21 Things I've Learned About Teaching

Professor Andrew E. Yagle
Dept. of Electrical Engineering
and Computer Science
The University of Michigan
Ann Arbor, Michigan USA

Outline of Presentation

- **#1-#6:** Planning to teach a new (to you) course.
- **#7-#12:** Giving lectures using a blackboard.
- **#13-#18:** Giving lectures using a laptop (like this).
- **#19-#21:** Miscellaneous

1. Why are you taking this course?

- WRONG ANSWERS:
- "Because this is a required course."
  Translation: "Because we (the faculty) say so."
  How well does that work with your children?
- "Because you need to know this material."
  Actually, this is the same as the previous reason.
- "To keep you off the streets."

1. Why are you taking this course?

- **BETTER ANSWERS**:
- **“Because this course will teach you Fourier transforms, which you will use in your future communications and electromagnetics courses.”**
- **“Because this course will teach you how to do image processing, which you can use in your optics, biomedical, or civil engineering JOBS.”**

1. Why are you taking this course?

- At University of Michigan, a 4-hour course costs about $6500 in tuition for out-of-state students.
- Students have a right to know why they should pay this for the course you are teaching.
- Following is what I do for the freshman course “Introduction to Engineering,” which teaches basics of design and technical communication.

So you want to be an EE...

- Most important: To know math & physics
- Employers look for: Technical competence (good grades in your engineering courses)
- What you will do: Apply directly what you learned in all of your engineering courses
- Your job: Electrical Engineer, obviously.
- Which statement/statements is/are wrong?

So you want to be an EE...

- Most important: To know math & physics
- Employers look for: Technical competence (good grades in your engineering courses)
- What you will do: Apply directly what you learned in all of your engineering courses
- Your job: Electrical Engineer, obviously.
- **ALL** of the above statements are **WRONG!**

U-M EE Alumni Say That:

- Most important in their professional experience

U-M EE Alumni Say That:

- Most important in their professional experience

1 Ability to function on a team

U-M EE Alumni Say That:

- Most important in their professional experience

1 Ability to function on a team

2 Oral communication skills

U-M EE Alumni Say That:

- Most important in their professional experience

1 Ability to function on a team

2 Oral communication skills

3 Written communication skills

4 Engineering problem-solving ability

5 Math, science,and engineering skills (yes, 5th)

6 Professional and ethical responsibility

2. Don’t rely on course prerequisites

- “You saw the sampling theorem in a previous course, so I will assume that you remember it and can use it.”

- Students DON’T remember it and CAN’T use it since:
- (a) They took the course a year ago and have forgotten;
- (b) They never learned it then, even though they passed;
- (c) It was covered differently, quickly, or not at all!

2. Don’t rely on course prerequisites

- Just because they saw the sampling theorem doesn’t mean they learned the sampling theorem.
- You only fully learn the contents of a course when you take the next course after that one.
- You must reteach material from previous course, especially about using it as a tool in your course.

3. Tips for problem sets (homework)

- 1st problem should be **straightforward** (not easy). Students should immediately know how to do it. Get one under their belt and build up confidence.

- 2nd and later problems should be harder; some require **several concepts** be used together to solve

- Final problem should be some sort of **design**; students **build** something and use their skills.

3. Tips for problem sets (homework)

- In Digital Signal Processing, the last problem always involves filtering a real-world signal; previous problems often mostly mathematics.
- Requires programming, so it will take longer.
- More satisfying to students when they finish it.

3. Tips for problem sets (homework)

- Urge students to start sets as early as possible.
- Make it possible for the students to start early: If a set is due Friday, should be able to start it over the weekend; finish after Monday lecture.
- DON'T require material from Wed. lecture!
- Some will wait until Thursday night (sigh). Be available to them by email that evening.

4. Tips for exams

- 1st problem should be straightforward (not easy). Students should immediately know how to do it. Get one under their belt and build up confidence.
- Don't give students something they haven't seen. Exams should NOT be "learning experiences."
- Students should look at exam afterwards and be angry that they missed any questions. If they still don't know how to do it, question was too hard.

4. Tips for exams

- **Multiple-choice** problem same as **fill-in-the-blank** (a) 10 (b) 20 (c) 40 (d) 60 (e) 80 Circle correct one
- Avoids partial credit "**noise**" and complaints;
- Helps students: **error correction** if no match;
- Is more **fair**: If a student can **eliminate** some choices, this improves chances of correct answer. This can be viewed as a form of partial credit.
- Is more **realistic**: no partial credit in real world!
- Admit it: Easy to grade. Fast return to students.

4. Tips for exams

- Many in EECS department use 12-16 page exam: One problem per page, plenty of room for work.
- But in grading, don’t usually trace through work (too hard to redo computation from some error).
- Wastes much paper and copying expenses.
- I use ONE sheet (two sides) for my exams. Write answers directly on exam, staple extra pages with any work (usually 1-2 pages). MUCH less paper!

EECS 451 EXAM #2 Fall 2008

PRINT YOUR NAME HERE:

HONOR CODE PLEDGE: "I have neither given nor received aid on this exam, nor have I concealed any violations of the honor code." Closed book; 4 sides of 8.5×11 "cheat sheet."

SIGN YOUR NAME HERE:

CIRCLE ONE: Undergraduate Graduate

Write your answer to each question in the answer space to the right of that question. Problems #1-15 are multiple choice (here same as fill-in-the-blank) worth 5 points each.

