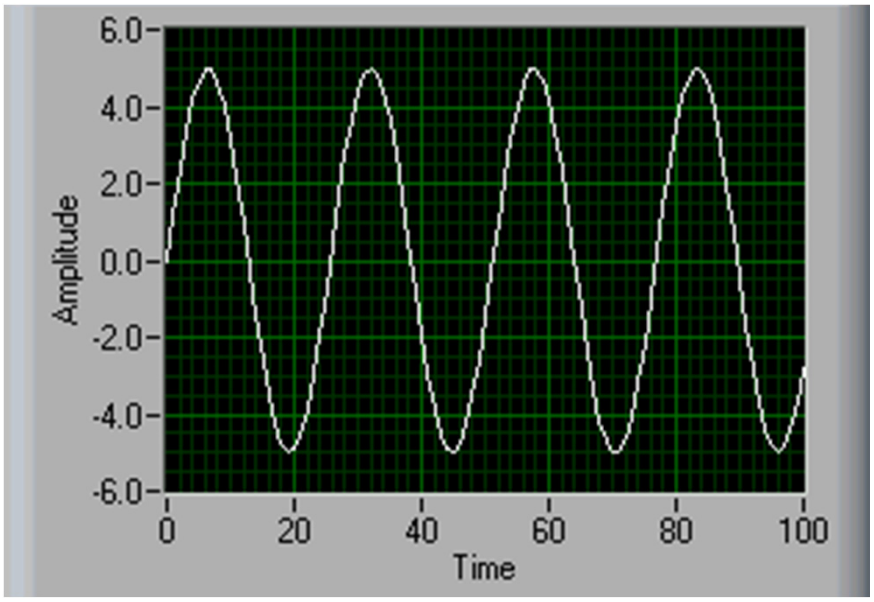
Signal Classification

Digital



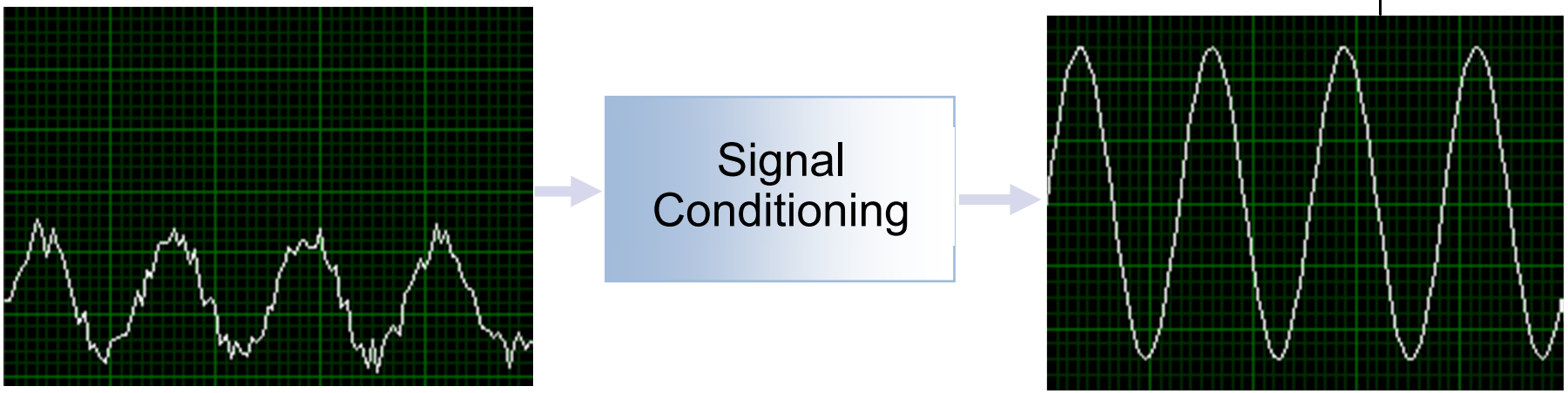
- Two possible levels:
  - High/On (2 - 5 Volts)
  - Low/Off (0 - 0.8 Volts)
- Two types of information:
  - State
  - Rate

Analog



- Continuous signal
  - Can be at any value with respect to time
- Three types of information
  - Level
  - Shape
  - Frequency (Analysis required)

Why Use Signal Conditioning?



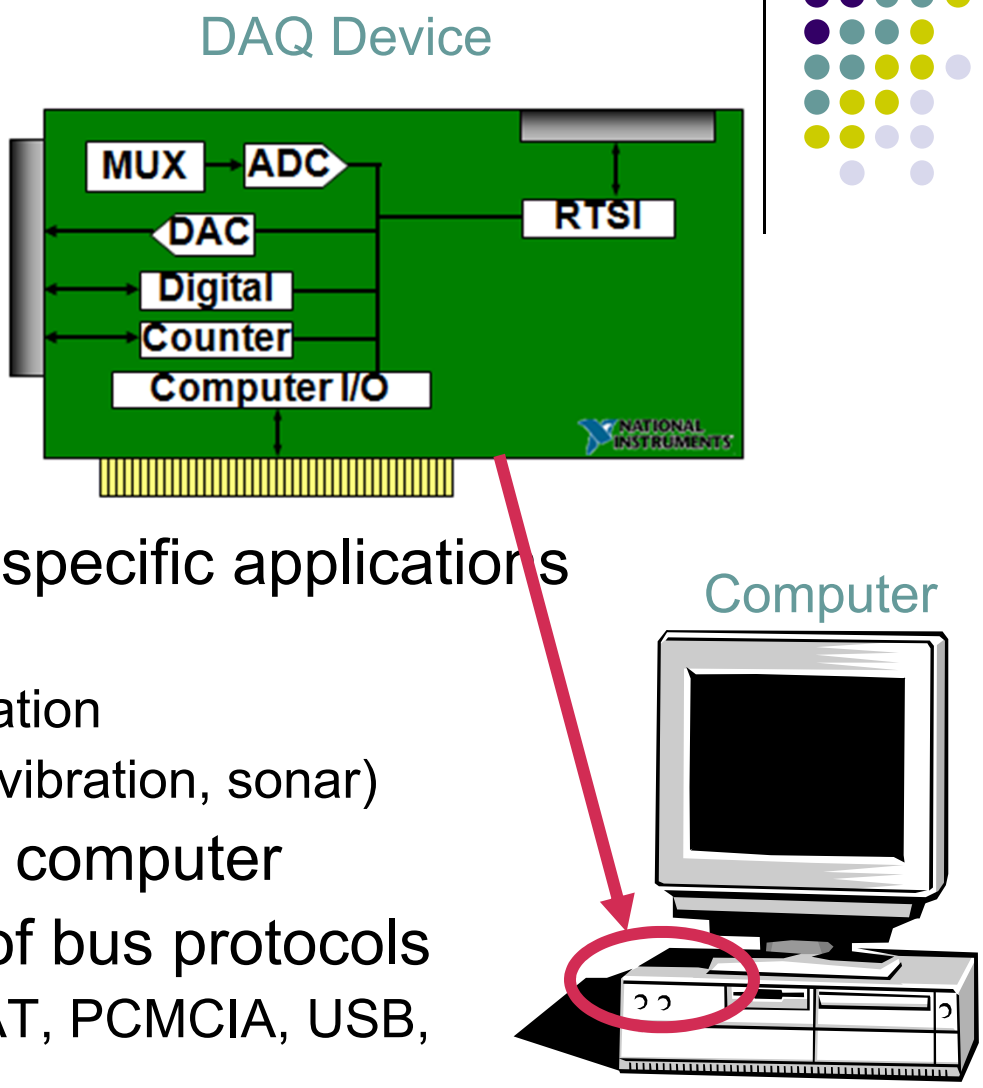
Noisy, Low-Level Signal

Filtered, Amplified Signal

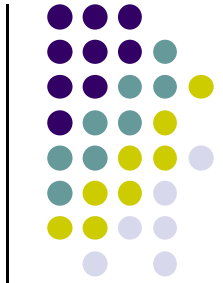
- Signal Conditioning takes a signal that is difficult for your DAQ device to measure and makes it easier to measure
- Signal Conditioning is not always required
  - Depends on the signal being measured

DAQ Device

- Most DAQ devices have:
  - Analog Input
  - Analog Output
  - Digital I/O
  - Counters
- Specialty devices exist for specific applications
  - High speed digital I/O
  - High speed waveform generation
  - Dynamic Signal Acquisition (vibration, sonar)
- Connect to the bus of your computer
- Compatible with a variety of bus protocols
  - PCI, PXI/CompactPCI, ISA/AT, PCMCIA, USB, 1394/Firewire

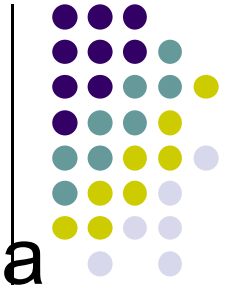


Configuration Considerations



- Analog Input
  - Resolution
  - Range
  - Amplification
  - Code Width
- Analog Output
  - Internal vs. External Reference Voltage
  - Bipolar vs. Unipolar

Resolution



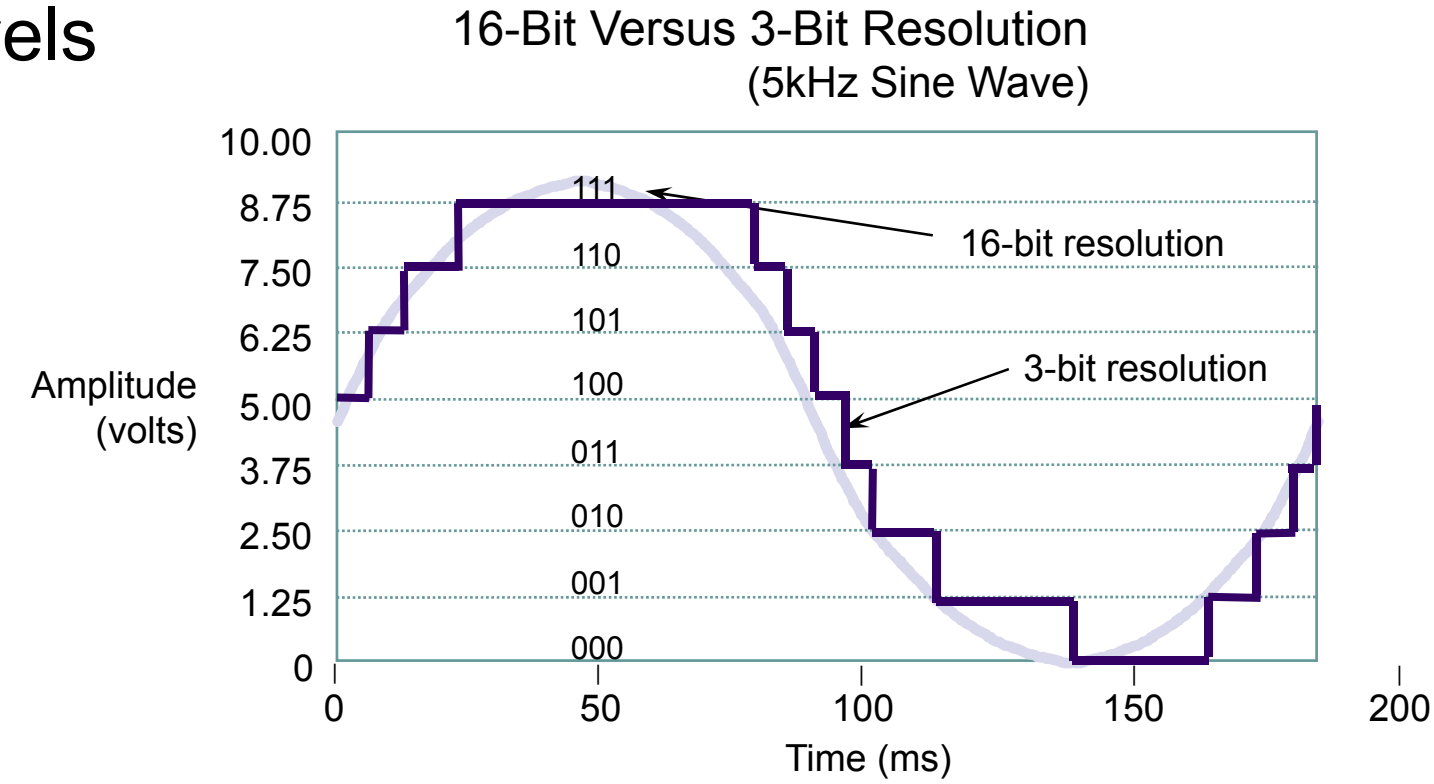
- Number of bits the ADC uses to represent a signal
- Resolution determines how many different voltage changes can be measured
- Example: 12-bit resolution

$$\text{\# of levels} = 2^{\text{resolution}} = 2^{12} = 4{,}096 \text{ levels}$$

- Larger resolution = more precise representation of your signal

Resolution Example

- 3-bit resolution can represent 8 voltage levels
- 16-bit resolution can represent 65,536 voltage levels

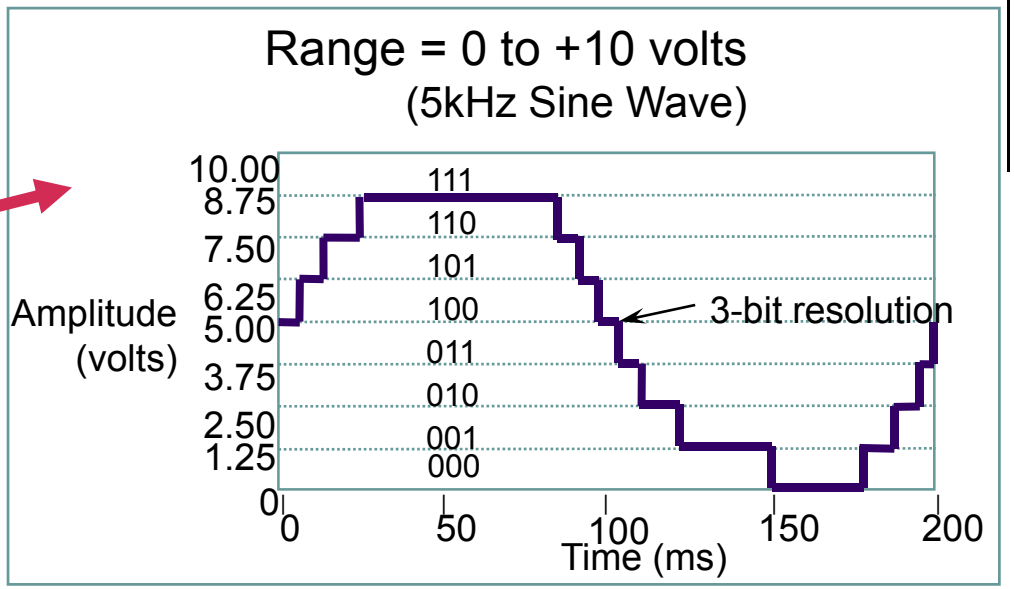


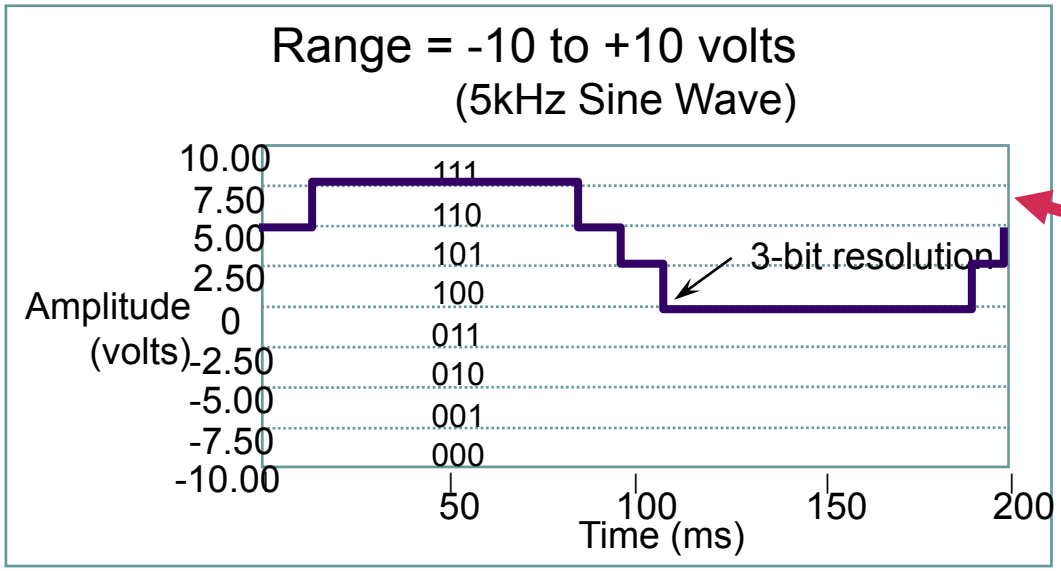
Range

- Minimum and maximum voltages the ADC can digitize
- DAQ devices often have different available ranges
  - 0 to +10 volts
  - -10 to +10 volts
- Pick a range that your signal fits in
- Smaller range = more precise representation of your signal
  - Allows you to use all of your available resolution

