ECE 30100 – Signals and Systems

J. V. Krogmeier

August 24, 2021

Summary of Course Info

Staff:

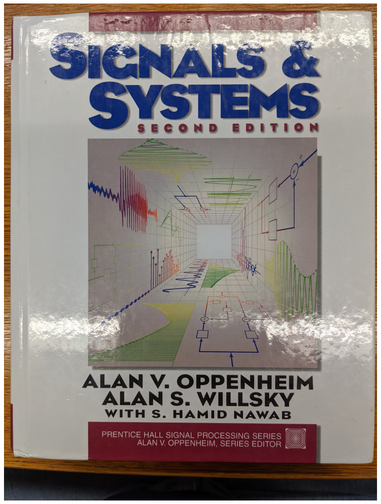
job	name	office	phone	email
lecturer	James V. Krogmeier	MSEE 274	43530	jvk at purdue dot edu
TA	Azwar Abdulsalam	online		abdulsal at purdue dot edu

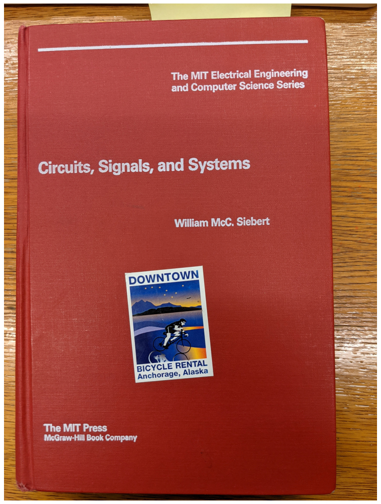
Office Hours for A. Abdulsalam: To be determined. A. Abdulsalam's office hours will be held via zoom.

Office Hours for J. V. Krogmeier: Monday/Wednesday 8:00 am to 9:00 am or by email appointment. Held via zoom. Changes to the times of office hours will be announced via email.

Text: A. V. Oppenheim and A. S. Willsky, *Signals and Systems*, 2nd edition, Prentice-Hall, 1997.

Web site: `https://engineering.purdue.edu/~jvk/301/fall21.html`





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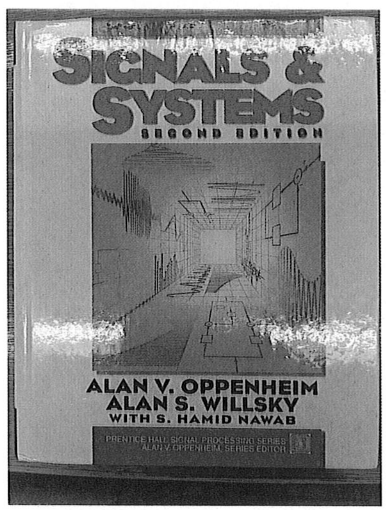

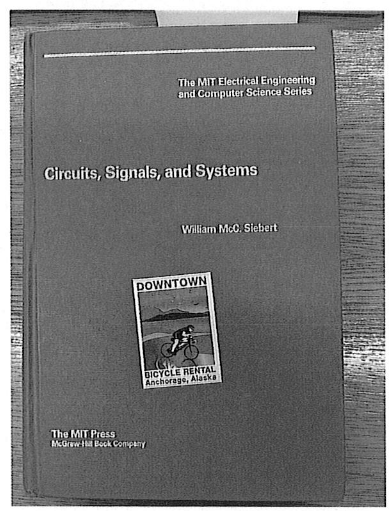

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Homework:

- Every week or two depending on lecture progress and the examination schedule.
- Turn in via Gradescope by the time and date indicated on each assignment.
- Questions posted on the web.
- Solutions posted on the web.
- Grading: some problems will be graded in detail and the others will be checked off as having been attempted.
- Rules: The only rule is that you cannot use an exact copy of another person's solution. So working in groups, using references, etc., are all fine. For your own benefit, please attempt the problems yourself. Otherwise the exams will appear impossibly difficult!

Exams:

- Three 75 minute exams in class:
  - Exam 1: Thursday September 23.
  - Exam 2: Thursday October 21.
  - Exam 3: Thursday November 18.
- A two-hour final during finals week.

Grades: An overall score will be computed using the algorithm below.

(a) All 75-minute exams that you did not take are replaced by the final exam after mean and variance normalization (assuming permission has been granted in advance).

(b) Then the overall score is computed as:

$$\text{overall score} = .10 * \text{homework} + .50 * \text{average of hour exams} + .40 * \text{final exam}$$

The course will **not** use the plus-minus grading system. Your final letter grade will be determined by rank ordering according to the overall score and applying a letter grade curve.

In the event of a major campus emergency, course requirements, deadlines, and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances.

Signals and Examples (OW pp. 1-38)

Signals and Examples (OW pp. 1-38)

Abstractly a signal: $x : \mathbb{R} \to \mathbb{C}$, $t \mapsto x(t)$ — Cont. time

$x : \mathbb{Z} \to \mathbb{C}$, $n \mapsto x[n]$ — ~~Dist.~~ Discrete time.

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* volt. acc. cap in RC circuit is a signal.
* image of a ~~scenery~~ scene recorded on retina or on CCD array in camera.
* time series of "T" on NYSE.
* EM fields ... space and time.