1. The DFT of $\{12, 8, 4, 8\}$ is: **(a)** $\{8, 1+j2, 4, 1-j2\}$ **(b)** $\{8, 1-j2, 4, 1+j2\}$ **(c)** $\{32, 4-j8, 16, 4+j8\}$ **(d)** $\{8, 2, 0, 2\}$ **(e)** $\{32, 8, 0, 8\}$

2. The DFT of $\cos(\frac{\pi}{4}n)$ is: **(a)** $\{4,0,0,0,0,0,0,4\}$ **(b)** $\{0,4,0,0,0,0,0,4\}$ **(c)** $\{0,0,4,0,0,0,4,0\}$ **(d)** $\{0,4,0,0,0,0,4,0\}$ **(e)** $\{0,0,0,4,4,0,0,0\}$

3. Which signal is eliminated by $y[n]-y[n-1]=x[n]+x[n-1]+x[n-2]$: **(a)** 1 **(b)** $\cos(\frac{\pi}{4}n)$ **(c)** $\cos(\frac{\pi}{3}n)$ **(d)** $\cos(\frac{\pi}{2}n)$ **(e)** $\cos(\frac{2\pi}{3}n)$

4. Which of these filters eliminates 375 Hz in a signal sampled at 1 kHz? $h[n]=$: **(a)** $\{1,1,1\}$ **(b)** $\{1,-1,1\}$ **(c)** $\{1,0,1\}$ **(d)** $\{1,0,-1\}$ **(e)** $\{1,\sqrt{2},1\}$

5. The response of $y[n]=8x[n]+3x[n-1]+4x[n-2]$ to $x[n]=\cos(\frac{\pi}{2}n)$ is: **(a)** $9\cos(\frac{\pi}{2}n)$ **(b)** $5\cos(\frac{\pi}{2}n+37^o)$ **(c)** $15\cos(\frac{\pi}{2}n)$ **(d)** $5\cos(\frac{\pi}{2}n-37^o)$ **(e)** $9\sin(\frac{\pi}{2}n)$

6. If $x[n]=\cos(\frac{\pi}{2}n)+\cos(\pi n)$ then $y[n]=x[n]+x[n-1]+x[n-2]+x[n-3]=$: **(a)** $\cos(\frac{\pi}{2}n)$ **(b)** $\cos(\pi n)$ **(c)** $2\cos(\frac{\pi}{2}n)+3\cos(\pi n)$ **(d)** $4x[n]$ **(e)** 0

7. The system having frequency response $[2e^{-j\omega}]/[1+3e^{-j2\omega}]$ is: **(a)** $y[n-1]=\frac{1}{2}x[n]+\frac{3}{2}x[n-2]$ **(b)** $y[n]+3y[n-2]=2x[n-1]$ **(c)** $y[n]=x[n]+3x[n-2]$ **(d)** $y[n]+3y[n-1]=2x[n]$ **(e)** $y[n]+3y[n-1]=2x[n-1]$

8. The filter eliminating discrete-time frequencies $\omega=\frac{\pi}{3}$ and $\omega=\frac{2\pi}{3}$ is: **(a)** $\{1,0,1,0,1\}$ **(b)** $\{1,0,1.25,0,1\}$ **(c)** $\{1,0,1.75,0,1\}$ **(d)** $\{1,.27,-1.46,.27,1\}$

9. The frequency response function of $y[n]+y[n-2]=x[n]-x[n-2]$ is: **(a)** $\tan(\omega)$ **(b)** $j\tan(\omega)$ **(c)** $\cot(\omega)$ **(d)** $-j\cot(\omega)$ **(e)** $\frac{1-e^{-j\omega}}{1+e^{-j\omega}}$

10. The system y(n)=x(n+1)+3x(n)+ax(n-1) has zero phase for all frequencies for a=: **(a)** 1/2 **(b)** 1 **(c)** 2 **(d)** 3 **(e)** No values of a

11. The system y(n)=x(n)+x(n-1)+ax(n-2) has a stable and causal inverse for a=: **(a)** 1/2 **(b)** 1 **(c)** 2 **(d)** 3 **(e)** No values of a

12. Which function *cannot* be the DTFT of any $x[n]$: **(a)** $\cos(2\omega)$ **(b)** $\sin(2\omega)$ **(c)** $\cos(\omega/2)$ **(d)** $|\sin(\omega/2)|$ **(e)** $\sin(\omega)$

13. The *cyclic* convolution $\{\underline{3},1,4\}$ⓒ$\{\underline{2},7,1\}$ is: **(a)** $\{\underline{6},23,18,29,4\}$ **(b)** $\{\underline{24},52,4\}$ **(c)** $\{\underline{6},52,22\}$ **(d)** $\{\underline{10},52,18\}$ **(e)** $\{\underline{35},27,18\}$

14. Which system has gain function $\sqrt{(3+4\cos\omega)^2+16\sin^2\omega}/\sqrt{(1+2\cos\omega)^2+4\sin^2\omega}$? **(a)** $3y[n]+4y[n-1]=x[n]+2x[n-1]$ **(b)** $y[n]+2y[n-1]=3x[n]+4x[n-1]$ **(c)** $4y[n]+3y[n-1]=2x[n]+x[n-1]$ **(d)** $2y[n]+y[n-1]=4x[n]+3x[n-1]$ **(e)** $y[n]=x[n]+x[n-1]$

[10] 15. For $H(\omega)=1+4e^{-j\omega}+3e^{-j3\omega}$, the response to $x[n]=1+2\cos(\frac{\pi}{2}n)+3\cos(\pi n)$ is $y[n]=$: **(a)** 0 **(b)** $8+4\sqrt{2}\cos(\frac{\pi}{2}n-\frac{\pi}{4})$ **(c)** $4\sqrt{2}\cos(\frac{\pi}{2}n-\frac{\pi}{4})-18\cos(\pi n)$ **(d)** $8+4\sqrt{2}\cos(\frac{\pi}{2}n+\frac{\pi}{4})-18\cos(\pi n)$ **(e)** $8+2\sqrt{2}\cos(\frac{\pi}{2}n-\frac{\pi}{4})-18\cos(\pi n)$

[10] 16. (Period=8, real, even) $x[n]\rightarrow\boxed{y[n]=x[n]-x[n-2]+x[n-4]-x[n-6]}\rightarrow y[n]$

Make a stem plot of $y[n]$ on the axis below. Don't worry about the vertical scale.