Range Example

- Proper Range
  - Using all 8 levels to represent your signal

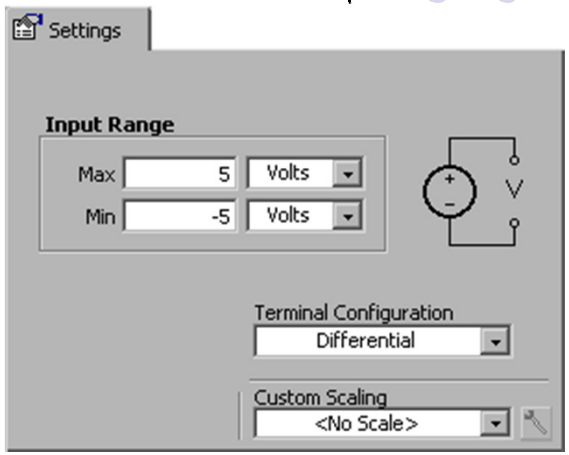


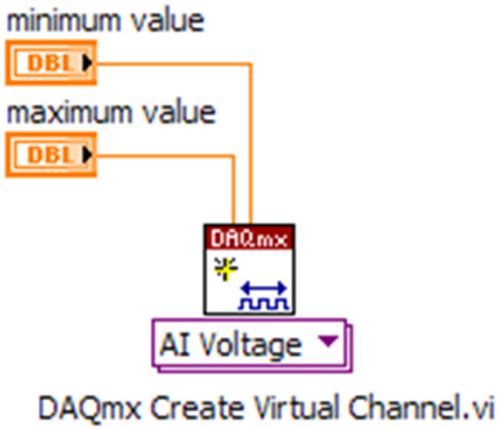


- Improper Range
  - Only using 4 levels to represent your signal

Amplification

- Max and min settings amplify or attenuate the signal for best fit in ADC range
- Settings are 0.5, 1, 2, 5, 10, 20, 50, or 100 for most devices
- You don't choose the amplification directly
  - Choose the input limits of your signal in LabVIEW or the DAQ Assistant
  - Proper amplification chosen by NI-DAQmx
- Proper amplification = more precise representation of your signal
  - Allows you to use all of your available resolution

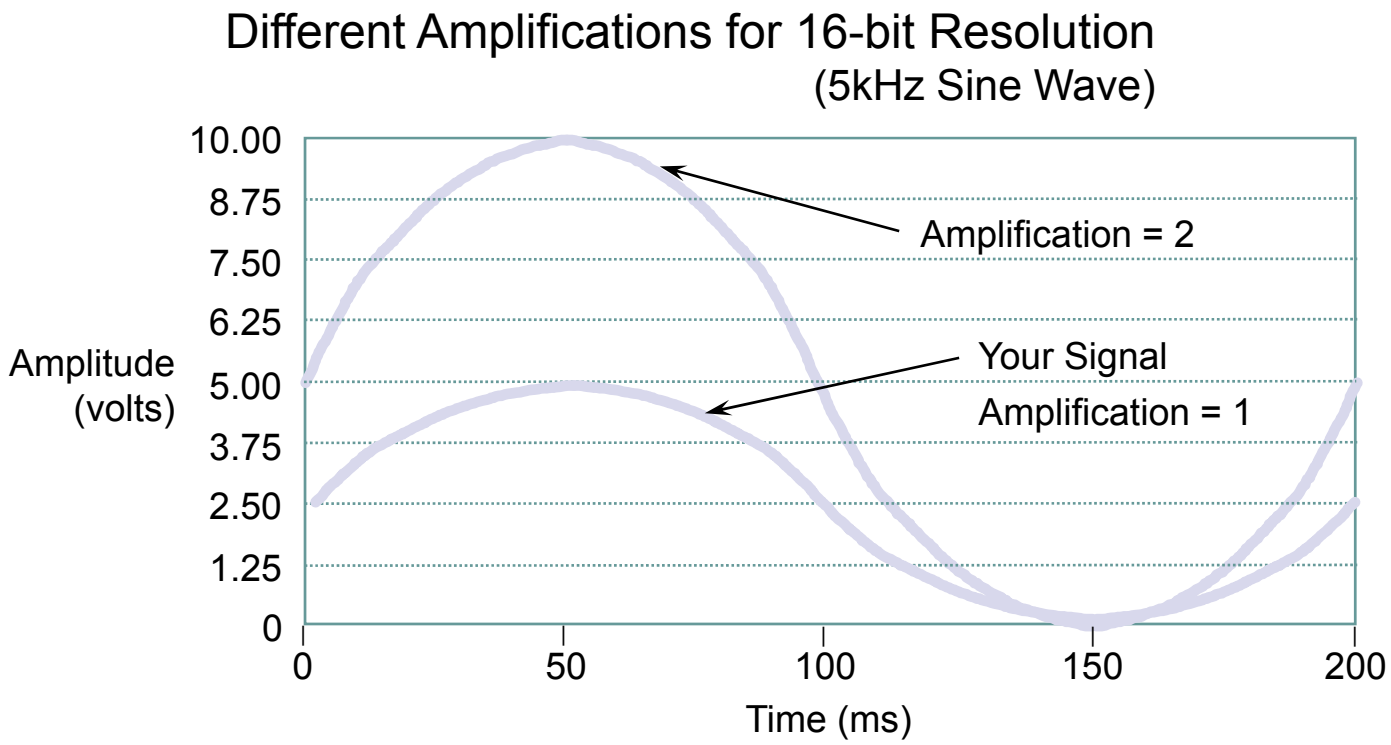




DAQmx Create Virtual Channel.vi

Amplification Example

- Input limits of the signal = 0 to 5 Volts
- Range Setting for the ADC = 0 to 10 Volts
- Amplification applied by Instrumentation Amplifier = 2



Code Width

- Code Width is the smallest change in the signal your system can detect (determined by resolution, range, and amplification)

$$\text{code width} = \frac{\text{range}}{\text{amplification} * 2^{\text{resolution}}}$$

- Smaller Code Width = more precise representation of your signal
- Example: 12-bit device, range = 0 to 10V, amplification = 1

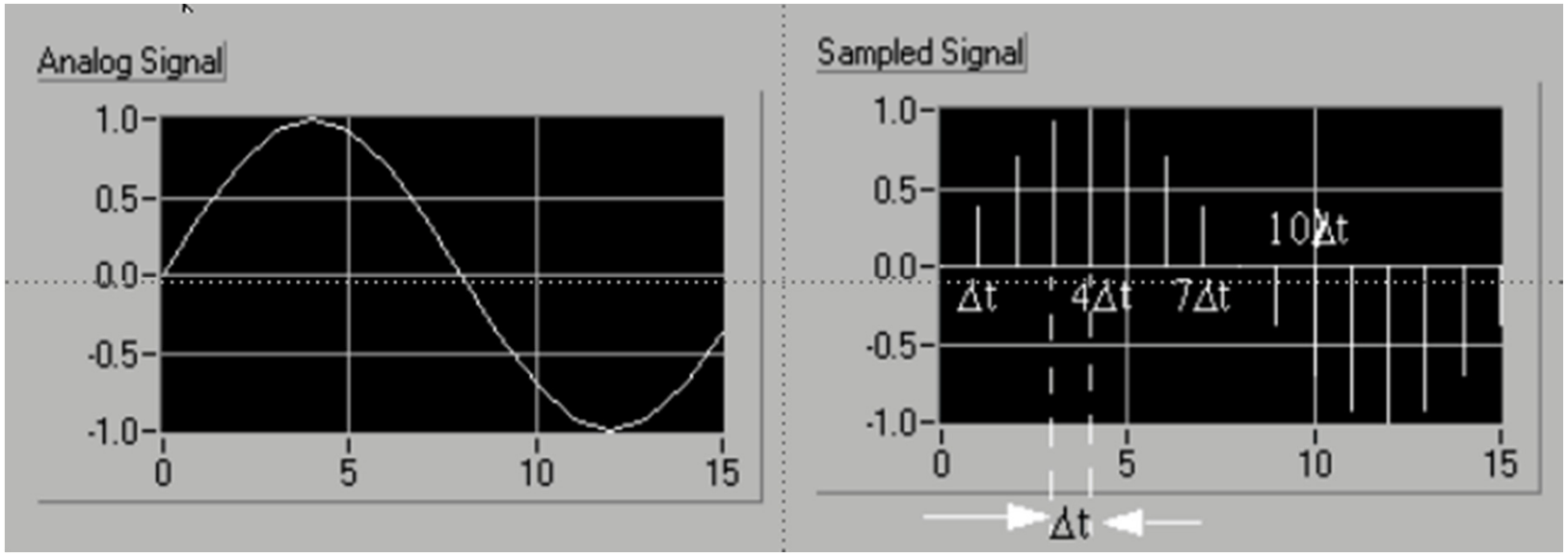
$$\frac{\text{range}}{\text{amplification} * 2^{\text{resolution}}} = \frac{10}{1 * 2^{12}} = 2.4 \text{ mV}$$

$$\text{Increase range: } \frac{20}{1 * 2^{12}} = 4.8 \text{ mV}$$

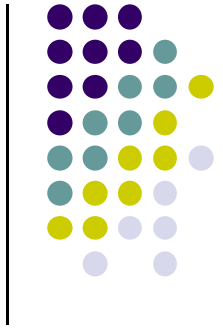
$$\text{Increase amplification: } \frac{10}{100 * 2^{12}} = 24 \text{ µV}$$

Sampling Signals

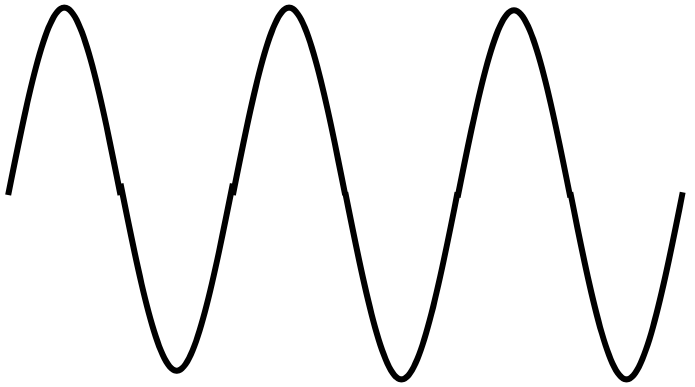
- Individual samples are represented by:
  $x[i] = x(i\Delta t)$, for $i = 0, 1, 2, \ldots$
- If N samples are obtained from signal x(t):
  $X = \{x[0], x[1], x[2], \ldots x[N-1]\}$
- The sequence $X = \{x[i]\}$ is indexed on i and does not contain sampling rate information



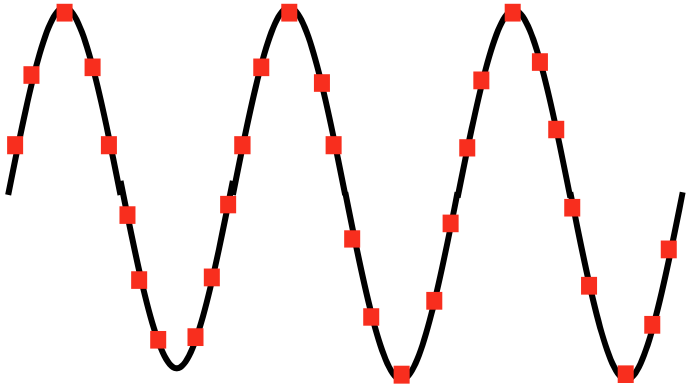
Sampling Considerations



- Actual analog input signal is continuous with respect to time
- Sampled signal is series of discrete samples acquired at a specified sampling rate
- Faster we sample the more our sampled signal will look like our actual signal
- If not sampled fast enough a problem known as aliasing will occur

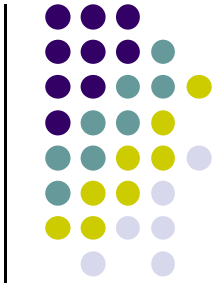


Actual Signal

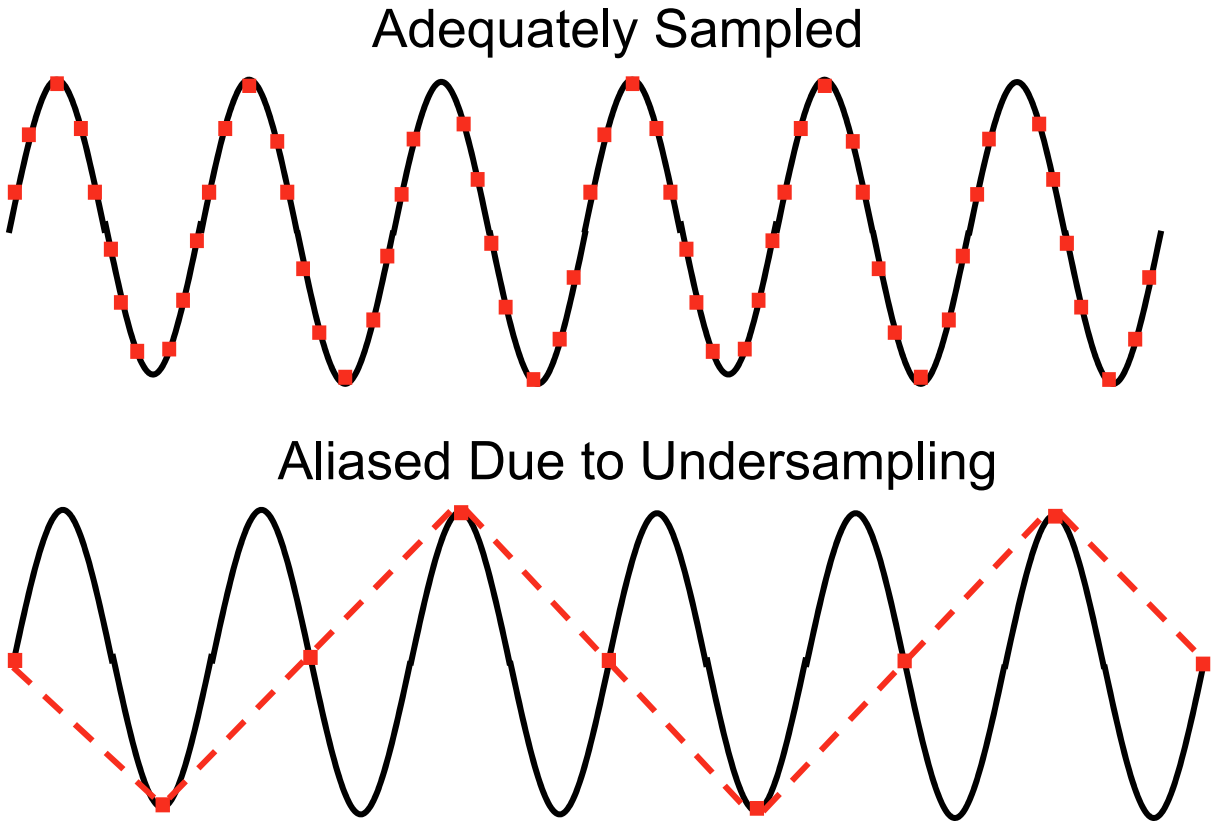


Sampled Signal

Aliasing



- Sample rate – how often an A/D conversion takes place
- Alias – misrepresentation of a signal



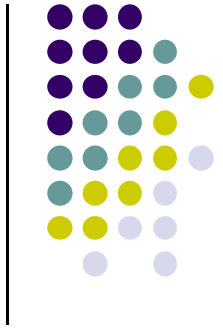
Aliasing effects of an improper sampling rate

Nyquist Theorem

- You must sample at **greater** than **2 times** the **maximum** frequency component of your signal to accurately represent the FREQUENCY of your signal.

- **NOTE:** You must sample between 5 - 10 times greater than the maximum frequency component of your signal to accurately represent the SHAPE of your signal.

