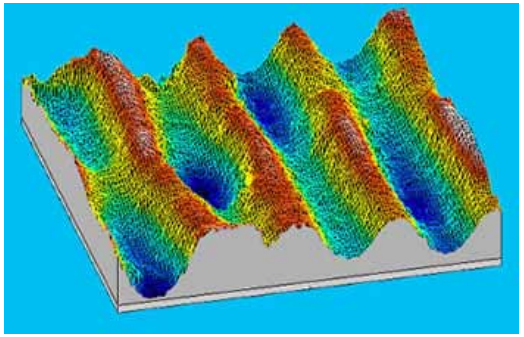
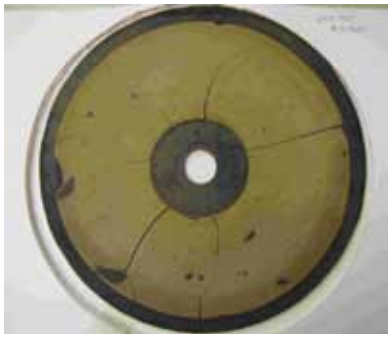
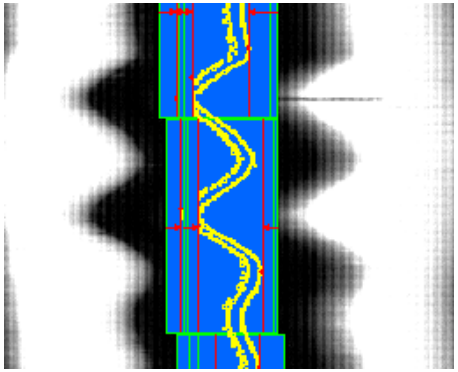
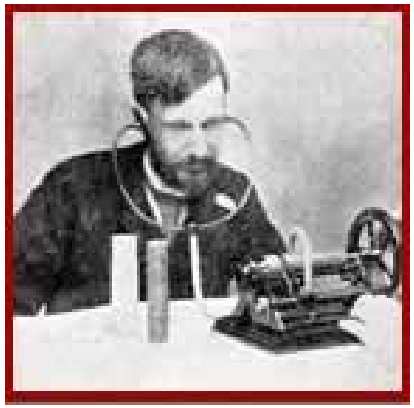
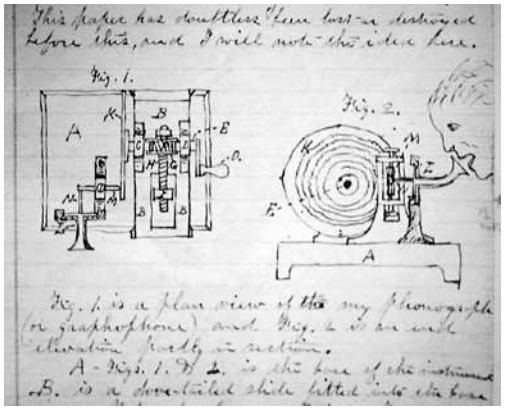



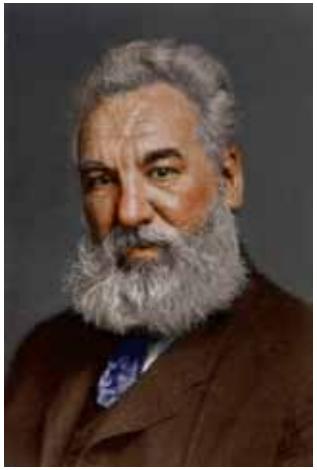


New Optical Technologies for Preserving Recorded Sound: Experiments with the Smithsonian's Earliest Recordings, 1880-1890

Carl Haber

Lawrence Berkeley National Lab



Introduction

- In this talk I will discuss non-invasive instruments and methods for recovering historic recorded sound.
- Address concerns of museums and libraries:
  - Preservation: Restore or stabilize delicate or damaged media
  - Access: Mass digitization of diverse media, automation
  - Assessment
  - Obsolete formats and legacy playback systems
- Present examples and status of the research.
- Recently we have applied this approach to the earliest recordings in the collection of the Smithsonian.

Collaboration and Support

Lawrence Berkeley National Lab: Earl Cornell, CH, Vitaliy Fadeyev, Robert Nordmeyer, students: Maryrose Barrios, Yin Huang
Library of Congress: Peter Alyea, Dianne van der Reyden, Elmer Eusman
Smithsonian NMAH: Carlene Stephens, Shari Stout
EIF Fribourg – Switzerland: Ottar Johnsen + students: Adrian Nicolet, Tobias Mueller, Marc Stadelmann
Thanks to Patrick Feaster for providing scholarship and insight into the SI collection

INSTITUTE of Museum and Library SERVICES

Smithsonian Institution

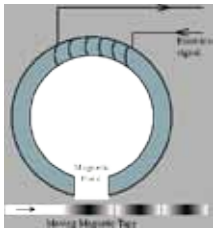
NATIONAL ENDOWMENT FOR THE HUMANITIES

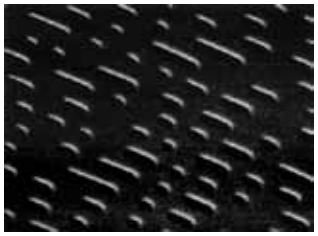
THE ANDREW W. MELLON FOUNDATION

John Simon Guggenheim Memorial Foundation
Fellowships to Assist Research and Artistic Creation

Reproduction Methods

- Dates refer to wide usage
- Mechanical: a stylus rides in an undulating groove, linked to a diaphragm or electrical pickup (Edison 1877 – 1980's)
- Magnetic: sound is stored in the magnetic orientation of a material (1948 – present)
- Optical: a pattern on film modulates a light beam (1920's – present)
- Digital: sound levels are stored as binary values on magnetic or optical (CD) discs or in a memory chip (1982 – present)

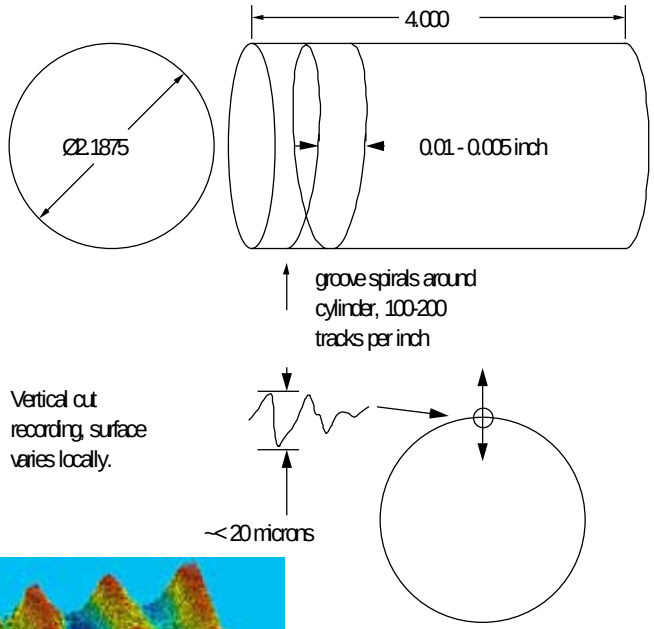


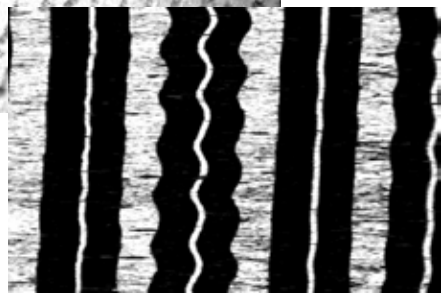


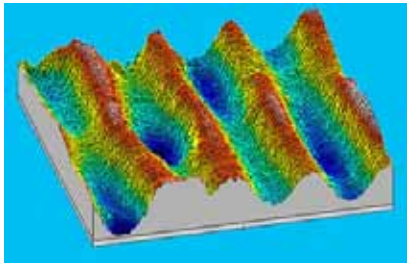
Mechanical Recording Principles

Cylinder: groove varies in depth (Vertical Cut)

Disc: groove moves from side to side (Lateral Cut)







Audio is encoded in micron scale features which are >100 meters long

History

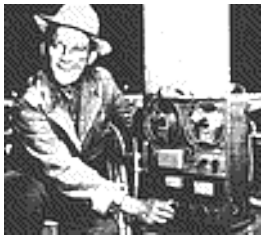
- 1853 Leon Scott: *Phonoautograph* paper recorder
- 1877 Thomas Edison invents sound reproduction on tin foil *Phonograph*

- 1880-5 Bell(s) and Tainter, Volta Lab research into audio formats, finally introduce wax cylinder
- 1887 Emile Berliner invents disc *Gramophone*
- 1925 Western Electric *Orthophonic* (electrical) system

end of the "**Acoustic Era**"

Discos fonográficos Pathé
Caras y Caretas (7/7/1906)

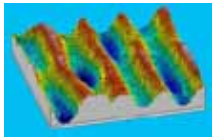
- 1929 Edison production ends, lacquer transcription disc introduced
- 1947 Magnetic tape in production use, Ampex 200A
- 1948 33 1/3 rpm LP introduced



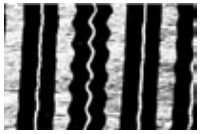
- 1958 Stereophonic LP on sale, uses 45/45 system
- 1963 Cassette magnetic tapes
- 1982 Compact Disc (*CD*)

end of the "**Analog Era**"

- 2001 Apple *IPOD*
- Late 2000's Massive online access to digital sound files



Non-Contact Digital Imaging

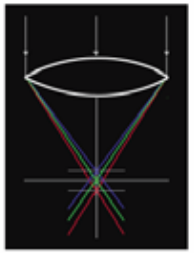


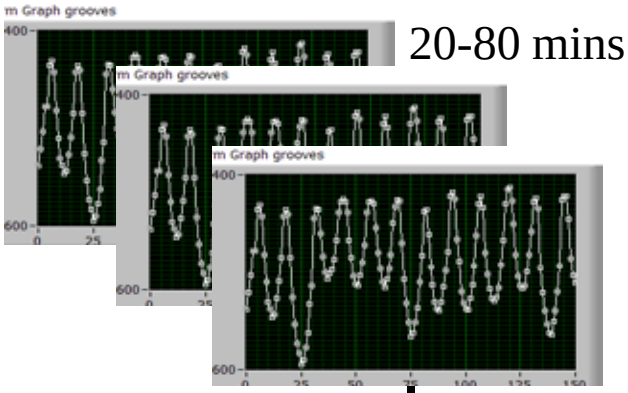
- Create a high resolution digital map of entire surface
- Computer plays record (image) with a virtual stylus
- Product
  - Standard digital sound files (ie .wav)
  - High resolution digital images which may be reanalyzed later as well
- Protects samples from further damage
- Repair existing damage through “touch-up”
- Reconstruct broken records
- Offload aspects of restoration to automated software