Signals – Time Domain

- Voltage across a capacitor in an amplifier circuit
- Image of a scene formed on the retina of the eye (formed on CCD array of a camera)
- Magnitude of the electric field of a propagating wave measured at a fixed point in space as a function of time
- Temperature measured by a thermocouple in a sensor

<u>Such signals carry information that one wishes to extract – or transform – or transmit – or encode.</u>

A signal is a function from a domain (e.g., time – a continuous variable) to a range (e.g., a subset of the real numbers, the complex numbers, etc.)

$$\begin{array}{rccc} x: & \mathcal{R} & \rightarrow & \mathcal{C} \\ & t & \mapsto & x(t) \end{array}$$

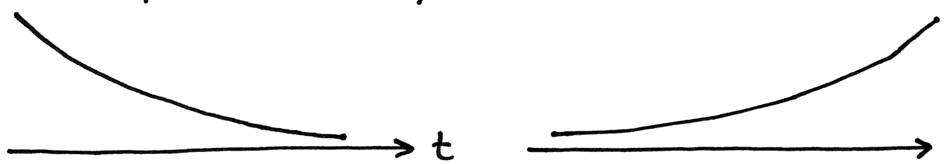
- Exponential
- Sinusoidal
- Complex sinusoidal

Generic CT Exponential Signals

Segment 2: Generic CT Exponential Signals

$$x(t) = Ce^{at} \qquad C, a \in \mathbb{C} \text{ (the complex numbers)}$$

- Real exponential: $C, a \in \mathbb{R}$ (the real numbers)



$C > 0,\ a < 0$ $\qquad$ $C > 0,\ a > 0$

- Complex sinusoid: $C \in \mathbb{C}$, $a = j2\pi f$ (ie pure imaginary)

$\Longrightarrow$ $x(t) = Ce^{at} = Ae^{j(2\pi f t + \phi)}$ $\qquad$ if $C = Ae^{j\phi}$

$\Longrightarrow$ Is periodic with period $T = 1/|f|$

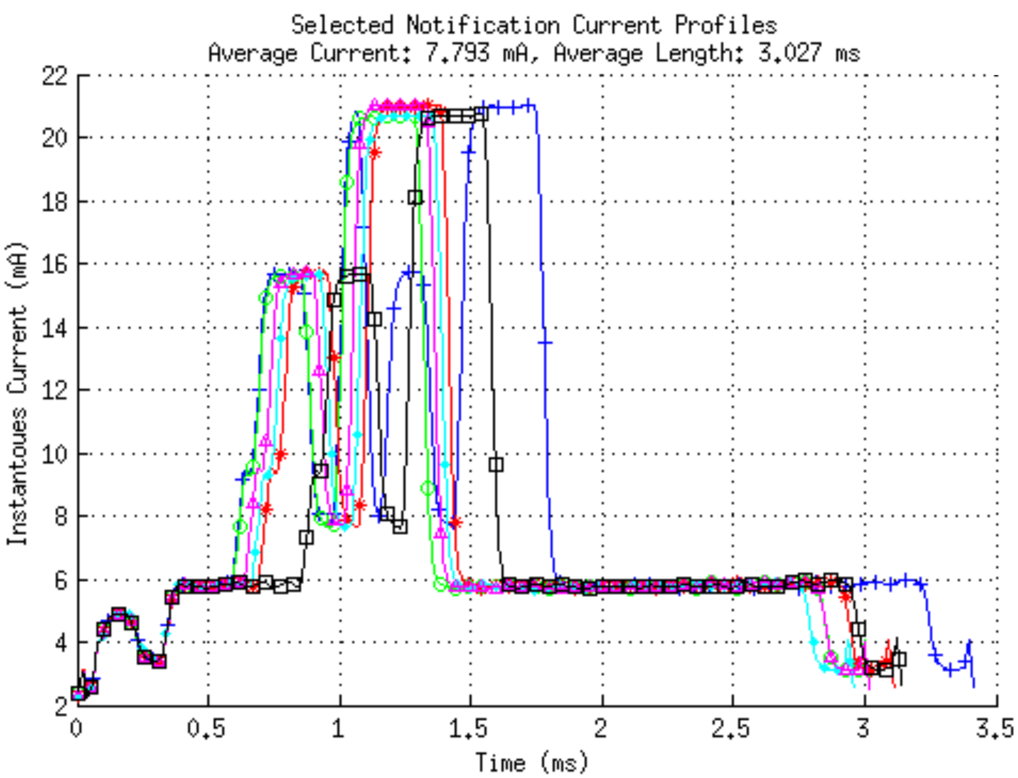
$\Longrightarrow$ From Euler $Ae^{j(2\pi f t + \phi)} = A\cos(2\pi f t + \phi) + jA\sin(2\pi f t + \phi)$

