MUSR 674: Electronic and Electroacoustic Measurement

Instructor: William Martens
It's my daughter Millie (at 18 months), in the Acoustical Measurement Lab at the University of Aizu.
Your textbook

- Available:
- right here;
- right now!

This will remain a useful reference for many years.
Related Reading

- It’s expensive:
- I have a copy

Other related reading will be posted online.
Your course website:

http://www.music.mcgill.ca/~wlm/courses/measurement

• **My office:**
  – Room 816 in Tour Ouest at 550 Sherbrooke

• **Office telephone:**
  – 514-398-4535 x-089795

• **When instructed, please also check on WebCT**
Online course description:

This course demonstrates the instruments, measurement procedures, and techniques used in a recording studio to determine the acoustical properties of a room and the transfer functions of devices used in a studio. Theoretical lectures on electronic test instrumentation and measurement methods are combined with practical application.
Course Focus:

The course focuses on problems in measurement of audio signals and characterization of audio devices.

Students will be given the chance to use tools such as sound level meters and spectrum analyzers, and will complete individual projects addressing measurement problems of their own choosing.
Lecture Schedule:

For the first five weeks of the course, the schedule follows the organization of the material in the course textbook,

After the first five weeks, the emphasis will be upon class projects intended for the final reports, which will require both written and oral presentation.

Grading is based upon final reports and the three written Lab reports (completion of other assignments is noted, but not scored).
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<th>Lecture Topic</th>
<th>Reading</th>
<th>Assignment</th>
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<td>Level Alignment</td>
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<td>2</td>
<td>Measurement of Nonlinearity</td>
<td>pp. 23-44</td>
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<td>Measurement Techniques</td>
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<td>4</td>
<td>Sets of Measurements</td>
<td>pp. 85-107</td>
<td>Lab 1: HRTFs</td>
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<td>5</td>
<td>Digital Domain</td>
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<td>6</td>
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<td>Auditory Quality</td>
<td>handout</td>
<td>Final Reports</td>
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</table>
Responsibilities?

• **Rule of Four (My job):**
  – Topics should be presented geometrically, numerically, algebraically, and descriptively (verbally).

• **Class Time Ratio (Your job):**
  – Spend at least 3 hours a week outside of class to learn the concepts presented superficially in lectures (read, review, research, etc.).
Just to check for agreement on terms, let’s look at this fundamental distinction:

Electronic versus Electroacoustic signals may be distinguished by noting whether air has been moved or not.

Microphones and speakers are the most popular electroacoustic devices to measure; while amplifiers are probably the most popular electronic devices to measure.

Shall we back up a step?
In the free field, sound travels as a pressure wave in all directions.

Measurement begins with capturing the pressure wave as an audio signal.
Basics of Signals

In Space:

\[ A \sin \frac{2 \pi x}{\lambda} \]

In Time:

\[ A \sin \frac{2 \pi t}{T} \]

Frequency (in Hz) is inversely related to Time (in sec):

\[ F = \frac{1}{T} \]
A microphone converts sound signals into audio signals.
A speaker reconverts **audio signals** into **sound signals**.
Overview of Measurement Types

Electronic

Acoustic

Electroacoustic
Electroacoustic measurements comprise the majority of acoustic measurements.
Electroacoustic measurements relevant to audio applications often predict human perception.
But psychoacoustics is in another course; so we should not digress, but…
What about measuring formant frequencies? Are these electroacoustic, or just acoustic?

Or are they psychoacoustic?
Can the broad, flat maxima on the left be measured for formant frequencies?

Why call a spectral maximum a formant?
Perhaps spectral maxima that carry information “resonating” with perceptual capacities should be called formants?

This is a phonetic definition of a formant.
So what will be covered in this course on electronic and electroacoustic measurement?