A “smart” copying machine for records

Basic Scanning Process

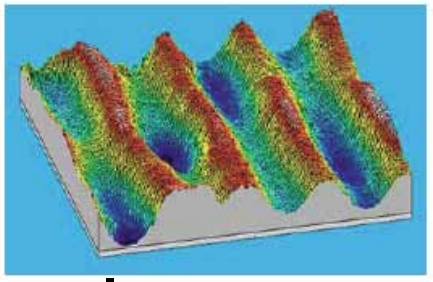
High resolution optical probe…creates a series of depth/intensity profiles of the surface



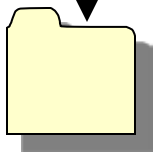


20-80 mins

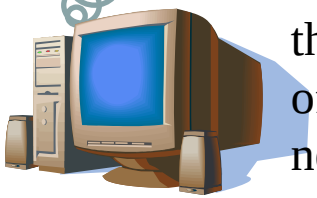
These are merged into a surface map



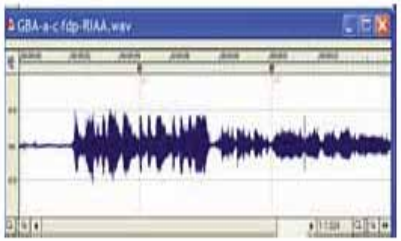
Map is archived



Calculate the motion of a virtual needle

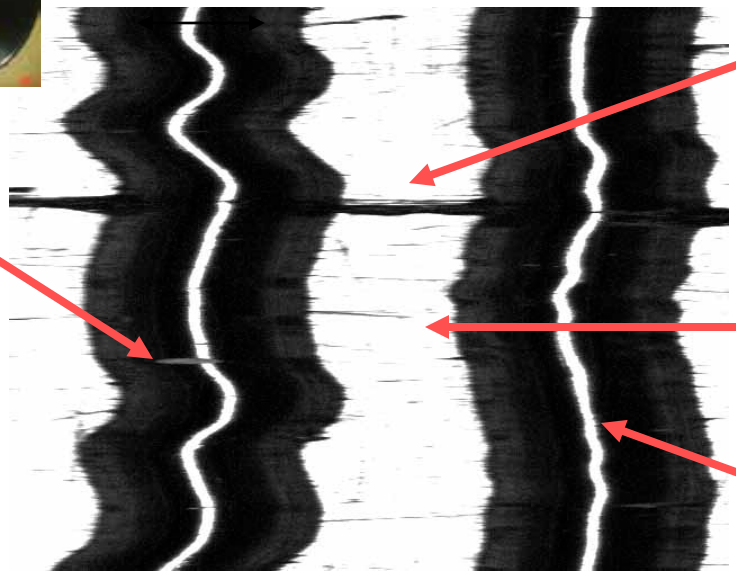


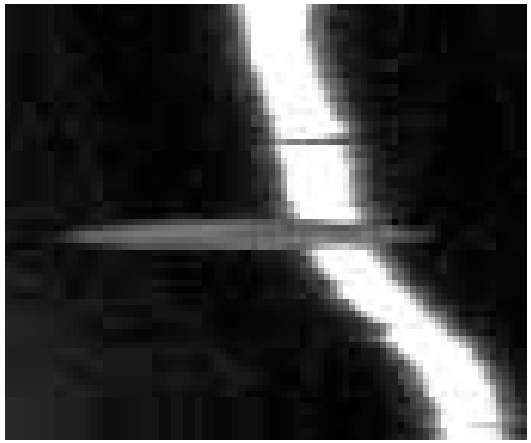
Create audio waveform



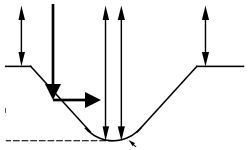
2D Imaging: Electronic Camera

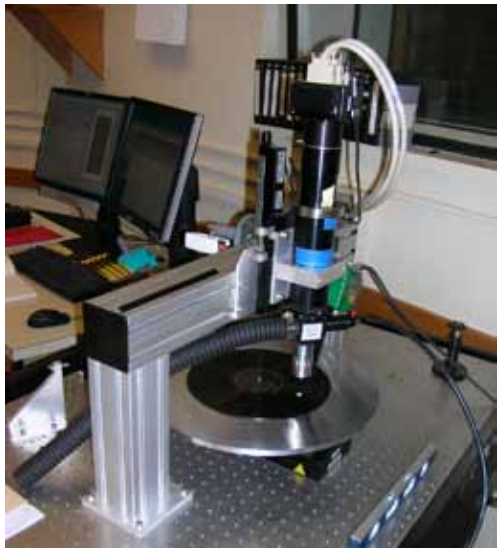
160 mm





Coaxial illumination



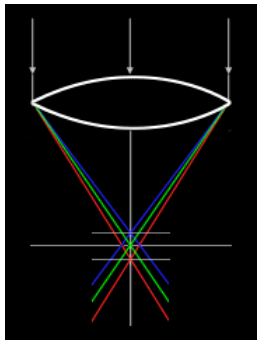


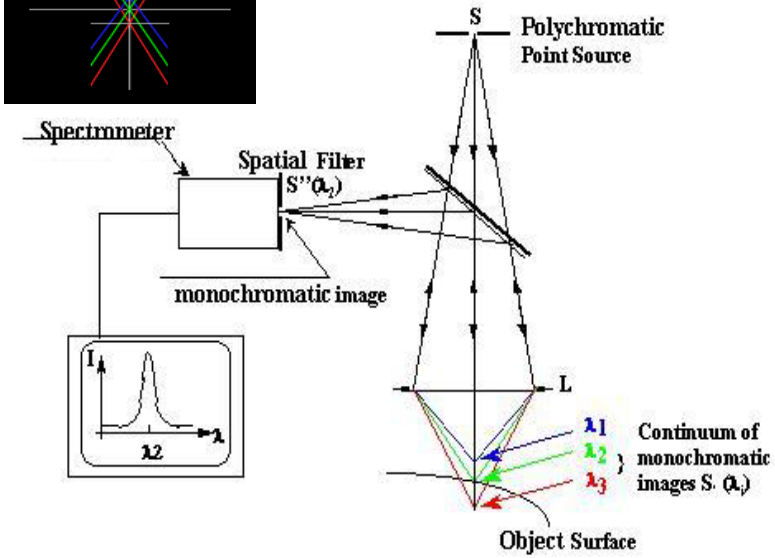
- Suitable for disc with lateral groove
- Require 1 pixel = ~ 1 micron on the disc surface
- High resolution = narrow depth of field, 10 – 20 microns
- High speed cameras allow near “real-time” imaging
- Extract groove information from high contrast edge transitions

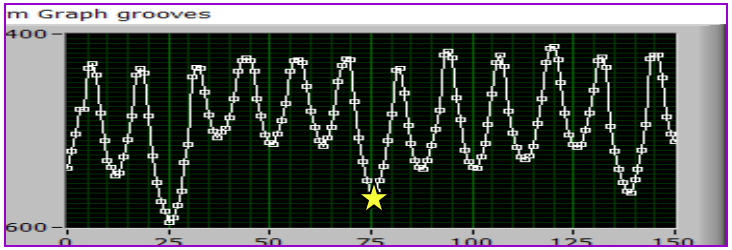
“IRENE”

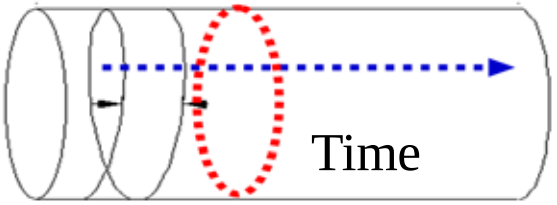
3D Imaging: Confocal Scanning Probe

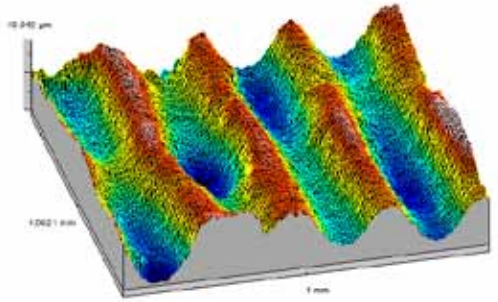
Required for cylinder with vertical groove modulation.







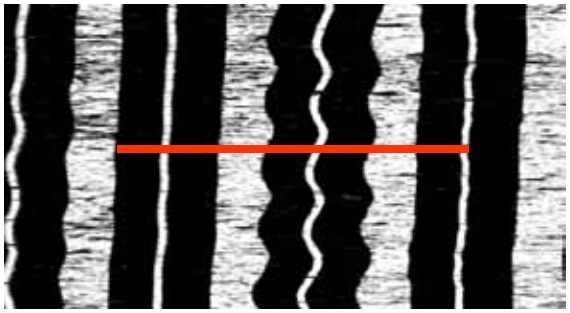


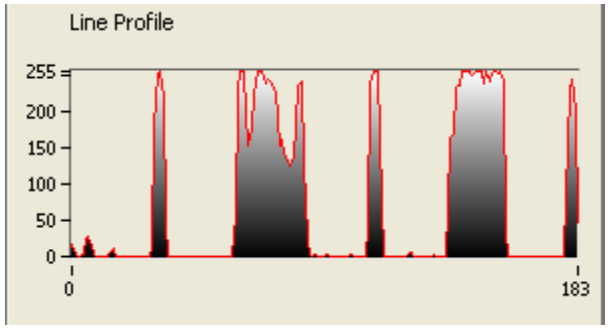


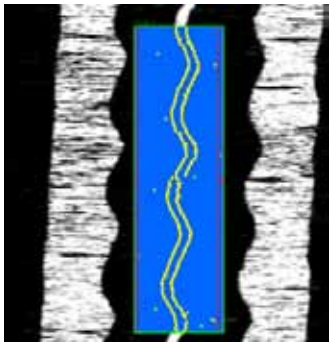
1 point at 2 KHz vs. 180 points at 1.8 KHz

3 days 30 minutes

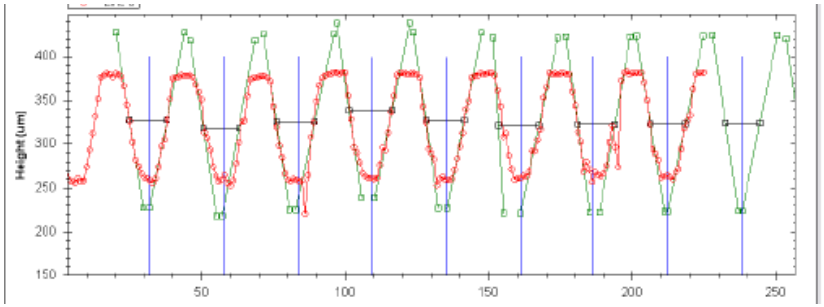
Image Analysis

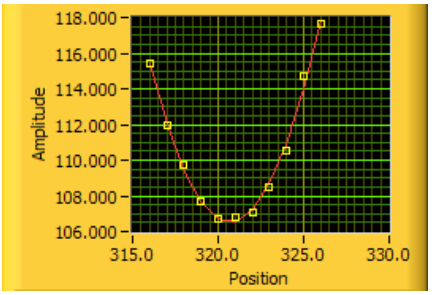






Edge detection



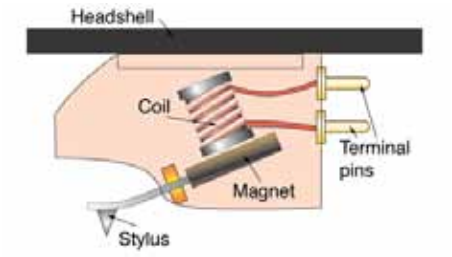


Surface parameterized by functions

- Feature extraction and measurement
  - Importance of characteristics and algorithms
  - Control of data quality: DOF, focus, intensity, bad points
- Measured characteristics of features provide a natural noise detection and removal tool

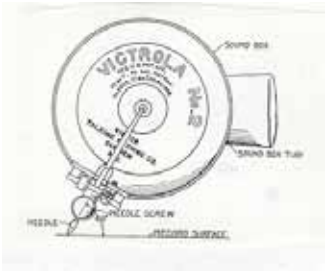
What is the relationship between "groove" and sound?