HINT: $(z^6-z^4+z^2-1)(z^2+1)=(z^8-1)$. What do the zeros do to periodic $x[n]$?

0 1 2 3 4 5

[10] 17. A LTI system has $H(z)=[(z-e^{j2\pi/3})(z-e^{-j2\pi/3})]/[(z-0.99e^{j\pi/3})(z-0.99e^{-j\pi/3})]$.

Sketch the relative magnitude of its frequency response (i.e., gain) on the plot below.

$-\pi$ 0 π

5. Teaching a course for the 1st time?

- Decide what you want to accomplish in course: what should students know how to do afterward?
- Choose goals and objectives for the course, e.g., "Ability to design an FIR filter by placing zeros"
- Only THEN do you decide which topics to cover;
- Decide order so that one topic leads to another;
- Write syllabus; include time for review & exams.

COURSE: EECS 215.**TITLE:**Intro. to Circuits.**PREREQUISITES:**Math 116 & Physics 240;**CO-REQS**:Math 216 & EECS 206	**REQUIRED**

TEXTBOOK: R.E. Thomas & A.J.Rosa, *Analysis and Design of Linear Circuits: Laplace Early*; A. Ganago, *Circuits Make Sense*; Wiley, 4th ed.

CATALOG DESCRIPTION: Introduction to electrical circuits. Kirchhoff's voltage and current laws; Ohm's law; voltage and current sources; Thevenin and Norton equivalent circuits; energy and power. Time-domain and frequency-domain analysis of RLC circuits. Operational amplifier circuits. Basic passive and active electronic filters. Laboratory experience with electrical signals and circuits.

COURSE OBJECTIVES:

1. To acquaint students with the basic concepts and properties of electrical circuits and networks;
2. To provide basic laboratory experience with analyzing and building simple filters and amplifiers;
3. To teach students how to analyze and design simple electrical filters and amplifiers using op-amps;
4. To teach students how to use phasors, s-plane analysis, and Bode plots for frequency response;
5. To prepare students for follow-up courses in the Circuits area of the Electrical Engineering program.

COURSE OUTCOMES [Program Outcomes Addressed]

1. Ability to analyze circuits using Kirchhoff's voltage & current laws; node & mesh analysis; [1,13]
2. Ability to analyze circuits containing ideal op-amps, capacitors, and inductors using s-plane; [1,14]
3. Ability to compute transient responses of circuits containing capacitors and inductors; [1,14]
4. Ability to compute frequency responses of circuits containing capacitors and inductors; [1,13]
5. Ability to compute transfer functions and Bode plots for simple circuits, and vice-versa; [1,3,13]
6. Ability to compute power dissipation, power factor, and maximum power transfer; [1,13]
7. Ability to use digital oscilloscopes, meters, and waveform generators in laboratory; [2,5,11]

PROGRAM OUTCOMES ADDRESSED: 1,2,3,5,11
PROFESSIONAL COMPONENT ADDRESSED: 13,14
PREPARED BY: Andrew E. Yagle on Nov. 8, 2004

CLASS/LABORATORY SCHEDULE:
LECTURES: 3 per week @ 50 minutes.
LABORATORY: 1 per week @ 2 hours.

TOPICS COVERED:

1. Kirchhoff's voltage & current
2. Node and mesh analysis
3. Ohm's law and ideal sources
4. Thevenin & Norton
5. Ideal op-amp circuits
6. Inductors and capacitors
7. Transient circuit response
8. Phasors, s-plane, impedance
9. Bode plot & frequency response
10. Filtering and simple filter

ASSESSMENT (Course outcomes)

1. 11 problem sets [1,2,3,4,5,6]
2. 11 labs [4,5,7]; students work in pairs; written reports
3. 3 closed-book examinations [1,2,3,4,5,6]

5. Teaching a course for the 1st time?

- Now take your syllabus and list of topics and **CUT IT BY ONE-THIRD (1/3)!** I mean it!

- The 1st time you teach a course you **always** put too much material and tasks into it!
- When **advising** students: If you know someone is teaching a course for the 1st time; **warn them**! Don’t advise not to take; will be unusually hard.

5. Teaching a course for the 2nd time?

Now that you know it was too hard and too much:

- **Better to teach some of the material very well than to teach all of the material not very well**
- **Emphasize those topics with which you are most comfortable, knowledgeable and able to teach**
- **Coverage will jitter about 10% term-to-term (this is one reason not to rely on prerequisites)**

6. Yours isn't their only course

- Students typically take 4-5 courses each term. Your course is only one of those four or five.
- Your course is the most important one they are taking (obviously); but students may disagree!
- Some of those other courses have associated labs. A lab takes as much time as another course.

6. Yours isn't their only course

- Students often have jobs; student societies; other extracurricular activities; interviews; i.e., lives.
- You have their attention for about 1 night/week. Usually this is the night before homework is due.
- Asking too much work of students will result in buffer overflow. Teach less material, but better.

Outline of Presentation

- **#1-#6:** **Planning to teach a new (to you) course.**
- **#7-#12:** **Giving lectures using a blackboard.**
- **#13-#18:** **Giving lectures using a laptop (like this).**
- **#19-#21:** **Miscellaneous**

7. Why are we learning this topic?

- **WRONG ANSWERS:**
- "Because it's in the syllabus." **Well, why is it?**
- "Because courses like this always cover this." **Well, why do they always cover this?**
- "Because it will be on the exam." **Oh, OK.**
- "To keep you off the streets."