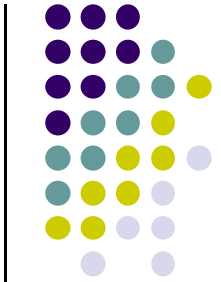
Nyquist Frequency

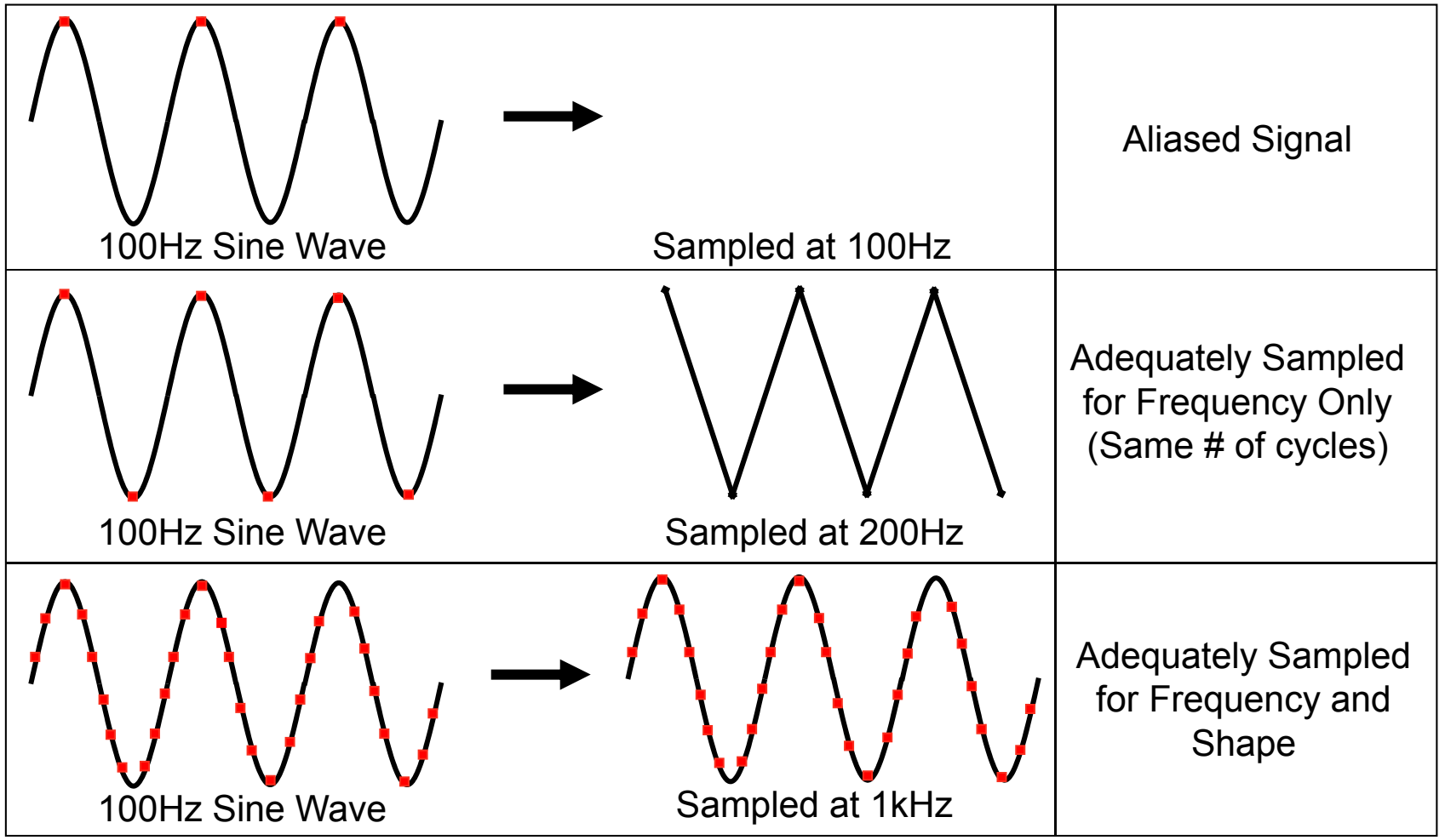


- Half the sampling frequency
- You will only get a proper representation of signals that are equal to or less than your Nyquist Frequency
- Signals above Nyquist Frequency will alias according to the following formula:

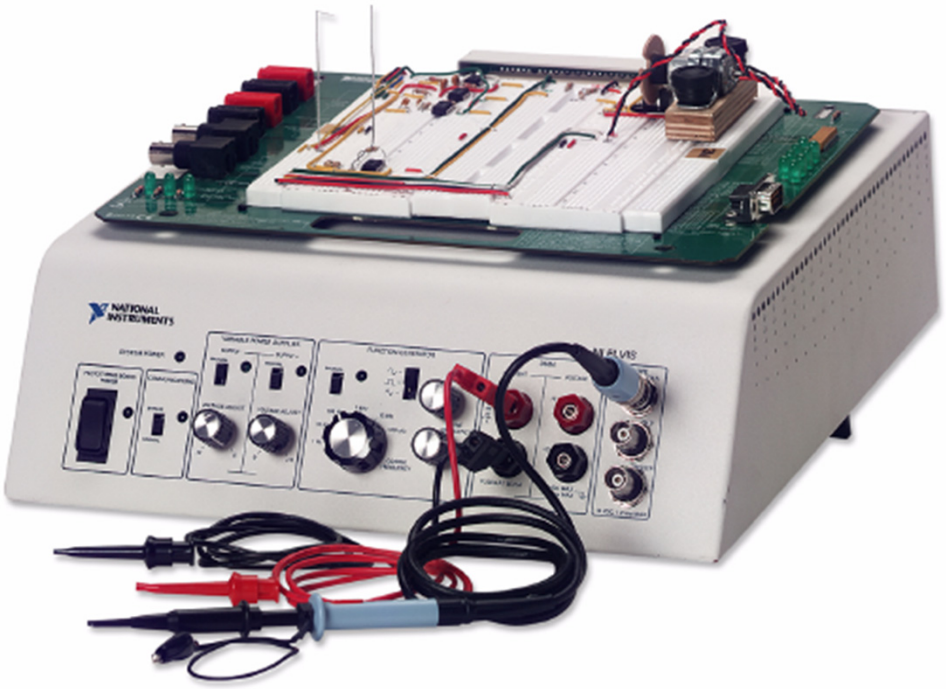
Alias frequency =
|(closest integer multiple of sampling frequency - signal frequency)|

Nyquist Example





NI ELVIS



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National

Instruments

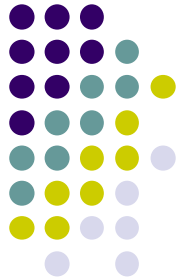
Educational

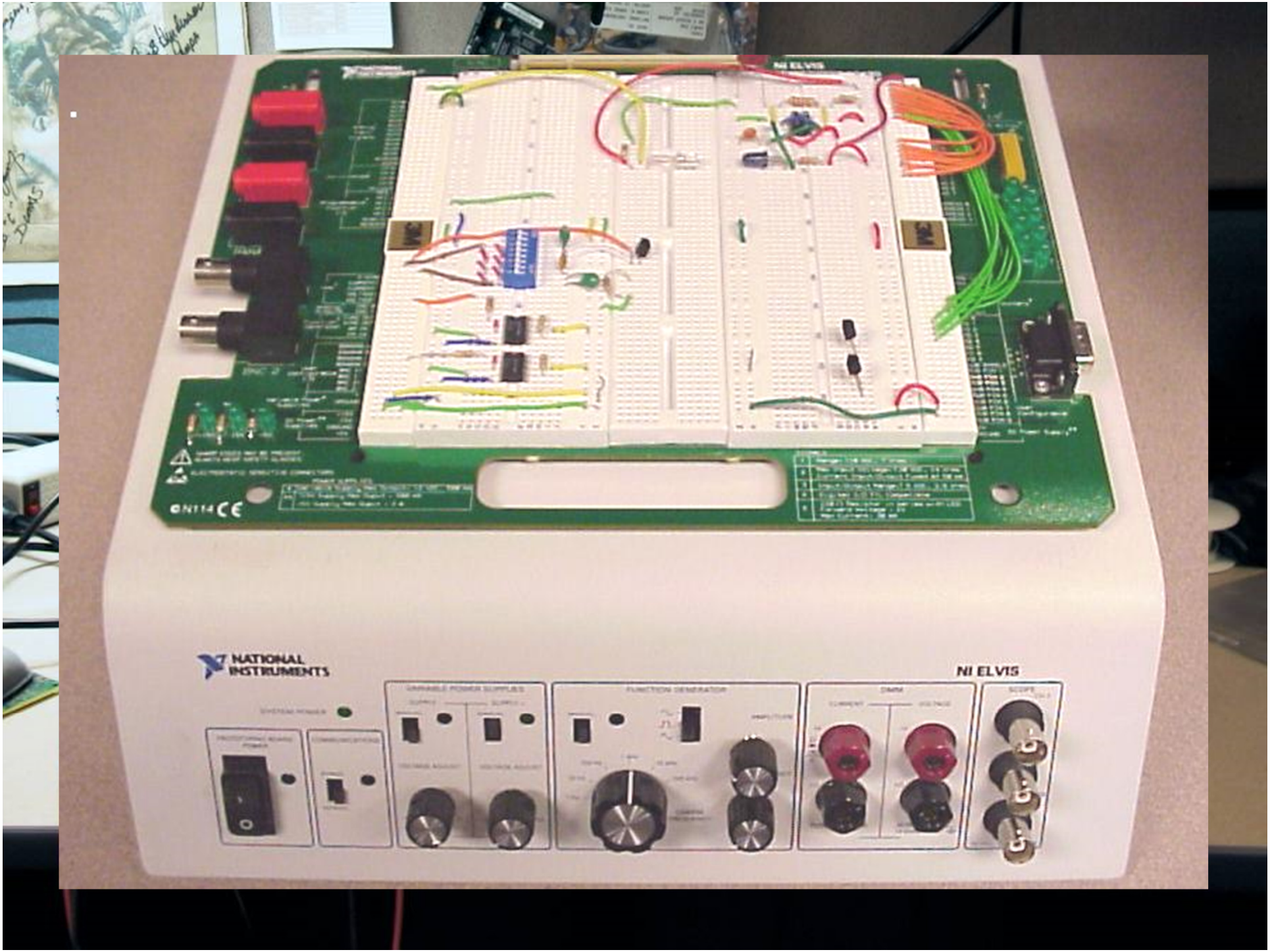
Laboratory

Virtual

Instrumentation

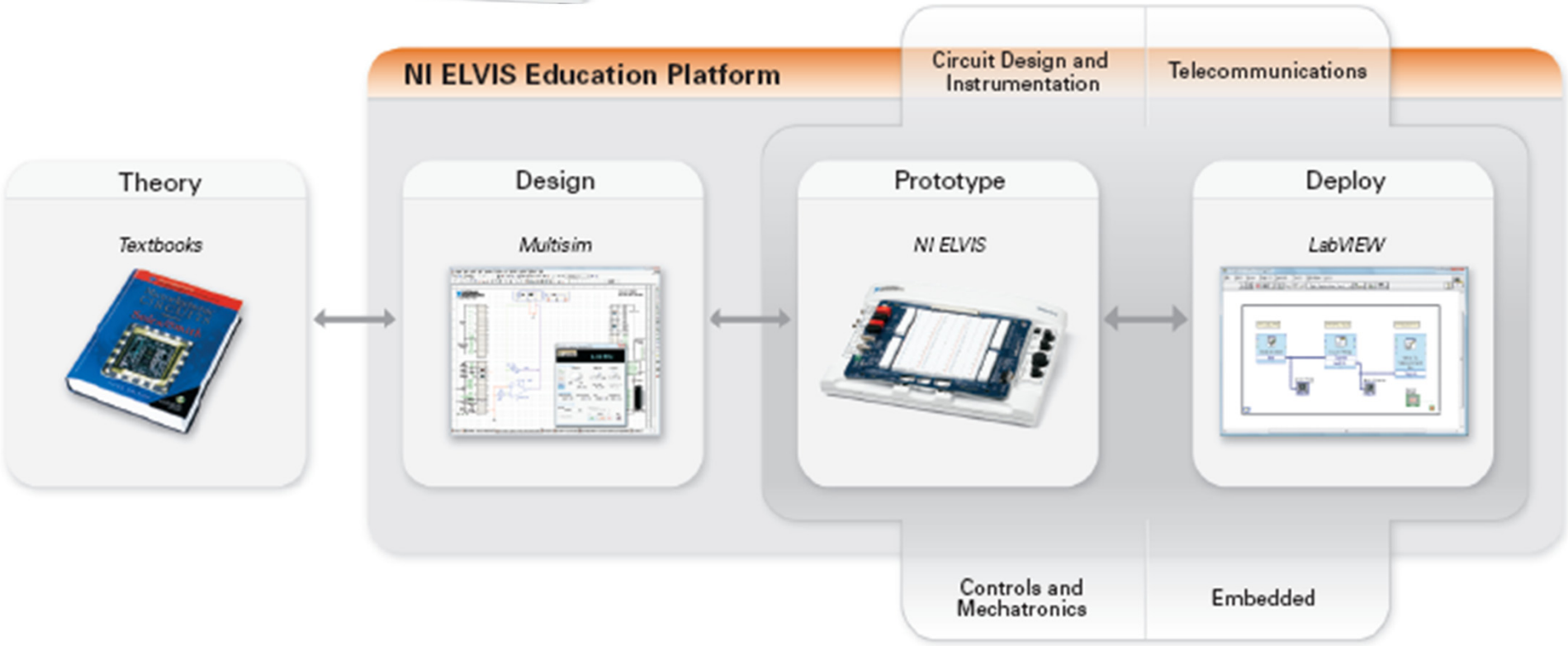
Suite (NI-ELVIS)




NATIONAL INSTRUMENTS
NI ELVIS

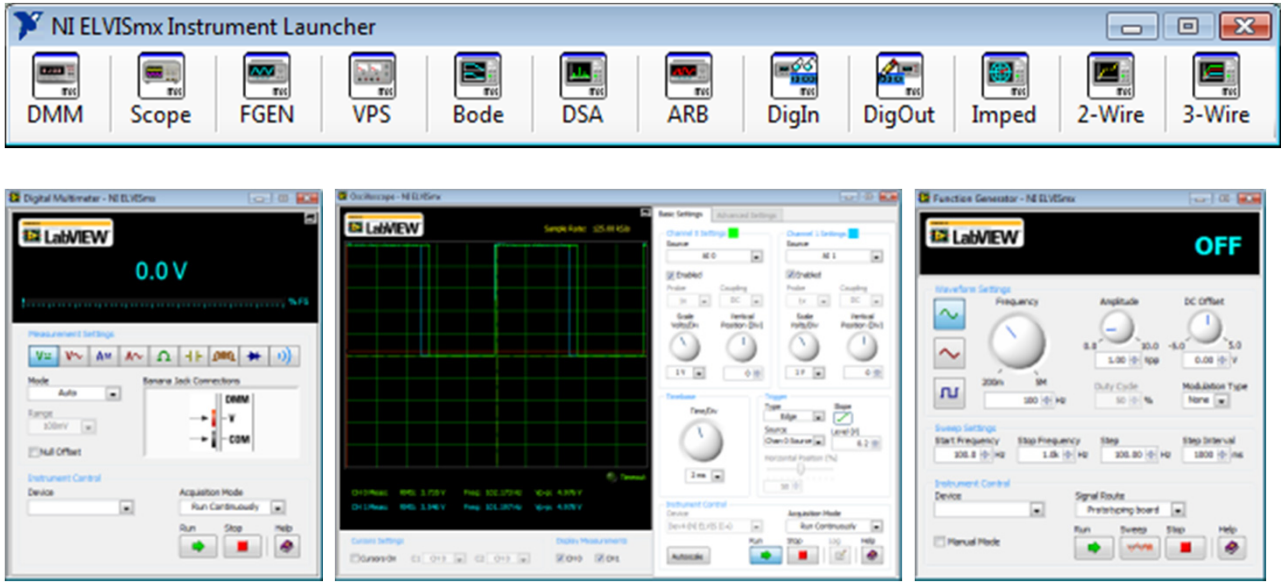
NI ELVIS Evolution

NI ELVIS II



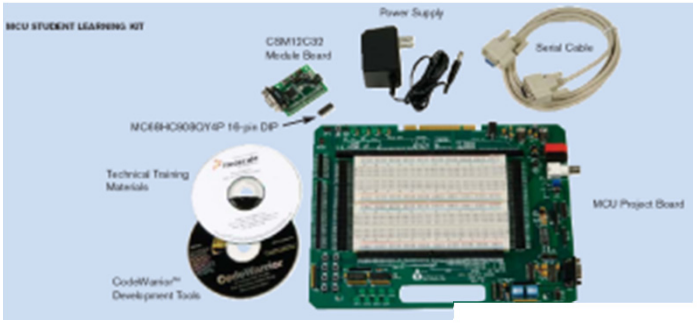
De ce NI-ELVIS?

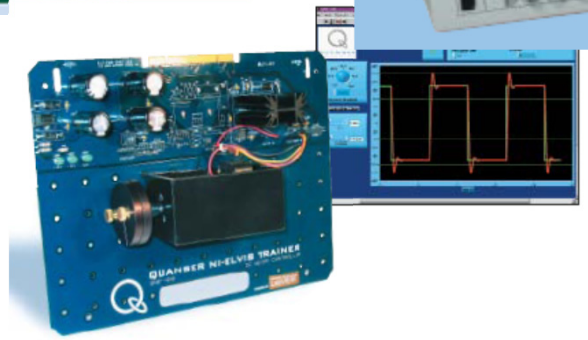
- National Instruments-Educational Laboratory Virtual Instrumentation Suite (NI-ELVIS)



Why NI-ELVIS?

