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3.042 Materials Project Laboratory
Spring 2008

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HEMONY

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Please see the diagram of bell nodals in https://www.msu.edu/~carillon/batmbook/chapter5.htm

3.042 Final Presentation

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Agenda

-
- 2) Bell History & Metallurgy
- 3) Experimental Setup
- 4) Casting
- 5) SEM/Micrograph Images
- 6) Mechanical Testing
- 7) Acoustical Results and Analysis

Bell Metallurigcal History

Tuned, elaborately decorated cast bells were already being made in China more than 2,500 years ago:

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Please see: http://upload.wikimedia.org/wikipedia/commons/8/80/Bianzhong.jpg

Color closeup image:

notice the intricate designs and gold inlay

Image removed due to copyright restrictions.
Please see p. 3 of http://www.savingantiquities.org/pdf/BagleyCPAC.pdf

Early European Bells

Images removed due to copyright restrictions.
Please see Fig. 18-21 in Williams, Edward. *The Bells of Russia: History and Technology*. Princeton, NJ: Princeton University Press, 1985.

Modern Bell Styles

Each Western culture developed their own unique bell design:

Images removed due to copyright restrictions.
Please see Fig. 118-121 in Williams, Edward. *The Bells of Russia: History and Technology*. Princeton, NJ: Princeton University Press, 1985.

Bell Metal Composition

The ideal “bell metal,” an alloy of copper with 23.5% tin, was developed over hundreds of years by trial and error:

> In the reign of Henry III [of England], two parts copper to one of tin were used. At the present day copper and tin in the proportion of 13 to 4 are used, and there is no doubt that small quantities of other metals found in old bell-metal are most likely impurities in the metals used to form the alloy.
>
> -W. W. Starmer, “Bells and Bell Tones” (1901)

13 to 4 ⇨ 23.5% Sn!

Experimental Setup

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Please see http://www.doitpoms.ac.uk/miclib/pds.swf?targetFrame=Cu-Sn

3 Compositions:
10%, 15%, 23.5% Sn

3 Processes:
as-cast, annealed, or water quenched

Annealing or Quenching from 620°C

*Destructive mechanical testing uses dogbones that have been water jet from cast plates

Bell Casting

Model Production

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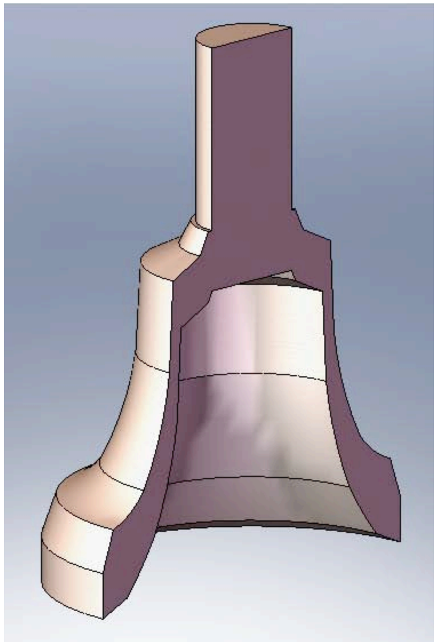
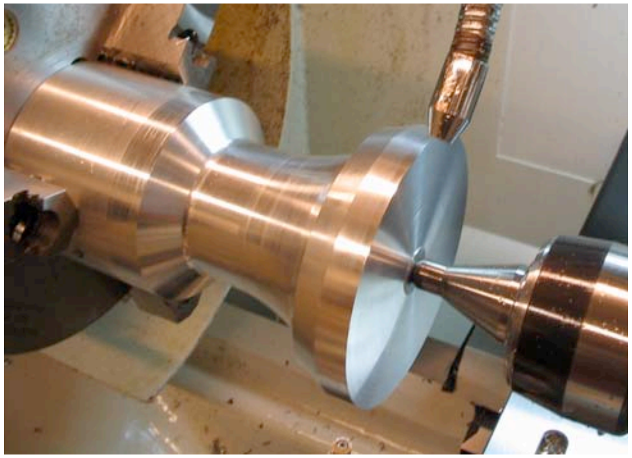
Please see: Fig. 118 in Williams, Edward. *The Bells of Russia: History and Technology*. Princeton, NJ: Princeton University Press, 1985.

- German bell pattern
- 1/2” offset for plate to hold model between flasks
- Lathe aluminum





Casting Process

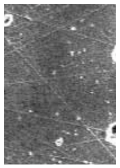
- Pack foundry sand around model
- Remove model
- Melt metals
- Pour alloy
- Remove casting from sand

SEM

Scanning Electron Microscopy

- Energy Dispersive Spectroscopy (EDS) for elemental analysis
- Actual overall compositions
  - 10% is **10%** Sn
  - 15% is **18%** Sn
  - 23.5% is **31%** Sn
- Compositions of different features help determine what phases are present

10% Sn Bronze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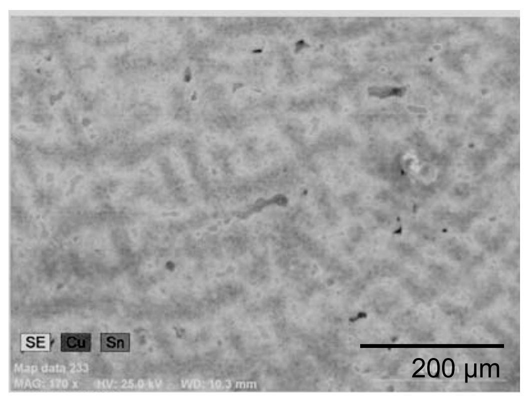
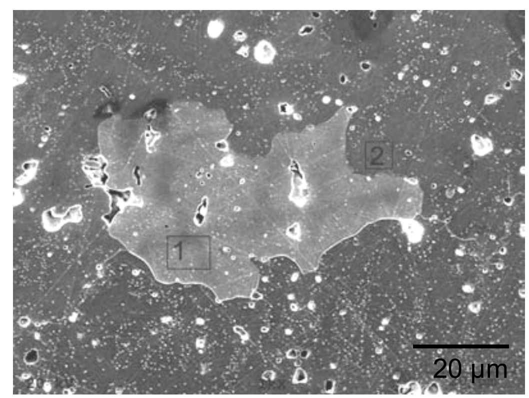
Please see: http://www.doitpoms.ac.uk/miclib/pds.swf?targetFrame=Cu-Sn

- As-cast: α, δ or ε
- Quenched: α
- After quenching, second phase is diffused out

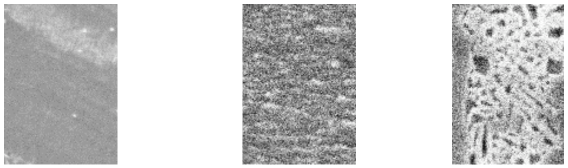
As-cast



Quenched



18% Sn Bronze



- As-cast: α, ε
- Quenched: α+ε, ε
- After quenching, ε phase moved to grain boundaries, α+ε forms

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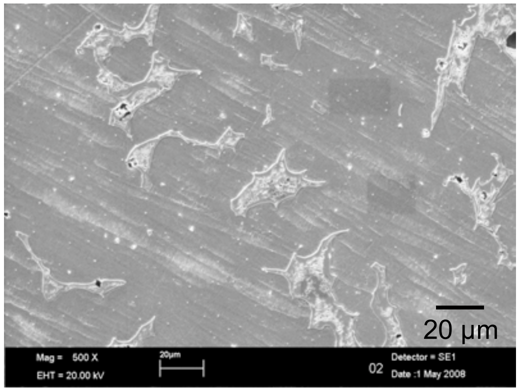
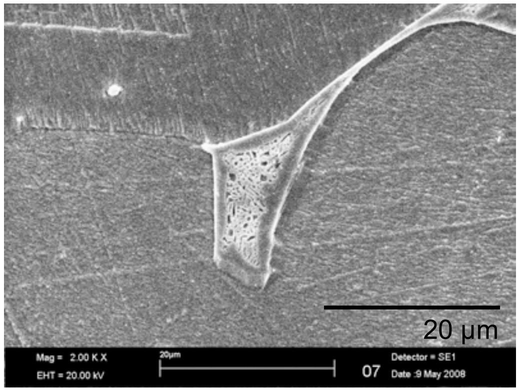
Please see: http://www.doitpoms.ac.uk/miclib/pds.swf?targetFrame=Cu-Sn

