

Syracuse University

SURFACE

Libraries' and Librarians' Publications

Libraries

5-2003

The Syracuse University Library Radius Project: Development of a non-destructive playback system for cylinder recordings

William A. Penn
Syracuse University

Martha J. Hanson
Syracuse University

Follow this and additional works at: <https://surface.syr.edu/sul>



Part of the [Library and Information Science Commons](#)

Recommended Citation

The Syracuse University Library Radius Project: Development of a non-destructive playback system for cylinder recordings by William A. Penn and Martha J. Hanson *First Monday*, volume 8, number 5 (May 2003), URL: http://firstmonday.org/issues/issue8_5/penn/index.html

This Article is brought to you for free and open access by the Libraries at SURFACE. It has been accepted for inclusion in Libraries' and Librarians' Publications by an authorized administrator of SURFACE. For more information, please contact surface@syr.edu.

First Monday, Volume 8, Number 5 - 5 May 2003

[HOME](#) [ABOUT](#) [LOG IN](#) [REGISTER](#) [SEARCH](#) [CURRENT](#) [ARCHIVES](#) [SUBMISSIONS](#)

[Home](#) > [Volume 8, Number 5 - 5 May 2003](#) > [Penn](#)



The Syracuse University Library
Radius Project: Development of a
non-destructive playback system
for cylinder recordings

by William A. Penn and Martha J. Hanson

Abstract

The Syracuse University Library *Radius Project*: Development of a non-destructive playback system for cylinder recordings by William A. Penn and Martha J. Hanson
Syracuse University Library's Belfer Audio Laboratory and Archive (Belfer) holds nearly 20,000 cylinder recordings produced during the 'cylinder era' of 1895-1929. Many cylinders have become deteriorated over the past one hundred years and cannot be played without suffering serious physical damage inflicted by the sharp styli (needles) of traditional mechanical playback machines. In some cases, even one pass of a stylus may irrevocably damage a cylinder. In response to the playback challenges of cylinder recordings, Syracuse University Library developed the *Radius Project: Development of a Non-Destructive Playback System for Cylinder Recordings*, funded by the Institute of Museum and Library Services.

Recorded sound on a cylinder is represented by the alternating motion/velocity of the groove over a period of time. In order to capture sounds from cylinders in a non-destructive way, the *Radius Project* developed a prototype playback system that uses a laser beam to interrogate the cylinder. The system reconstructs sounds from cylinders by using an optical heterodyne interferometer to exploit the temporal, rather than spatial, coherence of the laser. The interferometer obtains a precise measurement of the Doppler frequency shift (the rate of change of optical phase shift) caused by the motion of the modulated groove in the cylinder, using wavelength of light as the unit of measure. The ability of the *Radius* system to measure the rate of change of optical phase shift may provide the optimal approach for reconstructing historically accurate sound from cylinder recordings.

Successful completion of the *Radius* system will provide Belfer with the capability to preserve the sonic content of previously inaccessible cylinder recordings by producing high fidelity, historically accurate analog reproductions. In turn, and as copyright permits, Belfer will also be able to meet the changing needs and expectations of twenty-first century learners by contributing high fidelity, historically accurate digitized sounds from cylinders, thereby enriching the historical content of the World Wide Web.

Contents

[Introduction](#)
[Problems and challenges of cylinder playback](#)
[The *Radius Project* \(December 1999-January 2002\)](#)
[Relationship of the *Radius Project* to other initiatives](#)
[Features of sound and recordings](#)
[*Radius* system design](#)
[Testing *Radius* system performance](#)
[Conclusion](#)

Introduction

Syracuse University Library's Belfer Audio Laboratory and Archive (Belfer) is one of five major archives in the United States — the Library of Congress, New York Public Library, and the libraries of Stanford, Syracuse, and Yale Universities. Belfer holds more than 300,000 historical sound recordings in all formats, including a collection of nearly 20,000 cylinder recordings produced during the 'cylinder era' of 1895-1929. Of these cylinders, Belfer holds 15,000 commercially produced cylinders — approximately 85 percent of the total number of commercially produced two-minute and four-minute cylinders released during this period. Belfer's collection of commercially produced cylinders includes the following major labels:

- *Edison Gold Molded*: Two-minute wax cylinders, of which Belfer holds at least 75 percent (4,550) of the total numbers issued;
- *Edison Amberols*: Four-minute wax cylinders, of which Belfer holds at least 90 percent (1,800) of the total numbers issued; and,
- *Edison Blue Amberols*: Four-minute celluloid cylinders, of which Belfer holds at least 90 percent (7,488) of the numbers issued (commercial cylinder releases are identified by issue numbers).