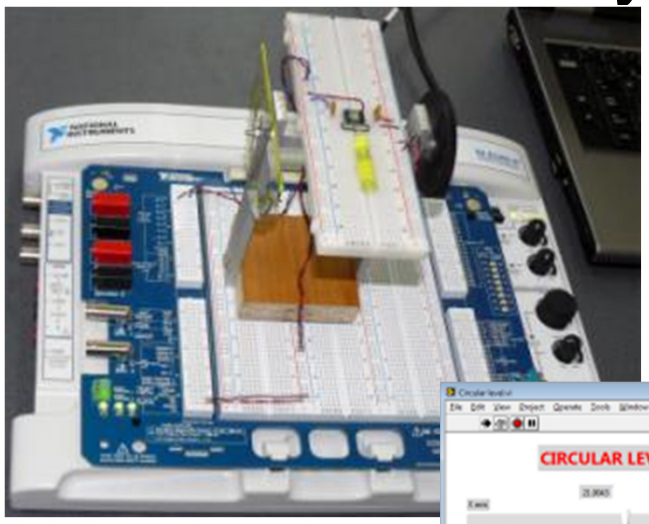
- There are add-on bords for NI-ELVIS





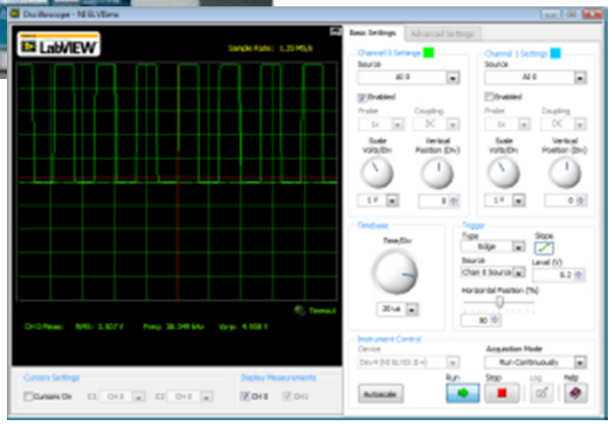
What can be done with the NI-ELVIS?

- Sensors study:



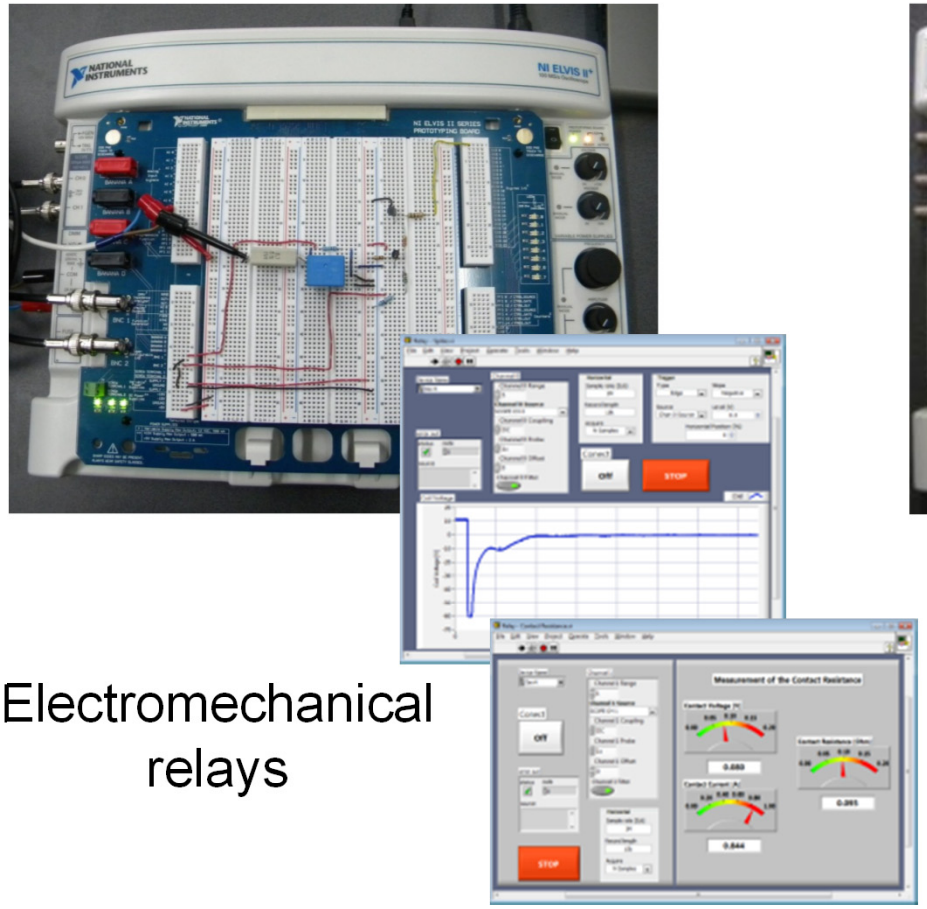
Accelerometers

Light sensors

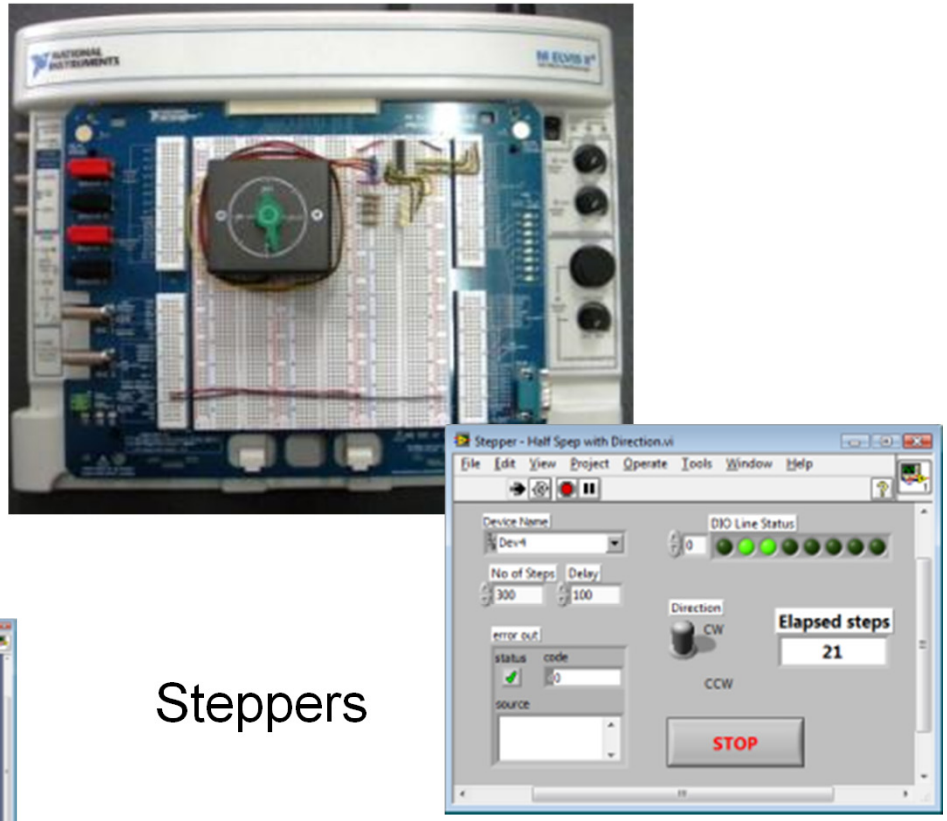


What can be done with the NI-ELVIS?

- Actuators



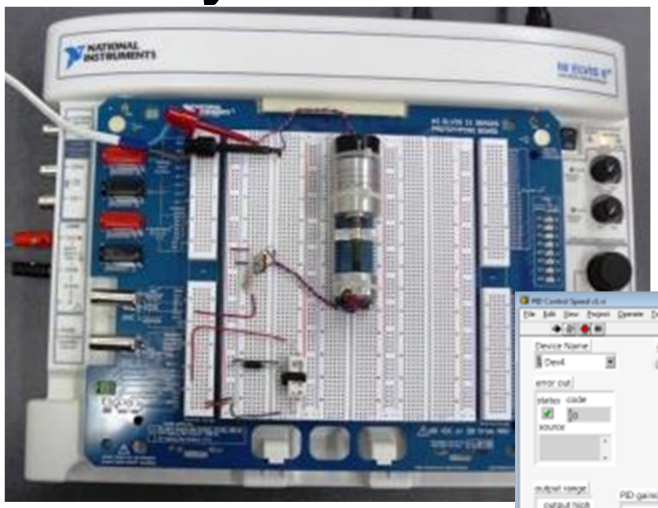
Electromechanical relays



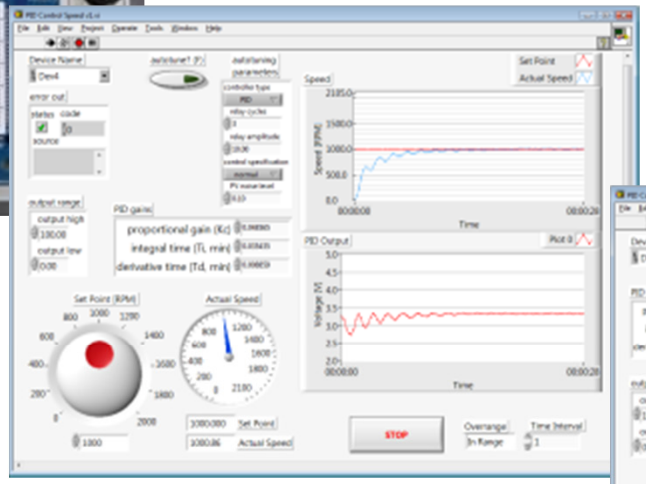
Steppers

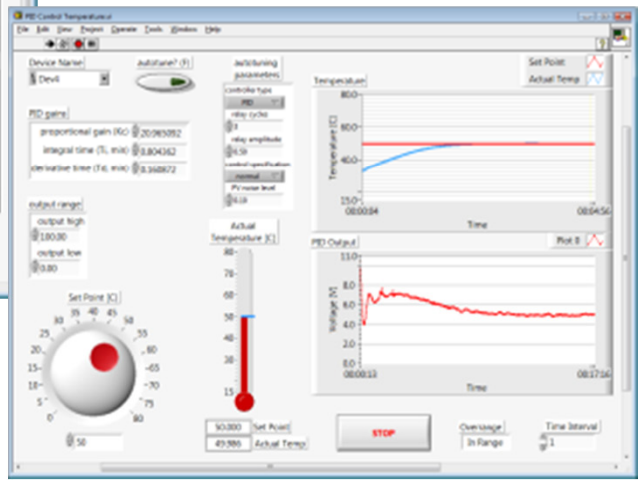
What can be done with the NI-ELVIS?

- System control (PID)



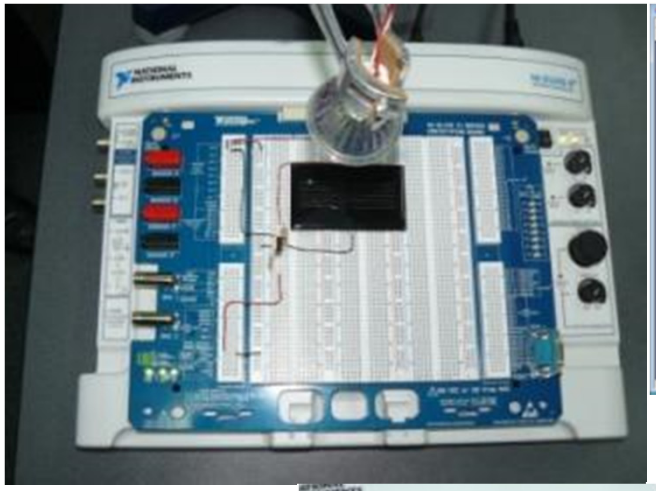
Speed and temperature control

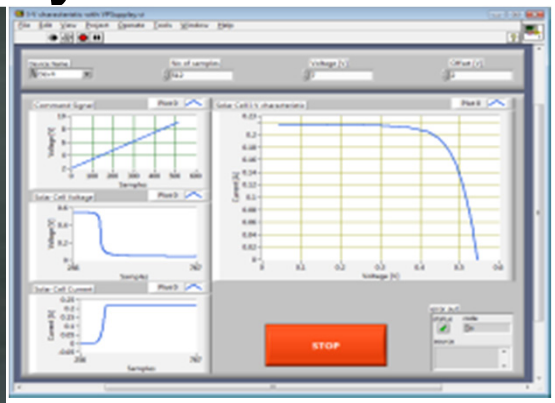




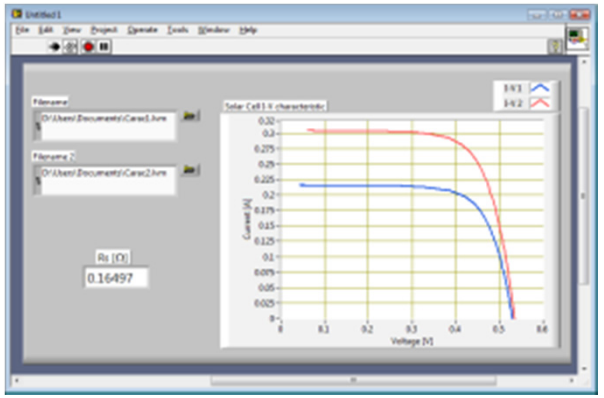
What can be done with the NI-ELVIS?

- Solar cells study



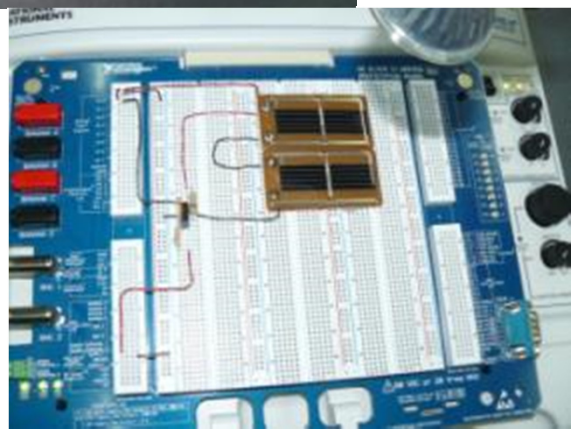


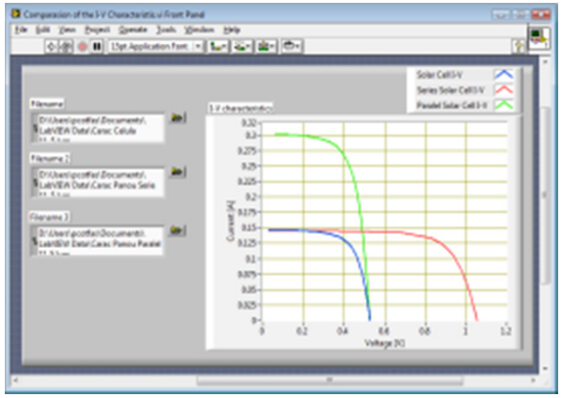
Rising the I-V characteristics



Rs determination

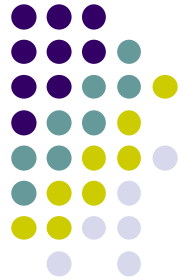
Solar panels





Series and parallel I-V characteristics

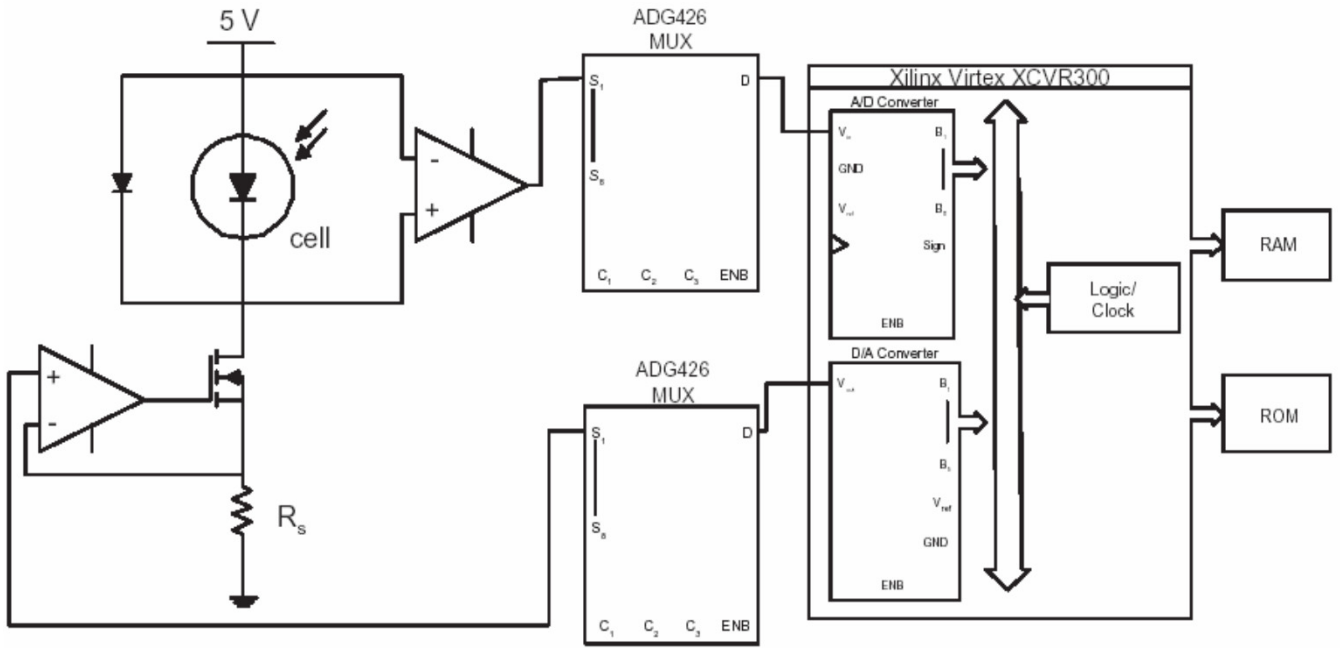
Examples of Virtual Instruments



- **Evaluation and Testing of the Solar Cell Measurement System Onboard the Naval Postgraduate School Satellite NPSAT1**
- **The Naval Postgraduate School Spacecraft Architecture and Technology Demonstration Satellite NPSAT1, launched in the fall of 2006, includet a system to measure the performance of new experimental *triple junction solar cells*.**
- **Presented at:**