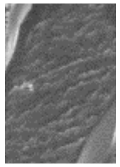
As-cast

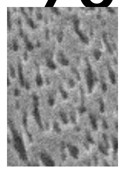


Quenched



31% Sn Bronze

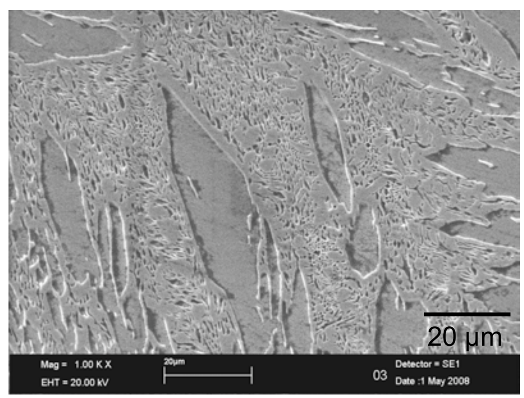




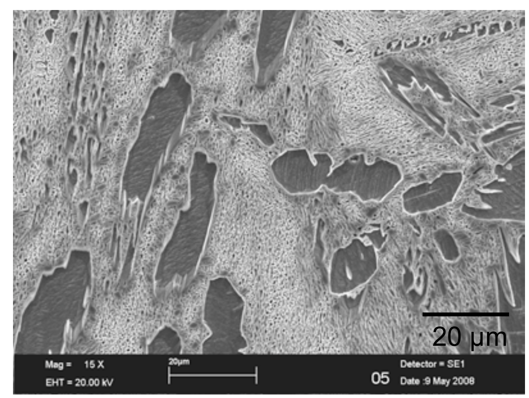
- As-cast: α+ε, ε
- Quenched: α+ε, ε
- After quenching, more ε can be seen

Image removed due to copyright restrictions.
Please see: http://www.doitpoms.ac.uk/miclib/pds.swf?targetFrame=Cu-Sn