Everything in the Metzler text, but also some more in depth examination of specific topics found in PACS® (Physics and Astronomy Classification Scheme)
Physics and Astronomy Classification Scheme®
(PACS)

PACS® is prepared by the American Institute of Physics in collaboration with certain other members of the International Council on Scientific and Technical Information (ICSTI) having an interest in physics and astronomy classification.
### PACS 43.58.xx

**Acoustical measurements and instrumentation**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.58.Bh</td>
<td>Acoustic impedance measurement</td>
</tr>
<tr>
<td>43.58.Fm</td>
<td>Sound level meters, level recorders, sound pressure</td>
</tr>
<tr>
<td>43.58.Gn</td>
<td>Acoustic impulse analyzers and measurements</td>
</tr>
<tr>
<td>43.58.Hp</td>
<td>Tuning forks, frequency standards; frequency meas.</td>
</tr>
<tr>
<td>43.58.Jq</td>
<td>Wave and tone synthesizers</td>
</tr>
<tr>
<td>43.58.Kr</td>
<td>Spectrum and frequency analyzers and filters</td>
</tr>
<tr>
<td>43.58.Mt</td>
<td>Phase meters</td>
</tr>
<tr>
<td>43.58.Ry</td>
<td>Measurement of Distortion: frequency, nonlinear, etc.</td>
</tr>
<tr>
<td>43.58.Ta</td>
<td>Computers and computer programs in acoustics</td>
</tr>
<tr>
<td>43.58.Vb</td>
<td>Calibration of acoustical devices and systems</td>
</tr>
<tr>
<td>43.58.Wc</td>
<td>Electrical and mechanical oscillators</td>
</tr>
</tbody>
</table>
The two most common signals used to make electronic and electroacoustic measurements are:

- Sine waves
- Gaussian Noise

They can be characterized in either:
- the time domain or
- the frequency domain.
Both stimuli continue forever.
Another common test signal

The frequency domain plot here could be representing either the signal itself, or the response of a filter to a white noise input.
So here’s a test of your prior knowledge (or intuition)

Given three signals of equal power, which will be the first to clip as the power is increased?

Sine Wave?
Gaussian Noise?
Square Wave?

This raises the question of how we measure the amplitude of a signal …
Amplitude Measurement: Peak vs. Root Mean Square

- **Peak** detection is appropriate when it is desired to measure amplitude with respect to potential clipping problems.
- **RMS** detection is the only amplitude measurement technique with an output proportional to signal **power**.
RMS = 1.0 for the Square Wave
RMS = 0.7071 for the Sine Wave
RMS = ~ .3 for White Noise
So here’s the answer to the test of your prior knowledge (or intuition)

Given three signals of equal power, which will be the first to clip as the power is increased?

- Sine Wave?
- Gaussian Noise?
- Square Wave?

For the same RMS power, the peak amplitude of Gaussian noise will be higher.
But what is the peak amplitude of Gaussian noise?

It can only be specified at a given probability...
As it’s amplitude can only be specified at a given probability, both it’s peak amplitude and its RMS level are also non-stationary…

...so how can we make practical measures of Sound Pressure Level for Gaussian noise?

- We must specify a duration (e.g., 1 ms)
- This is related to its response rate:
  - SLOW (.5 s)
  - FAST (.2 s)
Sound Level Meters
Is this a practical measurement course, offering useful hands on experience?

• Yes! Let’s begin now!
  – Consider how to measure Sound Pressure Level (SPL) in this room
• Let’s try using the RadioShack 33-2055:
  – A Sound Level Meter (SLM)
What are the parameters of the RadioShack SLM?

- **Weighting:**
  - A or C

- **Response:**
  - SLOW or FAST
What are the specs of the RadioShack SLM?