The collection includes a significant number of cylinders (approximately 2,756) issued under an assortment of other labels, such as *Columbia Records* (two-, three-, and four-minute wax cylinders); *Indestructibles* (two- and four-minute celluloid cylinders); *U.S. Everlasting* (two- and four-minute celluloid cylinders); *Lambert* (two- and four-minute celluloid cylinders), and the *Anglo-Italian Commerce Company*, *Busy Bee*, *Pathé*, *Leeds & Catlin* labels, which are primarily two-minute wax cylinders. In addition, Belfer's collection of more than 180,000 pre-LP disc records is one of the largest and finest in the country. Belfer also contains early radio broadcasts, as well as hundreds of spoken word recordings covering a wide range of personalities. Voices from the past include Thomas Edison, Amelia Earhart, Carl Sandburg, Albert Einstein, Dylan Thomas, Margaret Bourke-White, and Albert Schweitzer.

Problems and challenges of cylinder playback

Physical deterioration

Unfortunately, a portion of Belfer's substantial collection of century-old cylinder recordings has deteriorated, becoming moldy, brittle, and/or laced with micro-cracks. Such deteriorated cylinder recordings cannot be played without suffering serious physical damage inflicted by the sharp styli (needles) of traditional mechanical playback machines. In some cases, even one pass of a stylus may irrevocably damage a deteriorated cylinder recording. However, one pass of the stylus is rarely adequate for capturing the best sonic quality from a cylinder recording due to the unknown variations inherent in cylinder recordings. These unknown variations result primarily from the non-standard groove size and rotation speed typical of cylinders in the early years of production, as well as from changes in physical dimensions due to physical aging and damage. It is typical that the production of a high quality cylinder sonic reproduction requires several playback sessions from one cylinder recording (Figures 1-3 present images of cylinders in good, cracked, and moldy conditions).



Figure 1: Image of "good" cylinder recording (c. 1902-1909).

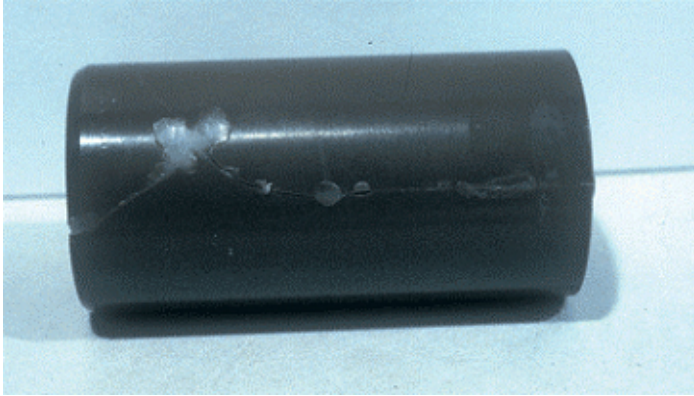


Figure 2: Image of cracked cylinder recording (c. 1902-1909).

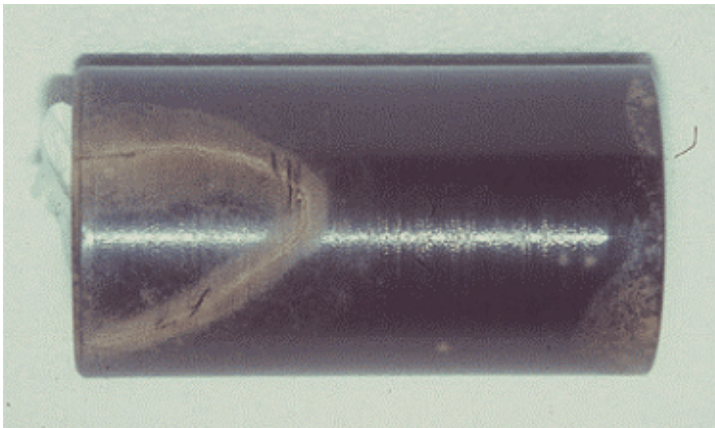


Figure 3: Image of moldy cylinder recording (c. 1902-1909).

