Development of the Signals and Systems Concept Inventory (SSCI) Assessment Instrument

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Overview:

- Signals & systems curriculum
- Motivation
- SSCI
  - Background
  - Design
  - Sample questions
  - Preliminary results
- Conclusions and future directions

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Signals and systems curriculum

Signals and systems is a core electrical engineering subject

Two “flavors”:

1. continuous-time (CT)
2. discrete-time (DT)

Standard textbooks include:

- Oppenheim and Willsky with Nawab, “Signals and Systems,” 2nd edition, Prentice Hall, 1997.
- Lathi, “Signal Processing and Linear Systems,” Berkeley-Cambridge Press, 1998.

Typically taught late sophomore or early junior year, e.g.,

- At George Mason University:
  - CT S&S - 2nd semester sophomore year
  - DT S&S - 1st semester junior year
- At University of Massachusetts Dartmouth:
  - CT S&S - 1st semester junior year
  - DT S&S - 2nd semester junior year

Several reasons to develop a standardized exam ⇒

Motivation

Reasons to develop a standardized exam:

- ABET 2000 assessment
- Pedagogical questions
  - DSP first? Analog first? Mixed?
  - Studio vs. lecture
  - Individual vs. collaborative

Deller and Wang, "Highlights of Signal Processing Education," IEEE Signal Processing Magazine, 1999.

Normalized gain is a useful performance measure:

$$\text{Gain} = \frac{\text{posttest} - \text{pretest}}{100 - \text{pretest}}$$

For a particular pedagogical format, gain controls for

- student background
- instructor style

R.R. Hake, Am. J. Phys. 66, 64-74, 1998.

SSCI development began late last year $\Rightarrow$

SSCI development timeline

January 2001: Initial draft $\longrightarrow$ CT-SSCI version 1.0

Spring 2001:

- Alpha-testing of CT exam at GMU and UMassD
  - 128 students from 5 classes
  - Initial results:
    - too long (30 questions)
    - too hard (mean=29.5)
- DT exam development

Summer 2001:

- CT exam revisions $\longrightarrow$ CT-SSCI version 2.0
  - elimination of distractors $\longrightarrow$ 4 choices
  - addition of new basic problems
  - reduction to 25 questions by focusing concept list
- DT exam revisions $\longrightarrow$ DT-SSCI version 1.0
  - changes mirror CT exam
- Recruitment of study participants

New phase of testing began in August $\Rightarrow$

Ongoing study

CT exam is being administered as pre- and post-test at 4 schools:

- George Mason University
- United States Air Force Academy
- United States Naval Academy
- University of Massachusetts Dartmouth

Collecting demographic data along with test scores:

- race
- gender
- GPA
- academic year
- grades for calculus, differential equations, circuits

DT exam is in the alpha-testing phase

- answer sheet facilitates distractor analysis
  - students can write in an alternate response
- given at UMassD and will be given at GMU
- post-exam interviews planned at GMU

More about the CT SSCI ⇒

SSCI-CT Version 2.0 Concept List

The continuous-time SSCI is designed to assess students' understanding of the following fundamental concepts:

- Mathematical background for signals and systems
- Linearity and time invariance
- Convolution
- Fourier and Laplace transform representations
- Filtering with LTI systems

SSCI design considerations ⇒

Design of the SSCI

SSCI emphasizes conceptual understanding as opposed to computational mechanics

Design considerations:

- Notational issues: ω (rad/sec) versus f (Hz)
  - brief description of frequency variable on cover page
  - distractors don't distinguish between ω and f
- Modality
  - use of graphs, equations, words
- Variational approach
  - for example: ask students what changes in the frequency domain when a time domain signal is varied
- Backwards reasoning
- Importance of math background questions
- Single concepts vs. synthesis
  - value in decoupling some concepts

Consider some examples $\Rightarrow$

SSCI question: LTI filtering of narrowband pulses

SEE LANDSCAPE SLIDE

SSCI question: high vs. low frequency

Figure 1 shows four signals $x_a(t)$ through $x_d(t)$, all on the same time and amplitude scale. Which signal has the highest frequency?