7. Why are we learning this topic?

- **BETTER ANSWERS**:
- **“Learning Fourier transforms allows us to:**
- **(a) Recover signals from their digital samples, which makes digital signal processing possible;**
- **(b) Modulate signals for communications, and employ AM, single sideband, etc. schemes; and**
- **(c) Filter noisy signals to reduce the noise.**
- **We can do some neat stuff once we learn this!**

7. Why are we learning this topic?

- When introducing a topic:
- (1) What is a Fourier Transform?
- (2) What is it FOR? (always a good question).
- (3) Where will we be using it? (show in syllabus).

- This is one sight on a tour, not one step on the Bataan death march! (sometimes seems that way)

8. KISS (Keep It Simple, Stupid!)

- Beginning of lecture: List lecture topics on board. Big help to students looking through their notes.
- State when ending a topic and starting another.
- End of lecture: Quickly review what you've done. You will have to leave time at the end for this.
- Inform students what topics are really important (no, not everything you cover is really important)
- Always note how a topic relates to previous ones.

8. KISS (Keep It Simple, Stupid!)

- Lecture handouts: I have had much success with handouts like the one shown in following slide.
- No staples! Keep to a page or two sides of a page.
- Reading decays geometrically with page number.
- President Ronald Reagan refused to read past the 1st page of any memo. Worked for him.
- Do you really read 25 page lecture handouts or homework solutions? (I didn't, and I was a nerd)

EECS 216 LECTURE NOTES

REVIEW (?) OF COMPLEX NUMBERS

DEF: $j=\sqrt{-1}$. Use j not i in EECS since i=current in EECS!
DEF: A complex number z can be written as $z=x+jy=Me^{j\theta}=M\angle\theta$
where: $x+jy$=**rectangular** form of z; $Me^{j\theta}=M\angle\theta$=**polar** form of z.
AND: $x=Re[z]$; $y=Im[z]$; $M=|z|$; $\theta=arg[z]$.
Real part Imag part Magnitude Argument or phase

LEMMA: **Euler's theorem:** $e^{j\theta}=\cos\theta+j\sin\theta$.
WHY? Insert $x=j\theta$ into the infinite series $e^x=1+x+x^2/2!+\ldots$.
ALSO: $\cos\theta=\frac{1}{2}(e^{j\theta}+e^{-j\theta})$; $\sin\theta=\frac{1}{2j}(e^{j\theta}-e^{-j\theta})$.

Converting rectangular form⇔polar form:

P→R: $Me^{j\theta}=x+jy$ where $x=M\cos\theta$ and $y=M\sin\theta$.
R→P: $x+jy=Me^{j\theta}$ where $M=\sqrt{x^2+y^2}$ and $\tan\theta=y/x$.

Summary: $\begin{cases} x=M\cos\theta \\ y=M\sin\theta\end{cases}$; $M=\sqrt{x^2+y^2}$; $\theta=\begin{cases}\arctan\frac{y}{x} & \text{if } x>0; \\ \arctan\frac{y}{x}\pm\pi & \text{if } x<0\end{cases}$.

EX#1: $+3+j4=5e^{+j0.927}$ since $5=\sqrt{3^2+4^2}$ and $+0.927=\arctan\frac{+4}{+3}$.
EX#2: $-3-j4=5e^{-j2.214}$ since $5=\sqrt{3^2+4^2}$ and $-2.214=\arctan\frac{-4}{-3}-\pi$.
HINT: Draw an *Argand diagram* ($Im[z]$ vs. $Re[z]$) to visualize.
Matlab: `abs(3+4j); angle(3+4j); real(3+4j); imag(3+4j)`

Adding, Subtracting, Multiplying, Dividing:

- **Add and subtract** complex numbers in **rectangular** form.

since: $(a+jb)+(c+jd)=(a+c)+j(b+d)$. **Note:** $Re[z+w]=Re[z]+Re[w]$.
EX: $5e^{j0.927}+\sqrt{2}e^{j0.785}=(3+j4)+(1+j)=4+j5=6.4e^{j0.896}$.

- **Multiply and divide** complex numbers in **polar** form.

since: $(M_1e^{j\theta_1})(M_2e^{j\theta_2})=(M_1M_2)e^{j(\theta_1+\theta_2)}$. **Note:** $|zw|=|z|\cdot|w|$.
EX: $(3+j4)(1+j)=(5e^{j0.927})(\sqrt{2}e^{j0.785})=5\sqrt{2}e^{j1.71}=-1+j7$.

- **Multiplying and dividing** in rectangular form:

$(a+jb)(c+jd)=(ac-bd)+j(ad+bc)$; $\frac{a+jb}{c+jd}=\frac{a+jb}{c+jd}\frac{c-jd}{c-jd}=\frac{ac+bd}{c^2+d^2}+j\frac{bc-ad}{c^2+d^2}$ (ugh)
EX: $(3+j4)(1+j)=(3\cdot1-4\cdot1)+j((4\cdot1)+(3\cdot1))=-1+j7=5\sqrt{2}e^{j1.71}$.

EX: Compute $2\sqrt{3}e^{j\pi/6}+2e^{-j\pi/3}$. Convert polar to rectangular:
$=(2\sqrt{3}\cos(\pi/6)+j2\sqrt{3}\sin(\pi/6))+(2\cos(\pi/3)+j2\sin(-\pi/3))$
$=(2\sqrt{3}(\sqrt{3}/2)+j2\sqrt{3}(1/2))+(2(1/2)-j2(\sqrt{3}/2))=4$. (!)

EX: $(2\sqrt{3}e^{j\pi/6})/(2e^{-j\pi/3})=\frac{2\sqrt{3}}{2}e^{j(\pi/6-(-\pi/3))}=\sqrt{3}e^{j\pi/2}=j\sqrt{3}$.