Deficiencies of mechanical playback systems

In addition to the re-recording challenges presented by the unknown variations inherent in cylinder recordings, mechanical playback systems are not only physically destructive to cylinders, but also sonically deficient. Two primary sonic deficiencies are: 1) low signal-to-noise ratio, which produces the familiar noisy, scratchy background interference heard by the listener; and, 2) signal distortion, which produces "garbled" sonic signals.

Bibliographic and sonic access

The provision of adequate bibliographic and sonic access to cylinder and other recordings is a serious challenge for sound archives in research library settings. Few archives have cataloged

their sound recordings, making it difficult for users to determine and locate what recordings a sound archive might contain. Belfer is one of the few sound archives that has made a strong commitment toward providing bibliographic access to cylinder and pre-LP 78 rpm recordings. With support from the Gladys Krieble Delmas Foundation (1998-2001), Belfer staff completed the cataloging of the cylinder recordings collection (nearly 20,000), made strong headway in cataloging the pre-LP 78 rpm recordings collection (nearly 180,000), and loaded the resulting catalog records into Syracuse University Library's Web-accessible online catalog, as well as into the Online Computer Library Center's Web-accessible *WorldCat* national database [1].

The provision of cost-effective sonic access to cylinder and other recordings is another serious challenge. Since few sound archives employ full- or even part-time audio engineers, staffs rely on expensive contract re-recording services. Cylinder recordings present a particularly difficult challenge, since cylinder playback requires specialized technical skills offered by few audio engineers. Contract work is expensive, funds to support sound archives are limited, the pool of individuals who are capable of re-recording cylinders is small, and the opportunities for training and/or apprenticeships in this area are practically non-existent. In response to the playback challenges of cylinder recordings, the Syracuse University Library developed the *Radius Project: Development of a Non-Destructive Playback System for Cylinder Recordings*, funded by the Institute of Museum and Library Services.

The *Radius Project* (December 1999-January 2002)

Background

The conceptual framework for the *Radius Project* [2] resulted from a partnership forged in 1996 between Syracuse University Library and the University's School of Engineering and Computer Science (ECS). At that time, these two campus partners began to develop a non-destructive cylinder playback system for Belfer's substantial collection of cylinder recordings, using a student/faculty research team headed by ESC faculty members Dr. William A. Penn (*Radius Project* Technical Coordinator) and Dr. Frederick W. Phelps.

This student/faculty research team determined that the only practical way to totally eliminate mechanical contact with a cylinder recording was to develop an optical system that used a focused laser beam for sound capture — that is, a playback system that used a beam of electro-magnetic propagation as a vehicle to interrogate the modulation of the recording groove. For reasons of spatial resolution, the wavelength of such a beam had to be substantially smaller than both the dimension of the groove and the recorded mechanical wavelength of the highest frequency that is to be recovered in playback. The student/faculty research team determined that an optical (laser) beam of light [3] would achieve this required wavelength. Having determined this, the team next needed to determine whether to employ a non-coherent (spatial) use or coherent (temporal) use of light.

Non-coherent use of light does not exploit the temporal phase of the return light, but such use might exhibit spatial coherence. In a playback system that employs only spatially coherent (non-coherent) use of light, the light reflected from a cylinder recording groove may assume certain spatial shapes or spatial directions, depending on the physical modulation imparted by the cylinder groove. Therefore, in a non-coherent system, these coherent light effects can be translated into only an *approximate* reproduction of the groove modulation produced by the cylinder recording. However, since the goal of the faculty/student team was to *accurately reconstruct* the recorded acoustic signal of a cylinder recording, they decided to employ coherent use of light, which exploits the temporal coherence of the laser beam.

Radius Project goals and strategy

As custodian of a collection that contains 85 percent of the total output of commercially produced cylinders in the United States, Belfer intends to preserve and retain these original recordings. Retention of these cylinders will allow for future capture of sound from the original artifacts, rather than from second-generation analog and/or digital masters. This retention strategy is similar to that taken by a research library when it decides to retain and preserve

original manuscripts (although these may also be accessible through facsimile editions, microfilm, and/or digital files), thereby ensuring their survival as original artifacts for a variety of current and future access endeavors.