- General case: $C = Ae^{j\phi}$, $a = r + j2\pi f$

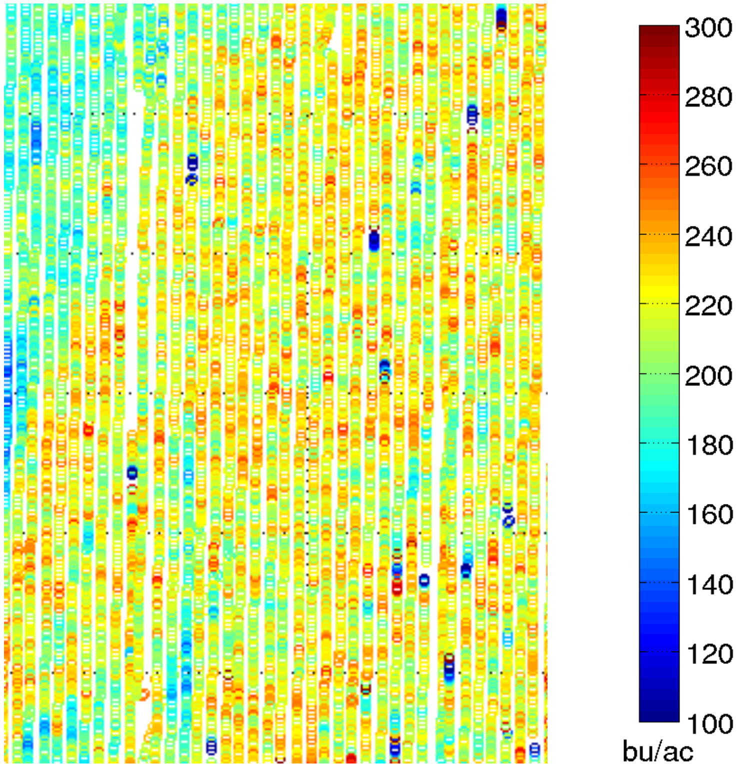
$\Longrightarrow$ $x(t) = Ae^{j\phi} e^{(r + j2\pi f)t} = Ae^{rt} e^{j(2\pi f t + \phi)}$

$$= Ae^{rt}\cos(2\pi f t + \phi) + jAe^{rt}\sin(2\pi f t + \phi)$$

Time Domain Signal: Current vs. Time in TI CC2540 Bluetooth Low Energy IC During Transition from Standby to Connection State