(a) $x_a(t)$ (b) $x_b(t)$ (c) $x_c(t)$ (d) $x_d(t)$

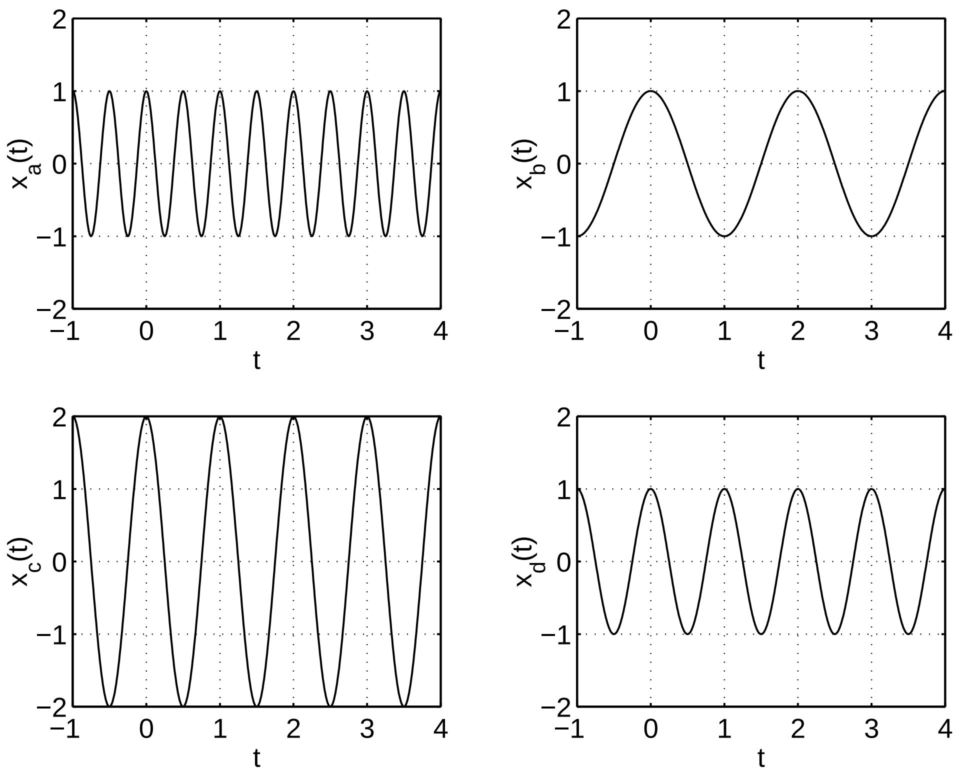


Figure 1: Signals $x_a(t)$ through $x_d(t)$ for Problem 1

SSCI question: LTI filtering of sinusoids

Consider the system with input $x(t)$ and output $y(t)$ shown in Figure 8. The magnitude and phase response (in radians) of the system are shown in Figure 9.