EECS 216 LECTURE NOTES

PHASORS: COMPLEX NUMBERS REPRESENT SINUSOIDS

Phasors: Represent sinusoid $x(t)=M\cos(\omega t+\theta)$ with complex no. $X=Me^{j\theta}$.
Note: $x(t)=Re[Xe^{j\omega t}]=Re[Me^{j\theta}e^{j\omega t}]=Re[Me^{j(\omega t+\theta)}]=M\cos(\omega t+\theta)$.
Why? $A\cos(\omega t+\theta)+B\cos(\omega t+\phi)=Re[Ae^{j(\omega t+\theta)}+Be^{j(\omega t+\phi)}]$
$=Re[e^{j\omega t}(Ae^{j\theta}+Be^{j\phi})]=Re[e^{j\omega t}(Ce^{j\psi})]=C\cos(\omega t+\psi)$.
where: $Ae^{j\theta}+Be^{j\phi}=Ce^{j\psi}$. Add sinusoids ⇔ add complex numbers!

EX#1: Simplify $x(t)=3\cos(\omega t)+3\cos(\omega t+120^o)+3\cos(\omega t+240^o)$.
Hard: Use cosine addition formula→mess. If do it right, get $x(t)=0$ (?!)
Easy: Phasors: $X=3e^{j0}+3e^{j120^o}+3e^{j240^o}=0\to x(t)=Re[Xe^{j\omega t}]=0$!
Why? Draw picture in complex plane: easy to see resultant of these=0!

EX#2: Show that $5\cos(\omega t+53^o)+\sqrt{2}\cos(\omega t+45^o)=6.4\cos(\omega t+51^o)$.
Hard: Use cosine addition formula twice. Left as exercise for student.
Easy: $5e^{j53^o}+\sqrt{2}e^{j45^o}=(3+j4)+(1+j)=(4+j5)=6.4e^{j51^o}$. QED.

1. Sinusoids must **all be at the same frequency** to add their phasors. If different frequencies: partition into sums at same frequency.
2. Use $\sin(\omega t+\theta)=\cos(\omega t+\theta-\pi/2)$ as necessary.
3. Multiplying sinusoids is NOT equivalent to multiplying phasors!

OTHER COMPLEX NUMBER FACTS:

DEF: **Complex conjugate** z^* of z is $z^*=x-jy=Me^{-j\theta}=M\angle-\theta$.
1. $|z^*|=|z|$; $|z|^2=zz^*$; $arg[z^*]=-arg[z]$; $(zw)^*=z^*w^*$.
2. $\frac{1}{z}=\frac{1}{z}\frac{z^*}{z^*}=\frac{z^*}{|z|^2}$. Compare to rectangular division formula.
3. $z=Me^{j\theta}\to z^*=Me^{-j\theta}$; $\frac{1}{z}=\frac{1}{M}e^{-j\theta}$; $-z=Me^{j(\theta\pm\pi)}$.
4. $A\cos(\omega t+\theta)=\frac{1}{2}(X+X^*)$ where $X=Ae^{j(\omega t+\theta)}=Ae^{j\theta}e^{j\omega t}$.
5. $Re[z]=\frac{1}{2}(z+z^*)$ and $|e^{j|z|}|=1$ for **any** complex z.

OTHER COMPLEX NUMBER TRICKS:

1. $Im[3+j4]=4$ **NOT** $j4$! **VERY common mistake!**
2. $e^{\pm j\pi}=-1$. $j=e^{j\pi/2}$ and $-j=e^{j3\pi/2}$ ⇔ $\cos(\omega t\pm90^o)=\mp\sin(\omega t)$.
3. $j(3+j4)=-4+j3=(1e^{j90^o})(5e^{j53^o})=5e^{j143^o}$: 90^o rotation.
4. Compute $\left|\frac{5(8+j)(8+j6)(5+j12)(5+j10)}{26(7+j4)(7+j24)(2+j11)}\right|=\sqrt{\frac{(25)(65)(100)(169)(125)}{(26)^2(65)(625)(125)}}=1$.
5. The following identity is true to an overall sign. Why?

$$\frac{(a+jb)(c+jd)}{(e+jf)(g+jh)}=\sqrt{\frac{(a^2+b^2)(c^2+d^2)}{(e^2+f^2)(g^2+h^2)}}\exp j[\tan^{-1}\frac{b}{a}+\tan^{-1}\frac{d}{c}-\tan^{-1}\frac{f}{e}-\tan^{-1}\frac{h}{g}]$$

9. Remember your audience

- Your lectures are given for THEM, not for you! (1st rule of [also non-]technical communication).
- Don't have to impress students with knowledge; they know that you are the teacher, not them.
- Don't impress faculty with how much you cover; they know what counts is how much you teach. Major issue for assistant (untenured) professors.

9. Remember your audience

- A good lecture should go down easy with students Afterwards, they should be wondering why they didn’t think of that before-seems so obvious now.
- Means you did a good job organizing material.
- But sometimes they will struggle with a topic.
- Will get a feel for which topics will give trouble after teaching a course the second time.

9. Remember your audience

- Comprehension of a difficult topic goes like this:
- Students **think** they understand it, but they **don't**
- Students realize they **don't** understand it, and that they have to dig deeper into it and struggle;
- Students finally realize they understand it when they can **USE** the topic to solve some problem.

10. Have patience (and right now!)

- Remember, back when you learned this material, you had trouble learning some of the topics, too. Did you ace all of your exams? (No, you didn't.)
- Worth reminding students of this every so often.
- Many students think everyone else in the course is having an easier time in it than they are.
- But don't rely too much on your own experience as a guide for which topics will be difficult.

10. Have patience (and right now!)

- You will have to explain many topics many times.