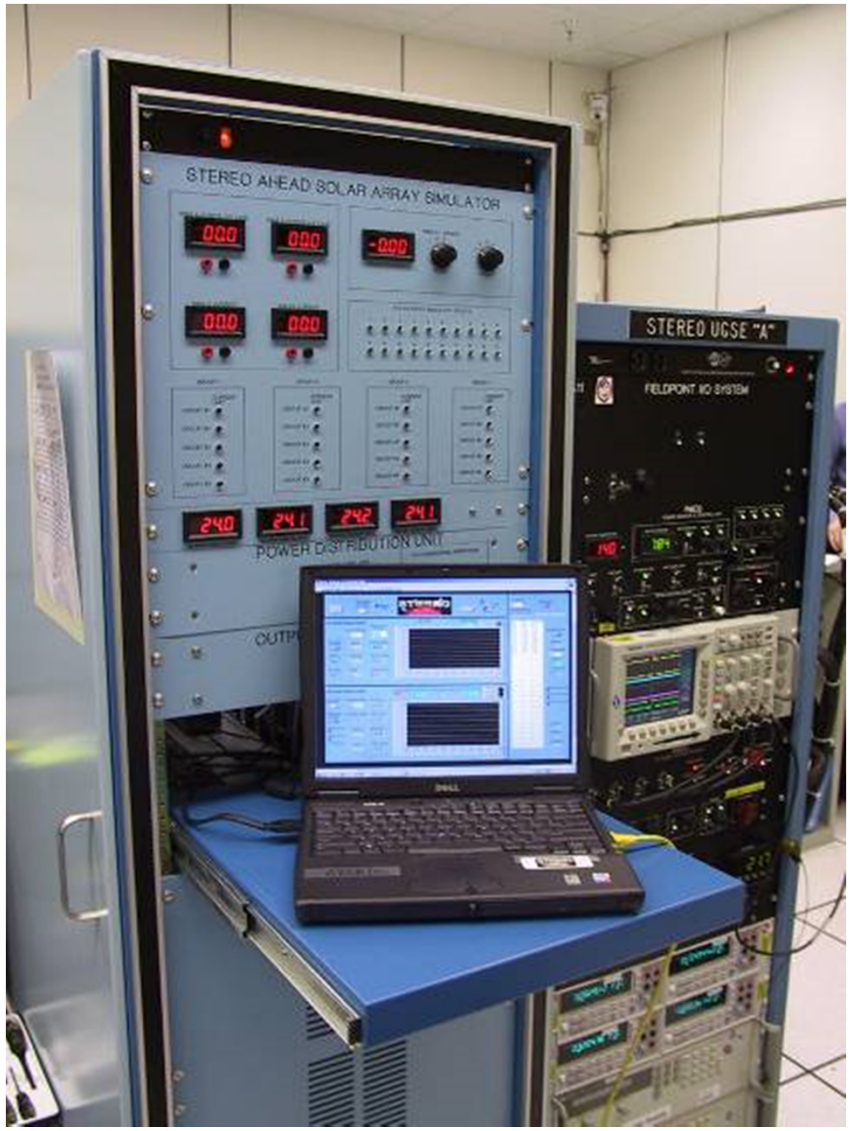
  22nd AIAA International Communications Satellite Systems Conference & Exhibit 2004

SMS Solar Cell Measurement System



- Vary the cell temperature (18°C, 28°C, and 38°C) and take I-V curves using the SMS circuit. Compare the output with curves produced by the HP6626A at the same temperature.
- Vary the temperature of the SMS circuit board electronics and observe any differences in the output from that taken under room temperature.
- Vary the light incidence angle on the cell and take curves using the SMS circuit. Compare the output of each angle to the HP6626A output for that same angle.
- Perform multiple traces and observe its repeatability (to produce the same output). Also ensure all four channels on the test circuit board will output the same result for the same cell.

National Instruments resource kit:



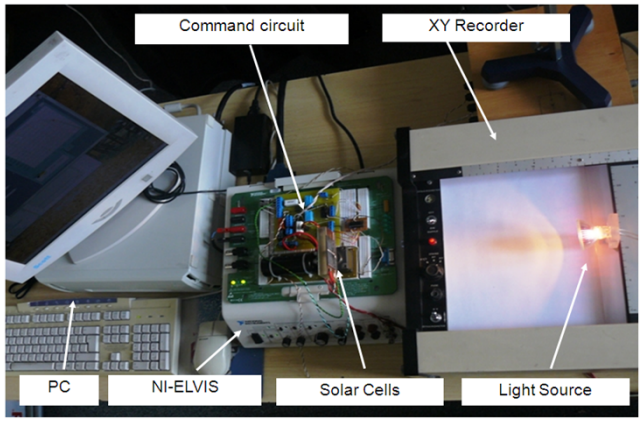
Johns Hopkins University Applied Physics Laboratory Uses NI LabVIEW and PXI to Simulate Spacecraft Solar Arrays

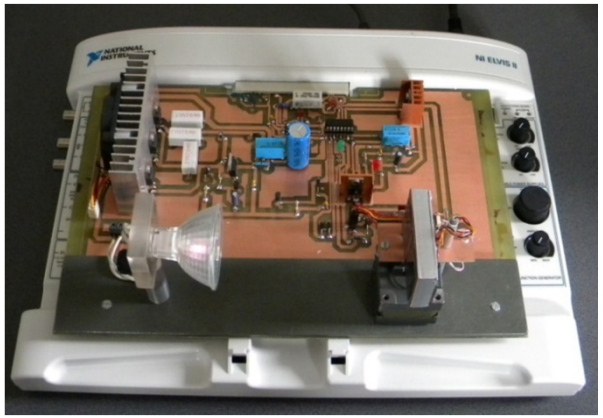
Developing a ground-based system to accurately simulate the operational conditions of spacecraft solar arrays and automate that process using National Instruments LabVIEW

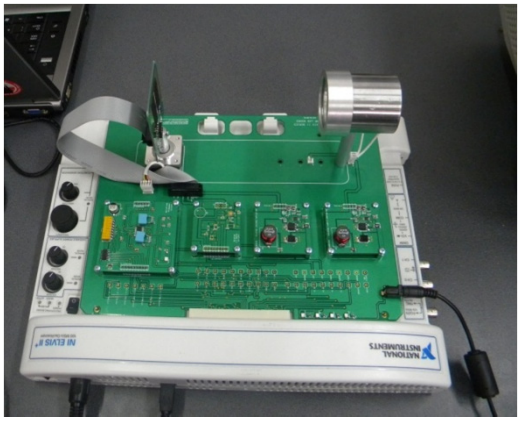
Using NI LabVIEW, PXI-1000B DC chassis, PXI-6713 analog output module, and PCMCIA-GPIB interface to control power supplies, integrate to existing GPIB systems, and automate the entire process

ftp://ftp.ni.com/evaluation/green/ekit/solar_power_resource_kit.zip

SolarLab





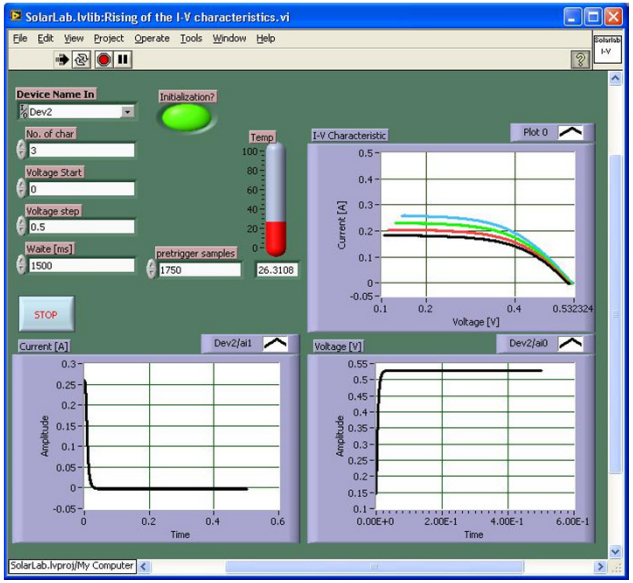


- unique add-on board for the NI-ELVIS platform
- to study the solar cells

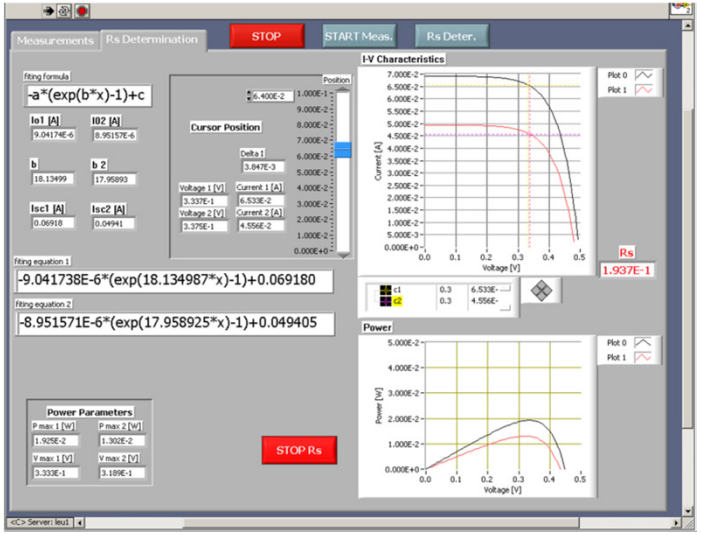
SolarLab

- The lab experiments that can be performed with this system are:
  1. Determination of solar cells parameters using the I-V characteristic;
  2. Determination of the series resistance of the photovoltaic cells using the methods:
     a) The two characteristics method;
     b) The area method;
     c) The generalized area method;
     d) Maximum power point method;
     e) Method of Quanxi Jia and Anderson;
     f) The simplified maximum point method;
     g) The original method.
  3. Determination of the shunt resistance of the photovoltaic cells;
     a) The generalized area method;
     b) The fitting method;
     c) The original method.
  4. Measurement of the solar cell impedance;
  5. Determination of the ideality factor of the diode;
     a) The generalized area method;
     b) Method of Quanxi Jia and Anderson;
     c) The original method.
  6. Study of the solar cell's parameters dependence upon the illumination level;
  7. Study of the solar cell's parameters dependence upon the temperature;
  8. Study of the solar cell's parameters dependence upon the incidence angle of the light radiation.

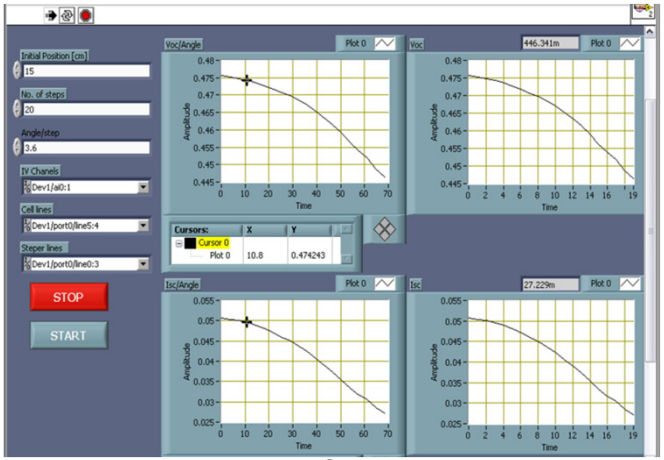
Solar Lab Applications



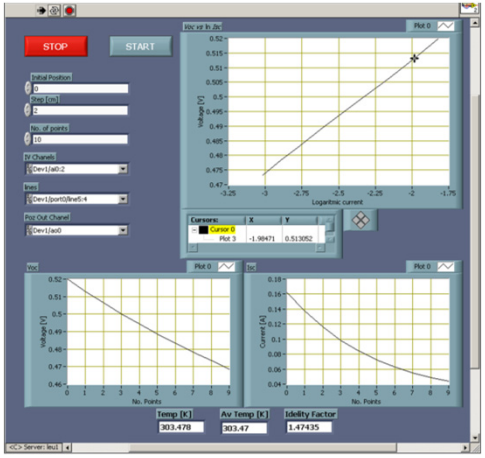
raising of the I-V characteristics



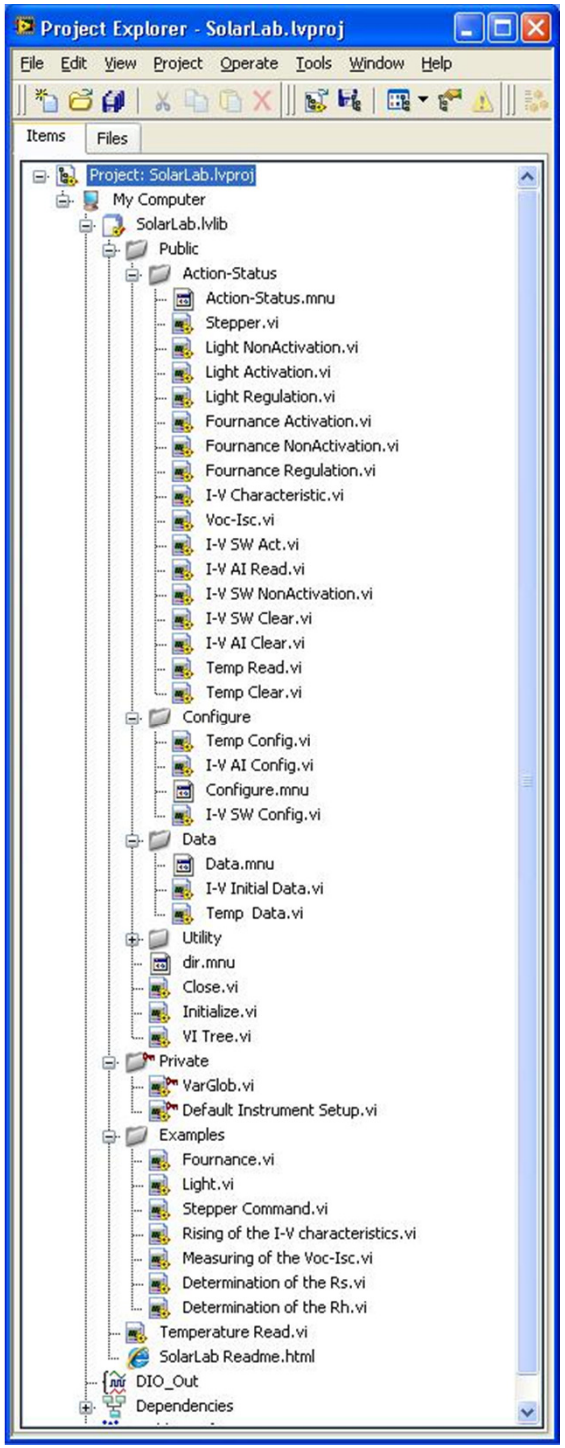
Determination of Rs



dependency of the incidence angle



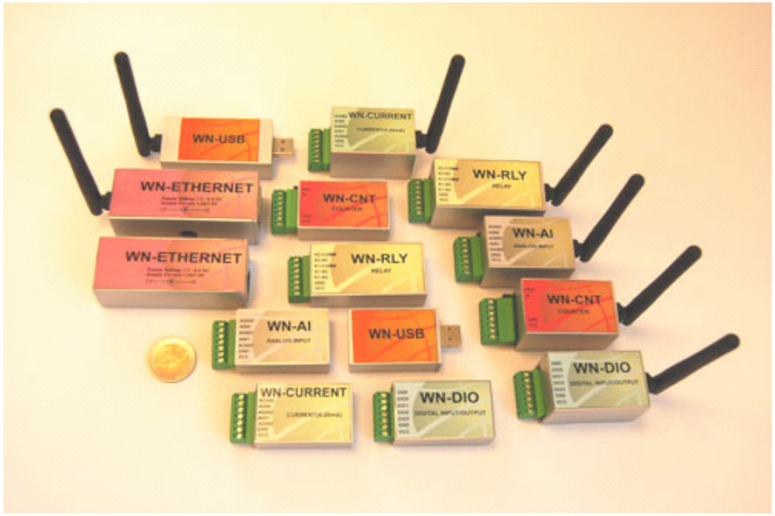
determination of the ideality factor



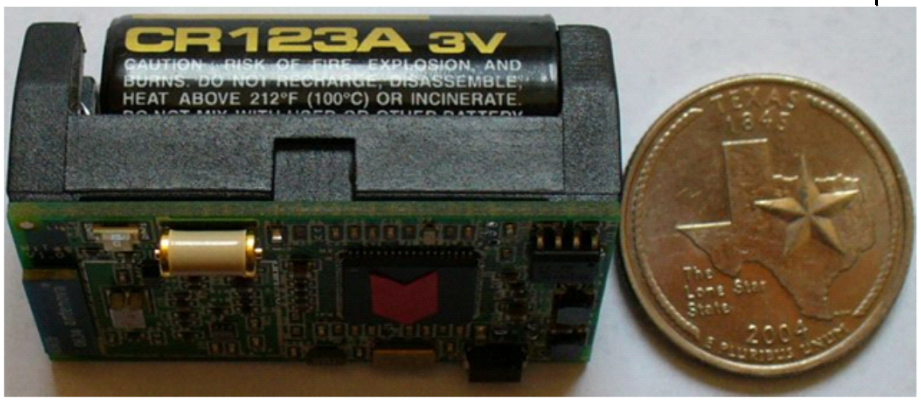
To conduct this kind of research – you need flexible instrumentation