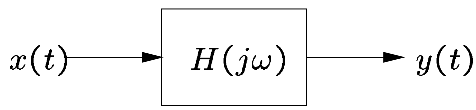


Figure 8: System for Problem 6

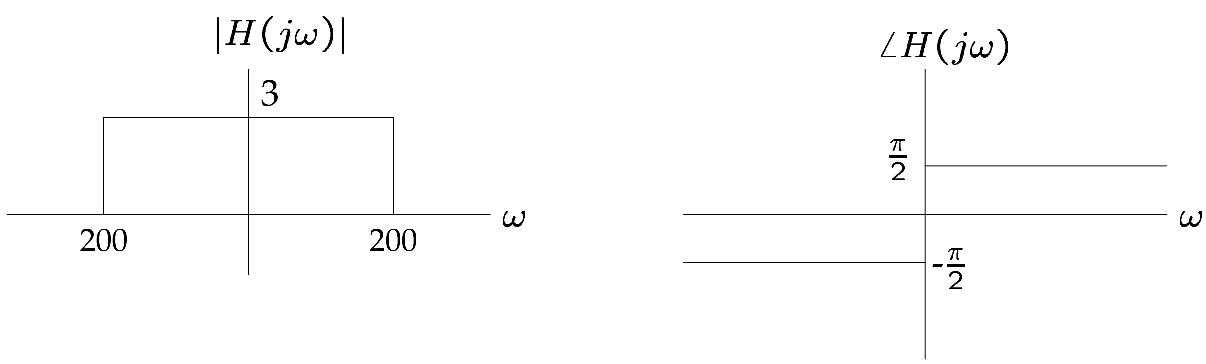


Figure 9: Magnitude and phase response of the system in Problem 6

Suppose that the input $x(t) = \cos(50t)$ for all time. What is the output $y(t)$?

(a) $3\cos(50t + \frac{\pi}{2})$

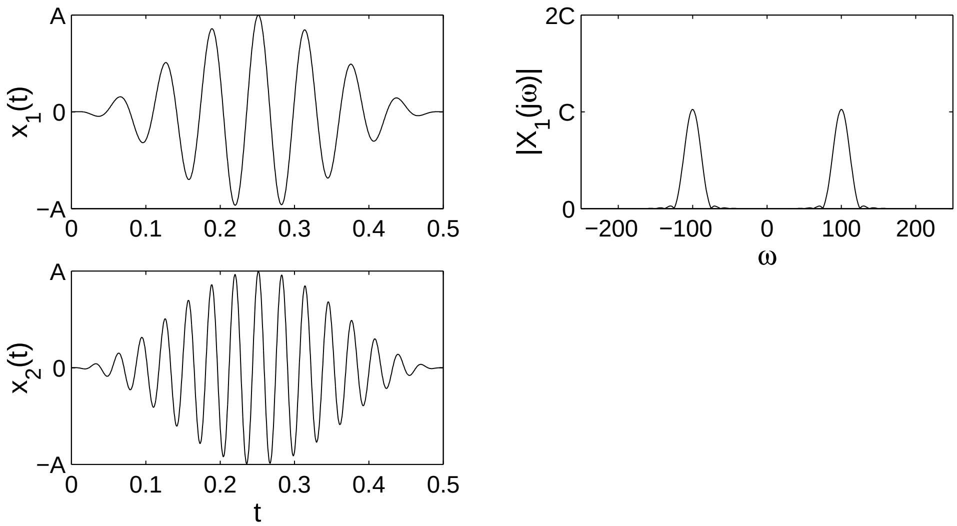
(b) $\cos(50t + \frac{\pi}{2})$

(c) $3\cos(50t)$

(d) $3\cos(200t)$

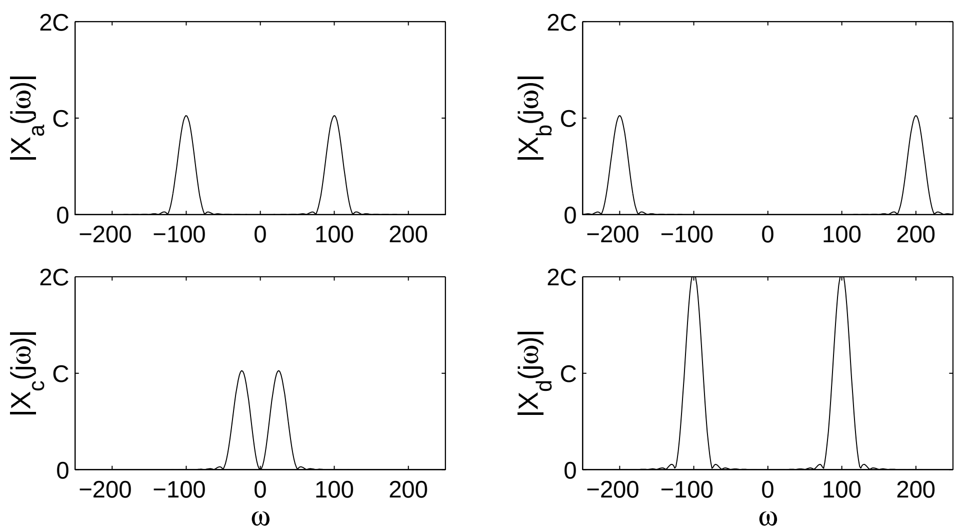
SSCI question: time-frequency relationships