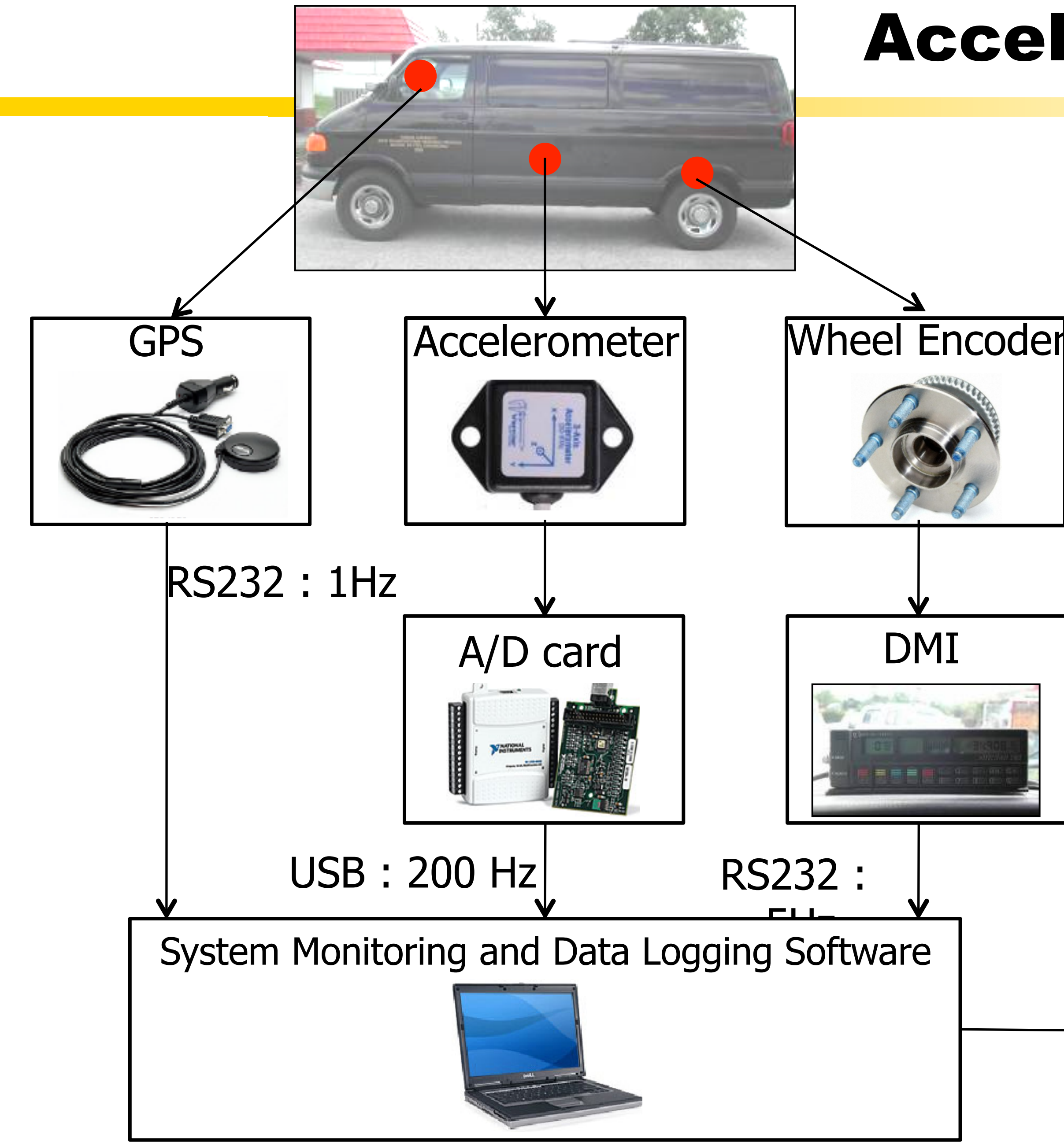


Yield Map for a Portion of a Corn Field in Central Indiana

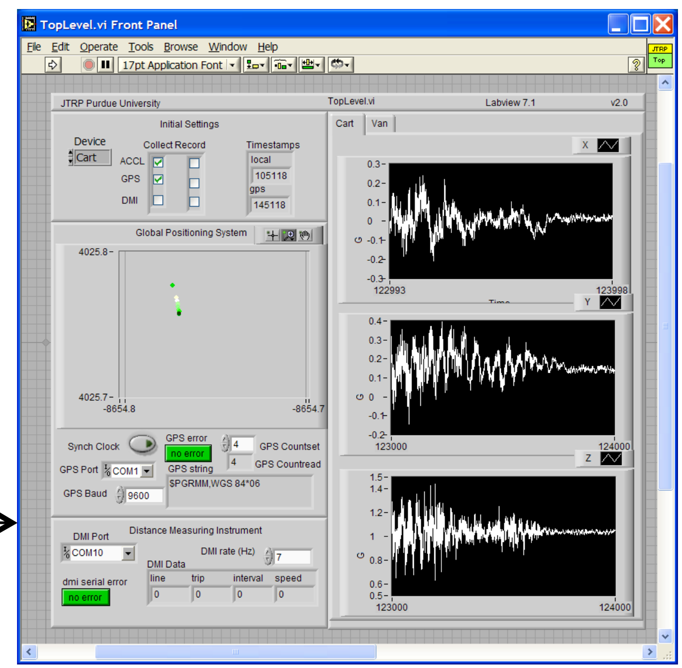


$$y(x, y) \text{ for } \begin{array}{l} x \in \mathcal{R} \text{ (easting)} \\ y \in \mathcal{R} \text{ (northing)} \end{array}$$

Vehicle Body Acceleration Meas.



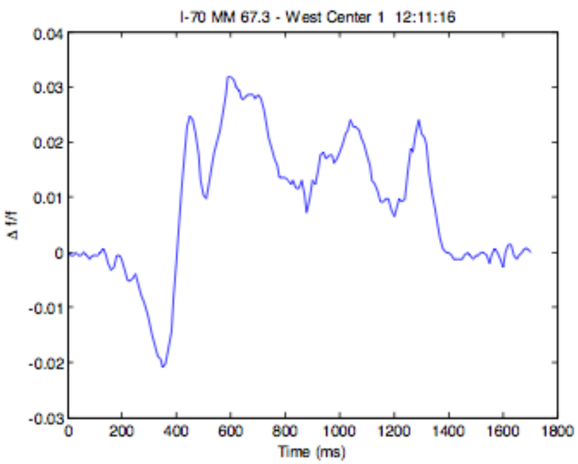
$$a_x(t)$$
$$a_y(t) \quad \text{for } t \in \mathcal{R}$$
$$a_z(t)$$