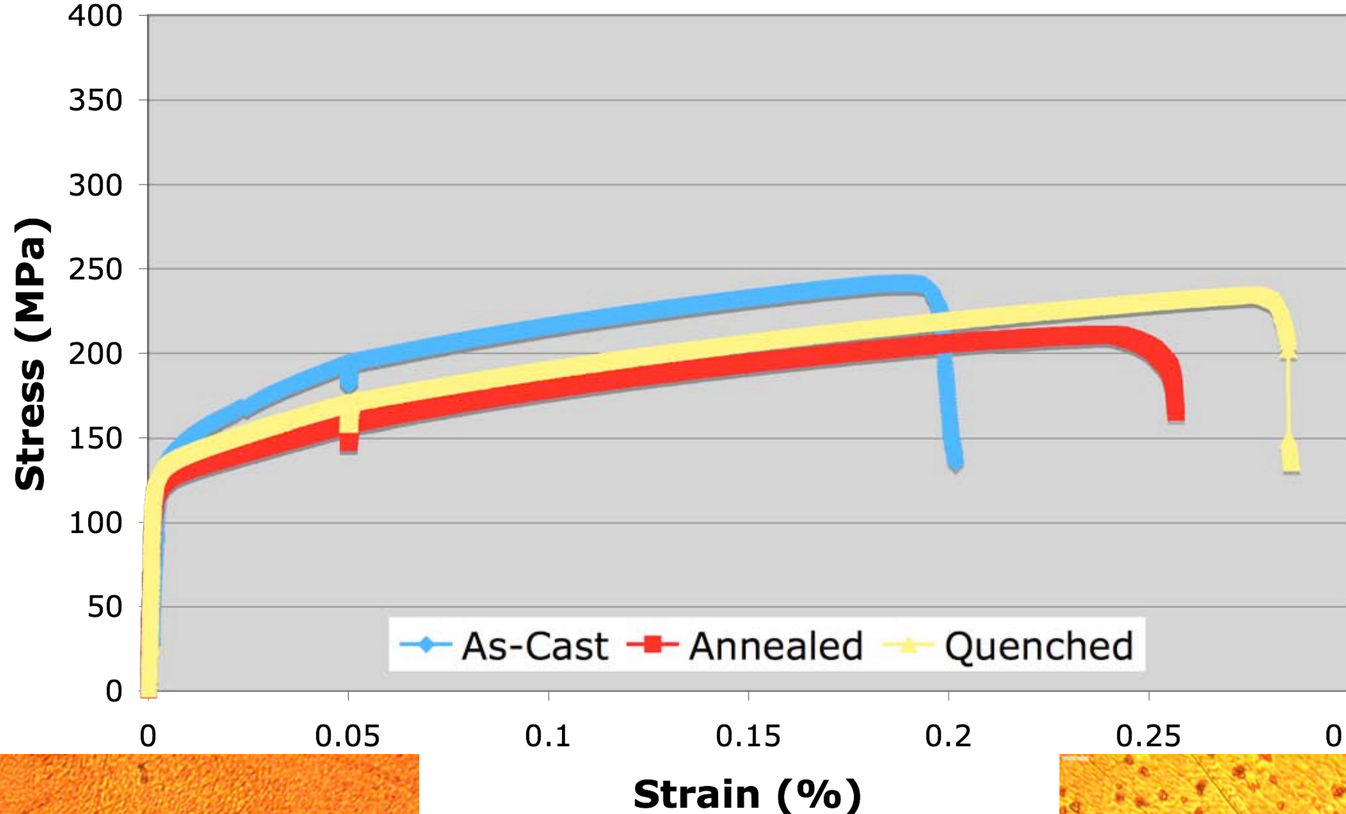
As-cast

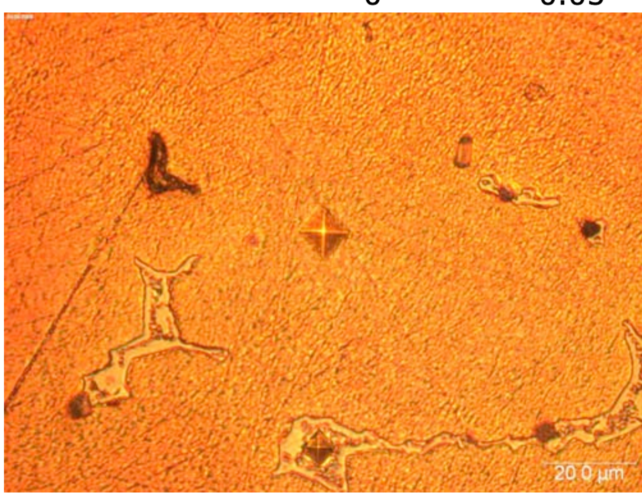


Quenched



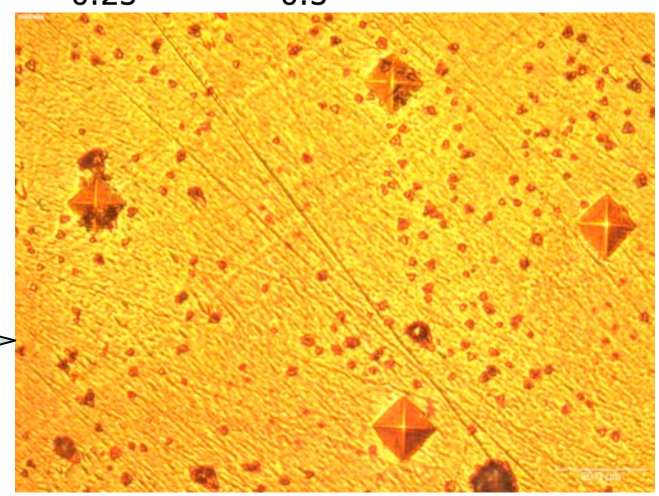
Mechanical Properties: 10% Sn



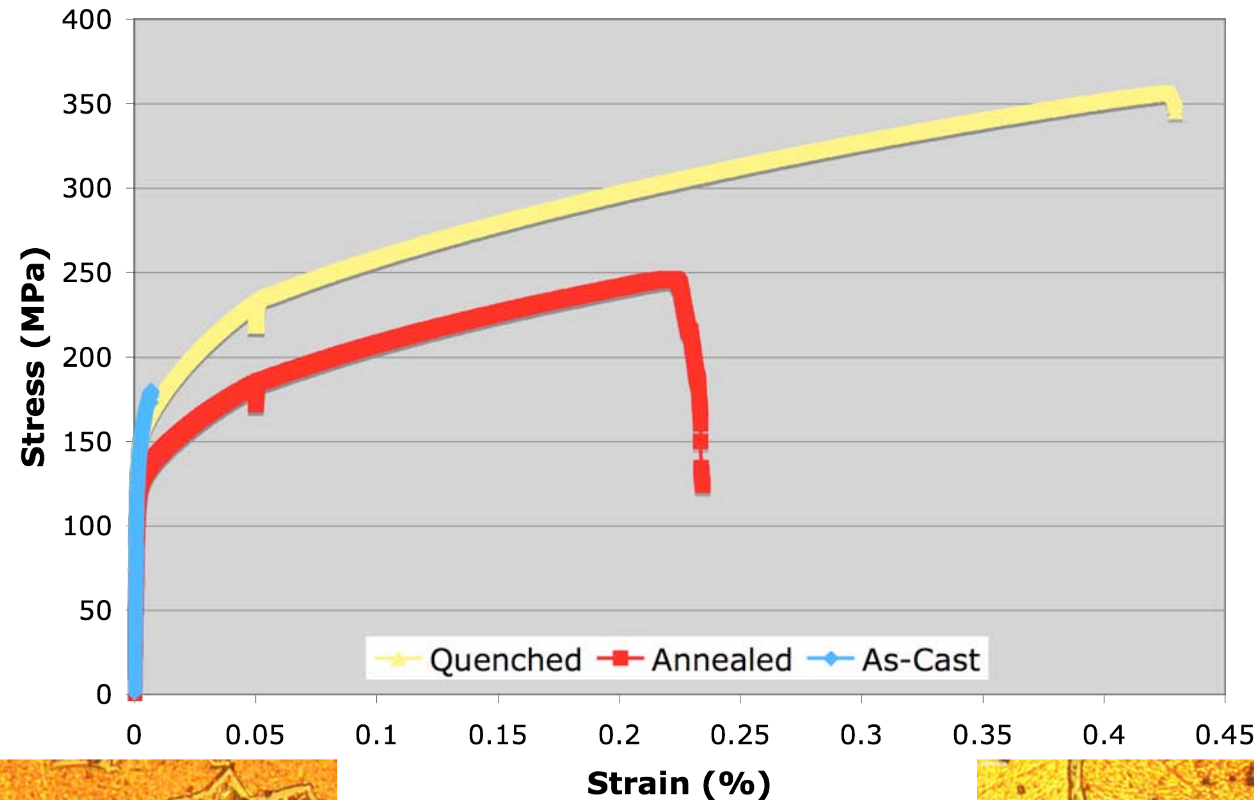


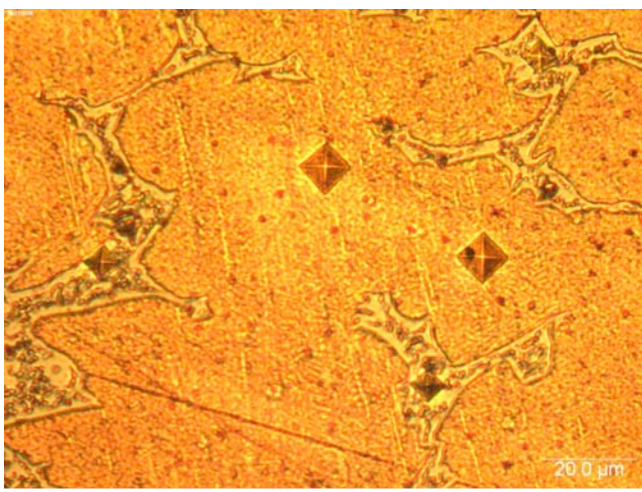
As-Cast

Quenched



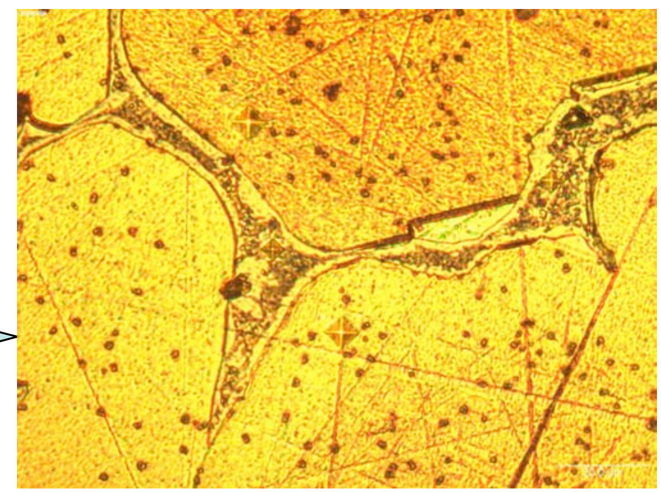
Mechanical Properties: 18% Sn



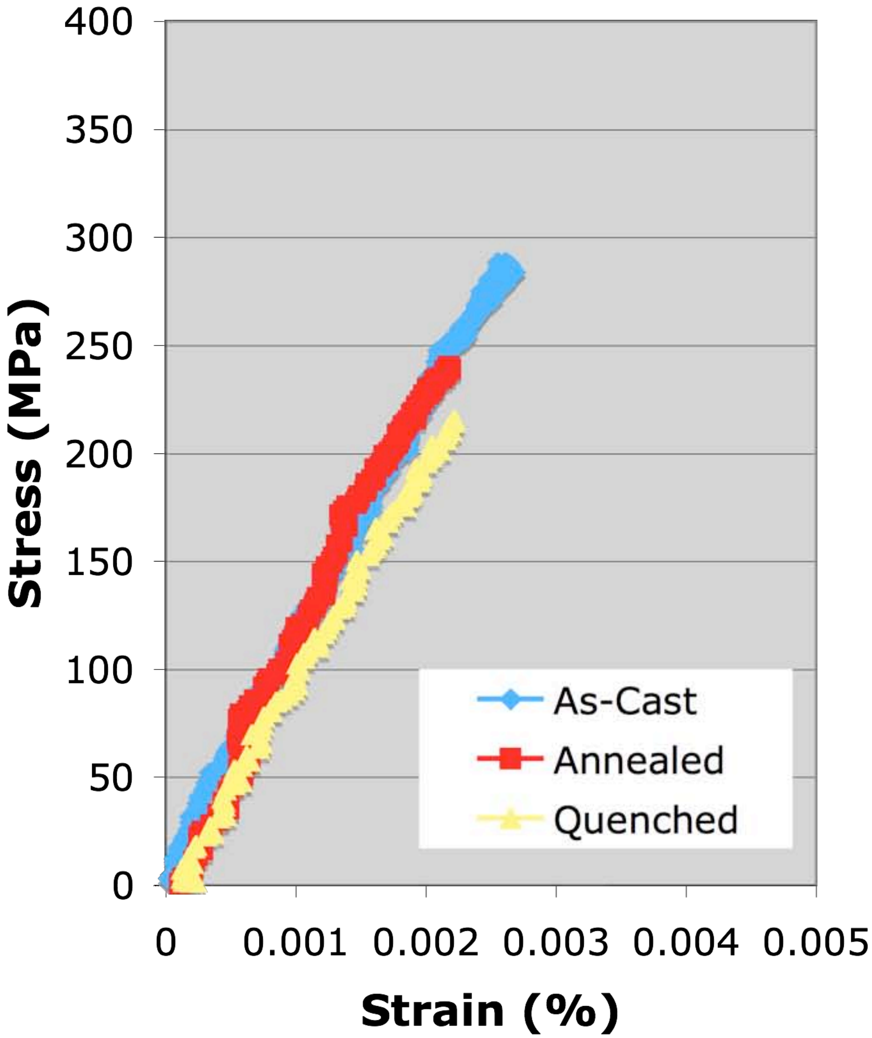


As-Cast

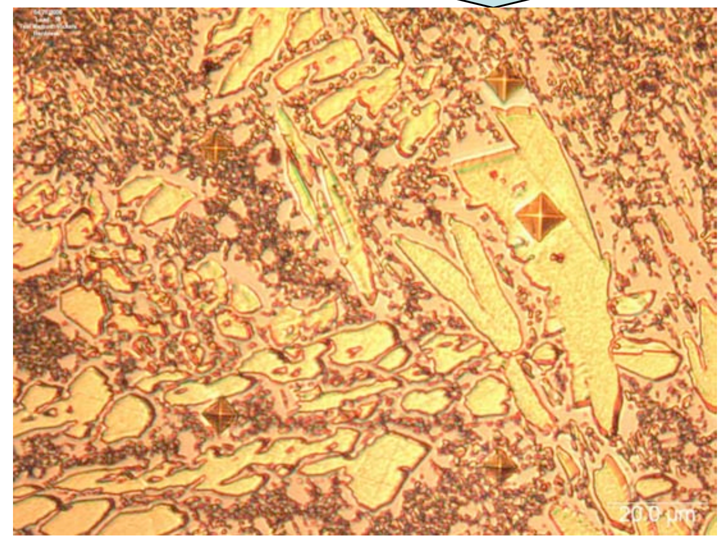
Quenched



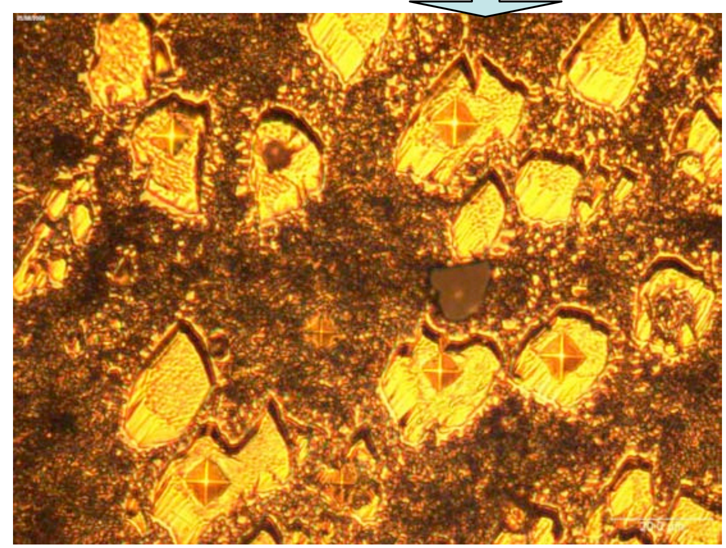
Mechanical Properties: 31% Sn

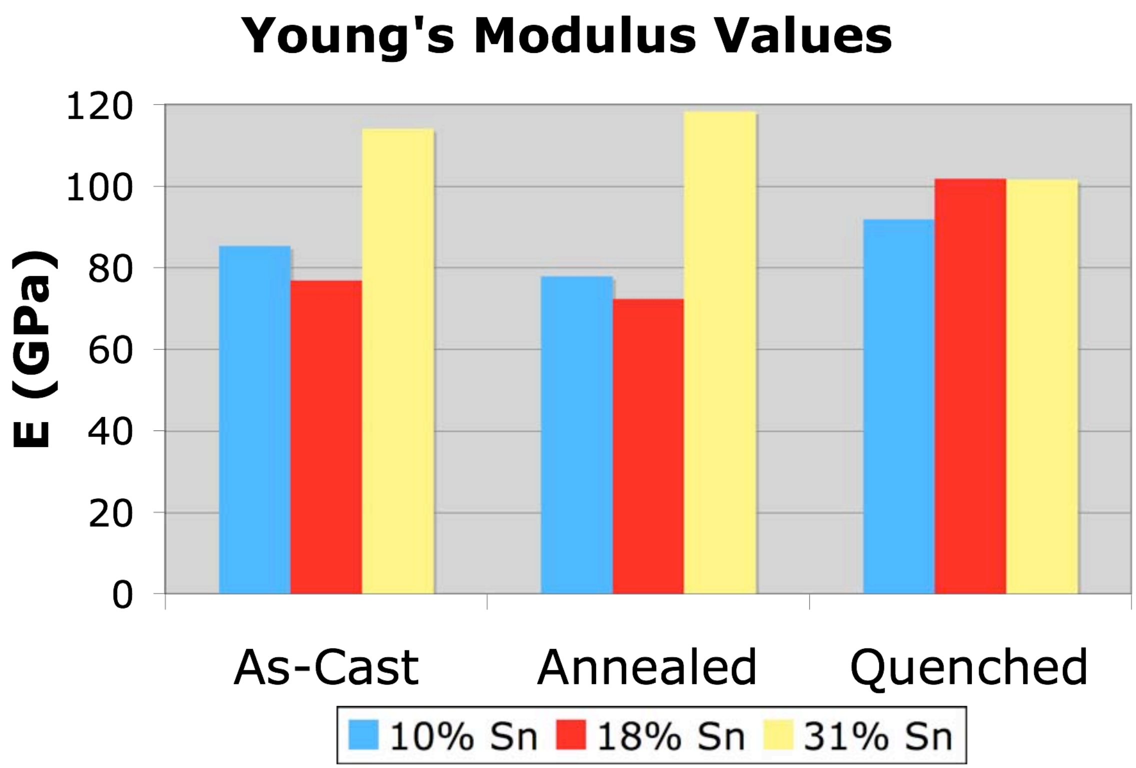


As-Cast



Quenched





	% Sn	E (GPa)	.2% Yield (MPa)	UTS (MPa)	RB
As-Cast	10	85.3	141.2	241.5	24
	18	76.9	150.4	180.1	48
	31	114.2	n/a	288.9	98
Annealed	10	77.9	124.1	215	10
	18	72.3	127.5	246.3	25
	31	118.4	n/a	244.2	98
Quenched	10	91.9	134.5	234.2	11