Therefore, as a primary custodian of our nation's cylinder recordings, Belfer needs the capability to provide non-destructive, cost-effective, and historically accurate playback for its cylinder recordings. The goal of the *Radius Project* was to develop such a playback system by coherent use of a laser-driven optical heterodyne system configuration for sound capture. Advantages of the *Radius* optical playback system include:

- Total elimination of mechanical contact with a cylinder recording;
- Rejection of stylus-induced noise;
- Suppression of some microscopic mechanical noises (scratches and pits) accomplished by a small but finite area of optical integration;
- High playback fidelity; and,
- Precise sensing (measuring) of the velocity signal of the cylinder carrier.

The goal and strategy of the *Radius* system architecture is to reconstruct historically accurate sounds from cylinder recordings. The system strategy is to obtain a precise measurement of the cylinder recording groove modulation, which is the vertical velocity signal of the cylinder carrier. The system achieves this by measuring the target velocity of the cylinder carrier from optical phase shift, using an optical heterodyne interferometer to exploit the temporal, rather than spatial, coherence of the laser. The interferometer obtains a precise measurement of the Doppler frequency shift (the rate of change of optical phase shift) caused by the motion of the modulated groove in the cylinder, using wavelength of light as the unit of measure. This precise sensing (i.e., measuring) of the velocity signal of the cylinder carrier is the unique aspect of the *Radius* system concept and the ideal variable to construct in an optical playback system for the reproduction of historically accurate sound. Indeed, the *Radius* system strategy may provide the optimal approach for reconstructing historically accurate sound from cylinder recordings.

Radius Project benefits

Successful completion of the *Radius* cylinder playback system will provide Belfer with the capability to produce high fidelity, historically accurate sonic access to its collection of nearly 20,000 cylinder recordings. In addition, successful completion will also provide Belfer with the eventual capability to:

- Offer non-destructive, cost-effective cylinder re-recording services for other archives, historical associations, individual collectors, and others throughout the United States and beyond;
- Provide enhanced bibliographic and sonic access to cylinder recordings by providing links from each MARC bibliographic record (through the 856 field) to digital sound and image files associated with each recording, thereby offering users a richer contextual setting for the original recordings; and,
- Meet the changing needs and expectations of 21st century learners by providing high fidelity, historically accurate sonic reproductions (in analog tape, cassette, and/or digital formats) of Belfer's previously inaccessible cylinder recordings to support and enhance learning, teaching, and research activities.

Relationship of the *Radius Project* to other initiatives

When Syracuse University Library submitted the *Radius Project* proposal to [IMLS](#) in 1999, the advent of digital technology had already sparked a few groundbreaking institutional initiatives to deliver portions of historical sound collections via the World Wide Web. At that time, as part of the American Memory Project, the Library of Congress provided digital access to 81 Edison disc recordings at their *Inventing Entertainment: The Motion Pictures and Sound Recordings of the Edison Companies* Web site [4], and planned to provide access to cylinder recordings, as well. Indiana University Library's IMLS-funded *Digitizing and Preserving the Hoagy Carmichael*

Collections project created a model for integrating multimedia materials, including sound recordings, photographs, and printed and textual materials, and distributing them via the Internet [5].

While developing the *Radius Project*, the authors of the proposal were aware that other researchers had conceived and investigated the use of an optical beam for sonic playback. The two most pertinent initiatives to the *Radius Project* proposal at the time were the:

- Laser-scanning phonograph record player by William K. Heine (Heine, 1977), developed specifically for disc records; and,
- Laser-beam reflection method developed by T. Iwai, T. Asakura, T. Kawashima, and T. Ifukube (Iwai et al., 1986) in the early 1980's (at the Research Institute of Applied Electricity at the University of Hokkaido in Japan), created to re-record wax cylinders from indigenous peoples living in the northern Japanese islands.

However, it is believed that these two investigations are based on non-coherent use, rather than coherent use of light, as pursued in the *Radius Project*.