Electro-magnetic case

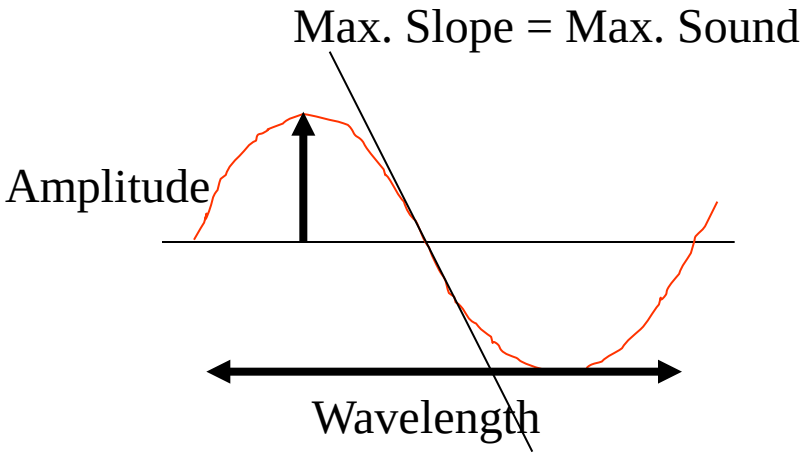


induction

Acoustic case



Diaphragm is over-damped to provide flat response



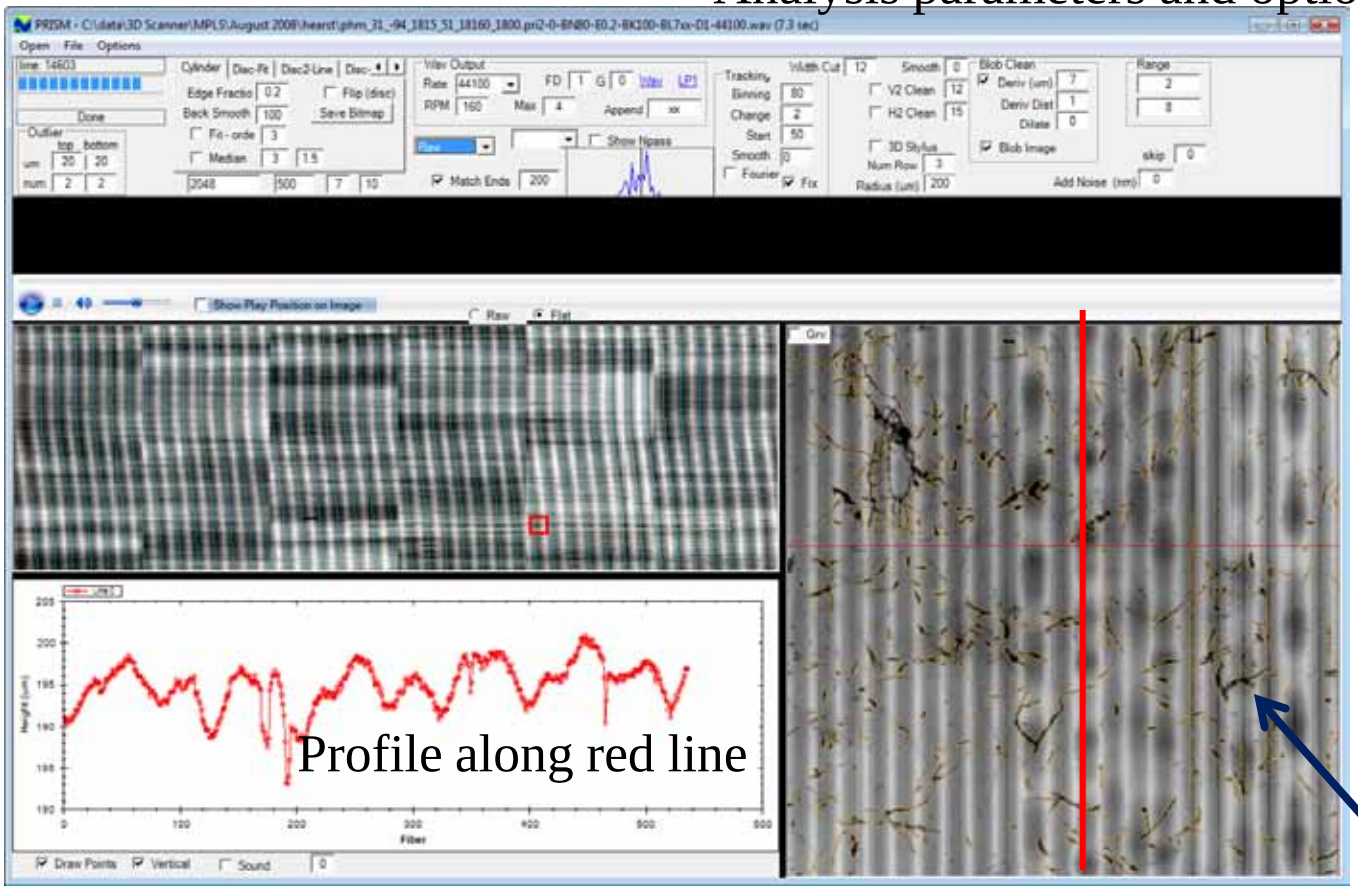
Sound = Stylus Velocity

$$A_p = \frac{v_p}{2\pi f}$$

("constant velocity condition")

3D Analysis Software

Analysis parameters and options



Overview of full data set

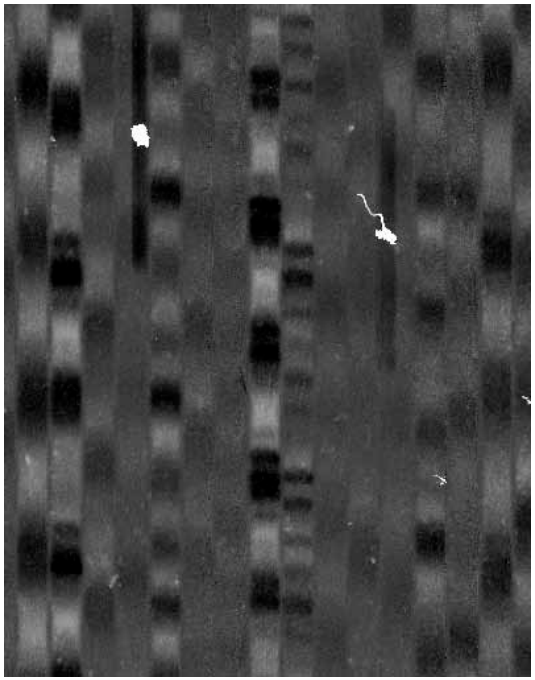
Zoomed in view

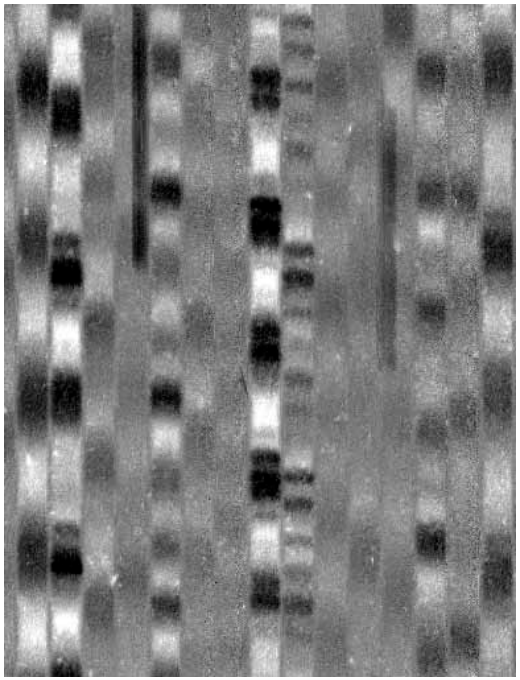
Depth image, black is deepest

Surface damage

The analysis package “PRISM” includes powerful tools and options for access to the data and image processing to remove defects and damage.

Example of Dust Removal





Dust particles appear WHITE because they are above the surface
(Relative brightness is scaled to maximum-minimum)

Developments

- Tests 2002-3 led to support from Library of Congress and others.
- IRENE: a fast 2D optical scanner for disc records 2006-7 (NEH)
  - Digital access to the most common media + special formats
  - Installed 2006 at Library of Congress, evaluation, upgrade
- 3D: a fast 3D scanner for cylinders and discs 2008-9 (IMLS)
  - Preservation and restoration of early and damaged recordings
  - Benefit from recent improvements in 3D probe technology
- Connecting to Collections: 2010-12 (IMLS)
  - Migration of technology into use at multiple collection sites
    - Test, and operation of IRENE at the LC Packard Campus
    - A “portable” IRENE for U Chicago South Asia Library in Chennia, India
  - Special Studies:
    - Wax field recorded and dictation cylinders
    - Damaged broken, unplayable, or rare recordings
    - Early experimental recordings
    - Cylinder molds and disc stampers

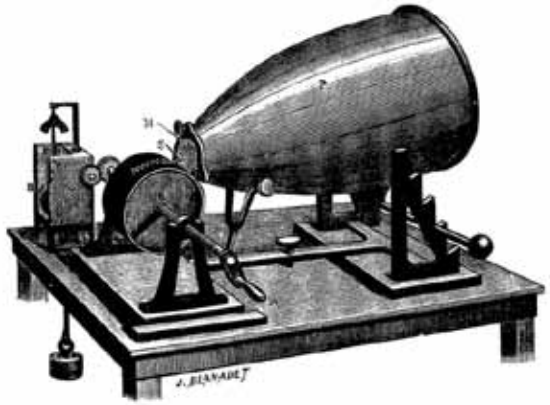
Timeline Examples

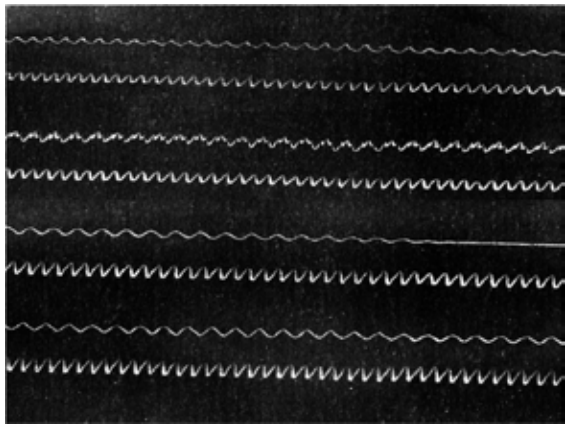
- Use history to describe examples of the optical scanning
- 1860 Leon Scott Phonoautograms
- (1877 Edison foils)
- 1881-1886 Volta Lab
- (Late 1880's Berliner Discs)
- 1887 Edison Talking Doll
- 1900's commercial and dictation cylinders
- 1910's – 1950's shellac, lacquer, and aluminum discs
- 1960's Plastic dictation belts