	18	101.9	160.1	352.3	38
	31	101.7	n/a	215.9	98

Summary

	10%	18%	31%
As-Cast	Precipitation hardening	Precipitation hardening	
Annealed	Precipitation hardening; fewer precipitates	Precipitation hardening; fewer precipitates	
Quenched	Solid solution strengthening; no precipitates	Precipitation hardening; fewer precipitates	

HEMONY

Acoustics

Good Bell?

- Minimal Noise
- Harmonic Series: **0.5, 1, 1.2, 1.5, 2**
- Lengthy Amplitude decay

Geometry

10TH

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Please see the diagram of bell nodals in https://www.msu.edu/~carillon/batmbook/chapter5.htm

1ST

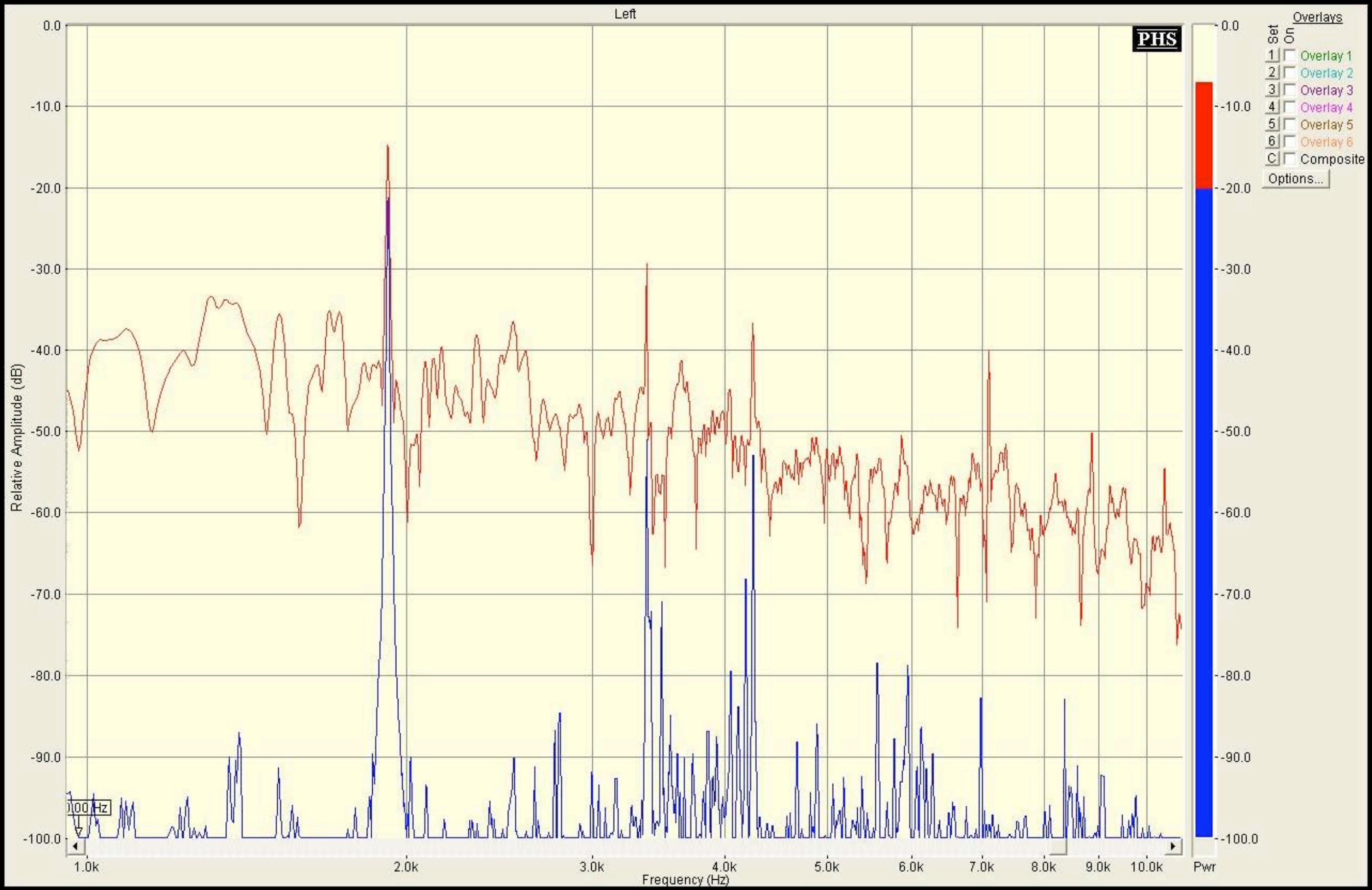
Acoustical Testing

Harmonic Partial Matrix: HERTZ

	1st	2nd	3rd	4th	5th	Wavespeed
10%	1921	2538	3369	4240	7083	1691 m/s
18%	1966	3521	4309	5082	7470	1754 m/s
31%	2162	3714	4762	6499	8047	1818 m/s