Features of sound and recordings

Physics of sound propagation

The features of sound and recordings demonstrate the phenomenon of sound propagation in a compressible medium — air. This phenomenon demonstrates that the local (molecular) velocity propagates as a wave that is synchronistic with the acoustic pressure wave. The analogy of surface waves propagating on a body of water may be helpful in understanding the physics of sound propagation. When a person riding in a boat experiences a passing water wave, it is a common experience that the boat 'bobs' up and down, but does not move with the wave. It is also easy to appreciate that no water (in a global sense) moves with the wave. Rather, the water 'sloshes' up and down and, to some extent, forwards and backwards, as the wave passes through. The important point is that there is no transport of the medium (water) with the wave at the wave velocity. The propagation is a result of an interchange between potential energy of the water (the wave crest being higher than the trough) and kinetic energy (involved in the small localized motion of the water, the most important part being the up and down motion).

The wave analogy is similar to the propagation of an acoustic wave in air. As the acoustic wave moves through a point in space, the air molecules move back and forth in the direction of the wave propagation, but are not transported with the wave. Rather, the air stays close to its original location, but the small back-and-forth motion causes alternate compression and rarefaction (decompression) of a given point of air. Thus, this back-and-forth motion gives rise to a "pressure wave" (compression) and an accompanying displacement or excursion of the air molecules, which in turn also implies a molecular velocity (as opposed to the wave velocity). When such a wave impinges on a microphone diaphragm, its motion assumes that of the adjoining medium. If the output of this microphone (usually amplified) is applied to a cutting stylus that is creating a mechanical recording, the stylus motion (and, therefore, the contour of the recorded groove) follows the molecular velocity of the air. The molecular velocity of the air also represents the pressure wave (see [Figure 4](#)).

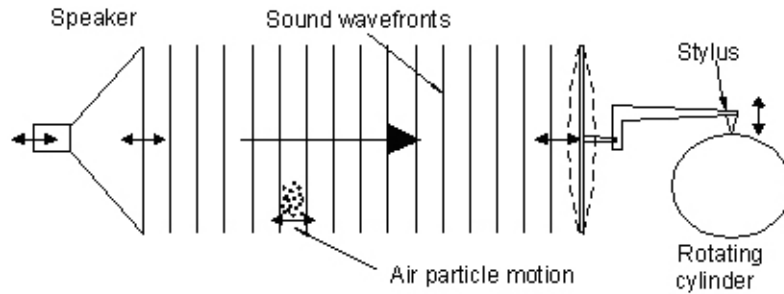


Figure 4: Features of sound and recordings.

In addition, the velocity or pressure determines acoustic intensity for all acoustic frequencies, while the molecular (or "virtual stylus") *displacement* varies as the reciprocal of frequency for a given intensity. In the context of the *Radius Project*, it is important to understand that acoustic pressure and molecular velocity in a sinusoidal acoustic wave (a pure tone) are in phase with each other, but displacement is not in phase with either of these. This confirms that molecular velocity is the key to determining the truest representation of the actual sound signal.

Achieving high playback fidelity

In order to achieve high playback fidelity, the cylinder playback speaker "cone" needs to accurately imitate the motion of the microphone. One of the important advantages of the *Radius* concept is that the mechanical modulation velocity imparted to the "virtual stylus" of the system is directly sensed (measured). The *Radius* system is able to measure this velocity in a fundamentally accurate way by using a laser beam and an optical interferometer.

[Figure 5](#) illustrates a laser beam that is projected on a target (mirror), where it is reflected back into an optical receiver. Consideration of this figure will reveal that the number of optical wavelengths represented in the path from the laser to the receiver will change if the mirror moves toward or away from the laser source. Specifically, this path will vary by twice the number of wavelengths that the mirror moves. This phase shift is measured by the *Radius* interferometer by using a comparison of the optical phase in a "reference leg" with that in the "signal leg," which is part of the interferometer. If the mirror is continuously moving (implying a velocity), then the phase shift measured by the interferometer will also be changing continuously. This can be characterized as a "Doppler frequency shift" of the light in the signal leg, and is analogous to the change in the pitch of a sound when one is moving with respect to the source of that sound. In the optical case, the wavelength is significantly smaller than that of the sound and, therefore, the Doppler frequency shift imparted to the signal is much larger for a given value of velocity.