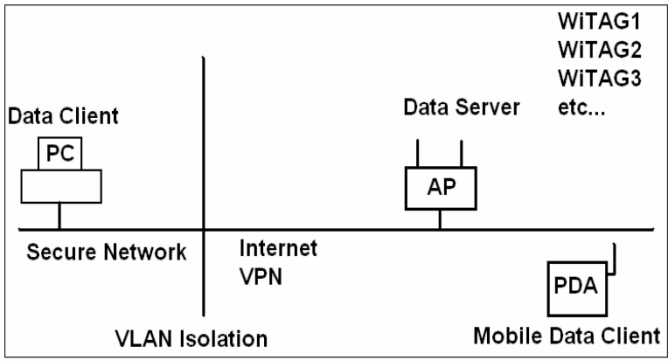
- Some new systems
- We work in direction of Wireless Systems
- Combine the WI-FI technology with active tag systems: WI-FI + TAG + Sensors
- Wi-TAG + sensors evoluate at >> the new Tag4M (see **www.tag4m.com**)
- The system use SoC from G2 Microsystems

WIRELESS SYSTEMS

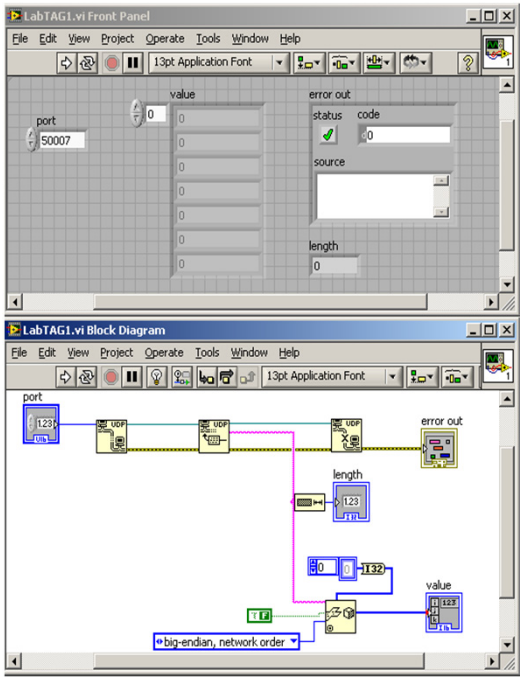


ZigBee and Wi-TAG systems





WiTAG Data Server Use Case



Now the new system:

TAG4M

Tag4M Cloud Instrument - Windows Internet Explorer
http://www.tag4m.com/
Google
File Edit View Favorites Tools Help
Norton
Cards & Logins
Convert
Select
Tag4M Cloud Instrument
Page
Tools
Tag4M
Search
Cores Electronic LLC
9806 Llano Estacado Ln Austin, TX, 78759, USA
Tel: (512) 905 - 0181
WiFi tags leverage RFID and the Internet to create an Instrumentation Cloud™
Home
Measurements
Products
Community
Store
Contact Us
Welcome to Tag4M
We offer WiFi tags that connect sensors to Web Pages on the Internet. Our tags leverage the low power, small size, low cost of RFID and the pervasive WiFi infrastructure that exists in enterprises, retail outlets, factories, and warehouses. Companies can, for a very low cost, connect sensors to tags in order to deploy a federation of measurement resources anywhere using Web Pages which can be hosted on any web-enabled hardware, whether on your desk, in your pocket or across the globe. In this way, we are starting to think about an 'instrumentation cloud' where not only the sensors but also the data logging, analysis, presentation and control applications can be anywhere you want them.
This week at Tag4M Community: Anturi Technology S.L. of Malaga, Spain developed the Tag4M.NET client application, posted at https://sourceforge.net/projects/anturitag4m/
Solar-powered Cloud Instrument™ sends sensor readings to real-time data-brokerage platform
The application proves the ability to run a low-power WiFi sensor tag from solar power, delivering its readings to Pachube, which has emerged as one of the leading public web application that enables people to tag and share real time sensor data from objects, devices and spaces around the world...
Press Release Pachube Feed
SolarCellPoweredTag AppNote LV to Pachube
Cloud Instrument™
Tag4M in the news
Sensors - The Instrumentation Cloud Brings Web-Centric...
Control Engineering EUROPE
Sensors - Web Tags Leverage RFID and the Internet...
International Association of Online Engineering(IAOE)
Test & Measurement World
Process and Control Today
Evaluation Engineering
Portal de Automatizacion Industrial
Markt&Technik-Die Messwolke
Books
Radio Frequency Identification (INTECH Feb. 2010)
Web Page Instruments
Tag4M - Web Page Instrument
Tag4M powered by Solar Cell
Solar Energy Meter
Grid Energy Meter
1pc Tag4M Cloud Instrument Evaluation Kit
$648
1pc Tag4m tag
$140
Internet | Protected Mode: On
90%

• Tag4M is small, low-power 802.11b/g tag for connecting sensors to the Internet.

• 1 analog-input channel, 14-bit, 0-10V

•3 analog-input channels 14-bit, [-200mV; +500mV]

•1 current-input channel 4-20mA

•4 DIO lines read/write

•Onboard temperature sensor: thermistor 10K +/-1 °C

•32-kHz realtime clock for wakeup and timestamping

•Data buffer: 10,000 readings in RAM, 30 readings in NVM

•Maximum sampling rate: single point read, 25 S/sec.

•Small size: 6.5 cm x 4.8 cm (2.55" x 1.88")

•2.4-GHz IEEE-802.11b/g WiFi transceiver

•On board ceramic chip antenna and connector for ext antenna

•32-bit RISC processor

•Onboard thermistor

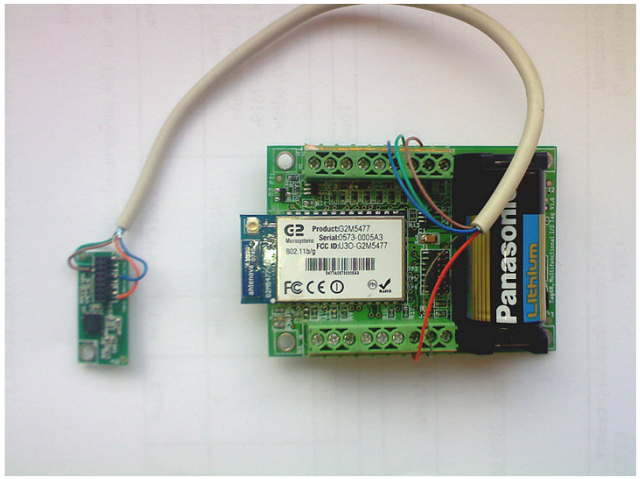
•Ultra-low power: 4 μA sleep, 50 mA Rx, 210 mA Tx (max)

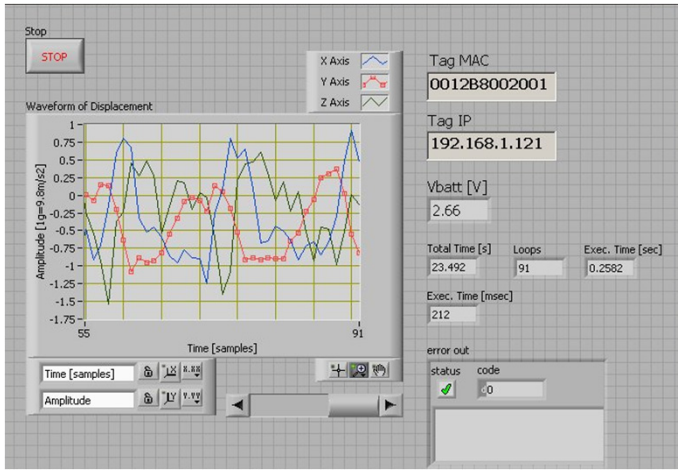
•Memory configuration: ROM 512 Kbytes (eCos OS, TCP/IP, LWIP, and Security) RAM 128 Kbytes (64 Kbytes available to user application) Non-volatile memory (NVM) 1,536 bytes (SPI) EEPROM 125Kbytes ("Save to Flash" data).

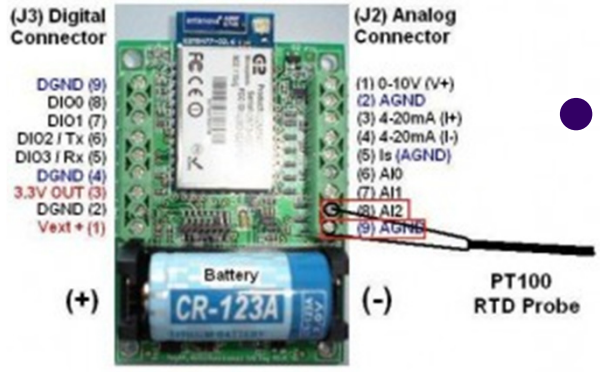
•Low power

Tag4m new version

- ADXL330 3-axis accelerometer with voltage outputs



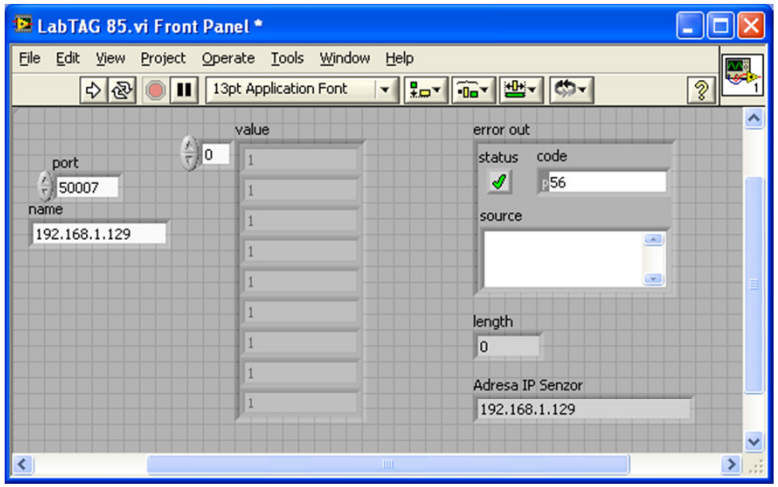


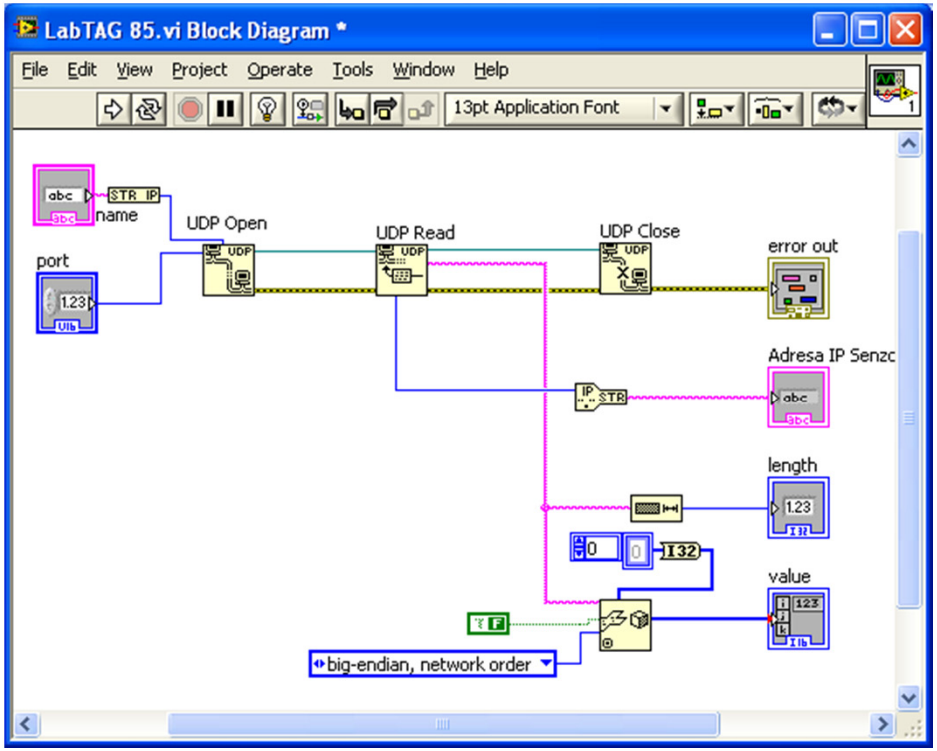


- PT100 connected to Tag4M

WEB and LabVIEW possibility to control

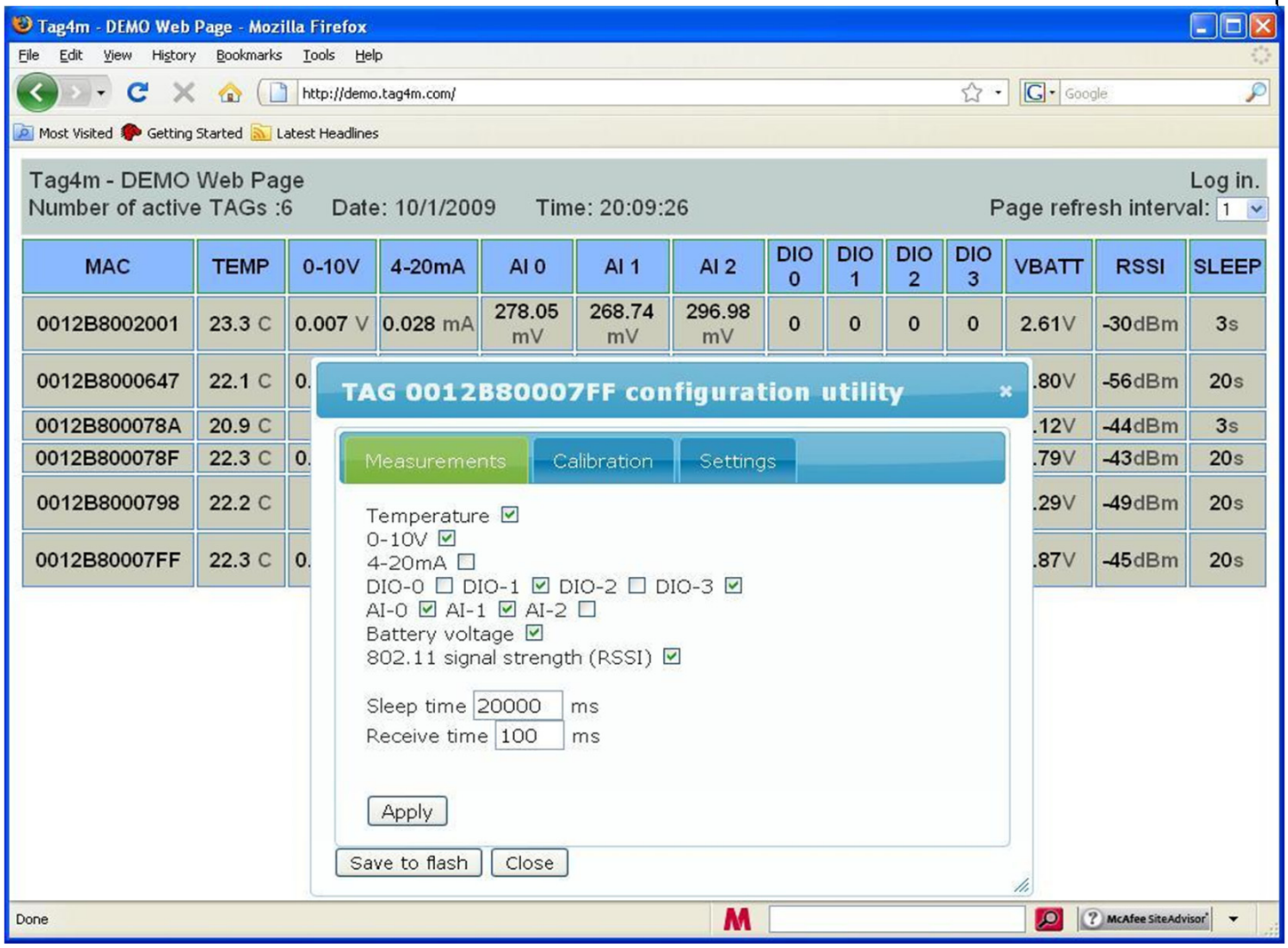
IP	Temperature	Humidity	Light	Position (X,Y,Z)	VBatt	RSSI	Sleep
192.168.200.121	28.2C	10.6%	0.400V	-1.48,0.24,1.42	3.30V	37dBm	3s
192.168.200.122	27.3C	14.5%	0.363V	-1.18,-1.70,2.24	3.30V	42dBm	3s
192.168.200.123	27.0C	68.5%	0.539V	-2.76,4.30,2.70	3.30V	44dBm	3s
192.168.200.124	28.1C	90.5%	0.535V	-1.34,2.58,-0.10	3.30V	40dBm	3s
192.168.200.125	29.4C	53.2%	0.323V	-1.86,-2.06,0.80	3.30V	42dBm	3s