Mag. Sensor Signatures from the same truck

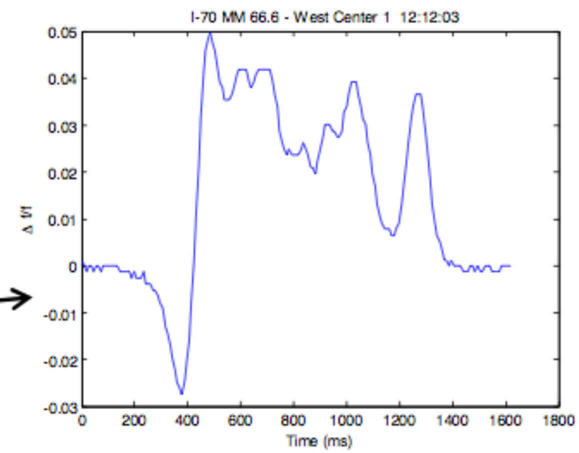
UPSTREAM SITE

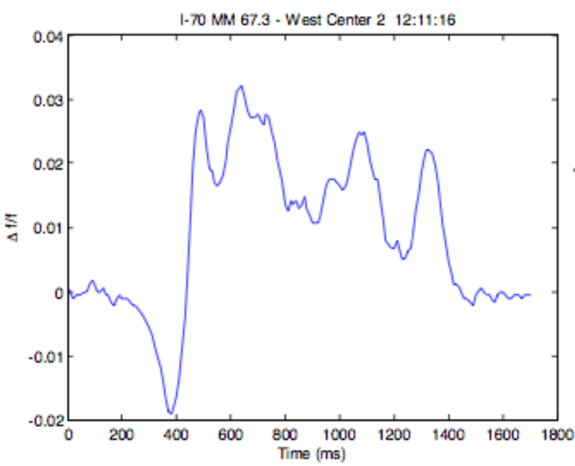
DOWNSTREAM SITE



UPSTREAM Loop 1

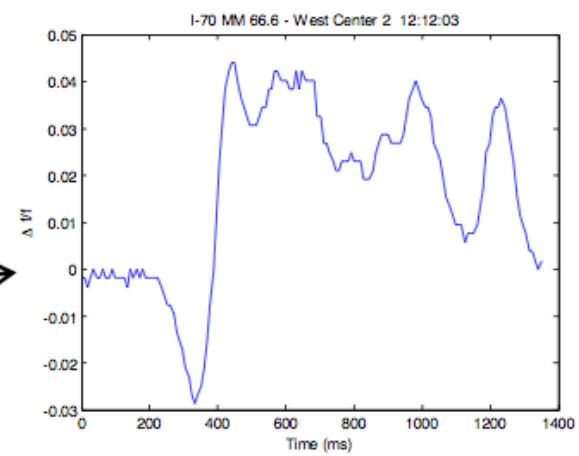
DOWNSTREAM Loop 1





UPSTREAM Loop 2

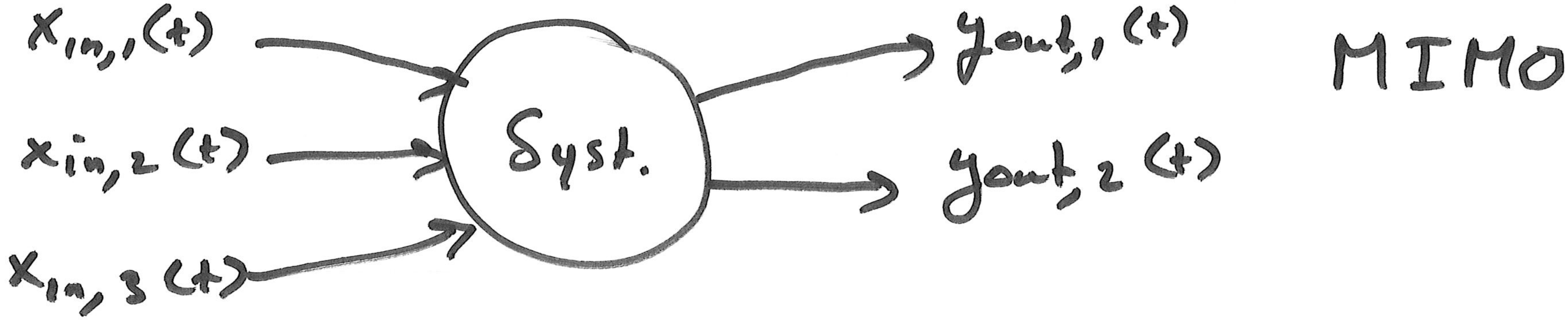
DOWNSTREAM Loop 2



Systems (OW pp. 38-43)

Systems (OW pp. 38-43)

301 point of view: Systems are black boxes...



Example: Charging an RC Circuit

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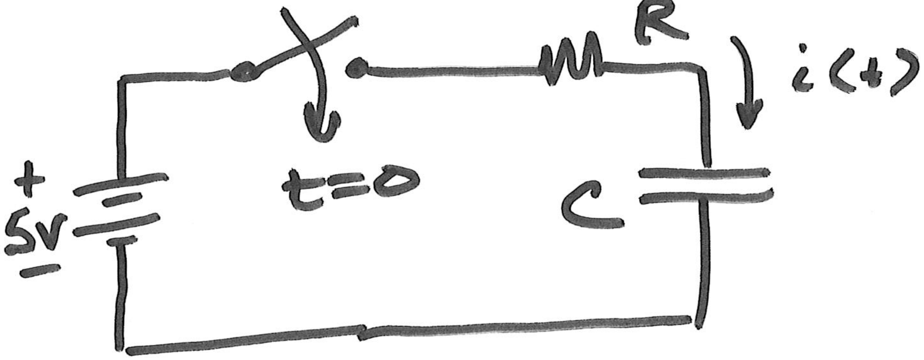
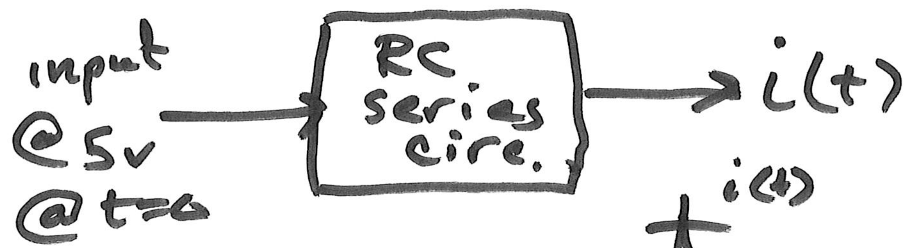
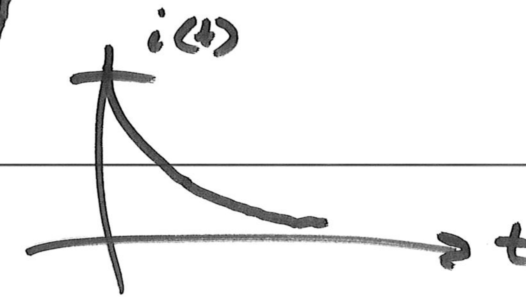






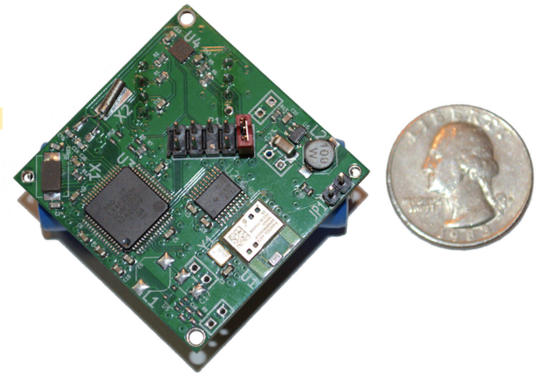
CT ⟼ CT

CT sigs ⟼ DT sigs. A/D conv.