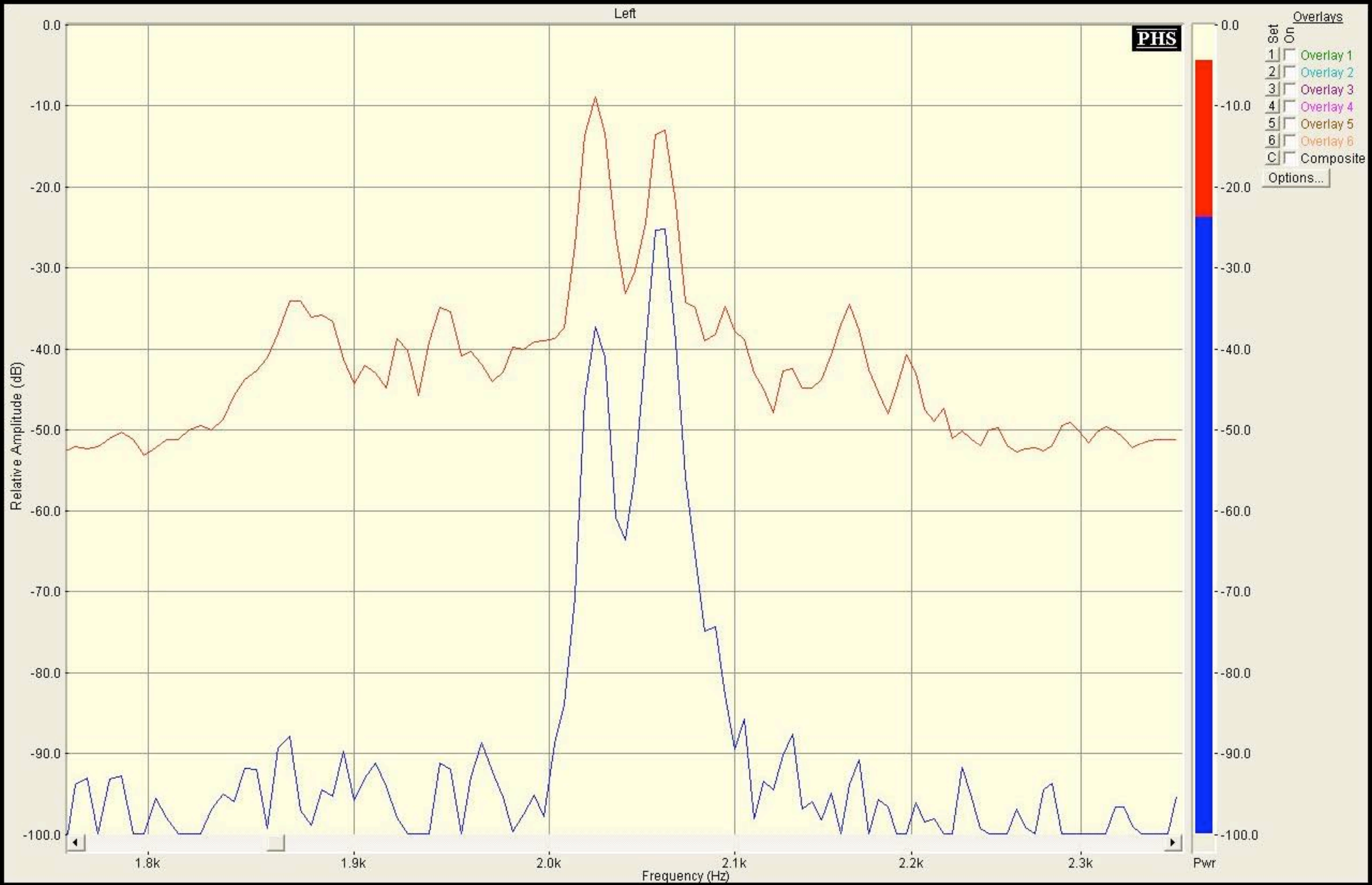
10% Sn

<u>Harmonic Multiple Sequence:</u> 1, 1.3, 1.7, 2.2, 3.7



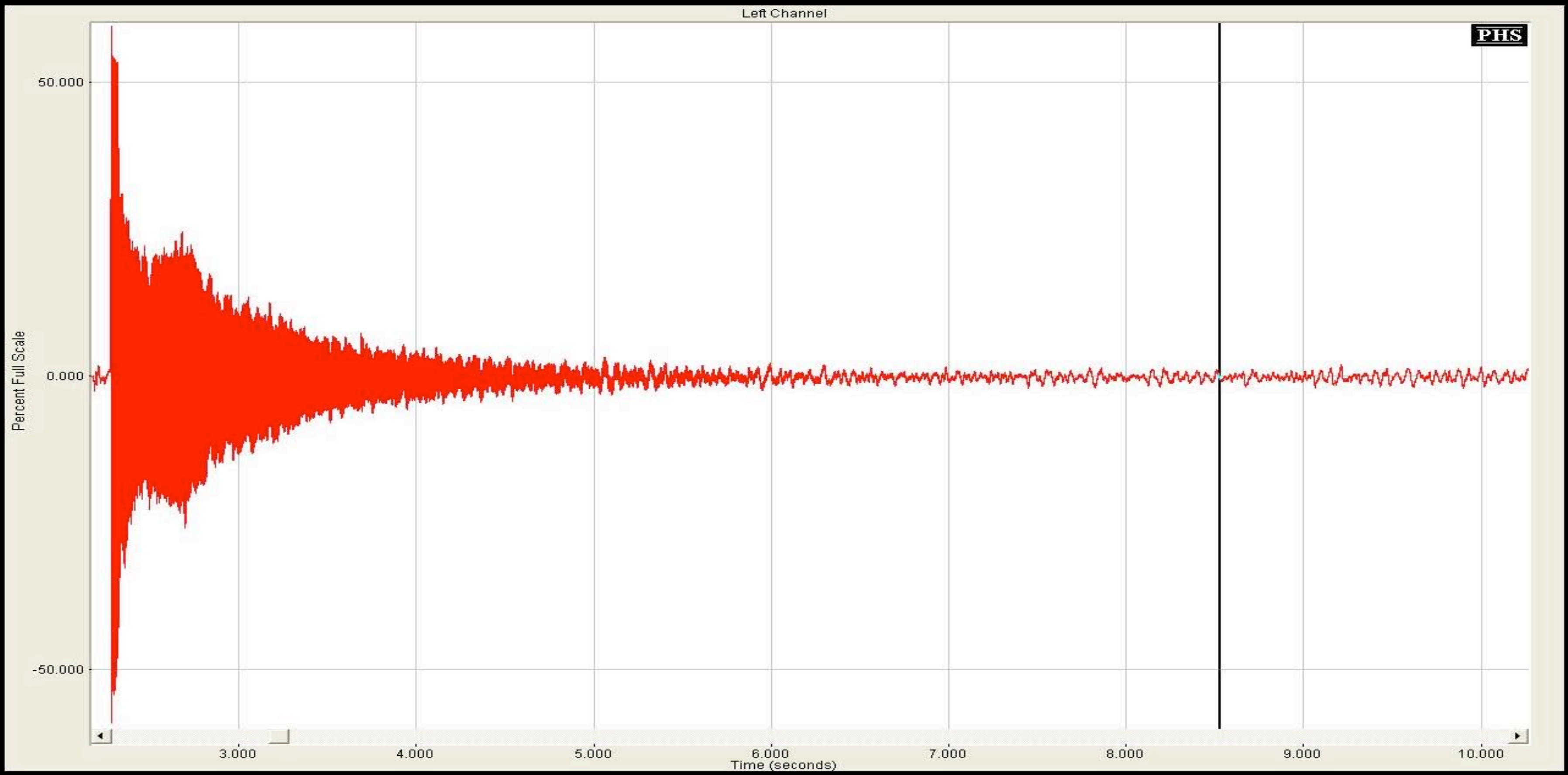
10% Sn

Source of Dissonance: Inharmonic Degeneracy



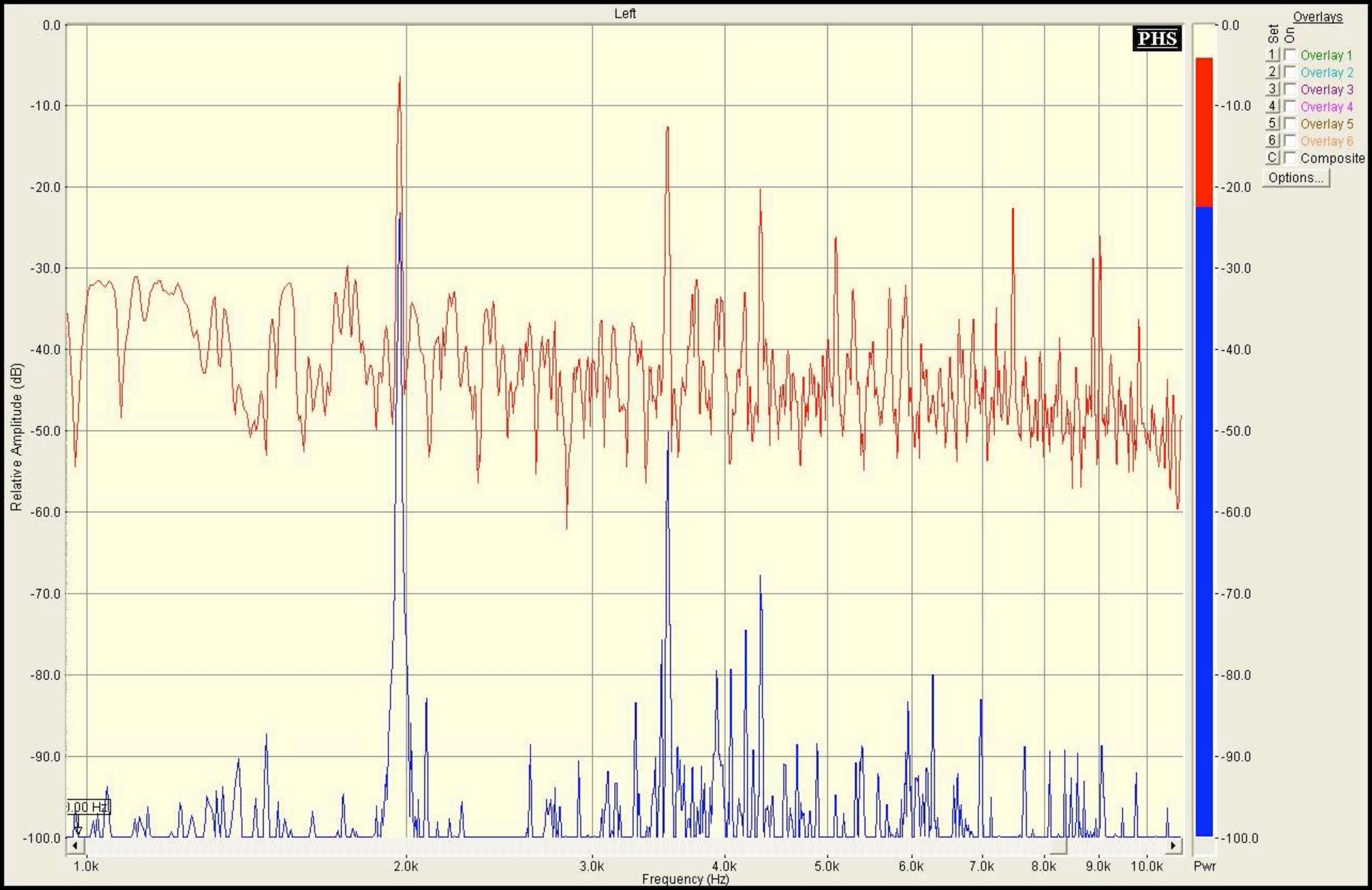
10% Sn