12:45

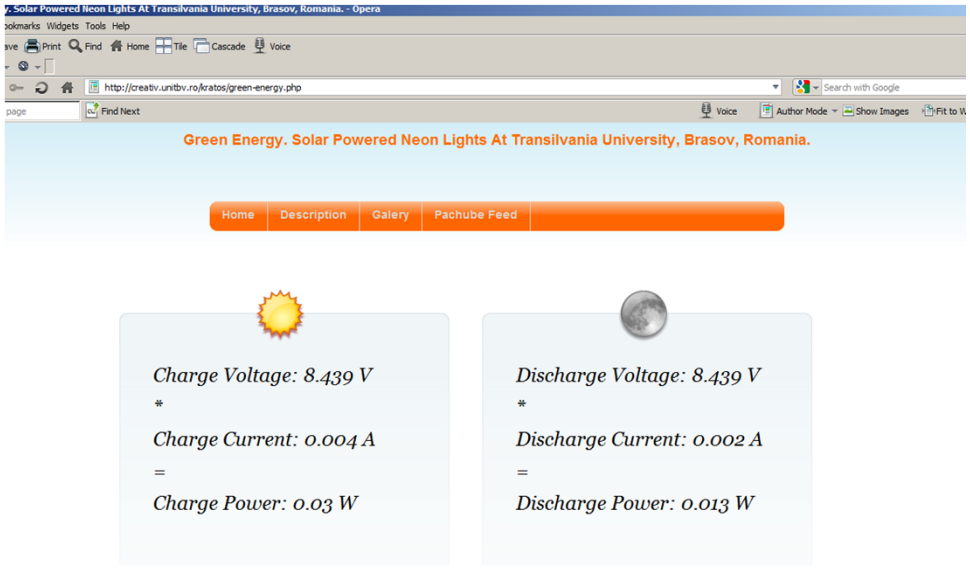
Web control


Tag4m - DEMO Web Page - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://demo.tag4m.com/
Most Visited Getting Started Latest Headlines
Tag4m - DEMO Web Page
Log in.
Number of active TAGs :6 Date: 10/1/2009 Time: 20:09:26
Page refresh interval: 1
MAC TEMP 0-10V 4-20mA AI 0 AI 1 AI 2 DIO 0 DIO 1 DIO 2 DIO 3 VBATT RSSI SLEEP
0012B8002001 23.3 C 0.007 V 0.028 mA 278.05 mV 268.74 mV 296.98 mV 0 0 0 0 2.61V -30dBm 3s
0012B8000647 22.1 C -56dBm 20s
0012B800078A 20.9 C -44dBm 3s
0012B800078F 22.3 C -43dBm 20s
0012B8000798 22.2 C -49dBm 20s
0012B80007FF 22.3 C -45dBm 20s
TAG 0012B80007FF configuration utility
Measurements Calibration Settings
Temperature
0-10V
4-20mA
DIO-0 DIO-1 DIO-2 DIO-3
AI-0 AI-1 AI-2
Battery voltage
802.11 signal strength (RSSI)
Sleep time 20000 ms
Receive time 100 ms
Apply
Save to flash Close
Done
McAfee SiteAdvisor

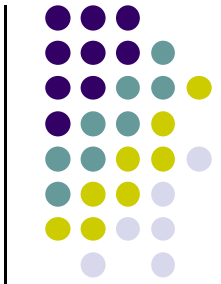
Examples

•The web application allow monitor a solar panel stand that charged a battery during the day, then powered a light during the night. The switch between charging and starting the light is enabled by a light sensor.
•*The monitored parameters are: the generated voltage, charge current, charge power, discharge current and discharge power*

The custom “Green Energy” interface



Low Frequency Noise
1/f NOISE

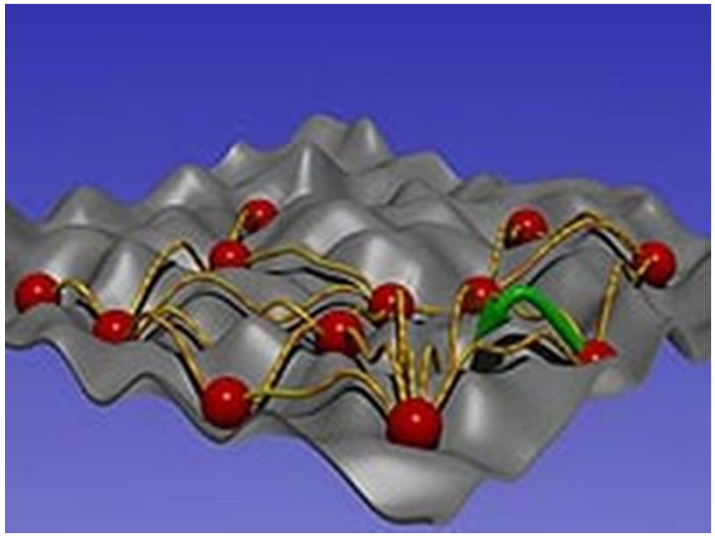


- "1/f noise" ("one-over-f noise"), "flicker noise" or "pink noise")
- is a type of noise whose power spectra *P(f)* as a function of the frequency *f* behaves like:

$$P(f) = 1/f^{a}$$

- where the exponent *a* is very close to 1 (that's where the name "1/f noise" comes from)
- If we mix visible light with different frequencies according to 1/f distribution, the resulting light may be pinkish
- Mixtures using other distributions should have different colors
- For example, if the distribution is flat, the resulting light is white (*P(f)=constant* noise is called "white noise")

1/f Noise
Theory and Applications



"One-over-f noise appears almost everywhere, from electronic devices and fatigue in materials to traffic on roads, the distribution of stars in galaxies, and DNA sequences," said Valerii Vinokour from Argonne's Materials Science Division.

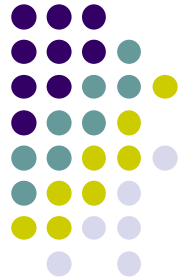
They establish that one-over-f noise is a generic property of Coulomb glasses and, moreover, of a wide class of random interacting systems and phenomena ranging from mechanical properties of real materials and electric properties of electronic devices to fluctuations in the traffic of computer networks and the Internet.” (Reported 10 May 2007)

Empirical relation of Hooge

- The work of many physicist and in particular of F. N. Hooge and collaborators, produced several empirical formulas for *1/f* noise
- In particular Hooge showed that the *1/f* voltage spectral density can be parametrized by the formula:

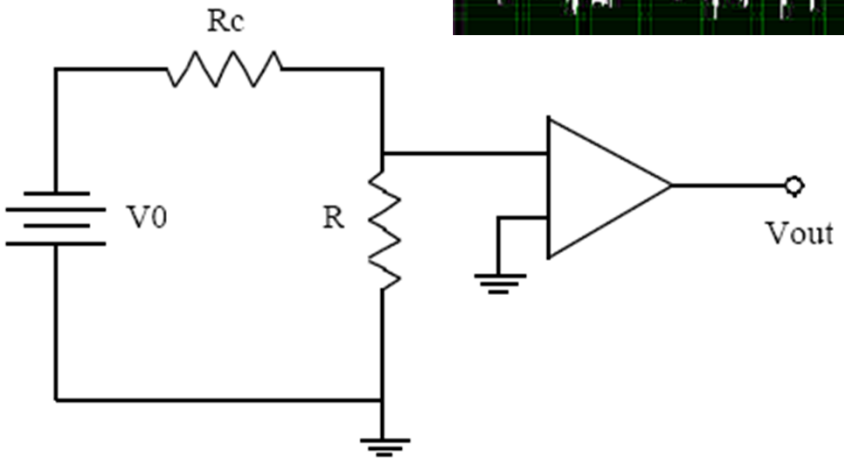
$$S_V(f) = \gamma \frac{V_{DC}^{2+\beta}}{N_c f^{\alpha}}$$

$$S_V(f) = \gamma \frac{V_{DC}^{2+\beta}}{N_c f^{\alpha}}$$



- Where: α, β and γ are constants, V_{DC} is the applied voltage and N_c is the total number of charge carriers in the sample.
- This formula relates *1/f* noise to the passage of current in the sample, and so people asked whether the noise was still present without a driving current.
- Clarke and Voss who found that *1/f* noise was indeed present at equilibrium and this result was later confirmed by Beck and Spruit

Measuring 1/f Noise / Models



- typical circuit used to measure voltage (or equivalently current or conductance) noise in the resistor R.

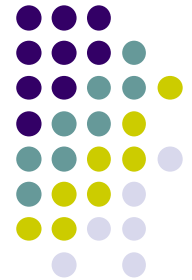
➢Do we have by now an "explanation" of the apparent universality of flicker noises?

➢Do we understand *1/f* noise?

➢Some researchers answer:

- there is no real mystery behind *1/f* noise,
- there is no real universality
- in most cases the observed *1/f* noises have been explained by beautiful and mostly *ad hoc* models.

Temperature dependence of 1/f noise and transport characteristics as a non-destructive testing of monocrystalline silicon solar cells



A.Ibrahim and Z.Chobola, Technical University of Brno, Physics department

15th World Conference on Non-Destructive Testing, 15-21 Oct. 2000 in Rome;

- Dependence of the noise spectral voltage density $S_V(f)$ in the frequency range 1Hz to 10^5 Hz and transport characteristic for a monocrystalline silicon solar cells have been investigated.
- The magnitude of the noise spectra for the Si solar cell shows a decrease of noise magnitude with increasing temperature between 300K to 400K.
- Also for I-V curves, both recombination-generation and diffusion current components are increases with temperature.

Noise and I-V Characteristics

- For small applied voltage the recombination-generation current flows through the solar cells,
- Increasing the applied voltage the diffusion current dominates
- Spectral voltage density decreases with increasing temperature of the cell as a result of equilibrium resistance fluctuations.

HOOGE empirical formula (**N** the number of the charge carriers in the sample, **f** the frequency and **V** the voltage across the sample) :

$$S_V(f)/V^2 = \alpha/Nf$$

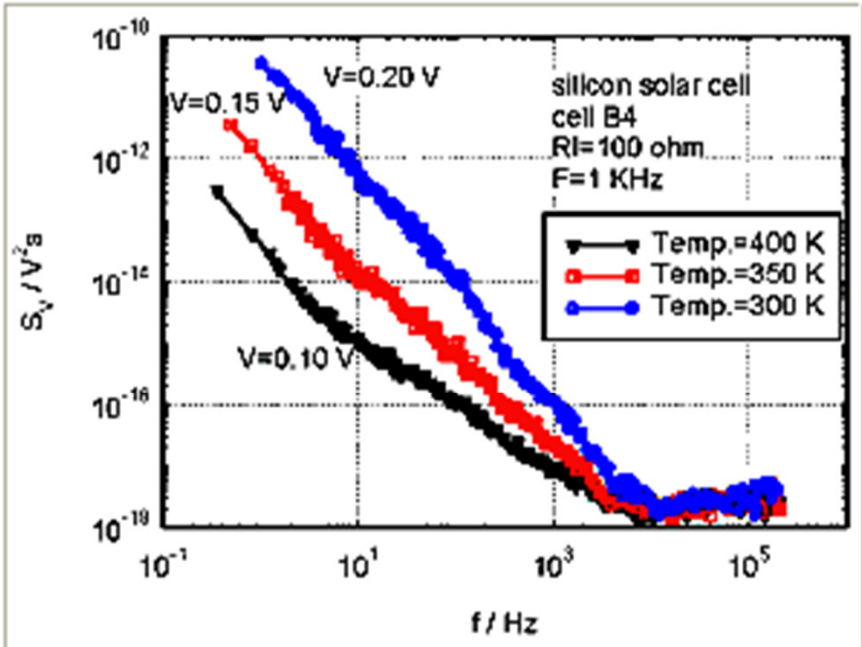


Fig 3: The $S_V(f)$ vs frequency for a Si solar cell at of structure n^+pp^{++} in a temperature range of 300-400K.

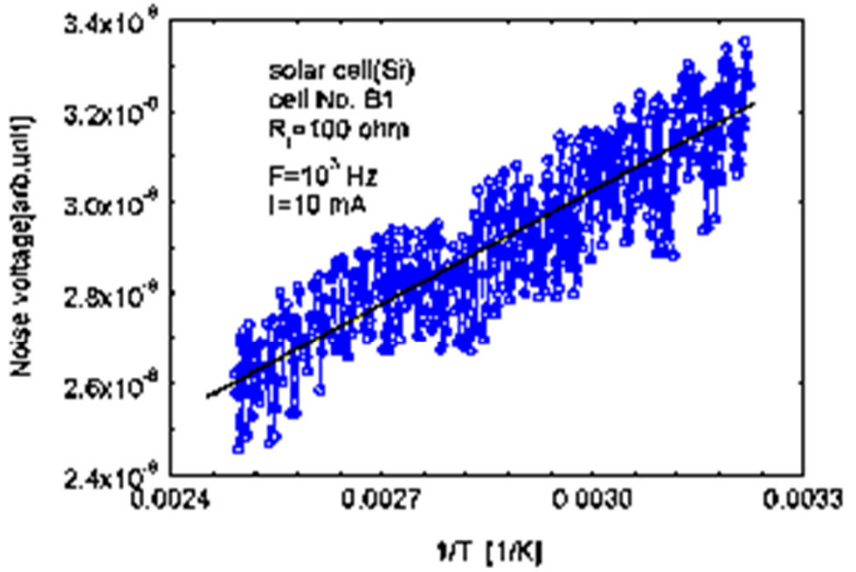


Fig 4: Noise voltage as a function of 1/T for the Si solar cell of structure n^+pp^{++}.

NOISE like:
Diagnostic and Reliability test

- The idea to use noise measurements to electronic device technology analysis, device diagnostics and reliability forecast has been addressed by several researchers, such as:

1. **A. Van der Ziel and H. Tong** , Low frequency noise predicts when a transistor will fail. *Electronics* **39** 24 (1966), pp. 95–97.
2. **L.J.K. Vandamme, R. Alabedra and M. Zommiti** , 1/*f* noise as a reliability estimation for solar cells. *Solid-State Electron* **26** (1983), pp. 671–674.
3. **Savelli M, Lecoy G, Dinet D, Renard J, Sauvage D.** 1/*f* noise as a quality criterion for electronic devices and its measurement in automatic testing. AET Conf Session 4, 1984. p. 1–27.
4. **J. Sikula, P. Vasina, V. Musilova, Z. Chobola and M. Rothbauer** , 1/*f* noise in GaAs Schottky diodes. *Phys Stat Sol (a)* **84** (1984), pp. 693–696.
5. **B.K. Jones** , Electrical noise as a measure of reliability in electronic devices. *Adv Electron Electron Phys* **67** (1994), pp. 201–257.
6. **D. Ursutiu and B.K. Jones**, Low-frequency noise used as a lifetime test of LEDs, 1996 *Semicond. Sci. Technol.* **11** 1133-1136

Low-frequency noise used as a lifetime test of LEDs,

D.Ursutiu, B.K.Jones, 1996 *Semicond. Sci. Technol.* 11 1133-1136

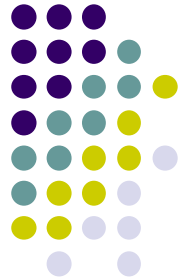
- *Low-frequency noise (1/f noise) has been measured in light emitting diodes (LEDs) which have been subjected to an accelerated life test by means of large forward bias current pulses.*
- *Over a large range of stress pulses the electrical and functional LED properties remain unaltered but an increase in the 1/f noise level was seen and this was correlated with the device reliability.*
- *The product* ***"initial noise" X "initial rate of noise increase"*** *correlated best with the LED lifetime.*

Noise as a tool for non-destructive testing of single-crystal silicon solar cells

