UNIVERSITÀ DI PISA

ELECTRONICS FOR BIONICS ENGINEERING

DANIELE ROSSI

Academic year	2020/21
Course	BIONICS ENGINEERING
Code	846II
Credits	6

Modules	Area	Type	Hours	Teacher(s)
ELECTRONICS FOR BIONICS ENGINEERING	ING-INF/01	LEZIONI	60	DANIELE ROSSI

Obiettivi di apprendimento

Conoscenze
The student who successfully completes the course will be able to demonstrate a solid knowledge of the main issues related to the design of sensor based electronic systems for bionics engineering. He or she will acquire the ability to analyse and design the building blocks of an analogue front-end for the acquisition, conditioning and conversion of biological sensor data, and will master the design methodologies adopted for instrumentation amplifiers, passive and active filters, analogue-to-digital and digital-to-analogue converters. He or she will then familiarise with standard digital interfaces utilised to transfer digitalised sensor data to an embedded microcontroller or microprocessor. The student will deepen his or her learning on the conditioning and digitalization chain of biological sensor data by familiarising with standard digital interfaces utilised to transfer digitalised sensor data to an embedded microcontroller or microprocessor. Finally, he or she will be exposed to state-of-the-art design methodologies adopted for tightly energy-/power-constrained electronic systems in wearable and implantable devices. Students will be exposed to actual application examples and will have the opportunity to consolidate their learning by working with advanced EDA tools. They will have the opportunity to carry out, on a voluntary basis, a mini-project activity for designing and simulating one (or more) of the building blocks composing an analogue front-end for an application of interest.

Modalità di verifica delle conoscenze
Oral examination usually consisting of three main questions, one of which might include the solution of an exercise similar to those seen during the course.
For those students having carried out the voluntary, mini-project activity, one of the three main questions will be on the topic covered by their mini-project.

Capacità
The aim of this course is to provide the students with a solid knowledge of the techniques and methods related to the design of sensor based electronic systems for bionics engineering.
The student who successfully completes the course will typically:

- Acquire the ability to analyse and design the building blocks of an analogue front-end for the acquisition, conditioning and conversion of biological sensor data
- Gain knowledge of standard digital interfaces utilised to transfer digitalised sensor data to an embedded microcontroller or microprocessor
- Familiarise with state-of-the-art design methodologies adopted for tightly energy-/power-constrained electronic systems in wearable and implantable devices

Modalità di verifica delle capacità
Oral examination usually consisting of three main questions, one of which might include the solution of an exercise similar to those seen during the course.
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Prerequisiti (conoscenze iniziali)
Basics on analog and digital electronics.

Programma (contenuti dell'insegnamento)
Introduction to biosignals: taxonomy of biosignals and applications of analog front-end. Typical frequency and amplitude of biosignals.
Biopotential amplifier: composing blocks and main characteristics; interference and noise filtering in biopotential amplifiers.