Minimal beat phenomenon apparent. Damped Harmonic Oscillator



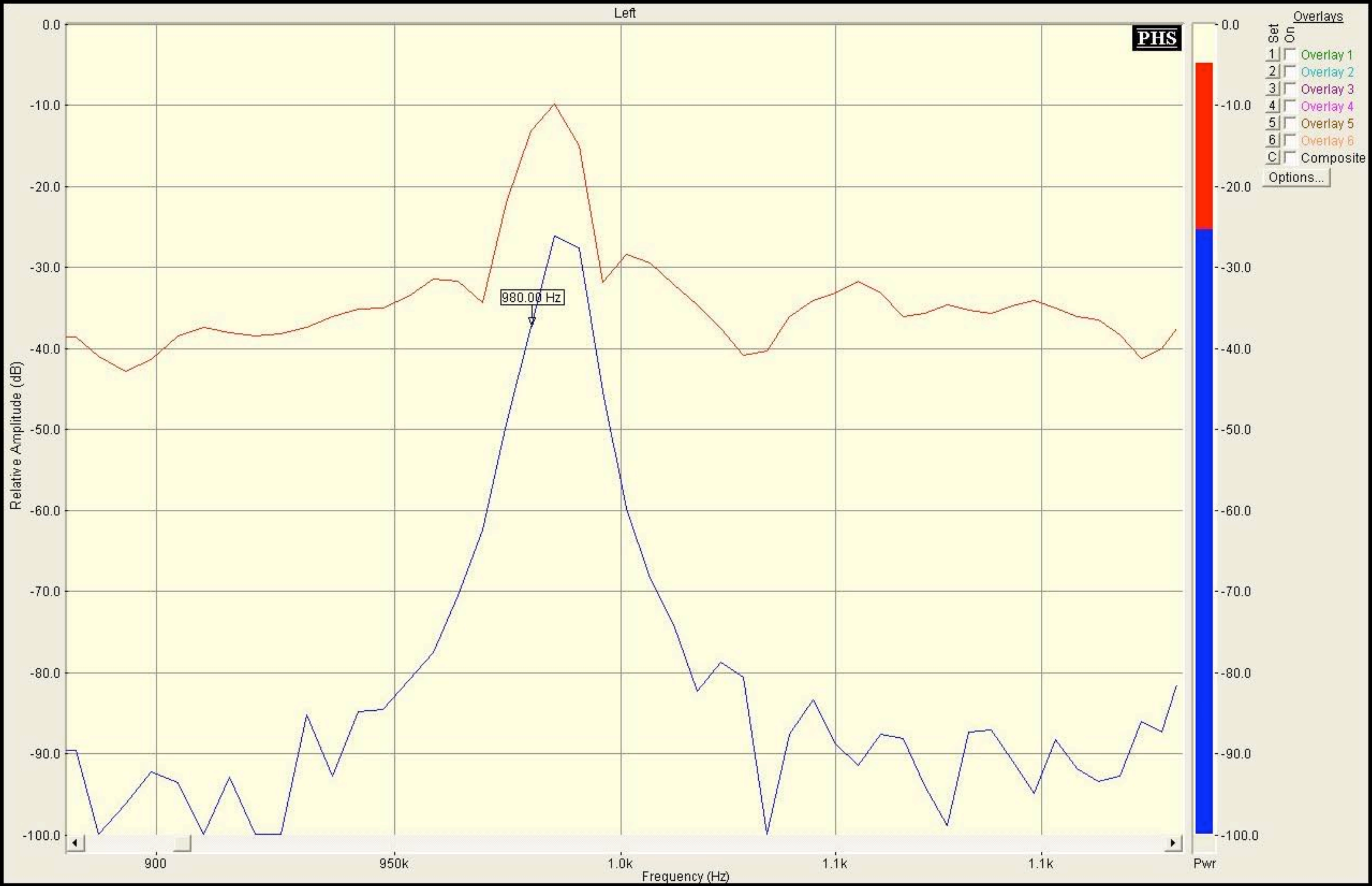
18% Sn

Harmonic Multiple Sequence: 1, 1.8, 2.2, 2.6, 3.8



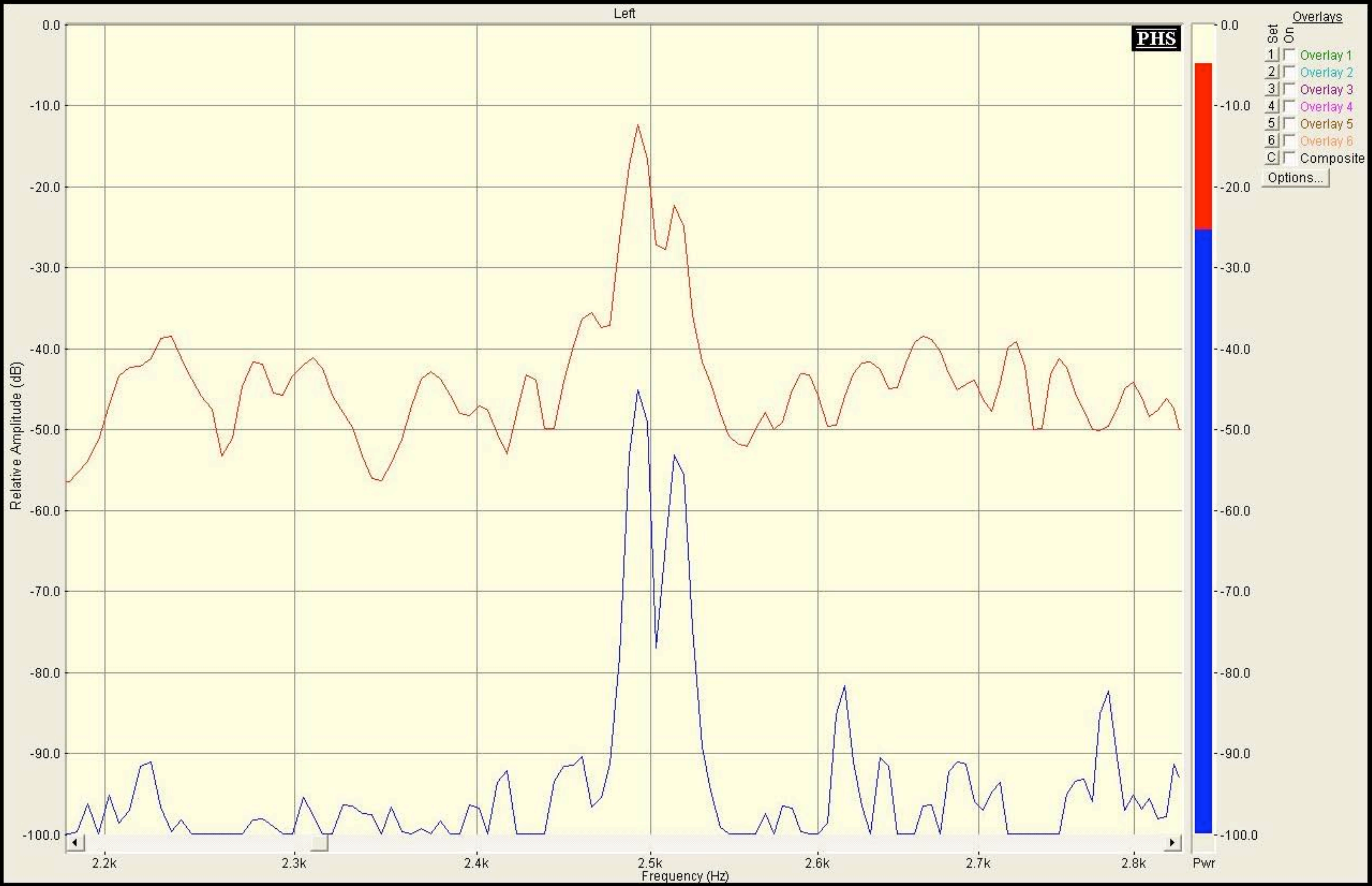
18% Sn

Hum Tone - Beautiful



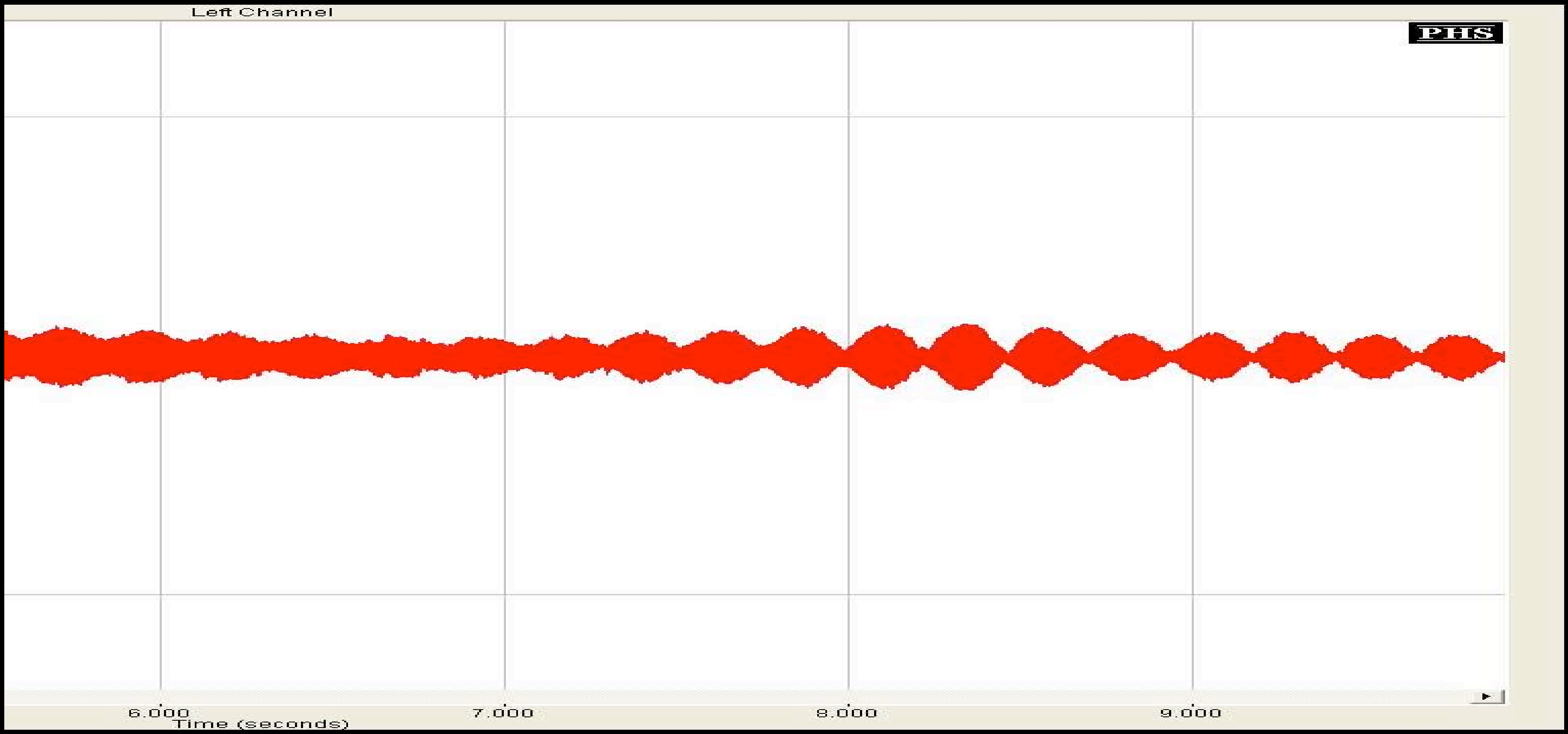