- **Range:**
  - 50 to 126 dB

- **Accuracy:**
  - 2 dB at 114 dB SPL

- **Reference:**
  - 0.0002 Micro Bar

### Specifications

<table>
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<tr>
<th>Feature</th>
<th>Details</th>
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</thead>
<tbody>
<tr>
<td>Battery</td>
<td>9-volt Alkaline</td>
</tr>
<tr>
<td>Microphone</td>
<td>Electret Condenser</td>
</tr>
<tr>
<td>Range</td>
<td>50 dB to 126 dB</td>
</tr>
<tr>
<td>Accuracy</td>
<td>± 2 dB at 114 dB SPL</td>
</tr>
<tr>
<td>Reference</td>
<td>0 dB = 0.0002 Micro Bar</td>
</tr>
<tr>
<td>Weighting</td>
<td>A and C</td>
</tr>
<tr>
<td>Display Response</td>
<td>Fast and Slow</td>
</tr>
<tr>
<td>Signal Output</td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>1 Volt Peak-Peak Min.</td>
</tr>
<tr>
<td></td>
<td>(Open Circuit, Full Scale at 1 kHz)</td>
</tr>
<tr>
<td>Impedance</td>
<td>10 Kilohms Min. Load</td>
</tr>
<tr>
<td>Distortion</td>
<td>Less than 2% at 1 kHz.</td>
</tr>
<tr>
<td></td>
<td>0.5 V p-p Output</td>
</tr>
<tr>
<td></td>
<td>(Input: Mic Out, Output: 10 Kohm)</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>0 °C to 50 °C (32 °F to 122 °F)</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-40 °C to 65 °C (-40 °F to 149 °F)</td>
</tr>
<tr>
<td>Dimensions (HxWxD)</td>
<td>159 × 64 × 44 mm (6 ¼ × 2 ½ × 1 ¾ Inches)</td>
</tr>
<tr>
<td>Weight</td>
<td>165 g (5.8 oz)</td>
</tr>
</tbody>
</table>
How to Measure SPL at Multiple Frequencies

Sound Signal → SLM Mic with Narrow Bandpass Filter → True RMS Detector → Volt Meter

Broadband Noise
How to Measure a Device at Multiple Frequencies

Input Signal → Device Under Test → Narrow Bandpass Filter → True RMS Detector → Volt Meter
But it matters how you hook up the Device Under Test (DUT)

Should you use Monster Cable™ for the connections?
Monster Cable
Is Different?

Cables—the Final Link
Monster Cable's legendary microphone and musical instrument cables, found in many of the world's top recording studios, are used religiously by engineers, producers and musicians alike.

Engineered for Better Sound
While other cables can smother sound, increase distortion and flatten bass, link® cables utilize unique patented technologies such as multi-gauge Bandwidth Balanced® wire networks and Time Correct® windings to transfer complex music signals between components with greater accuracy and perfect phase alignment.
High-performance speaker cable for audiophile music and home theater systems. Features Monster's patented Time Correct® windings for more accurate music and soundtrack reproduction and MultiTwist™ construction for improved sonic imaging and clarity.
A comparison of speaker cables will be highly dependent on the interaction between the complex load or impedance of the loudspeaker-amplifier and the cable [R. Greiner, Amplifier-Loudspeaker Interfacing, J. Audio Eng. Soc. Volume 28 Number 5 pp. 310-315 (May 1980)]. The loudspeaker-cable-amplifier can be treated as a lumped line element where the electrical properties of the cable are series resistance, series inductance, shunt conductance and shunt capacitance. Most well designed amplifiers are not sensitive to cable load, but speakers can be more sensitive… To minimize any frequency response effects related to these interactions the loudspeaker should have a flat measured complex impedance response across its frequency range.
Ironically, many of the audiophiles who hear or claim to hear cable differences tend to use poorly designed exotic tube amplifiers and speakers having difficult electrical loads. Such devices are prone to creating frequency response changes when exotic cables are swapped in and out.

These differences can be MUCH more easily measured than the phase alignment variations due to Time Correct® windings.

Eliminating these differences will allow listeners to focus on the more exotic, (subliminal?) sonic nuances of the cables, often claimed in marketing and advertising materials.
Ironically, many audiophiles compare speaker responses that are measured anechoically (in a room with minimized reverberation), and yet do their listening in rooms that have significant early reflections. These reflections contribute to gross variation in the response of the speakers when measured at various listening locations within the room, … as well as “shredding” the measured phase response.