Instrumentation amplifier (INAMP) and its main properties; Common Mode Rejection Ratio (CMRR) and Power Supply Rejection Ratio (PSRR).
Differential difference amplifier as on INAMP: differential and common mode signals and gains; CMRR as one of the most important features; examples of CMRR calculation; CMRR calculation with un-matched resistances; impact of resistance tolerance on CMRR value; input resistance and impact of unbalanced source impedances on CMRR; CMRR and PSRR as a function of frequency; example and analysis of data-sheets of differential difference amplifiers; summary of the main limitations of the differential difference amplifier as an INAMP.
3-OPAMP INAMP: input buffer to match the input impedances; external gain resistor and voltage gain calculation; internal vs external gain resistors. Examples of datasheet: 3-OPAMP, precision INAMPs INA128 and INA131: analysis of the main features and possible applications; saturation of the input stage: problem and possible solutions.
3-opamp INAMP example of application: portable ECG and its main features, input guarding and right-leg voltage reference.
Introduction to 2-OPAMP INAMP and its main characteristics; gain and CMRR analysis; example of datasheet for a 2-OPAMP INAMP for low-power applications.
Wheatstone bridge (WB): balanced and unbalanced WB; arm ratio and WB sensitivity; push-pull configuration; differential signal and connection to an INAMP; examples of bridge circuits with actual INAMP (AD627 and AD623); problems of external reference voltage generation and possible solutions.
Noise and noise sources in electronic circuits; stochastic process and power spectral density; thermal noise in resistors and noise equivalent voltage and current generators.
Isolation amplifier (ISO-amp): motivation and main features; galvanic isolation; generic block diagram of an ISO-amp. Parameters to qualify an ISO-amp: isolation voltage, isolation impedance, leakage current and Isolation Mode Rejection Ratio (IMRR). Main features and examples of different technologies to realise an ISO-amp: Transformer-coupled ISO-amp, Optically-coupled ISO-amp, and Capacitive-coupled ISO-amp; Comparative analysis of different ISO-amp technologies.
Introduction to main simulation features of LTSPICE; DC, transient and frequency analysis with LTSPICE; LTSPICE analysis of OPAMP AD8032 and INAMP AD8421.
Basics on analog filters; continuous time and discrete time filters; ideal and practical filters. Resonant series and parallel RLC circuit: Bode diagrams of the equivalent impedance, resonance frequency and quality factor.
Second order passive low pass (LP), high pass (HP), band pass (BP), band stop (BS) and all pass (AP) filters: RLC circuit and transfer function; Bode diagrams, bandwidth, Q factor and damping ratio. Wideband and narrowband BP and BS filters; notch filter.
Generic biquad filter function and position of poles and zeroes on the complex plane to generate the different filters. Sensitivity of filter parameters with respect to components.
Higher order filter as a combination of first and second order filters.
Second order active filter: Sallen-Key cell for LP, HP and BP second order active filters: circuit, transfer function, resonant (cut-off) frequency and quality factor. Examples of components' sizing and tuning. Sensitivity of Q and f0 against the different components. Twin-T Notch filter: circuit, frequency response, resonance and quality factor.
Multiple Feedback (MFB) second order active filter: motivation and basic cell structure; BP, LP and HP MFB filter: circuit, transfer function and main parameters. Comparison between Sallen-Key and MFB filters.
State variable filters: motivation; block diagram and circuit topology, transfer function, main parameters and components' sizing. Biquadratic cell (Tow-Thomas filter).
Frequency response of Butterworth LP filters, Chebyshev LP filters and Bessel LP Filters.
Introduction to switched-capacitor filters: basic principle, switched-cap resistors, main characteristics; sampling process, aliasing and Nyquist frequency; examples.
Digital-to-analog converters (DACs): basic principles and ideal transfer function; reference voltage and resolution; main DAC properties and problems: linearity, differential non-linearity and integral non-linearity, monotonicity, conversion speed; summing amplifier as main DAC components; binary weighted resistor DAC: basic principle and circuit structure; main properties and limitations. Example of 4-bit 8-bit binary-weighted resistor DAC. R-2R DAC: basic idea; Thevenin resistance of the R-2R ladder; block diagram and output voltage expression; main characteristics and advantages over the binary weighted resistor DAC.
Analog-to-digital converters (ADCs): main components and characteristics of an ADC, sampling, quantization and encoding, resolution and accuracy.
Successive approximation register (SAR) ADC: block diagram and algorithm; operation of a SAR ADC and conversion speed; frequency limitation, need for sampling, sample and hold (S&H).
Flash ADC, Dual slope ADC and architecture, and Delta-Sigma ADC: block diagram operation analysis and main characteristics.
ADC aliasing and Nyquist rule on maximum frequency. Quantization error: definition and measurement; quantization error with a ramp input and rms value calculation; quantization noise with a sinusoidal input and statistical analysis. Other sources of errors and non-linearity. ADC architectural properties and trade-offs; comparative analysis of the different ADC architectures. Example of components datasheets.
Digital interfaces: importance of interfacing in a data-acquisition system; definition of digital interface; taxonomy: synchronous and asynchronous digital interfaces; serial and parallel digital interfaces; point-to-point and shared bus connections. Serial synchronous interfaces: Serial Peripheral Interface (SPI) and Inter-Integrated Circuit bus (I2C): basic architecture and operation; characteristics and comparative analysis. Universal Asynchronous Receiver/Transmitter (UART).
Introduction to state-of-the-art design methodologies adopted for tightly energy-/power-constrained electronic systems in wearable and implantable devices: Clock gating; power gating; dynamic voltage an frequency scaling; ultra-low power techniques.

Bibliografia e materiale didattico

J. Millman, C. Halkias, “Integrated Electronics”, McGraw-Hill (any edition).
R. Jaeger, “Microelectronics”, McGraw-Hill (any edition).
Teaching and learning material (slides, notes, data sheets, etc.) provided by the lecturer.

Modalità d'esame

Oral examination usually consisting of three main questions, one of which might include the solution of an exercise similar to those seen during the course.

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