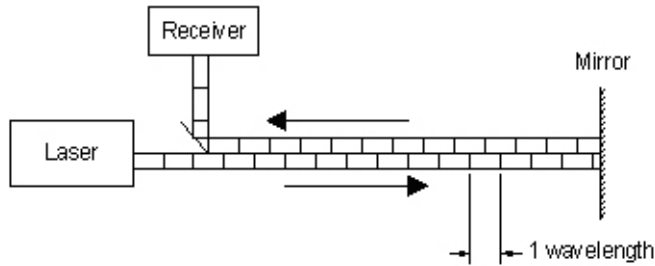


Figure 5: The unique *Radius* concept: Measuring target velocity from optical phase shift.

Radius system design

The *Radius* system architecture is comprised of five major sub-systems:

- Cylinder rotation and transport sub-system;
- Optical delivery sub-system;
- Heterodyne interferometer sub-system;
- Signal demodulator; and,
- Tracking sub-system.

[Figure 6](#) illustrates the essential sub-systems of the complete apparatus.

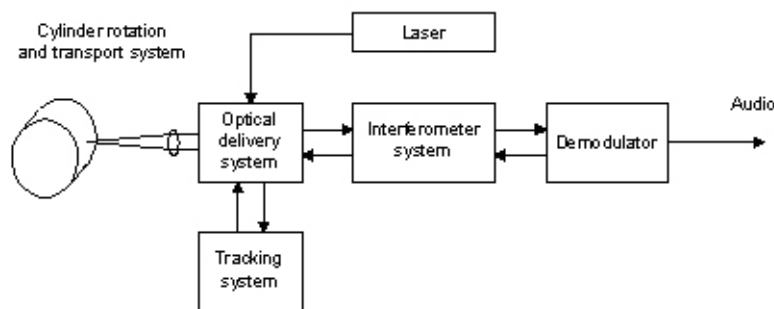


Figure 6: *Radius* system diagram.

This figure shows that the system delivers a laser beam through an optical delivery system to the groove of the rotating cylinder. The light is reflected back through this delivery system to the optical interferometer, and then to the demodulator that converts the frequency modulation signal to an audio signal voltage. A tracking system controls a mirror in the delivery system that automatically keeps the beam directed into the center of the groove.

Radius cylinder rotation and transport sub-system

To expedite the construction of a rotation and transport system, the *Radius* team used as a

base the *Archeophone* cylinder playback system invented and manufactured by Henri Chamoux (Paris, France). Mr. Chamoux's device is a very high quality unit that uses a conventional playback stylus. The *Archeophone* provides several interchangeable mandrels on which the cylinders are mounted and, therefore, can play a variety of types of cylinders. The device accommodates prescribed rotation speeds by using a high precision rotation rate regulator, for which Mr. Chamoux also provides a digital speed gauge and display.

The *Radius* technical team modified (with Mr. Chamoux's permission) the *Archeophone* for use in the *Radius* system. They modified the base of the device to raise the mounting plate of the rotator so that the axis of the rotator is on the same level as the hub of the tone arm. The team discarded the tone arm and stylus cartridge, and replaced them with an optical delivery system or "optical head" designed and constructed by the *Radius* technical team (see [Figure 7](#)).

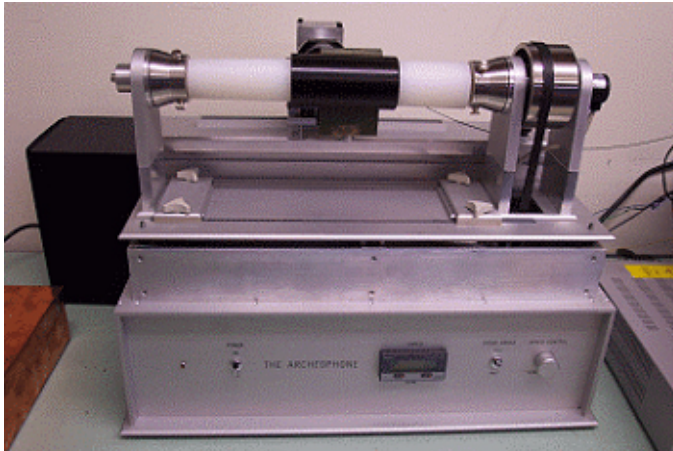


Figure 7: Cylinder driver (modified *Archeophone* with optical head).