DT sigs ⟼ CT sigs D/A conv.

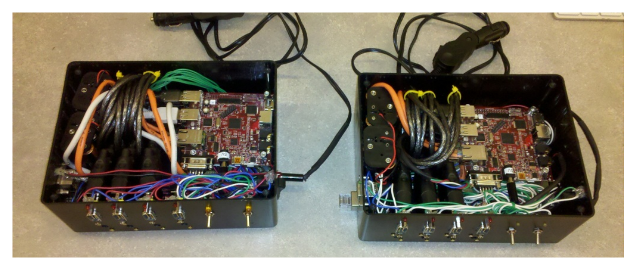
DT sigs ⟼ DT sigs digital circ. or computer.

Sensor Systems or Sensor Networking Systems



- A pressure sensor with wireless connectivity

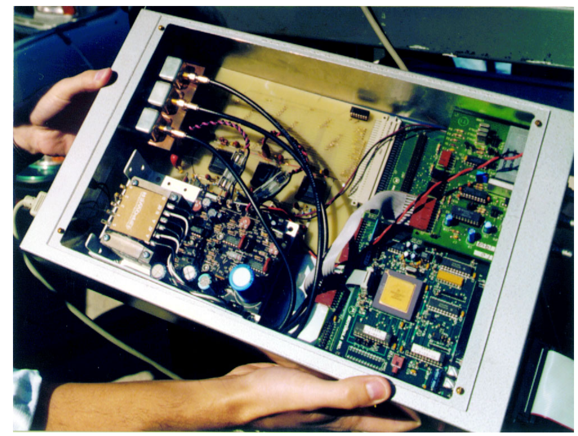
- As part of a time domain reflectometer used to measure soil density and water content



