EE228
Applications of Course Concepts
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Purpose

• Describe applications of concepts in EE228. Applications may help students recall and synthesize concepts.

• Also discuss:
  – Some advanced concepts
  – Highlight important concepts that arise in subsequent courses. ‘TTR’ ‘Things to Remember’
Communications is an Important Area of Signal & Systems

- With RF need to broadcast in MHz range to provide:
  - Efficient radiation from antenna
  - Good propagation of waves
  - Reasonable antenna size
- However, message signal $x(t)$ is at baseband.
- AM Approach: Multiply by ‘carrier’ $c(t)$ at $f_c$ (simplified version)

\[
x(t) \times c(t) = \cos(2 \pi f_c t)
\]

Application Advanced – EE 314, EE 416
What Does the RF Spectrum of A Radio Station Look Like?

- How can we find \( R(f) = X(f) \ldots C(f) \)?
- \( C(f) \) carrier spectrum looks like: __________
- Given \( X(f) \), what is \( R(f) \)?

Application
What Does the RF Spectrum of One Radio Station Look Like?

• How can we find $R(f) = X(f) \ast C(f)$?
• $C(f)$ carrier spectrum looks like: 2 impulses
• Given $X(f)$, what is $R(f)$?

Application
What Does the RF Spectrum of Many Radio Stations Look Like?

\[ |R(f)| \]

Application
What Does the RF Spectrum of Many Radio Stations Look Like?

- What other communication system packs many signals into a single medium, for distribution around town? (Use frequency multiplexing).
  - Packed side-by-side in spectrum.
  - Medium: Coax
  - Most students have it!

Application
Only Positive Frequencies Exist In Real Life!

• However, note that Fourier’s methods predict the spectrum of a modulated signal correctly!

• Another explanation:
  \[ \cos(A) \cos(B) = \cos(A+B) + \cos(A-B) \]
  If A is the carrier then multiplication results in the upper and lower ‘sidebands’.

• Fourier needs negative frequencies to properly synthesize real signals.

• Negative frequencies OK in discrete domain 😊
Models of Subsystem Blocks Permit Concatenation

- Concatenating H2 leaves H1 unchanged.
- Hence, No loading effects!
- What conditions (inside block, associated with inputs and outputs) are needed for no loading?
Models of Subsystem Blocks Permit Concatenation

• Concatenating H2 leaves H1 unchanged.
• Hence, No loading effects!
• What conditions (inside block, associated with inputs and outputs) are needed for no loading?
  – Hi-Z input, Low-Z output
  – (Consider a voltage divider).
Generally Avoid Differentiation Operation as a Subsystem Block

• Property of Fourier Transform:
  Given the FT pair: $x(t) \leftrightarrow X(f)$
  Then: $x'(t) \leftrightarrow j 2 \pi f X(f)$

• How is $X(f)$ affected by differentiation?

• Why is this bad? (Consider that noise is typically present at all frequencies).

• Integral generally safer… Any problem frequencies?
Generally Avoid Differentiation Operation as a Subsystem Block

• Property of Fourier Transform:
  Given the FT pair: \( x(t) \leftrightarrow X(f) \)
  Then: \( x'(t) \leftrightarrow j2\pi f X(f) \)

• How is \( X(f) \) affected by differentiation?
  *Magnitude increased with frequency, \( f \).*

• Why is this bad? (Consider that noise is typically present at all frequencies).
  *Amplifies high frequency noise considerably!*

• Integral generally safer… Any problem frequencies?
  \( \text{Integral } \{x(t) \, dt\} \leftrightarrow X(f) / j2\pi f + 0.5 X(0) \delta(f) \)
Speech Recognition Via Correlation

- Even with an identical speaker, still must accommodate signal delay.

```
"Hello"
```
```
"Hello" delayed
```

Introduce Correlation: \[ r(\tau) = \int x_1(t) x_2(t + \tau) \, dt \]

Compare to convolution? ________________
When does \( r(\tau) \) have a peak? ________________
Speech Recognition Via Correlation

- Even with an identical speaker, still must accommodate signal delay.

Introduce Correlation: \[ r(\tau) = \int x_1(t) x_2(t + \tau) dt \]

Compare to convolution? **No time-reversal**
When does \( r(\text{tau}) \) have a peak?
*When”Hello”s aligned, (and hence recognized)*
Can We Eliminate the Time Shift Problem for Recognition?

- Consider property of Fourier Transform

\[ x(t - \tau) \Leftrightarrow e^{-j2\pi f \tau} X(f) \]

- How is X(f) changed? ____________
- How can we employ this for recognition?

Application
Can We Eliminate the Time Shift Problem for Recognition?