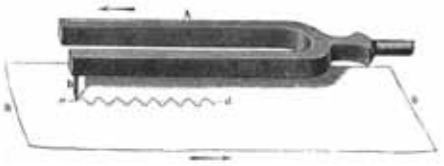
Early Recorded Sound

Phonautograph
Leon Scott
1853

Scott enscribed sound on paper and could not play it back

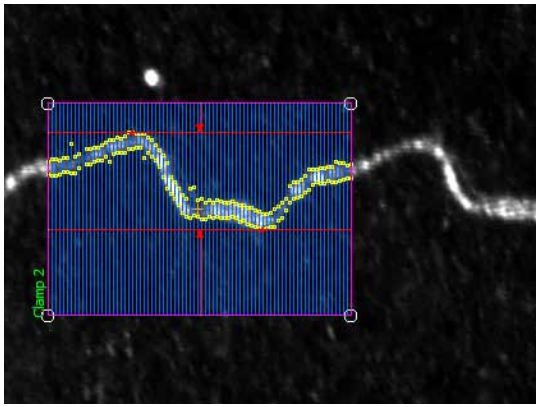


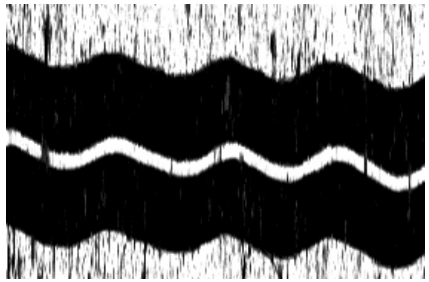


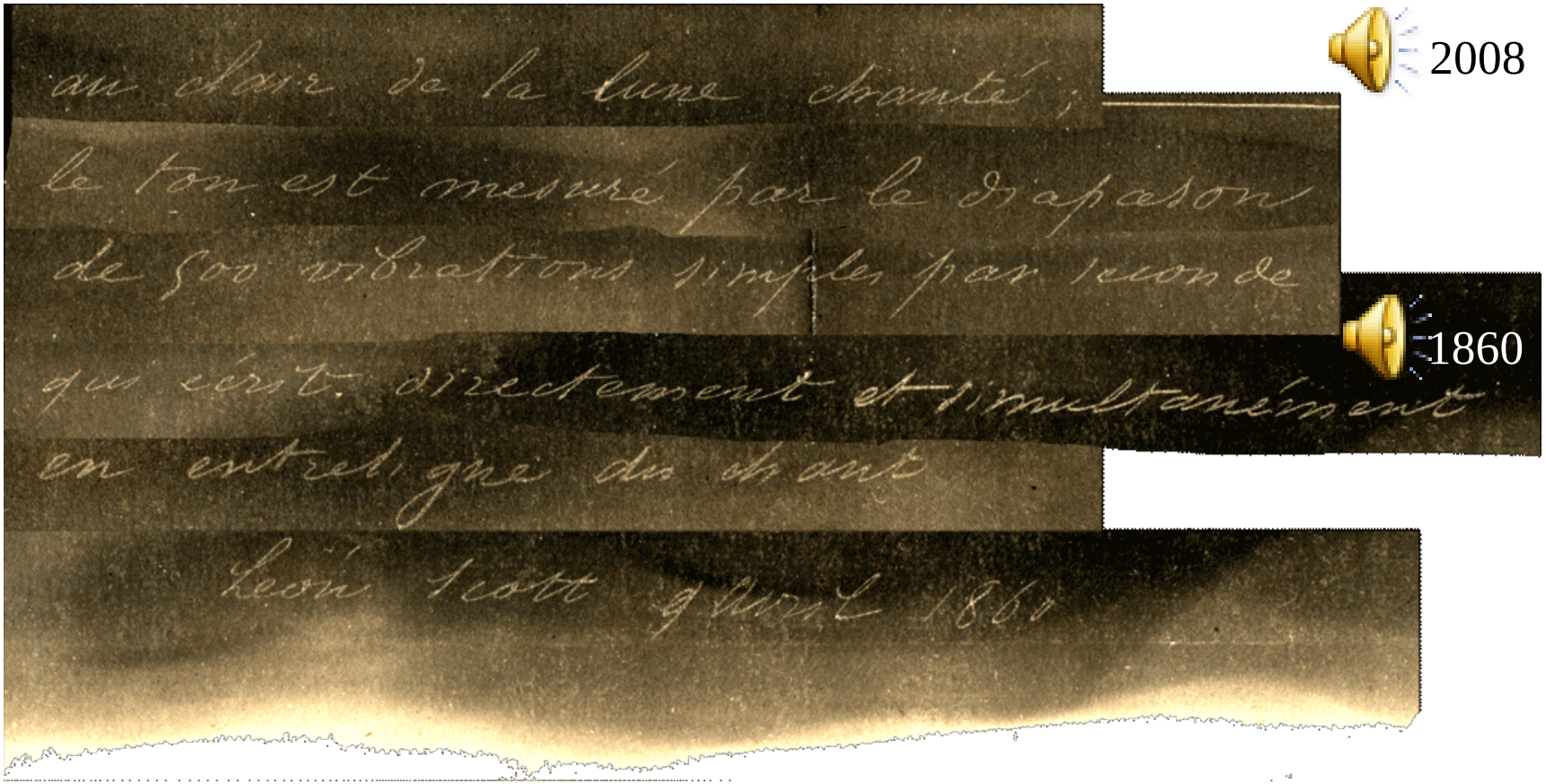


Recorded April 9, 1860
Deposited in the French Academy of Sciences

…visually similar to "IRENE" 2D scans, can processed and analyzed by the same tools…



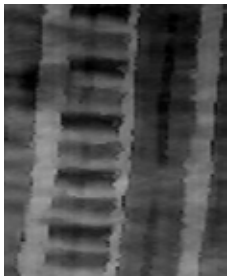


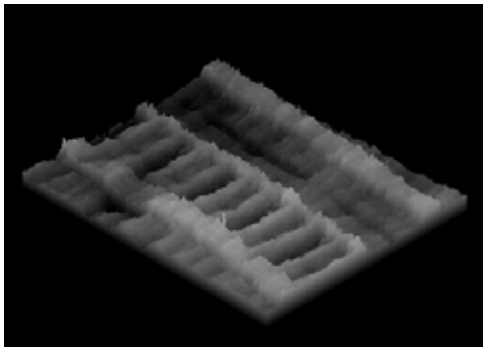


"Au Clair de la Lune" ["By the Light of the Moon"] sung;
"…the pitch is measured by the tuning fork of 500 simple vibrations per second which writes directly and simultaneously in interlinear space of the song"

Léon Scott 9 April 1860

Edison Talking Doll ~1887
"Twinkle twinkle little star…."





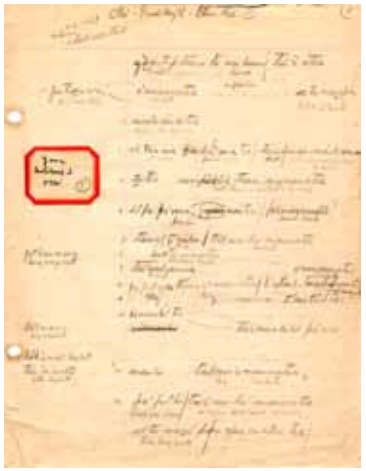
- This item was an experimental prototype for product sold by Edison some years later
- It is believed to be the first known recording of a woman and the first recording made for commercial purposes
- The product was a flop and Edison referred to the dolls as "little monsters", he had them buried.
- One site notes, "a complete disaster, terrifying children and costing their parents nearly a month's pay."

Example: Ishi Cylinders (1911) at the UCB Hearst Museum

Sam Batwai, Alfred L. Kroeber, and Ishi

"The Story of Wood Duck" This narrative is ~2.5 hours long and is contained upon 51 wax cylinders

Recorded and translated by Prof. T.T. Waterman



Cylinder 14-1596

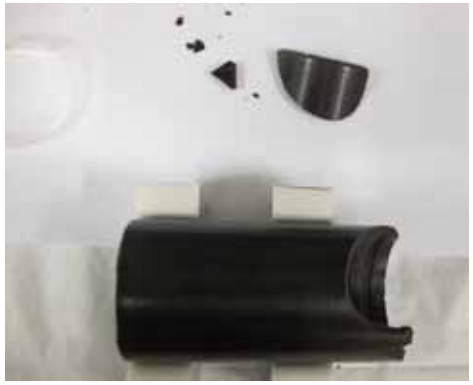
Stylus version

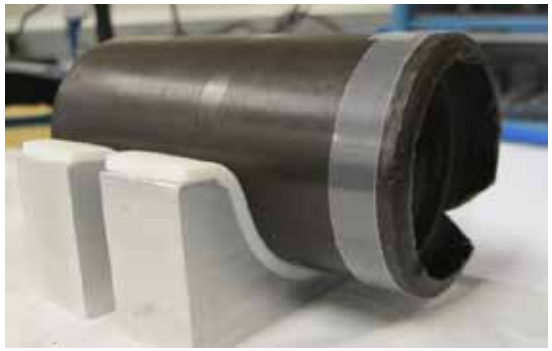
Optical version

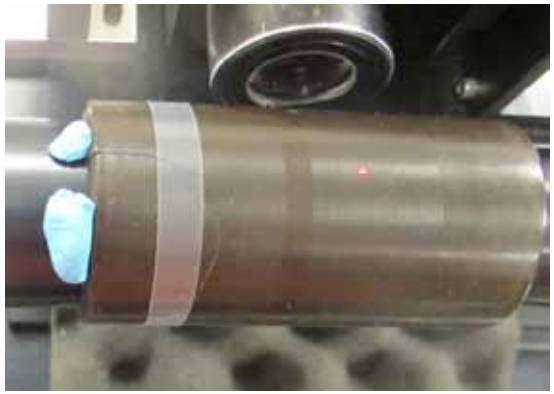
Gypsy Fortune Teller early 20th Century

- You will soon go to a ball or large gathering and meet a new friend.
- A sincere friend seeks to help you in matters of importance to you.
- Your troubles can be avoided by changing your attitude towards them.
- You will have unexpected fortune(?) in a letter.
- The first years of your life will be the unhappiest.
- You will be married three times, each time more happily.
- A person who has made trouble for you in the past will become your friend.