18% Sn

BEAT PHENOMENON



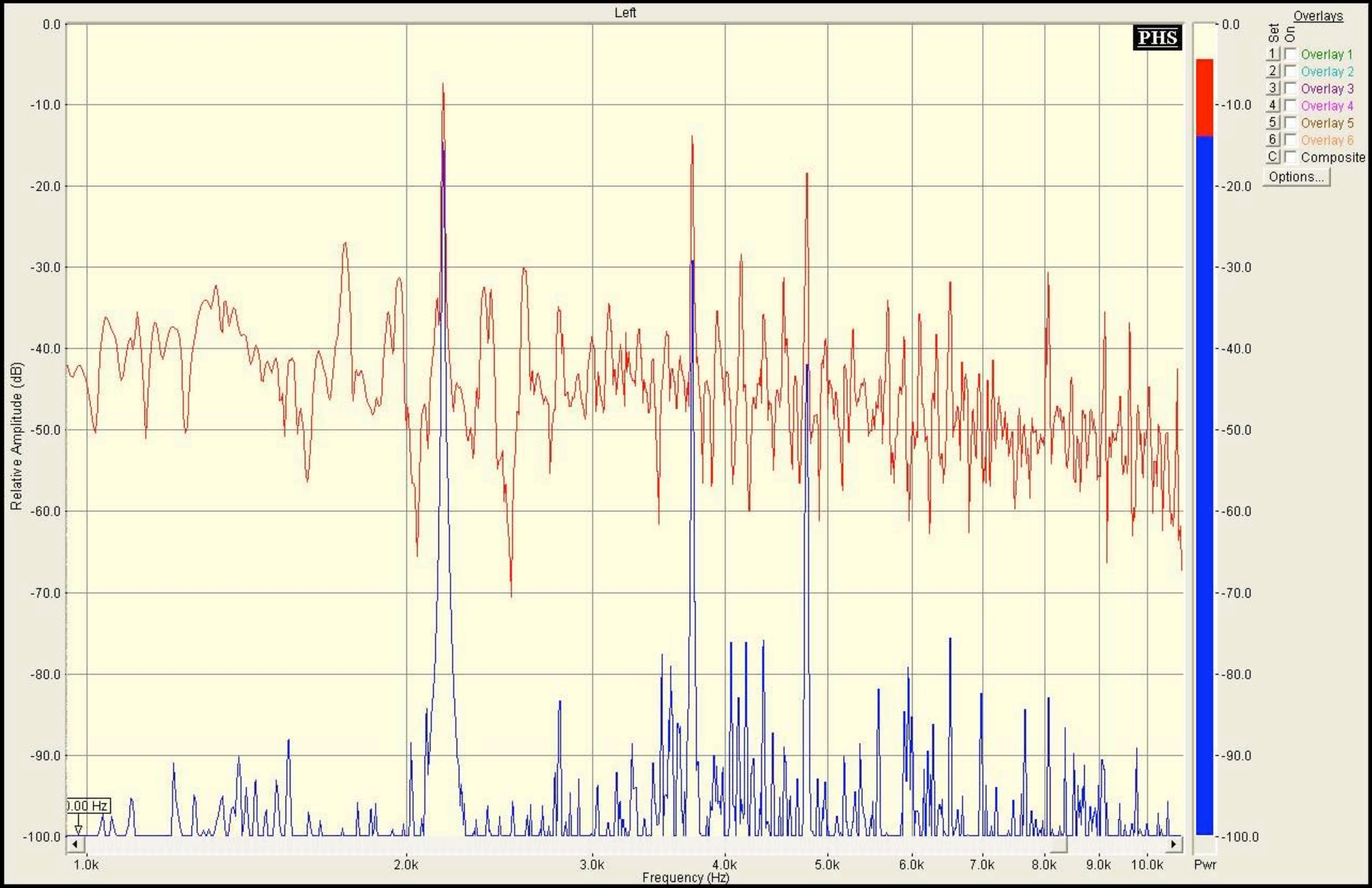
18% Sn - *Wall Profile Inconsistency*

$$\sin(2\pi f_1 t) + \sin(2\pi f_2 t) = 2\cos\left(2\pi \frac{f_1 - f_2}{2} t\right) \sin\left(2\pi \frac{f_1 + f_2}{2} t\right)$$