- You will have to show students how to use them. Don't assume they see how to apply a topic, even if they can work a simple problem with it.

- You will need to explain how topics inter-relate. This will help students understand topics as well.

11. Carefully define notation

- **Define** terms and variables whenever introduced.
- A short **glossary** at the beginning of lecture to review notation can be very helpful to students- they can refer to it while reading through notes.
- Always give **units** (dimensions) of variables. Units always tell a story; very often they tell the answer
- Point out **dimensionless** quantities when arise; put equations in dimensionless form if possible.

Dimensional Analysis Example

- **GOAL**: Determine formula for the period of a swinging pendulum, without any physics!

- **MODEL**: Period=(mass)^a(length)^{b}g^c where g=acceleration of gravity (32 ft/sec^2) and a,b,c are unknown constants to be found.

- **SOLUTION**: Equate exponents on both sides of the formula using dimensional analysis:

Dimensional Analysis Example

- Period=$(\text{mass})^a(\text{length})^b g^c$. Dimensions:
- time=$(\text{mass})^a(\text{length})^b\,(\text{length}/\text{time}^2)^c$

- Mass: a=0. Length: 0=b+c. Time: 1=-2c.
- Solve: a=0, b=1/2, c=-1/2
- Formula: Period=$[\text{Length}/g]^{1/2}$
- Actually: Period=$2\pi\,[\text{Length}/g]^{1/2}$
- 2π dimensionless-can't infer dimensionally.

12. Involve audience in the lecture

- **Ask students if they are familiar with a topic.** ***Most raise hands*****: ask "can you work a problem"** **Many will** ***put down hands*****, but gives you an idea**
- **Also do this after presenting a topic.**
- **Ask simple questions during lecture. Usually someone will answer; that will break the ice.**

Outline of Presentation

- **#1-#6:** **Planning to teach a new (to you) course.**
- **#7-#12:** **Giving lectures using a blackboard.**
- **#13-#18:** **Giving lectures using a laptop (like this).**
- **#19-#21:** **Miscellaneous**

13. Don't go too long if using slides

- Gives students time to ask questions one-on-one.
- Gives students time to go to the bathroom, talk to other students in class, check or send messages.
- Good time for a break in this lecture-right now!

14. Don’t go too fast if using slides

- Students like lectures using a blackboard. Why? Because using chalk/marking pens keeps lecturer from going too fast! Acts as a speed governor.
- Lecturer has to write on the board everything that students have to write in their notebooks.
- Slides obviates this-now lecturer can go faster.

15. Don't put too much on one slide

- Don't confuse this with "no staples" handouts.
- Slides are <u>different</u> from handouts:
- <u>Slides</u> are read and heard in real time in class;
- <u>Handouts</u> are read at leisure, more slowly.

- Compare the next 3 slides. Which are clearer?

University of MICHIGAN

DARPA

Slightly Underdetermined H: Procedure

- **THEN**: $y=Hx \rightarrow [H\ {-y}][x^T\ 1]^T=0$ (include y in H).
- Rename: $H=[H\ {-y}]$ and $x^T=[x^T\ 1]^T$ in the sequel.
- $0=Hx=\sum h(i,j)x(j)=\sum H(i,k)^* X(k)=\underline{Hx}$ (DFT of H,x).
- $\underline{x}=\underline{Gw}$ where $\underline{G}$ spans right nullspace of $\underline{H}$.
- **BUT**: $\underline{G}$ and vector $\underline{w}$ have dimensions N-M.
- **SO**: $S(k)^*\sum \underline{G}(i,k)\underline{w}(k)=0$ is N equations in (N-M) unknowns $\underline{w}(k)$ and K unknowns S(k), or N linear equations in (N-M)(K) unknowns $S(k_1)\underline{w}(k_2)$

Slightly Underdetermined H: Procedure

- **THEN**: $y=Hx \rightarrow [H\ -y][x^T\ 1]^T=0$ (include y in H).
- Rename: $H=[H\ -y]$ and $x^T=[x^T\ \ 1]^T$ in the sequel.

- Now $y=Hx$ has become $0=Hx$. Using Parseval:
- $0=Hx=\sum h(i,j)x(j)=\sum H(i,k)^{*}X(k)=\underline{H}\underline{x}$ (DFT of H,x).

- $\underline{x}=\underline{G}\underline{w}$ where $\underline{G}$ spans right nullspace of $\underline{H}$.

Slightly Underdetermined H: Procedure

- **BUT: G and vector w have dimensions N-M.**
- **SO: $S(k)*\sum G(i,k)w(k)=0$ is N equations in (N-M) unknowns w(k) and K unknowns S(k). Becomes:**

N linear equations in (N-M)(K) unknowns $S(k_1)w(k_2)$

16. Don’t put much algebra on a slide

- In fact, don’t do much algebra in lecture at all.
- Students’ eyes glaze over while frantically trying to copy down equations you are scribbling.
- They will miss or miscopy some equations.
- You may miss or miscopy some equations!

- Put derivations or examples on a handout.
- DON’T do what is on the next slide!

EECS 216 LECTURE NOTES

REVIEW (?) OF COMPLEX NUMBERS

DEF: $j=\sqrt{-1}$. Use j not i in EECS since i=current in EECS!
DEF: A complex number z can be written as $z=x+jy=Me^{j\theta}=M\angle\theta$
where: $x+jy$=**rectangular** form of z; $Me^{j\theta}=M\angle\theta$=**polar** form of z.
AND: $x=Re[z]$; $y=Im[z]$; $M=|z|$; $\theta=arg[z]$.
Real part Imag part Magnitude Argument or phase

LEMMA: **Euler's theorem:** $e^{j\theta}=\cos\theta+j\sin\theta$.
WHY? Insert $x=j\theta$ into the infinite series $e^x=1+x+x^2/2!+\ldots$.
ALSO: $\cos\theta=\frac{1}{2}(e^{j\theta}+e^{-j\theta})$; $\sin\theta=\frac{1}{2j}(e^{j\theta}-e^{-j\theta})$.