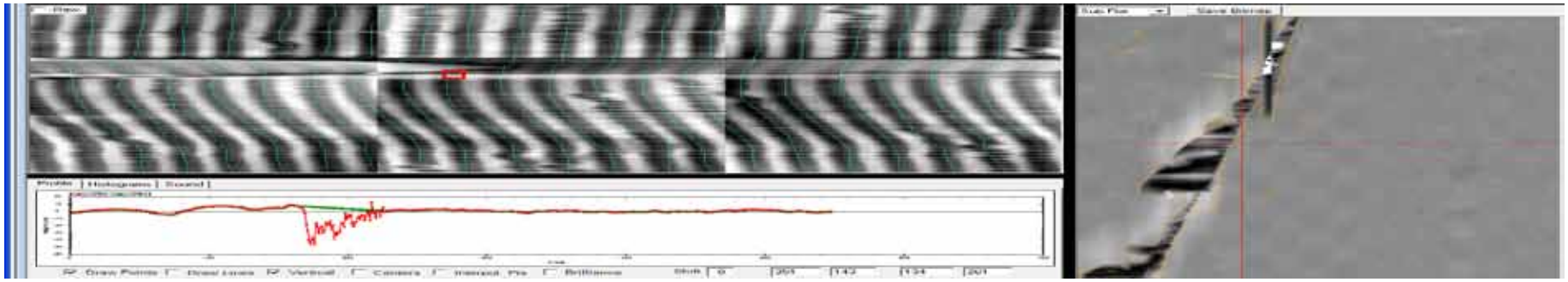
Broken Wax Cylinder





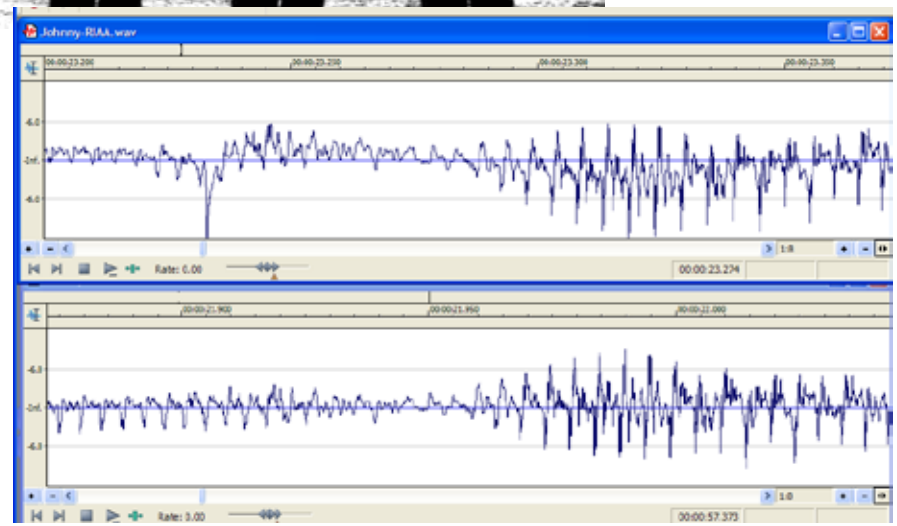


- Temporarily constrain pieces on the mandrel with plastic straps and (re-useable) putty, shift strap, scan in segments



“Johnny”: Les Paul and Mary Ford

1953 recording, shellac 78 rpm disc is worn and scratched, distorted



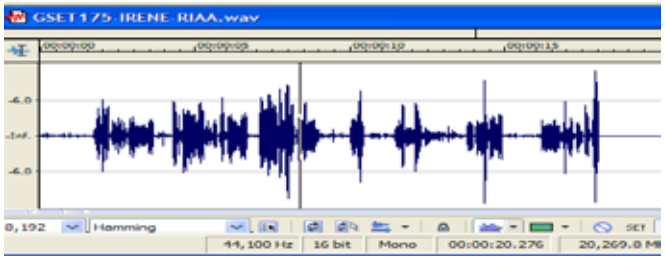
Stylus version has a clear skip due to scratch

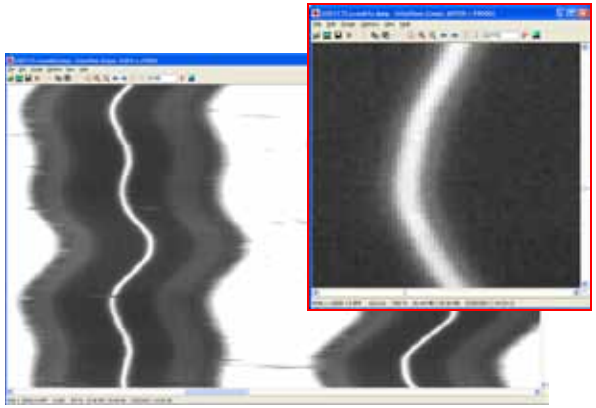
IRENE

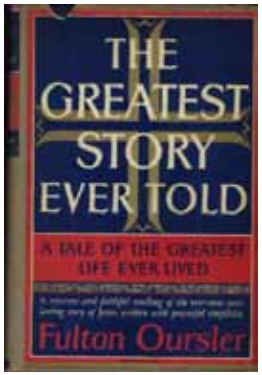
Lacquer Transcription Discs

Stylus

33 1/3 rpm, 16 inch radio transcription discs ~1950







IRENE

Stylus

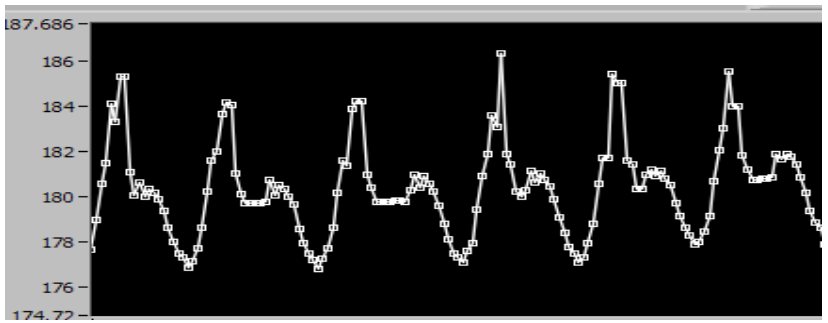
1947 Studio “take”
Mutt Carey and his NY’rs
Shim-Me-Sha-Wabble

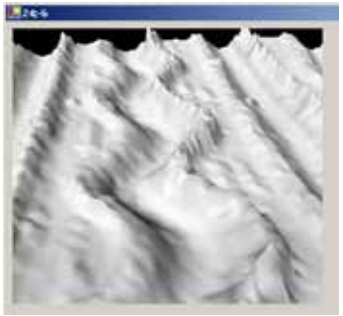
IRENE

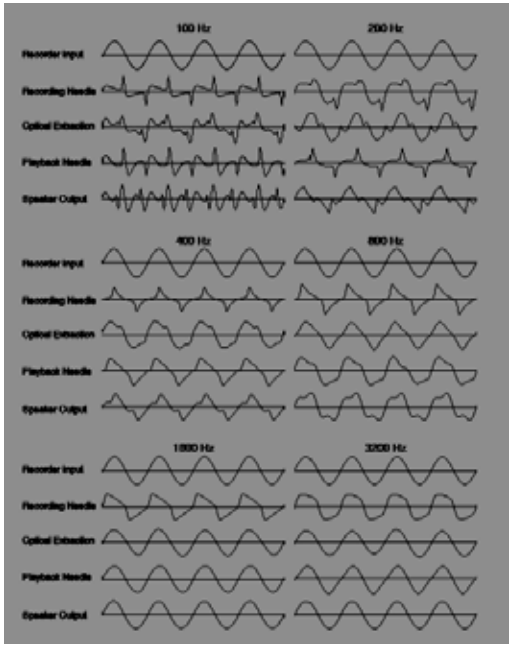
Sound effects

Plastic Dictation Belts

- Dictation, telephone and radio monitoring 1940's-1970's
  - US Presidential phone conversations
- Groove is embossed, lateral modulation, shallow
- Never meant as an archival medium, poor storage





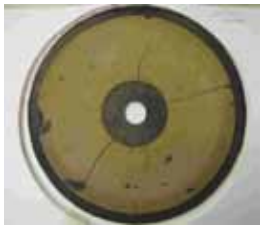


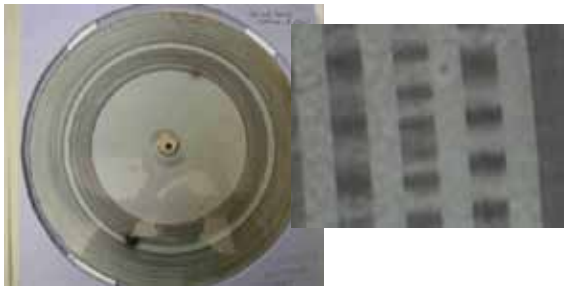
Smithsonian Collection
Historical Perspective

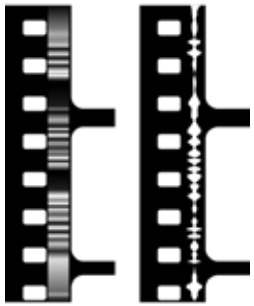
- Edison recorded and reproduced sound 1st in 1877 using embossed foil as the media.
- The Volta Laboratory Associates collaborated during the period 1880-1886 with a goal of further developing the technology of sound recording
- They investigated a large number of directions, materials, and processes.
- While they eventually settled on the wax cylinder as their preferred approach, the research (they abandoned) prefigured many aspects of the later developments in analog recorded sound formats.
- A period of significant creativity and innovation

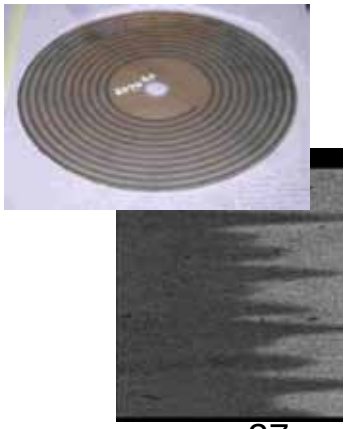
Volta Lab Innovations

- While others speculated or tested some of these ideas earlier, the Volta Associates went much further…
- Laterally cut discs
  - Example of format which became the 78/45/33 $^{1}/_{3}$ rpm disc
  - Electro-formation of master and mass production stamping
- Vertically cut discs
  - Format which became the Edison "Diamond" and Pathe disc
- Photographic discs
  - Basic principle of the later optical film sound tracks
  - Variable density, area
- Wax Cylinders
- Magnetic ink
- Tape systems