Radius optical delivery sub-system

The *Radius* optical delivery sub-system consists of:

- A pair of tracking detectors through which the laser beam passes between and then immediately impinges on the cylinder groove;
- An electrically controlled mirror ("galvanometer") that directs the fine position of the laser beam;
- A fixed mirror to feed the controlled mirror;
- A main objective lens that focuses the beam to a small spot at the groove;
- A micrometer controlled translation stage to provide focusing control;
- A small telescope to expand the cross section of the beam for focusing by the object lens;
- An optical fiber "collimator" that matches the small light beam in the optical fiber feed to the telescope; and,
- An output fiber which attaches to the interferometer.

The action of the telescope and final objective lens provides a focused beam in the groove that has a focused diameter of approximately 10 microns. The beam is reflected from the bottom of the groove, and passes back through the system in the reverse direction, and finally reaches the same output fiber that delivered it. The beam then passes through this fiber also in the direction opposite to the original projected beam, and a beamsplitter in the interferometer sorts the projected beam and received beams. The fact that the transmitted beam and reflected (or received) beam travel along the same path in opposite directions create an architecture that is commonly designated a "monostatic" system. Some of the light that is reflected from the cylinder groove is scattered, and does not re-enter the interferometer. This light is intercepted by the two tracking detectors, and this provides a means for developing a control for the tracking system.

The entire optical head is mounted on a plate provided with a means for attachment to the *Archeophone* tone arm stub in the rear of the head, and the front of the optical head is provided with wheels that ride on a monorail situated on the *Archeophone* top plate of the

housing of the hub drive system (see [Figure 8](#)). Thus, the entire optical head moves along with the precessing cylinder groove during playback, and is controlled by the tracking system.

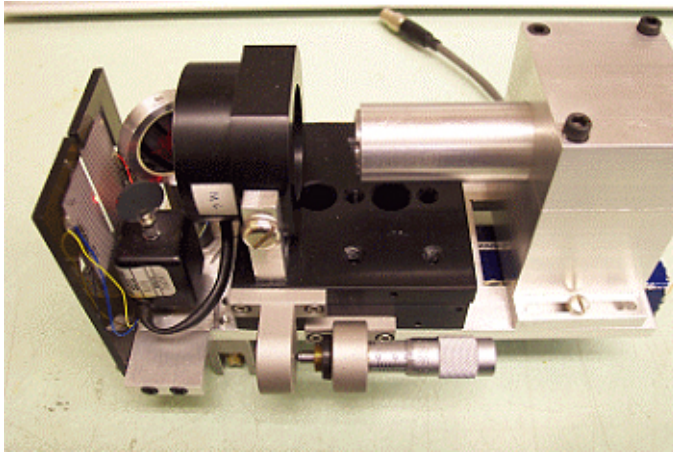


Figure 8: Radius system optical head and tracking sensor.

Radius optical heterodyne interferometer sub-system

The *Radius* optical heterodyne sub-system was constructed using optical fiber. The original research and development effort in 1996 achieved "proof of concept" using conventional free space beam propagation, characterized as using "unguided" optical beams. In the current *Radius* system, the optical beams are "guided" in optical fibers (see [Figure 9](#)).

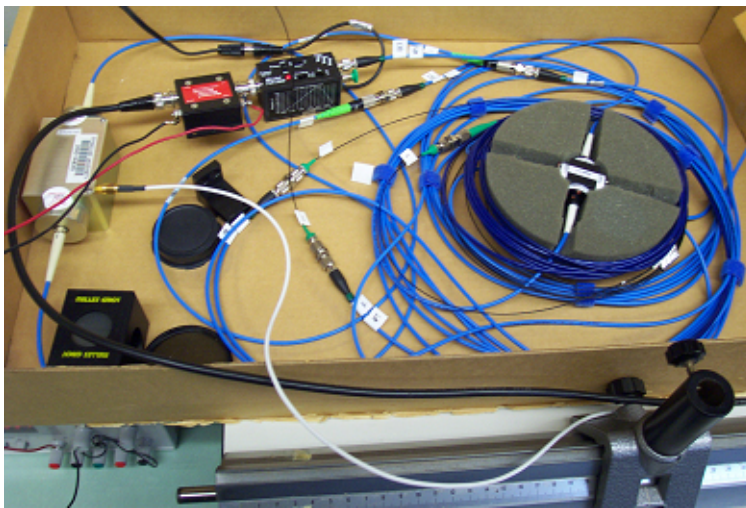


Figure 9: Radius system fiber interferometer.