Converting rectangular form⇔polar form:

P→R: $Me^{j\theta}=x+jy$ where $x=M\cos\theta$ and $y=M\sin\theta$.
R→P: $x+jy=Me^{j\theta}$ where $M=\sqrt{x^2+y^2}$ and $\tan\theta=y/x$.
Summary: $\begin{cases} x=M\cos\theta \\ y=M\sin\theta \end{cases}$; $M=\sqrt{x^2+y^2}$; $\theta=\begin{cases}\arctan\frac{y}{x} & \text{if } x>0; \\ \arctan\frac{y}{x}\pm\pi & \text{if } x<0\end{cases}$.

EX#1: $+3+j4=5e^{+j0.927}$ since $5=\sqrt{3^2+4^2}$ and $+0.927=\arctan\frac{+4}{+3}$.
EX#2: $-3-j4=5e^{-j2.214}$ since $5=\sqrt{3^2+4^2}$ and $-2.214=\arctan\frac{-4}{-3}-\pi$.
HINT: Draw an *Argand diagram* ($Im[z]$ vs. $Re[z]$) to visualize.
Matlab: `abs(3+4j); angle(3+4j); real(3+4j); imag(3+4j)`

Adding, Subtracting, Multiplying, Dividing:

- **Add and subtract** complex numbers in **rectangular** form.

since: $(a+jb)+(c+jd)=(a+c)+j(b+d)$. **Note:** $Re[z+w]=Re[z]+Re[w]$.
EX: $5e^{j0.927}+\sqrt{2}e^{j0.785}=(3+j4)+(1+j)=4+j5=6.4e^{j0.896}$.

- **Multiply and divide** complex numbers in **polar** form.

since: $(M_1e^{j\theta_1})(M_2e^{j\theta_2})=(M_1M_2)e^{j(\theta_1+\theta_2)}$. **Note:** $|zw|=|z|\cdot|w|$.
EX: $(3+j4)(1+j)=(5e^{j0.927})(\sqrt{2}e^{j0.785})=5\sqrt{2}e^{j1.71}=-1+j7$.

- **Multiplying and dividing** in rectangular form:

$(a+jb)(c+jd)=(ac-bd)+j(ad+bc)$; $\frac{a+jb}{c+jd}=\frac{a+jb}{c+jd}\frac{c-jd}{c-jd}=\frac{ac+bd}{c^2+d^2}+j\frac{bc-ad}{c^2+d^2}$ (ugh)
EX: $(3+j4)(1+j)=(3\cdot1-4\cdot1)+j((4\cdot1)+(3\cdot1))=-1+j7=5\sqrt{2}e^{j1.71}$.

EX: Compute $2\sqrt{3}e^{j\pi/6}+2e^{-j\pi/3}$. Convert polar to rectangular:
$=(2\sqrt{3}\cos(\pi/6)+j2\sqrt{3}\sin(\pi/6))+(2\cos(\pi/3)+j2\sin(-\pi/3))$
$=(2\sqrt{3}(\sqrt{3}/2)+j2\sqrt{3}(1/2))+(2(1/2)-j2(\sqrt{3}/2))=4$. (!)

EX: $(2\sqrt{3}e^{j\pi/6})/(2e^{-j\pi/3})=\frac{2\sqrt{3}}{2}e^{j(\pi/6-(-\pi/3))}=\sqrt{3}e^{j\pi/2}=j\sqrt{3}$.

EECS 216 LECTURE NOTES

PHASORS: COMPLEX NUMBERS REPRESENT SINUSOIDS

Phasors: Represent sinusoid $x(t)=M\cos(\omega t+\theta)$ with complex no. $X=Me^{j\theta}$.
Note: $x(t)=Re[Xe^{j\omega t}]=Re[Me^{j\theta}e^{j\omega t}]=Re[Me^{j(\omega t+\theta)}]=M\cos(\omega t+\theta)$.
Why? $A\cos(\omega t+\theta)+B\cos(\omega t+\phi)=Re[Ae^{j(\omega t+\theta)}+Be^{j(\omega t+\phi)}]$
$=Re[e^{j\omega t}(Ae^{j\theta}+Be^{j\phi})]=Re[e^{j\omega t}(Ce^{j\psi})]=C\cos(\omega t+\psi)$.
where: $Ae^{j\theta}+Be^{j\phi}=Ce^{j\psi}$. Add sinusoids ⇔ add complex numbers!

EX#1: Simplify $x(t)=3\cos(\omega t)+3\cos(\omega t+120^o)+3\cos(\omega t+240^o)$.
Hard: Use cosine addition formula→mess. If do it right, get $x(t)=0$ (?!)
Easy: Phasors: $X=3e^{j0}+3e^{j120^o}+3e^{j240^o}=0\rightarrow x(t)=Re[Xe^{j\omega t}]=0$!
Why? Draw picture in complex plane: easy to see resultant of these=0!

EX#2: Show that $5\cos(\omega t+53^o)+\sqrt{2}\cos(\omega t+45^o)=6.4\cos(\omega t+51^o)$.
Hard: Use cosine addition formula twice. Left as exercise for student.
Easy: $5e^{j53^o}+\sqrt{2}e^{j45^o}=(3+j4)+(1+j)=(4+j5)=6.4e^{j51^o}$. QED.

1. Sinusoids must **all be at the same frequency** to add their phasors. If different frequencies: partition into sums at same frequency.
2. Use $\sin(\omega t+\theta)=\cos(\omega t+\theta-\pi/2)$ as necessary.
3. Multiplying sinusoids is NOT equivalent to multiplying phasors!