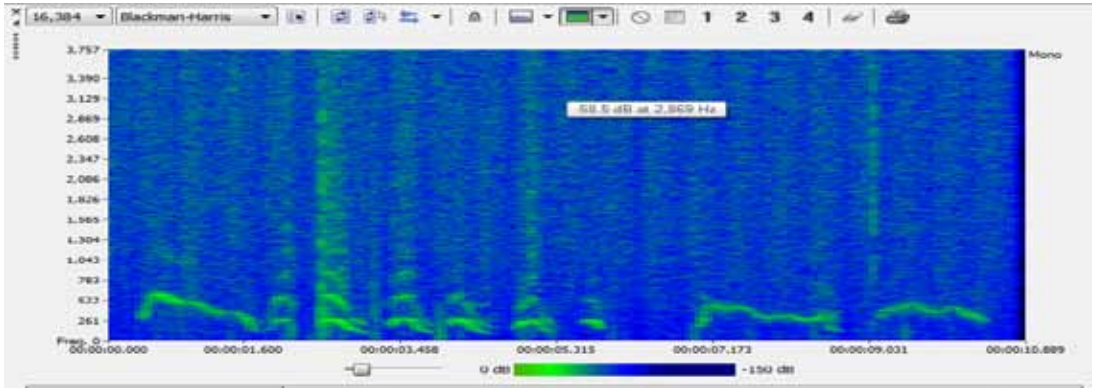


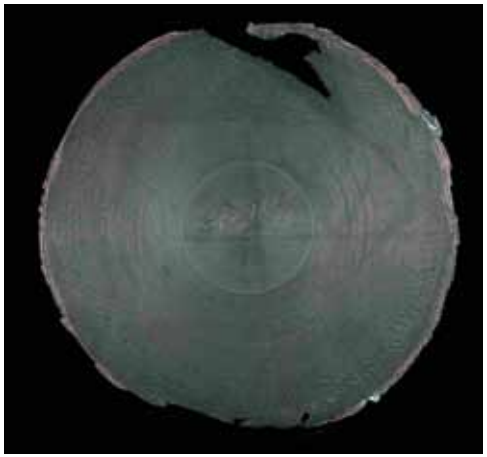
Transduction

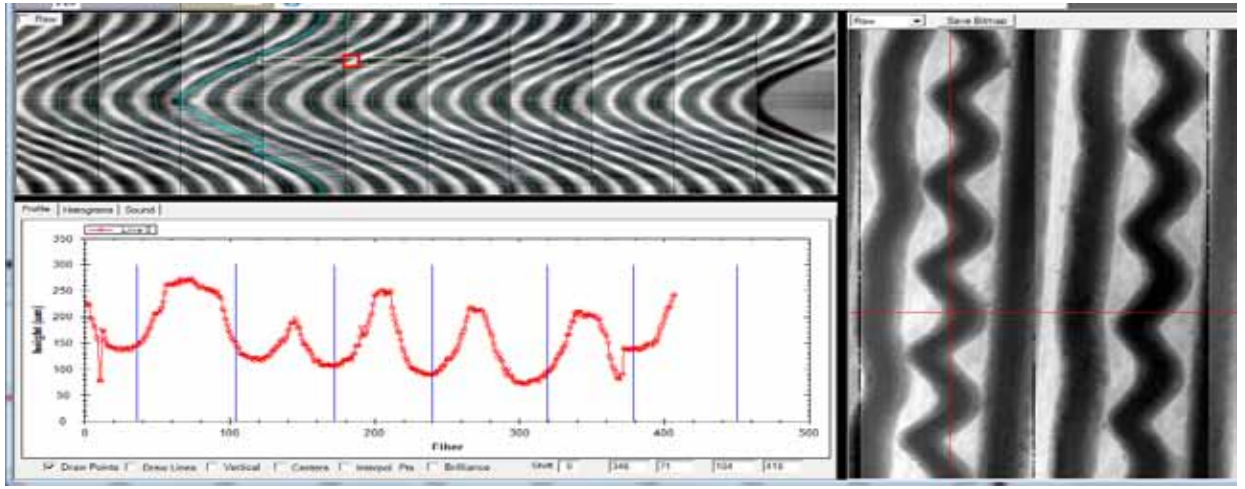
- While Edison used a stylus to both cut (record) and replay sound from metal foil, the Volta Associates investigated a more diverse set of methods
- Photography
- Mechanical Stylus cuts into wax
- Liquid Jets
- Air Jets
- Mechanical stylus/magnetic ink and magnetic reader

Electroformed Copper Stamper (1881)

Trrrrrr 1 2 3 4 5 6 trrrr trrrrr







Accompanying Notes

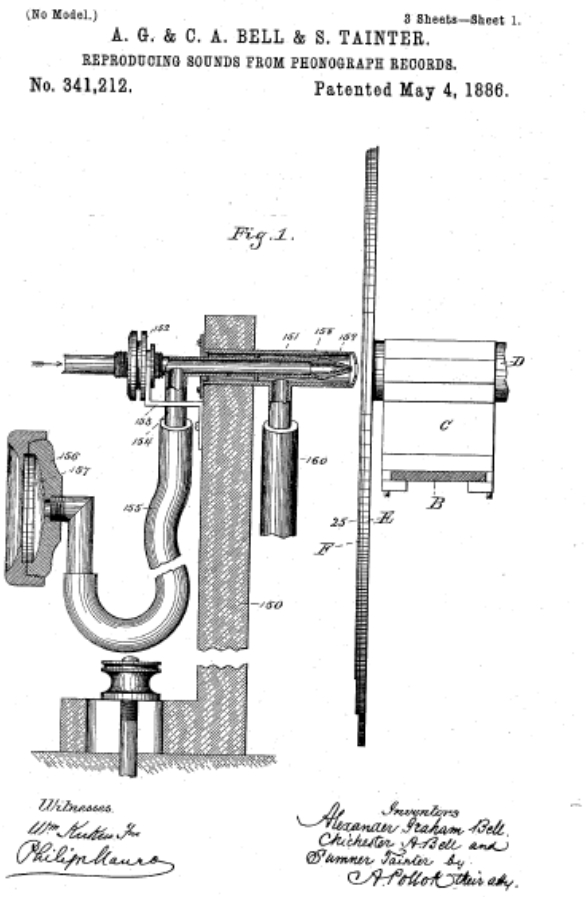
Charles Sumner Tainter, Home Notes Oct. 17, 1881

"Our object is to use the copper electro-type for the purpose of forming records or phonograms in other substances by stamping, or printing, and to use these stamped copies for reproducing the sounds originally recorded in the composition.

In this way a piece of music, for instance, can be recorded once, and any number of copies made from this original record, and the music reproduced from any each of the copies."

Air Jets

- "On the Sympathetic Vibrations of Jets", Chichester A. Bell, Philosophical Transactions of the Royal Society of London, Vol. 177 (1886), pp. 383-422


(No Model.) 3 Sheets—Sheet 1.

A. G. & C. A. BELL & S. TAINTER.

REPRODUCING SOUNDS FROM PHONOGRAPH RECORDS.

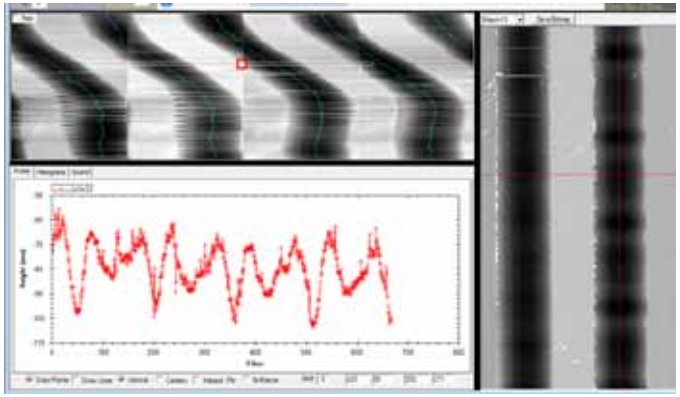
No. 341,212. Patented May 4, 1886.

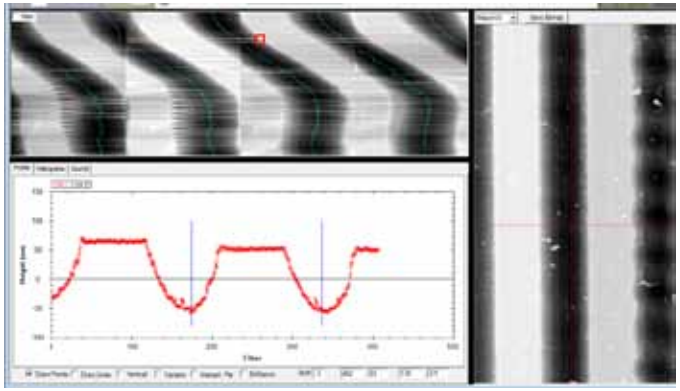
Fig. 1.

Witnesses.
Wm Kutten Jr.
Philip Mauro

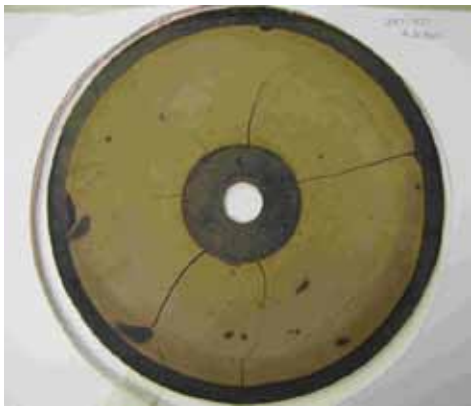
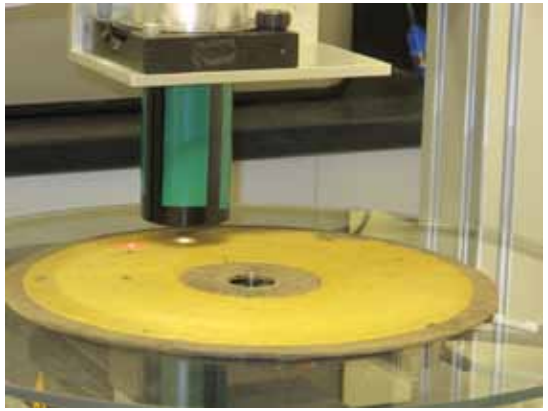
Inventors
Alexander Graham Bell,
Chichester A. Bell, and
Sumner Tainter by
A. Pollok their atty.