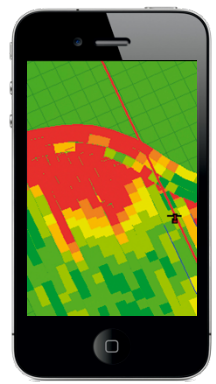
- In a generic data logger

Communication Systems

- Software defined radio

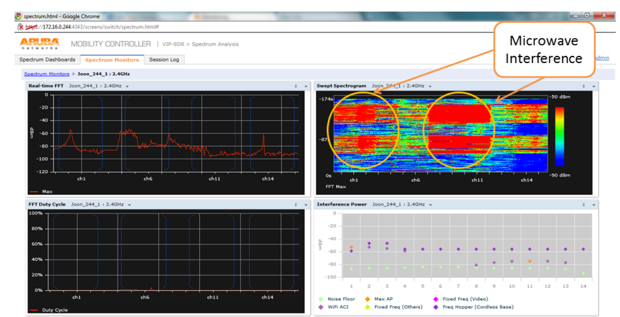


- Early experimental transmit diversity scheme



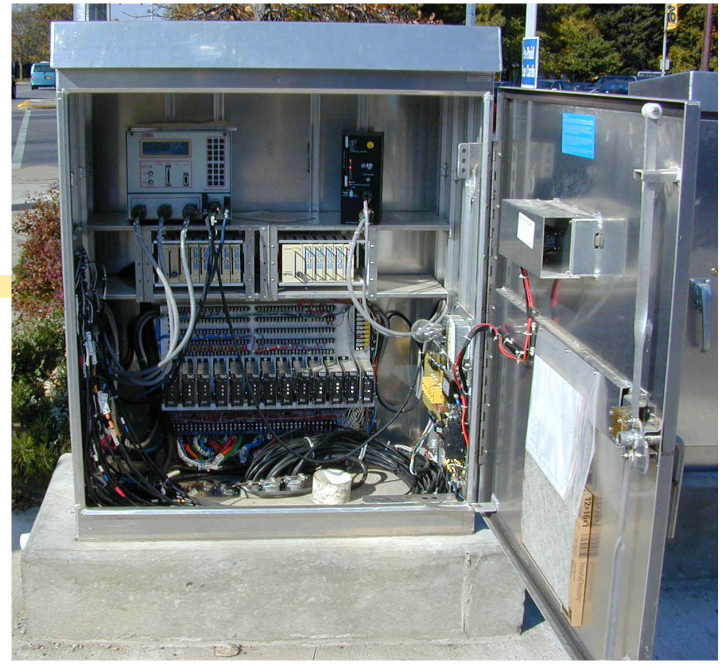
- Modern smart phones

- Spectrum sensing for WiFi interference classification

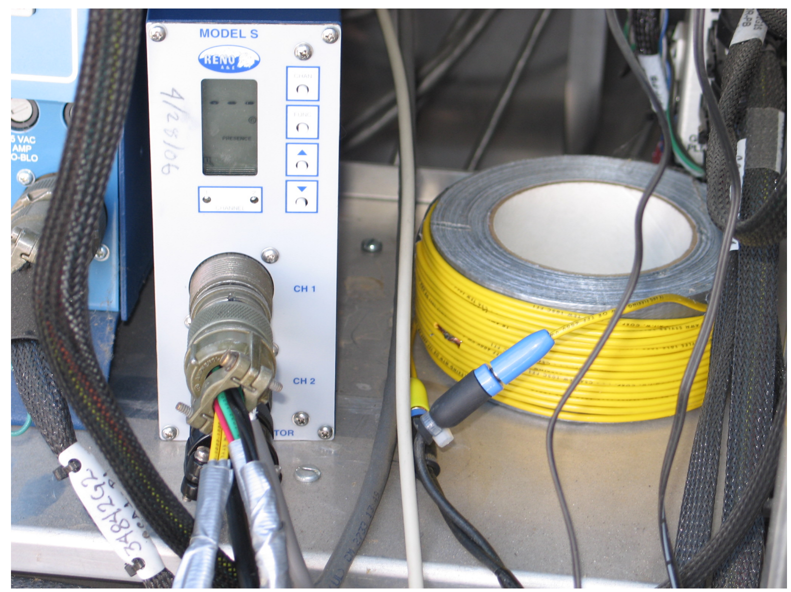


Transportation Systems

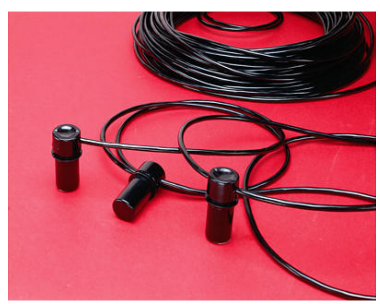
- Traffic signal control and coordination



- Inductive loop sensor systems and vehicle signature loggers

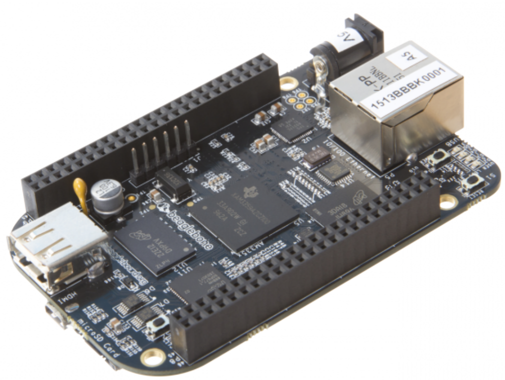


- Magnetic perturbation sensor systems

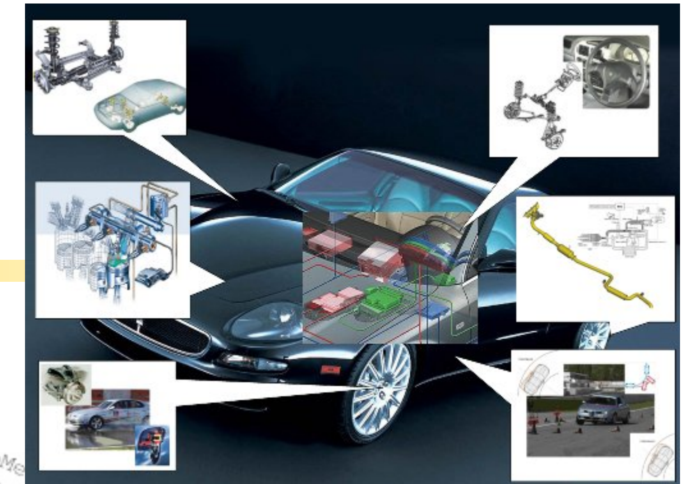


Systems In Agricultural Engineering

- High precision GPS and autosteer machines
- CANBus sensors and inertial navigation
- IsoBlue (http://isoblue.org/)