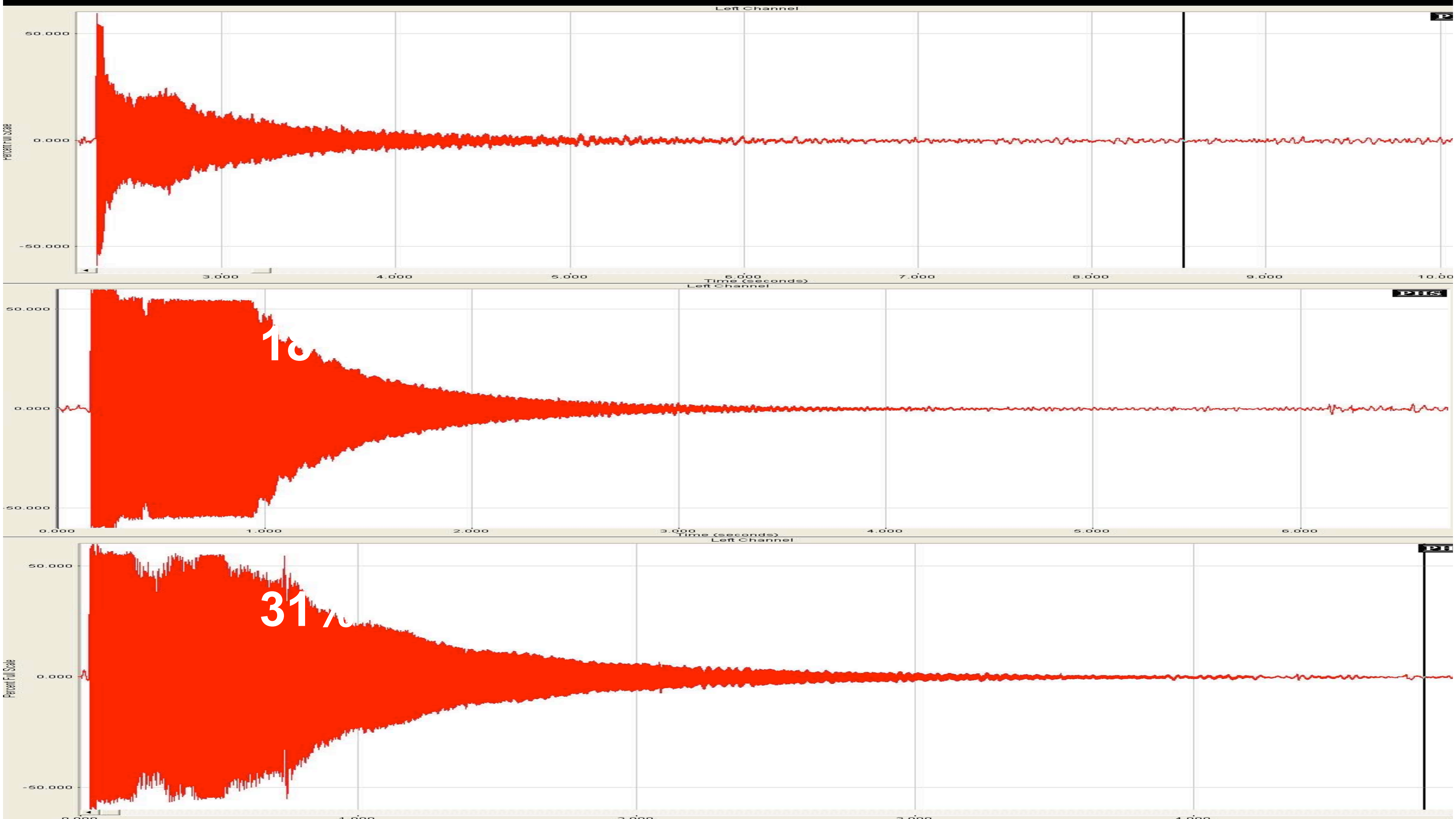


31% Sn

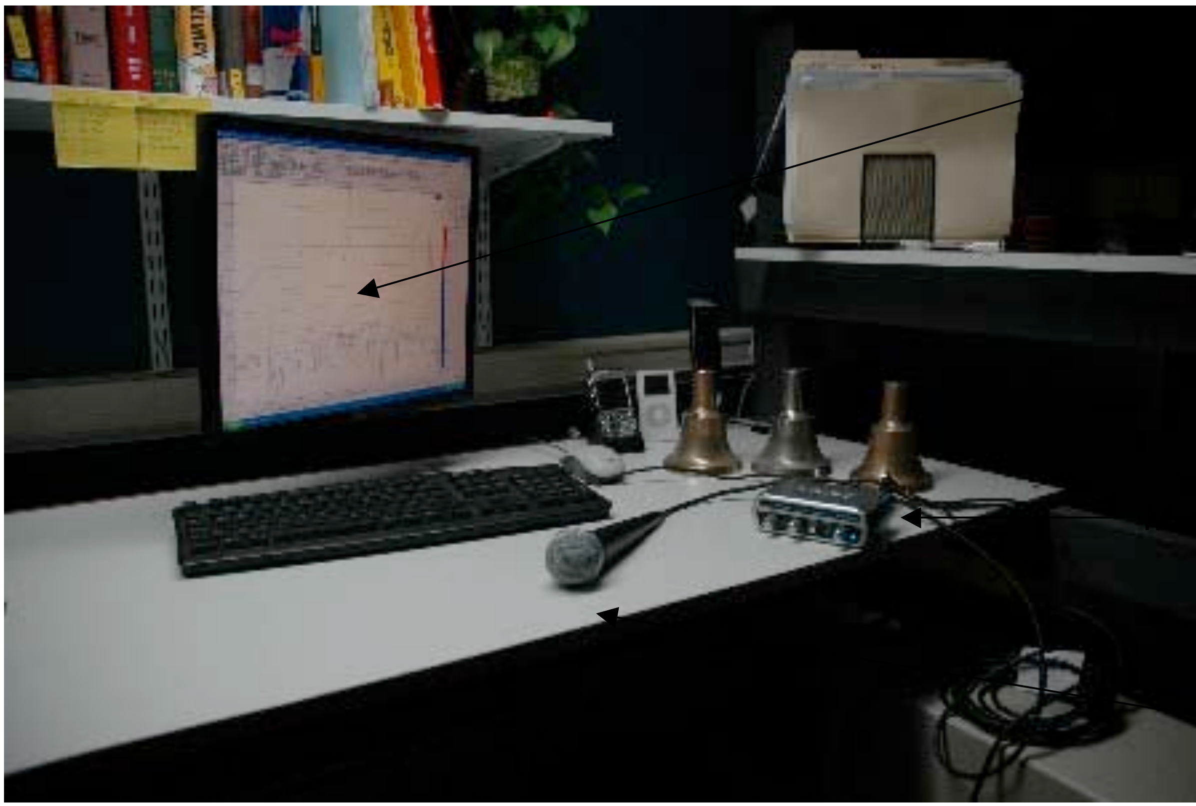
<u>Harmonic Multiple Sequence:</u> 1, 1.7, 2.2, 3, 3.7



Attenuation Comparison



FFT Acquisition Setup

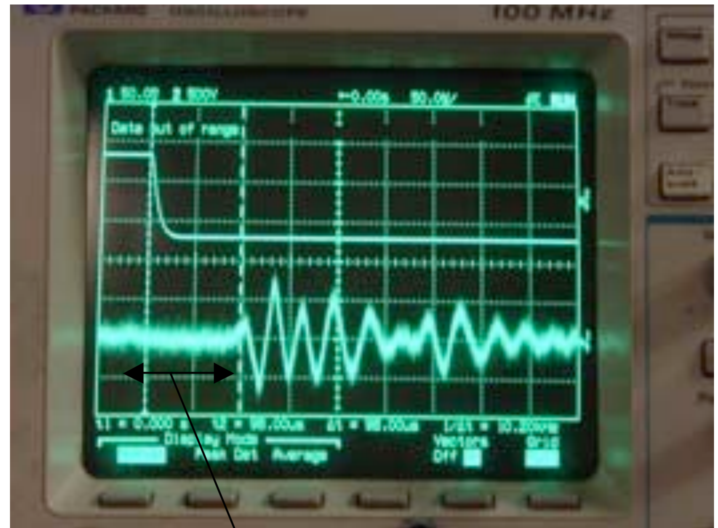


Pioneer “Spectra Plus”

udio USB Audio Interface

Beta-58 Microphone

Setup - Wavespeed



Piezoelectric transducers -
Driver and Receiver

Phase lag for pulse reception

Further Experimentation

Localized heating of upper waist - Proven in experiment that annealing provides a lower young’s modulus for all three alloys. Creates a more elastic connection to (hard) crown.

Upper Waist

This will decrease the bell’s frequency, but increase its time for attenuation. Mass of sound bow does not need to be removed.

Acknowledgements

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Prof. Ray Ashoori (Physics Dept.)