Vertically Cut Wax on Brass
Air Jet Playback



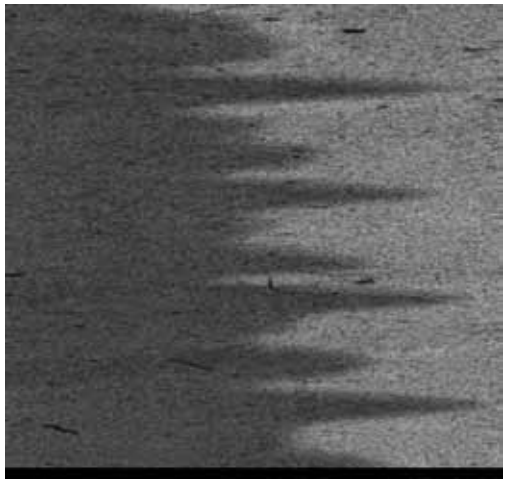


Wax on Binder Board
Air Jet Playback

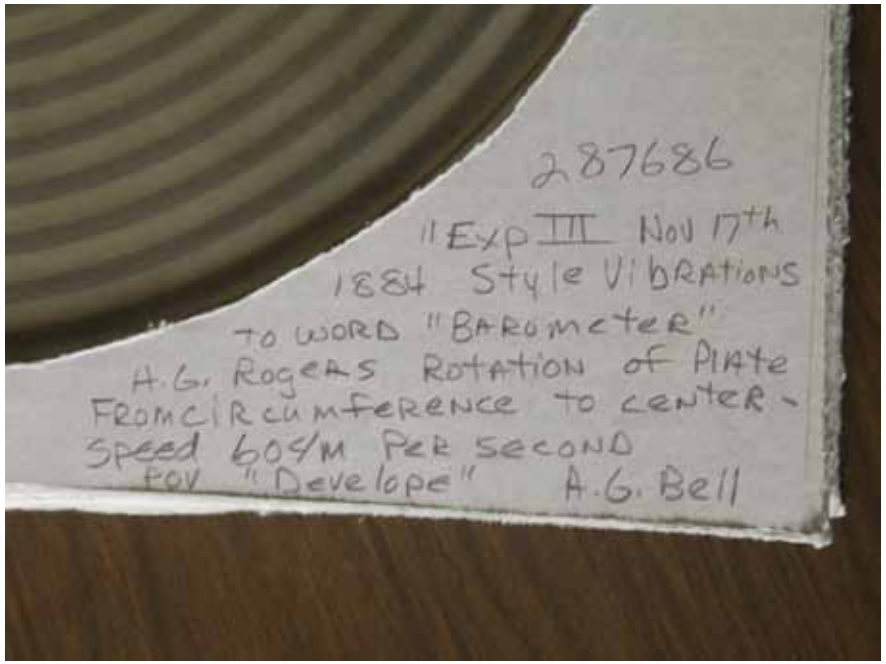




—erected, and the mills went into operation in 1826. The enterprise did not prove a success, the company became embarrassed, and the property was sold to a new company, which was incorporated as the Jackson Company in 1830 the name being complimentary to Captain T. Jackson of Boston, who was a heavy owner in the newer company. The old machinery was taken out, and new machinery for the manufacture of cotton cloth put in. The company originally had 2 mills and a capacity of 11,588 spindles, but now has 3large mills possessing a large and [...] within a few years, 512 looms,

Optical Sound Recorder (1884)

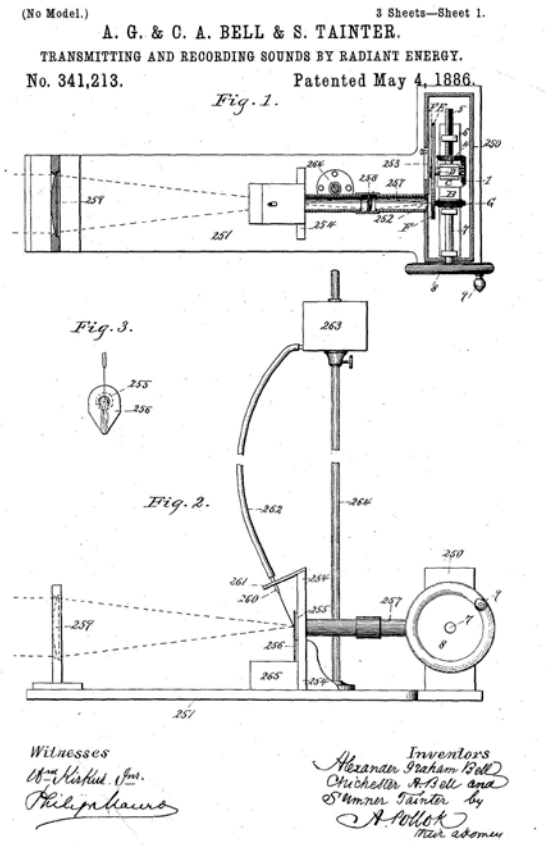


Variable area
Constant linear velocity
Discussed in Patent 341213



Optical Sound Recorder (1885)

Variable density
Discussed in Patent 341213


(No Model.) 3 Sheets—Sheet 1.

A. G. & C. A. BELL & S. TAINTER.

TRANSMITTING AND RECORDING SOUNDS BY RADIANT ENERGY.

No. 341,213. Patented May 4, 1886.

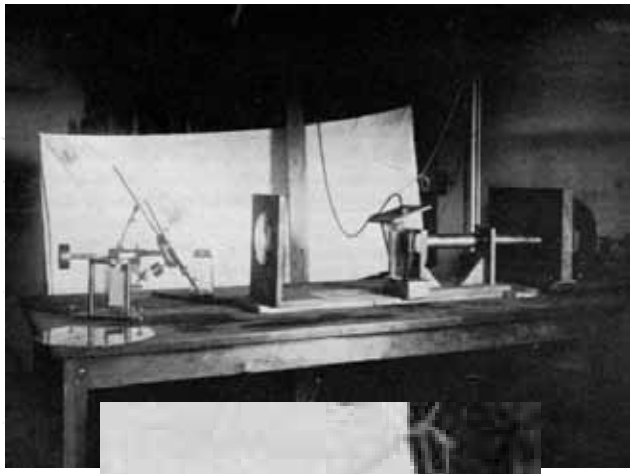
Fig. 1.

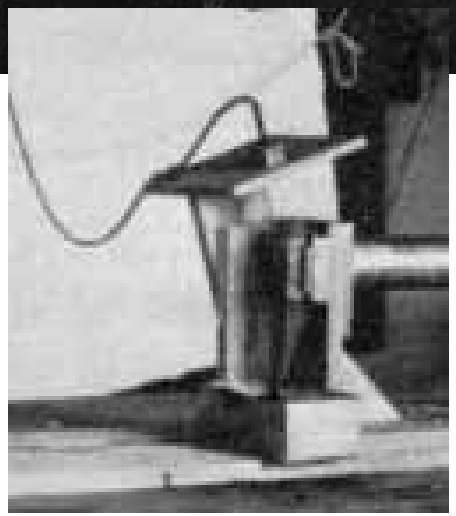
Fig. 3.

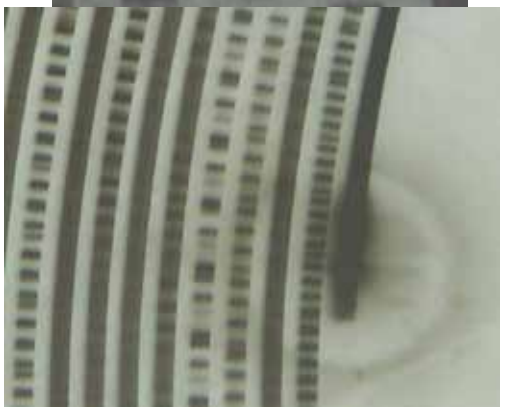
Fig. 2.

Witnesses
Philip Mauro

Inventors
Alexander Graham Bell
Chichester A. Bell and
S. Sumner Tainter by
A. Pollok
their attorney

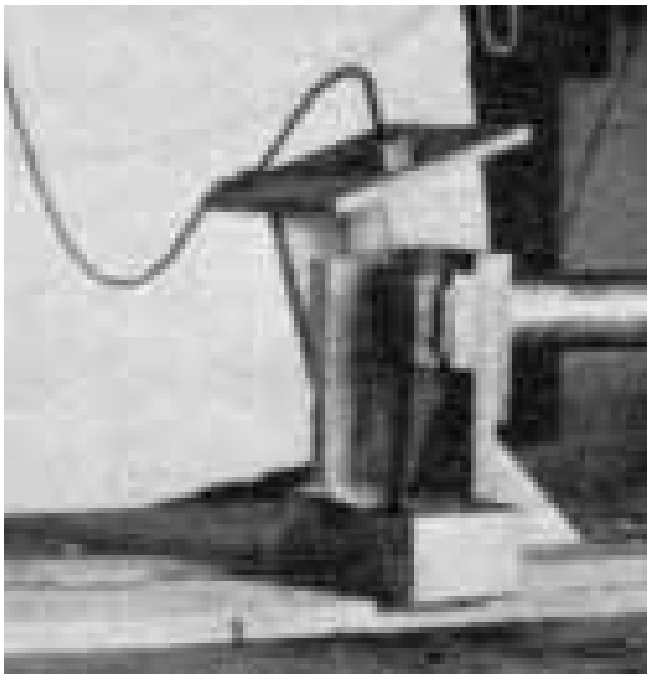






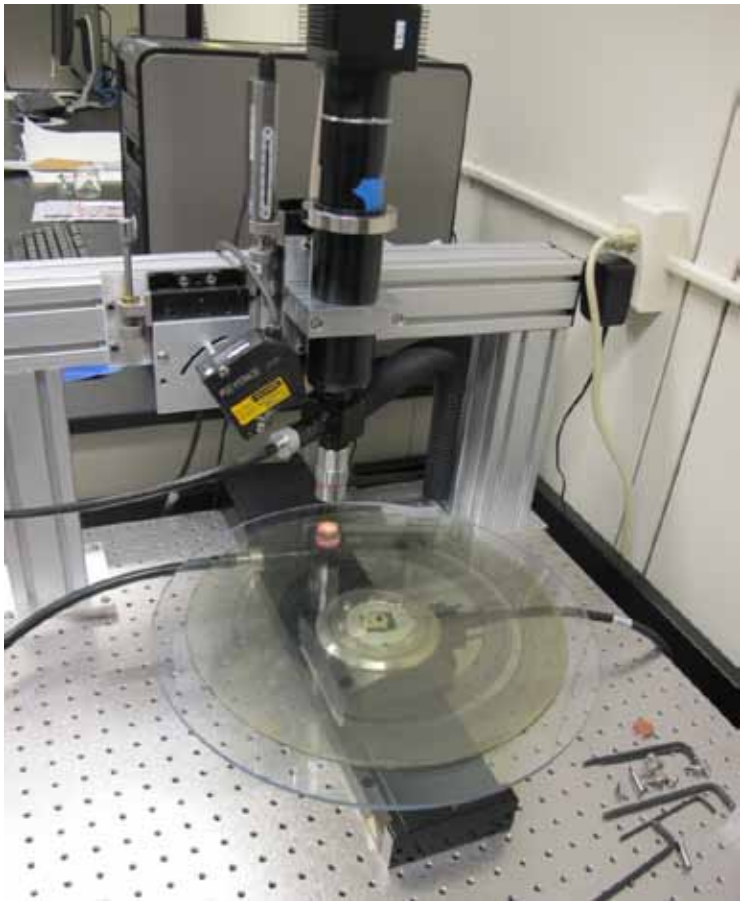
Liquid Jets

- "A jet of bichromate of potash solution, vibrated by the voice, was directed against a glass plate immediately in front of a slit, on which light was concentrated by means of a lens. The jet was so arranged that the light on its way to the slit had to pass through the nappe and as the thickness of this was constantly changing, the illumination of the slit was also varied. By means of a lens ... an image of this slit was thrown upon a rotating gelatine-bromide plate, on which accordingly a record of the voice vibrations was obtained."