Systems In Consumer Goods

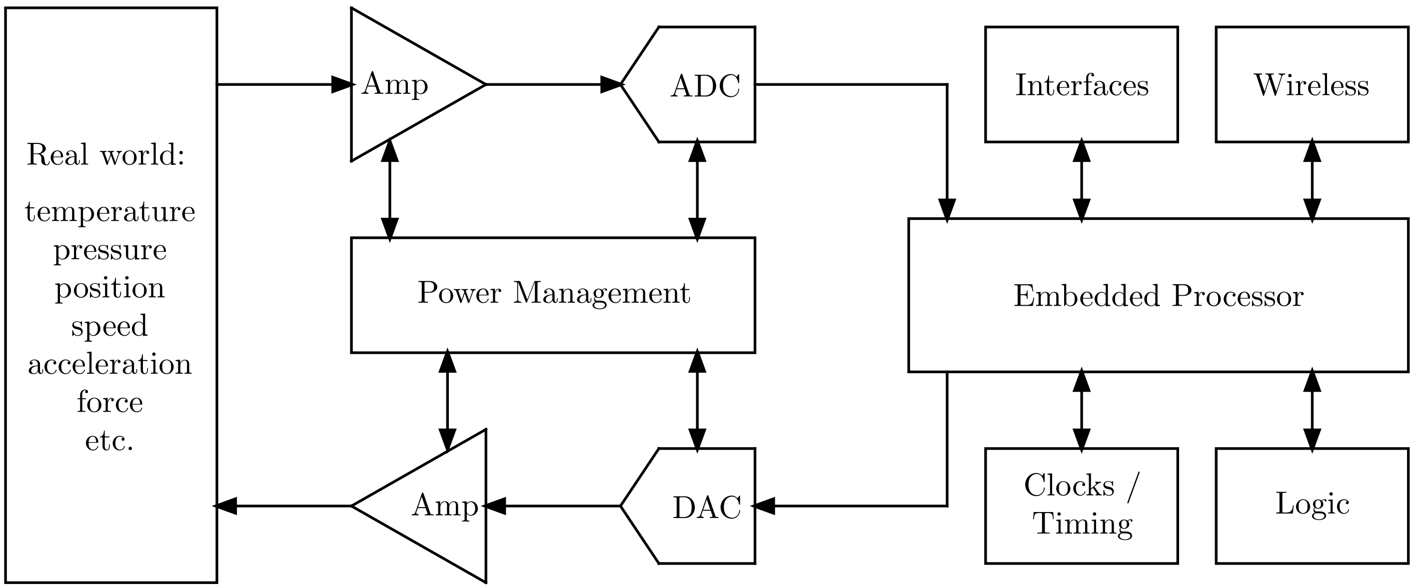


- Automobiles
- Toys
- Televisions
- Washer/dryer
- Ovens

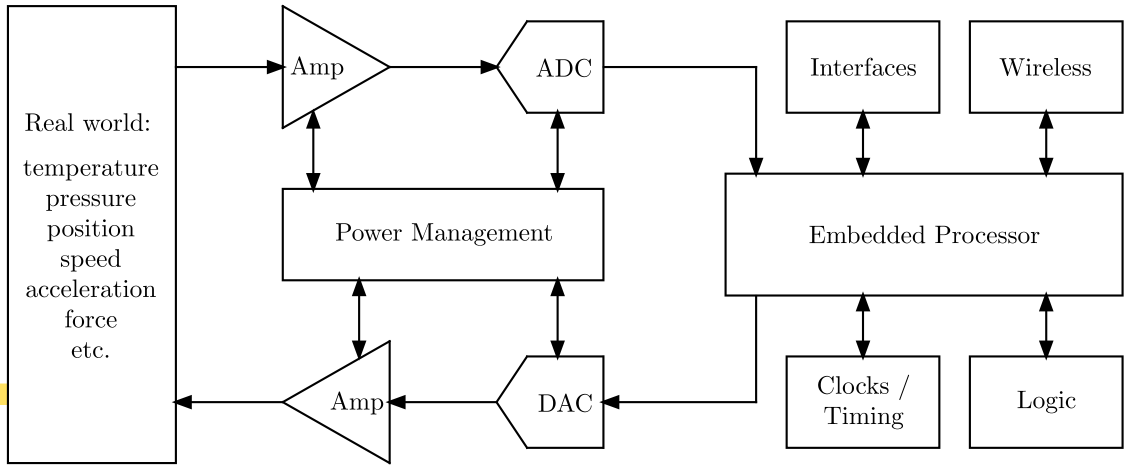
What Considerations Come Up in System Design?

- Real time performance (as opposed to average performance) ... i.e., considerations of worst case in order to meet time constraints
- Power/energy consumption
- Cost
- Often simultaneously design hardware and software

A Generic Embedded System Architecture



This course IS about … Signal Processing



- Review of Continuous-Time (CT) Signal Processing
  - Time and frequency domains
  - LTI filtering
  - Deterministic and random signals
- Introduction to Discrete-Time (DT) Signal Processing
- The Sampling Theorem
- Use of DT Methods to Effect CT Signal Processing
- Practical and Non-Ideal Considerations
  - ADCs, DACs, and finite precision
  - Serial communications, PWM
  - Timing jitter

Simple Example: Matrix-Vector Multiplication

Simple Example: Matrix-Vector Multiplication

Inputs: x, y are 2×1 real vectors $\quad x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad y = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$

(DT sigs, 2 time units long)

$$x \longrightarrow \boxed{A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}} \longrightarrow y = Ax$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} a_{11} x_1 + a_{12} x_2 \\ a_{21} x_1 + a_{22} x_2 \end{bmatrix}$$

This is a linear system:

$$x^a \longrightarrow \boxed{A} \longrightarrow y^a \quad \text{and} \quad x^b \longrightarrow \boxed{A} \longrightarrow y^b$$

$$\Longrightarrow \quad \alpha x^a + \beta x^b \longrightarrow \boxed{A} \longrightarrow \alpha y^a + \beta y^b$$

This System is Linear:

Useful Property of Linearity

Useful Property of Linearity

Suppose

$y^a = Ax^a$

$y^b = Ax^b$

$x^a, x^b \in \mathbb{R}^2$ are nonzero & non-co-linear

$\Downarrow$

$\{x^a, x^b\}$ are a basis for $\mathbb{R}^2$

Given any x^c there is a unique expression

$$x^c = \alpha x^a + \beta x^b$$

$$\Longrightarrow y^c = \alpha y^a + \beta y^b$$

Natural Choice

$$x^a = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$x^b = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

A is general

"Linear" only T.I. if have another assump..