Z. Chobola, Institute of Physics, University of Technology, Brno

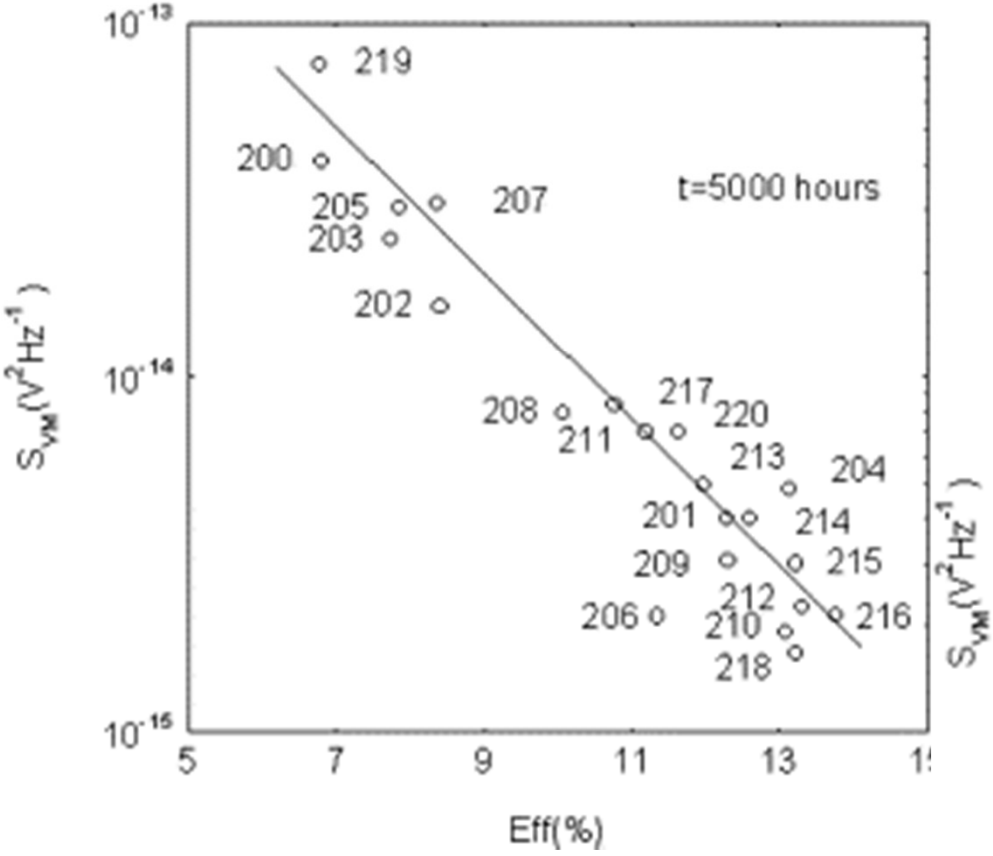
- Noise spectral density related to defects is of 1/*f* type and its magnitude was found to be proportional to the square of the DC forward current at low injection levels.
- It has been established that samples showing low noise feature offer high-conversion efficiency.
- It has also been found out that there is a strong correlation between the sample initial-condition noise and the efficiency after 5000 h of combined stressing.
- Stress comprising an temperature of 400 K and a DC electric field were applied to a total of 20 solar cells for a period of 5000 h

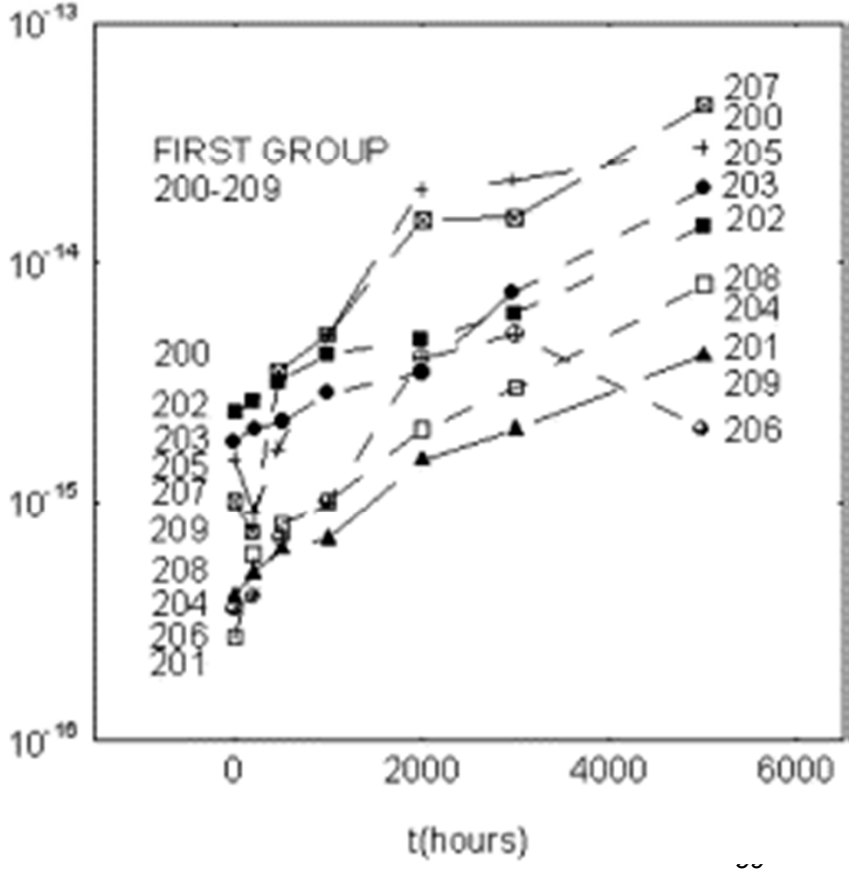
CONCLUSIONS FROM NOISE MEASUREMENTS



- Noise spectral density related to defects is of 1/*f* type and the current noise spectral density is proportional to the square of DC current in the low-injection mode.
- Samples with lower noise have higher efficiency.
- The average value of the noise spectral density of the entire ensemble increases with stressing time.
- It has been found out that there is a strong correlation between the initial-state noise and the conversion efficiency after 5000 h of combined stressing.

NOISE after STRESS



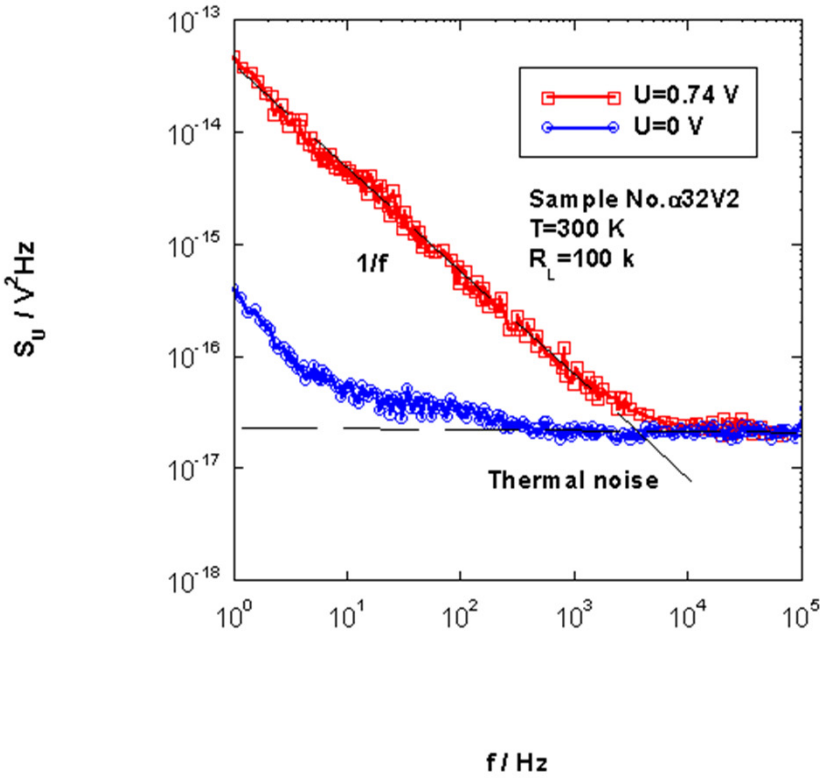


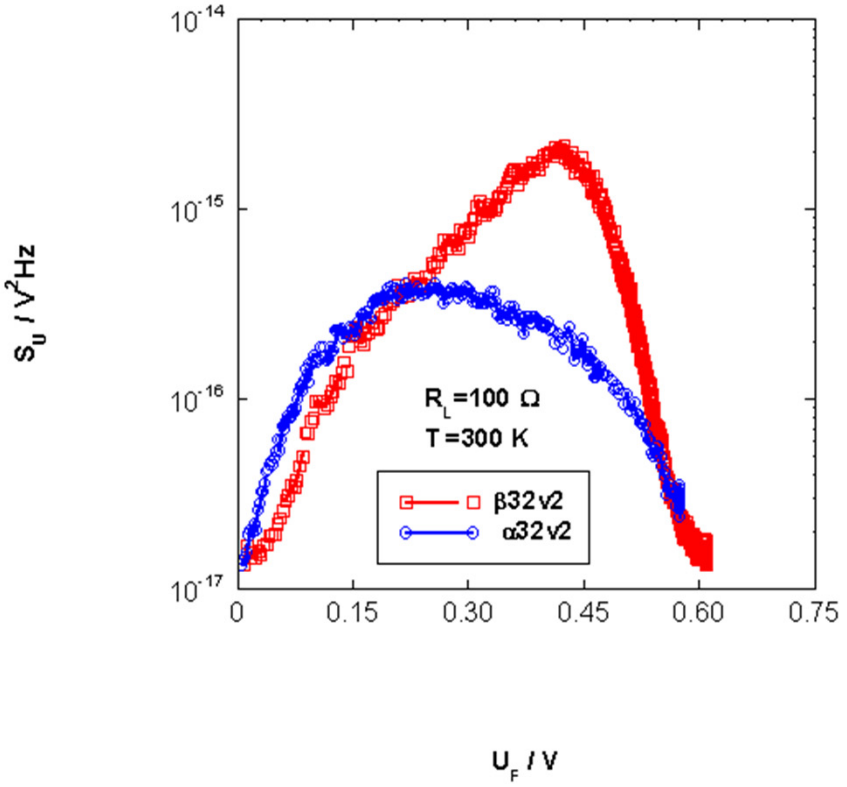
COMPARING CONTACT TECHNOLOGIES BY 1/F NOISE IN PHOTOVOLTAIC CELLS

J.Vaněk, J. Kazele, Z. Chobola, Technical University of Brno,

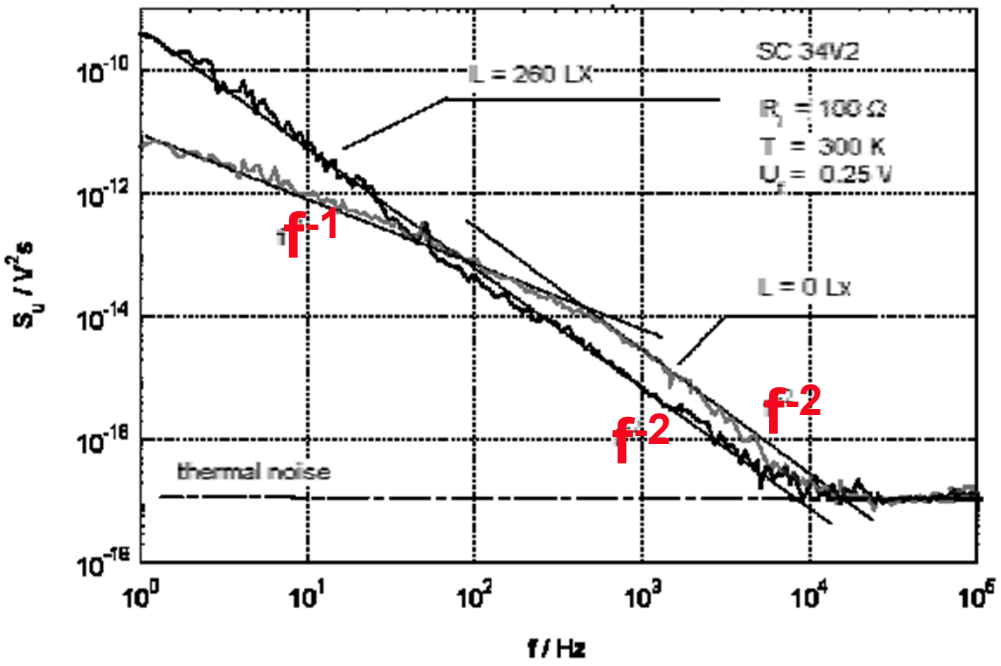
- Authors compared new technology contacts with old technology by using I-V characteristic and noise spectroscopy.
- The old expensive technology "Alpha technology" is making contact by sputtering copper layer after PN junction making on both sides on silicon wafers.
- The new technology "Beta technology" is making contact by screen printing silver alloy pasta (this technology is no so expensive as alpha technology)
- Experimental results obtained from I-V characteristic and monitoring of spectral voltage noise density curves point to higher qualities of alpha technology.

Alpha and Beta samples Noise





NOISE and ILLUMINATION



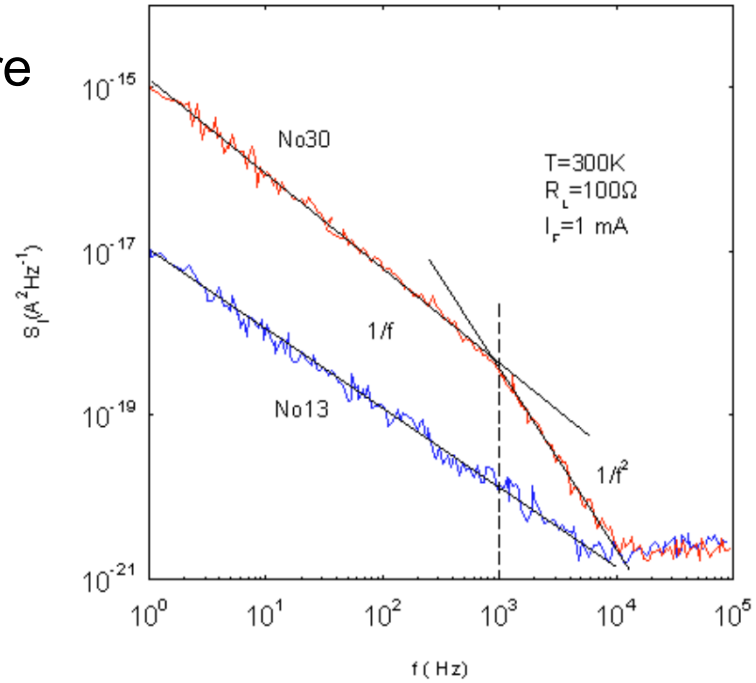
Solar cell Noise voltage versus frequency for different illumination

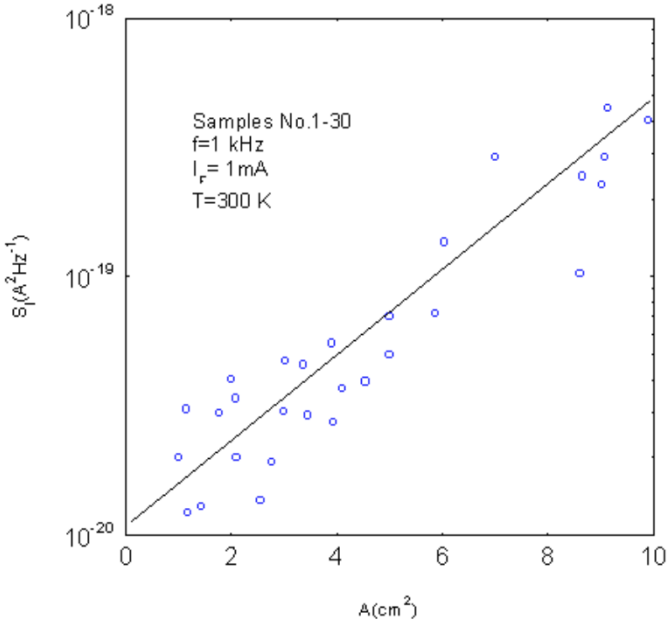
- When illuminated, the samples produce G-R noise whose relaxation frequency is below 1 Hz. The light-induced noise spectral density drop which was observed at frequencies around 10^3 Hz, with respect to the dark values, is due to the decrease in the PN junction differential resistance, which is caused by illumination.
- On the other hand, higher noise spectral densities, compared with the dark sample values, as measured at frequencies below 10^2 Hz, are due to the occurrence of 1/f noise in these samples in the dark.

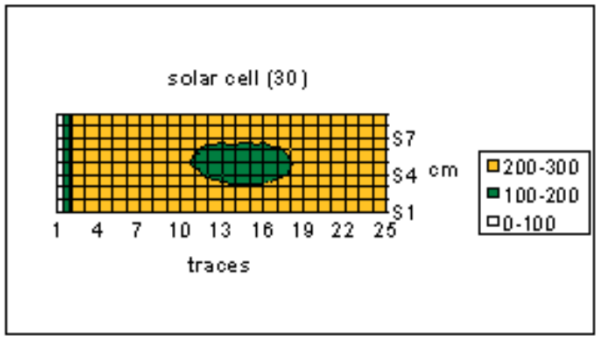
NOISE AND SCANNING BY LOCAL ILLUMINATION AS RELIABILITY ESTIMATION FOR SILICON SOLAR CELLS

Z. CHOBOLA and A. IBRAHIM - *Brno University of Technology,*

- By 1/f noise measurements, one can determine if there are defects in the structure or not
- By light scanning the areas of the local defects can be identified.
- Therefore, these techniques can give us a description of the quality of the product.

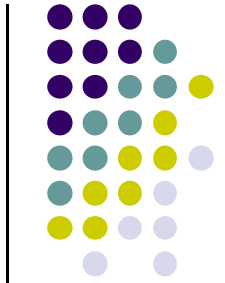






CONCLUSIONS

- Noise measurements in Solar Cells start to be a new and powerful techniques of investigation
- This new technology can be used independently or better in combination with other techniques
- Correlation between noise and reliability (proved for a lot of electronic devices) can be used in quality evolution monitoring (in time) for solar panels
- Selection of the best cells for special application can be done using the noise parameters



Thanks for your attention !