- Consider property of Fourier Transform

\[ x(t - \tau) \iff \underbrace{e^{-j2\pi f \tau}}_{FT} X(f) \]

- How is \( X(f) \) changed?  \textit{Phase only.}
- How can we employ this for recognition?

\textit{Compare magnitudes. No shifting. Do need both “Hello”s within range of transform integration.}

\textit{Application}
Fourier Transform Popular For Digital Signal Processing

- A/D samples signals (44.1KHz for CD)
- Processing via arithmetic, not RLC. Can be implemented in software, firmware, hardware.
- FFT is Fast Fourier Transform. Computationally efficient.
- FFT permits processing in frequency domain
  - Compression, Voice Recognition, Display Spectrum, Phased Array

Advanced – EE328
What is the Spectrum Of a Tone Burst?

• How can we model a short (time-limited) sinusoidal signal? _______________

• How can we find the spectrum of the time-limited signal? ________________
What is the Spectrum Of a Tone Burst?

• How can we model a short (time-limited) sinusoidal signal? *Multiply by rect()*

• How can we find the spectrum of the time-limited signal? *Convolution of sinc with impulses.*
Short Tone Burst Has ‘Spectral Leakage’ Effect
Wider Pulses <- FT -> Narrow Sinc
No Signal Can Be Simultaneously Limited in Both Time and Frequency

Can’t make both duration and bandwidth arbitrarily small!

TTR
Impulse Response $h(t)$ of Ideal LPF Filter is a Sinc

- $H(w) \leftarrow \text{FT} \rightarrow h(t)$
- These signals are duals of previous examples.
Ideal Filter Not Realizable!

• What are problems associated with $h(t) = \text{sinc}(t)$?
  
  – _____________________
  – _____________________
  – _____________________
  – _____________________
Ideal Filter Not Realizable!

• What are problems associated with $h(t) = \text{sinc}()$?
  – Sinc is noncausal
  – Sinc has infinite absolute area, hence system unstable.
High Frequency Content Needed to Construct Sharp Corners

- Sums of harmonic contributions to (one period of) square wave shown.
- More harmonics needed for sharper corners
- Note non-uniform convergence (varying amount of error).
- Note convergence to midpoint of discontinuity.
Choose Right Tool for Right Job

• Variety of tools to find the spectra of signals & systems.
• Fourier Series for periodic signals.
• Fourier Transform for non-periodic signals or to find Frequency Response, H(f), H(w). Steady state response.
• H(w) also from Bode, via graphical evaluation using poles & zeros in s-plane, or substituting H(s = jw).
• Laplace Transform need complete response, includes steady state and transient responses.
ROC Important for Analysis Of Non-Causal Systems Via Laplace

\[ X(s) = \int_{0}^{\infty} x(t) e^{-st} dt \]

- Laplace Transform exists only for cases which are absolutely integrable. Hence \( |x(t)e^{-st}| < \infty \)
- For example, with \( x(t) = e^{-\alpha t} \) the Laplace Transform \( X(s) \) only exists – is finite valued – in part of the s-plane. Which portion? ______
- Formally, need jw axis to be within ROC for inverse Laplace operation to be possible.
- Not an issue for causal signals and systems.

Advanced TTR
ROC Important for Analysis Of Non-Causal Systems Via Laplace

\[ X(s) = \int_{0-}^{\infty} x(t)e^{-st} dt \]

- Laplace Transform exists only for cases which are absolutely integrable. Hence \( |x(t)e^{-st}| < \infty \)

- For example, with \( x(t) = e^{-\alpha t} \) the Laplace Transform \( X(s) \) only exists – is finite valued – in part of the s-plane. Which portion? \(-\alpha < \Sigma, \text{ for } \alpha > 0\)

- Formally, need \( jw \) axis to be within ROC for inverse Laplace operation to be possible.

- Not an issue for causal signals and systems.
Two-Sided Laplace Transform Handles Non-Causal Signals

- Signals must be absolutely integrable for all time. \[ |x(t)e^{-st}| < \infty \]
- Method: Multiply \( Y(s) = H(s) X(s) \), then sort out the causal and non-causal parts and perform inverse Laplace separately on each.
- Typically a topic in graduate courses.
Whistle Detector Has Design Requirement: Delay & F-Discrimination

- Given: K, F0 of BPF, Vt of Threshold.
- What other parameters affect off-delay?
- What other parameters affect on-delay?

Application
Whistle Detector Has Design Requirement: Delay & F-Discrimination

- Given: $K$, $F_0$ of BPF, $V_t$ of Threshold.
- What other parameters affect off-delay? $BPF$ $Q$ and $LPF$ time constant
- What other parameters affect on-delay? $LPF$ time constant

Application
Spell Check

• Bode: Engineer, Scientist and Mathematician
• Bodie: Ghost Town in Northern CA