OTHER COMPLEX NUMBER FACTS:

DEF: **Complex conjugate** z^* of z is $z^*=x-jy=Me^{-j\theta}=M\angle-\theta$.

1. $|z^*|=|z|$; $|z|^2=zz^*$; $arg[z^*]=-arg[z]$; $(zw)^*=z^*w^*$.
2. $\frac{1}{z}=\frac{1}{z}\frac{z^*}{z^*}=\frac{z^*}{|z|^2}$. Compare to rectangular division formula.
3. $z=Me^{j\theta}\rightarrow z^*=Me^{-j\theta}$; $\frac{1}{z}=\frac{1}{M}e^{-j\theta}$; $-z=Me^{j(\theta\pm\pi)}$.
4. $A\cos(\omega t+\theta)=\frac{1}{2}(X+X^*)$ where $X=Ae^{j(\omega t+\theta)}=Ae^{j\theta}e^{j\omega t}$.
5. $Re[z]=\frac{1}{2}(z+z^*)$ and $|e^{j|z|}|=1$ for **any** complex z.

OTHER COMPLEX NUMBER TRICKS:

1. $Im[3+j4]=4$ **NOT** $j4$! **VERY common mistake!**.
2. $e^{\pm j\pi}=-1$. $j=e^{j\pi/2}$ and $-j=e^{j3\pi/2}\Leftrightarrow\cos(\omega t\pm90^o)=\mp\sin(\omega t)$.
3. $j(3+j4)=-4+j3=(1e^{j90^o})(5e^{j53^o})=5e^{j143^o}$: 90^o rotation.
4. Compute $\left|\frac{5(8+j)(8+j6)(5+j12)(5+j10)}{26(7+j4)(7+j24)(2+j11)}\right|=\sqrt{\frac{(25)(65)(100)(169)(125)}{(26)^2(65)(625)(125)}}=1$.
5. The following identity is true to an overall sign. Why?

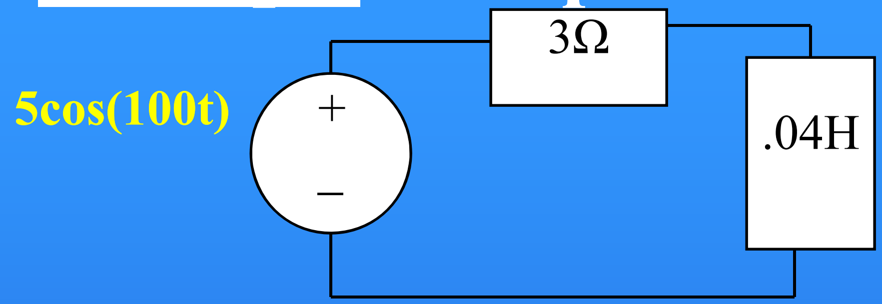
$$\frac{(a+jb)(c+jd)}{(e+jf)(g+jh)}=\sqrt{\frac{(a^2+b^2)(c^2+d^2)}{(e^2+f^2)(g^2+h^2)}}\exp j[\tan^{-1}\frac{b}{a}+\tan^{-1}\frac{d}{c}-\tan^{-1}\frac{f}{e}-\tan^{-1}\frac{h}{g}]$$

17. Keep examples simple as possible

- Examples should be just complicated enough to illustrate the procedure, or the point being made. Anything longer will only obscure these.
- Use small integers so students can trace through your computations-makes them easier to follow.
- Try to make result seem numerically reasonable.

17. Keep examples simple as possible

- **Example**: compute the current in this circuit:



- **Solution**: Use phasors. Inductor $Z=j100(.04)=j4$.
- $\text{Current}=I=5/(3+j4)=1e^{-j53}$ where 53 in degrees.
- $i(t)=\cos(100t-53^{o})$. Easy to trace these numbers.
- Not realistic values, but can now do with them.

17. Keep examples simple as possible

- Some engineering educators criticize this-they believe numbers should be real-world realistic, e.g., “120.4 volt” vs. “5 volt” voltage source.

- I disagree-use real-world numbers in homework.

- Use simple numbers in lecture (comprehension) and on exams (to demonstrate comprehension).

18. Liven lectures up with sound

- Adobe Acrobat 9.0 (free!) reader can play sounds
- Keeps students from going to sleep, at least.

- Also, vary background and format of slides; dark background may make the room too dark for students to take notes (and stay awake).

- Following sound is from Intro. to Engineering.

Outline of Presentation

- **#1-#6:** Planning to teach a new (to you) course.
- **#7-#12:** Giving lectures using a blackboard.
- **#13-#18:** Giving lectures using a laptop (like this).
- **#19-#21:** Miscellaneous

19. Use an outline to mark progress

- Occasionally repeat the original outline slide, with the next topic in lecture highlighted on it.
- Allows audience (and you!) to keep track of time (and avoids audience looking at their watches).
- Also reminds audience of where the next topic fits into the overall lecture, and what the students should (you hope) have already learned from it.

20. Use wisecracks and jokes

- Shows you have a sense of humor, breaks tension.
- Makes students look forward to coming to class.
- Can (slightly) help understand the present topic.
- Makes students pay attention (if funny enough).

21. Have fun!

- ”Nothing was ever achieved without enthusiasm” –Ralph Waldo Emerson
- If you are enthusiastic, students will be also. Enthusiasm is contagious!
- Students can always tell how much you care.
- If you enjoy teaching, students may think you’re nuts, but they will enjoy taking your course more

Thank you for listening!

- Thanks to Benson (P.C. Yeh) for inviting me to give this talk to you while I was here in Taiwan.
- Thanks to Benson for his help in teaching Digital Signal Processing for 3 terms at U-M (2002-03).
- Remember, have fun teaching and presenting!
- Any questions?