Chichester Bell, quoted in Tainter's unpublished autobiography

Measurement Process (2011)



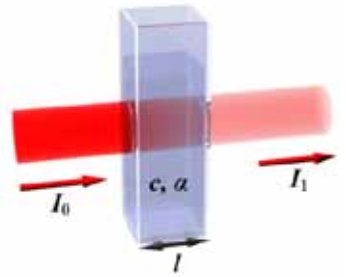
What is the relationship of photographic density to sound?

- Observed density variations suggests some proportionality to the original audio signal, but what is the actual dependence?
- Empirical restoration to an audible form is possible, based upon a simple linear model, but left still with some ambiguity
- To go further requires an understanding of the entire recording, exposure, and measurement process. This could be an aspect of further study.

Further Possible Analysis

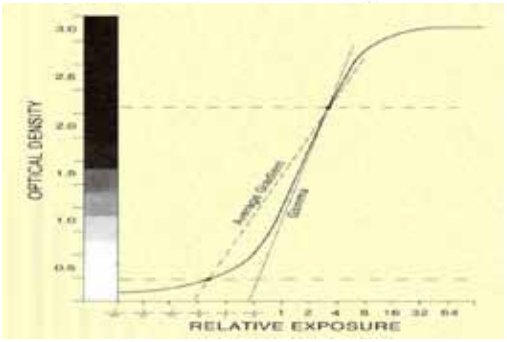
Modulation of incident light, I(t), by optical recording system

$$I(t) = I_0 e^{-A(t)b}$$



HD curves, property of the emulsion

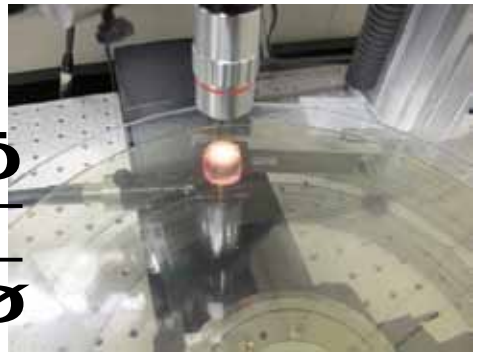
$$density = g\log(I(t))$$



J(t) is the intensity measured in the scan

$$density = \log(\frac{J_0}{J})$$

$$A(t) = \frac{1}{b}\ln\left(\frac{1}{I_0}\left(\frac{J_0}{J}\right)^{\frac{1}{g}}\right)$$



…H G Rogers

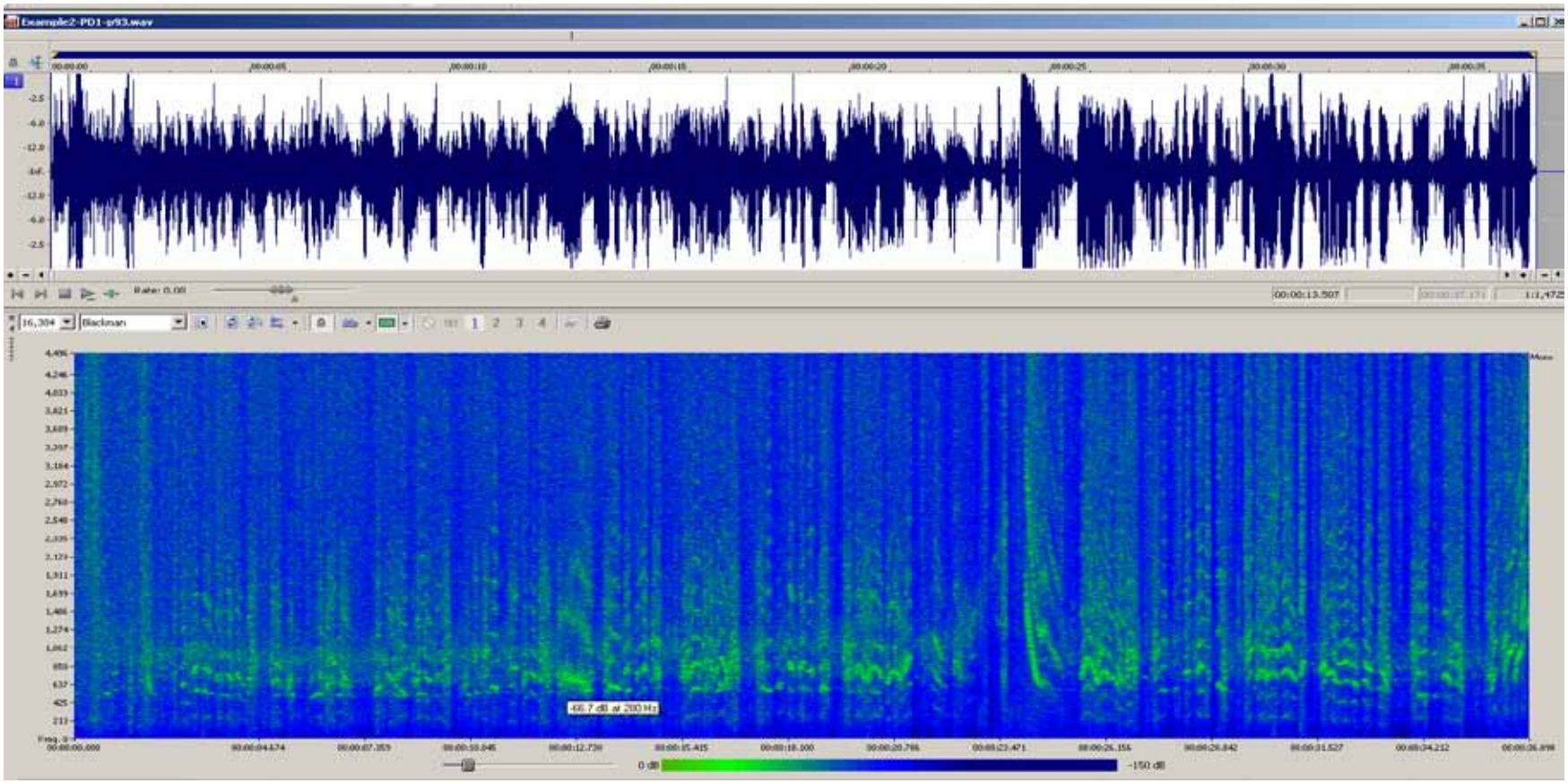
It's the 11th day of March 1885

Trrr..?who put in the pipe ??

Mary had a little lamb and its fleece was white as snow. Everywhere that Mary went..oh no!

Trrr.. Mary had a little…

How's that for high? Trrr…



Synergy with the Visual Arts

feature article

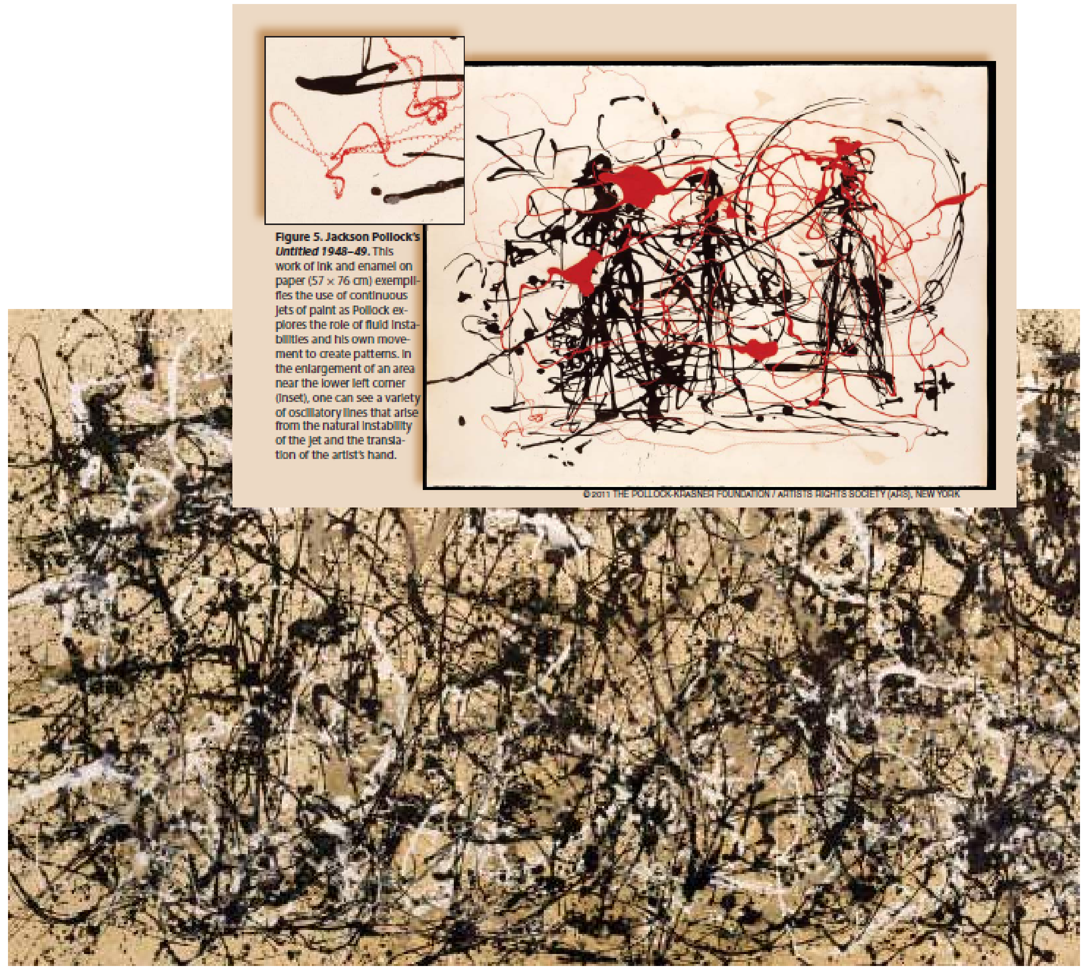
Painting with drops, jets, and sheets

Andrzej Herczyński, Claude Cernuschi, and L. Mahadevan

A fluid dynamics analysis of Jackson Pollock's technique opens his and other artists' work to quantitative exploration.

www.physicstoday.org June 2011 Physics Today 31

Physics Today June 2011



Future Directions

- A present focus of the research is to further develop the optical scanners for larger scale transfer projects.
  - Library of Congress Culpeper NAVCC study
  - Ethnographic cylinder scanning pilots
  - More machines for more sites?
- A major effort on the bulk of Volta collection could be the basis of a new project
- A number of ideas and directions for furthering the scanning technology and algorithms…

Summary/Conclusions

- Optical scanning instruments and methods are well suited to restoring a broad range of historical recorded media.
- For the Volta Laboratory materials, have shown that many experimental and obsolete formats can be readily accommodated.
- Studies of these materials illuminates the process of invention and technological creativity in the late 19th century.

IRENE Details

- http://irene.lbl.gov/ recent pdf's posted
- http://irene.lbl.gov/examples.html
- http://irene.lbl.gov/Volta-Release.html

Backup