These differences can be MUCH more easily measured than the phase alignment variations due to Time Correct® windings.
Complicating Acoustic Phenomena

Reflection  Scattering  Diffraction

How to measure these features is an ongoing concern in listening room design and evaluation.
Measurement in Rooms

- Placing a loudspeaker in a reverberant room makes an enormous difference, …
Again, we might ask about what should be measured...

Should the criteria be psychoacoustic?
In sound recording applications (capture, reproduction, etc.), psychoacoustic criteria are appropriate.

Perhaps quality control in the process of microphone and loudspeaker manufacture requires only electroacoustic criteria....

...but these criteria clearly were informed by psychoacoustic evaluation at some point in research and development.
Let’s Consider An Example

• Would speech sound to be transmitted to a human listener be better captured by a shotgun microphone or a dummy head?
• An important factor is intelligibility….

…but other performance parameters might be important in a cocktail party situation.
Let’s do anechoic comparisons of two systems
- *Sphere-mounted omnidirectional mics*
- *Shotgun microphone*

**Measurement Parameters**
- *Magnitude Response over Frequency*
- *Magnitude Response over Space*
- *Magnitude Response over Time*
Microphone Specs

Omni

Shotgun
Beyond the provided specs, the off-axis frequency dependence is a concern in some applications.
Magnitude response was measured over both space and frequency using the B&K 2012 Analyzer.
The attenuation pattern is not a simple high-frequency roll-off (darkening) as the source moves further off-axis…

…it shows peaks and dips that can contribute to real timbral variation.

For example, at an incidence angle of 90°, the spectral envelope matches that of the vowel sound /U/ as in “hood.”
Shotgun microphone response:
Off-axis frequency dependence

2nd formant frequency around 1200 Hz
Omnidirectional Microphone

Mounted on a sphere
Shotgun and sphere responses: Narrowband space dependence
Considering Human Receivers

- Sound captured by remote system.
- Sound received by a human listener.
- Special weighting for intelligibility ($G_{iw}$).
$G_{iw}$ sums the system response over 14 one-third-octave bands ranging in center frequency from 200Hz to 4kHz, applying weighting coefficients that correspond to the contributions made to speech intelligibility assumed for each frequency band

– Most heavily weighted are the four bands ranging from 1.6 to 3.15 kHz

This is the intelligibility weighted directivity index employed in Rabinowitz and Maxwell, JASA, 94(3), 1332-1342.
Shotgun and sphere responses: Broadband space dependence
Worth Considering:

• How do we know what to measure?
• How do we know what to model?
• What will they be used for?
• Is predicting human perception the goal of the measurements?
• What kind of measuring instruments are we looking for?
What are Instrumental Measures?

- Sound Level Meters vs. Loudness Meters?

Problem: Predicting Perception
What’s new in the last 10 years?

• After years of designing instrumental measures that fail to predict human perception, the field has begun to shift attention to what Blauert (1993) termed *Aurally Adequate Sound Measuring Technology* (AASMT)

• **Premise**: Measurement works best when based upon adequate models of human perception.

• **Status**: Audio engineers have not succeeded in designing a simple and effective loudness meter.
Applications Preview

• Instrumental measures need to be based upon more than “psychoacoustic parameters”…

• They need to be based upon comprehensive computational models of human auditory information processing (but that’s covered in a different course than this).

What’s required is: Experimental Confirmation
An assignment, already?

– Multichannel Level Alignment
  • How can it be done for typical surround sound reproduction systems (in typical rooms)?

– Very simple, yes?
  • It’s just 5 loudspeakers in a circle, measured at a point in the center of the circle.
  • If it’s so simple, then why are there so many technical papers about this task?
  • And why is there such dissention between experts?

– Your Assignment:
  • Write a one-page overview of the problems faced here.
  • Not seeking correct answers, only thoughtful consideration (see the handout).
Next Week?

• **Amplitude Measurement:**
  – The dB unit, etc.

• **Do the reading:**
  – Metzler pp. 1-22

• **Please submit your completed assignment via email (to wlm@music.mcgill.ca) by Friday (the 16\textsuperscript{th} of September).**