Signals $x_1(t)$ and $x_2(t)$ are shown below. The Fourier transform magnitude, $|X_1(j\omega)|$, for signal $x_1(t)$ is shown on the right side of the figure.



Which of the plots shown below could be $|X_2(j\omega)|$, the Fourier transform magnitude for signal $x_2(t)$?

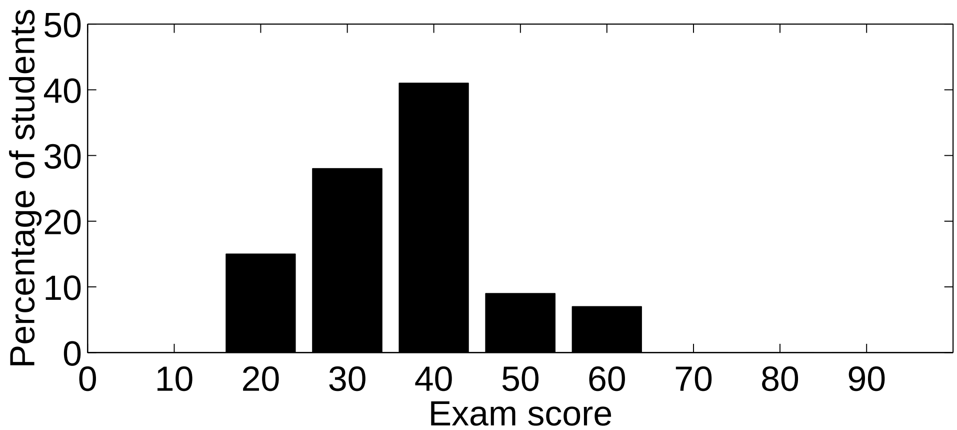
(a) $|X_a(j\omega)|$ (b) $|X_b(j\omega)|$ (c) $|X_c(j\omega)|$ (d) $|X_d(j\omega)|$



Pre-test results

68 pre-tests from UMassD and GMU have been analyzed

- Mean=41, standard deviation=10.3
- Histogram:



Results for 4 highlighted problems:

		School	
Topic	GMU (55)	UMassD (13)	Total (68)
frequency	90.9%	100%	92.6%
filtering sinusoids	60%	84.6%	64.7%
time/frequency	14.5%	46.2%	20.6%
filtering pulses	18.2%	23.1%	19.1%

Time/frequency relationships seem to be key problem:

- 81% of students who missed time/frequency question also missed pulse-filtering question

Conclusions and future directions

Summary:

- SSCI Version 2.0 is well-calibrated
- Pre-testing does make sense for signals & systems
- Linked questions diagnose student confusions

Future work:

- Establish a baseline for normalized gain
- Examine bias issues
- Look for performance predictors
- Analyze correlation statistics
- Test at broader range of schools

Acknowledgments:

ASU: Evans, Hestenes

GMU: Beale, Ephraim, Kreidl

UMassD: Estes, Jarvis, Payton

USAFA Wright, USNA Welch, BU: Nawab

Copies of exam and concept list available

To participate in this study, contact us:

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