[Figure 10](#) illustrates the essentials of an optical heterodyne interferometer.

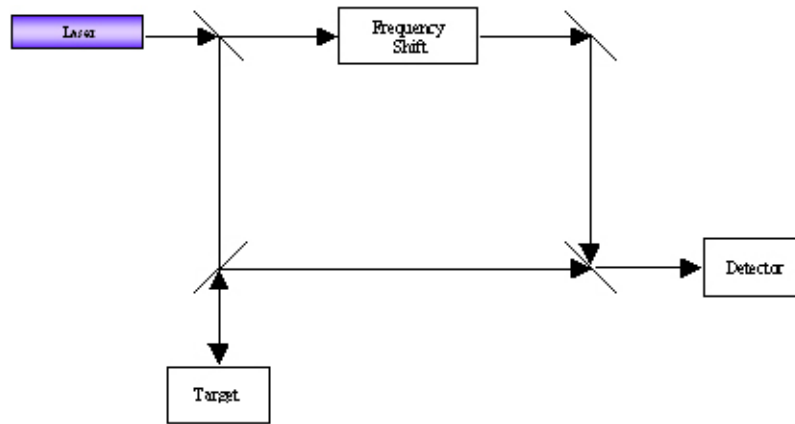


Figure 10: Essentials of an optical heterodyne system.

The laser provides a source of coherent light as a beam of small diameter, usually about one millimeter (mm) in diameter. The particular laser used in the *Radius* design is a Helium-Neon (HeNe) laser operating at a wavelength of 633 nanometers (nm), which provides a visible beam with a red color. The heterodyne sub-system contains a beamsplitter that splits the laser into two directions, creating a reference beam and a signal beam (Figure 9 shows the reference leg as the frequency shifted beam and the signal leg as the target beam). One of the two beams is frequency shifted, so that the optical frequency in the reference leg differs from that in the signal leg by this shift. Theoretically, either leg can provide the frequency shift — in the original unguided system the shift was accomplished in the reference leg (as shown in Figure 10), but in the present *Radius* system the shift is accomplished in the signal leg.

The reference leg is routed by fiber in the *Radius* guided case (by a mirror in the original unguided case) to an output beam combiner, which contains a beamsplitter used in reverse. The signal leg directs the beam to the target (i.e., the cylinder groove) where another beamsplitter reflects and directs the light to the final output combiner. The two combined beams, now collocated, pass to an optical detector, which is a square-law device. The square-law characteristic enables the optical detector to produce a mixing of the two beams that generates the sum and difference frequencies of the two optical beams. The component represented by the difference frequency carries the original phase modulation imparted to the laser beam by the rotating cylinder groove. This signal is found in the electronic output of the optical detector, and can be demodulated to recover the desired audio signal by electronic circuits.

It is instructive to list the actual values of the frequencies used in the interferometer in hertz (cycles per second). The optical frequencies are very large, and even a small fractional shift represents a fairly high electronic radio frequency as an output carrier. We can suppose that the laser frequency, corresponding to the wavelength of 633 nm (red light), is exactly 474,000,000,000,000 hertz (the exact number to this many places depends on a large number of circumstances). In Figure 10, this would be the frequency in the signal leg. The selection of the frequency shift is 100,000,000 hertz (100 megahertz). Therefore, the frequency in the reference leg becomes 474,000,100,000,000 hertz. When these two beams reach the output optical detector they "beat" with each other to produce the difference frequency of 100,000,000 hertz, which is the same as the original frequency shift. This beat frequency is obtained in electronic form on the output side of the detector. The phase modulation found on the new lower frequency carrier (100 MHz) is identical to that on the original optical signal beam. The selection of the frequency shift was strategic, in that 100 MHz is in the center of the frequency modulation (FM) broadcast band. Thus, this signal can be demodulated and played on an ordinary FM radio receiver.

The optical frequency shift is accomplished by an acousto-optical (AO) cell (see Figure 11). A sinusoidal drive (usually applied by an electro-mechanical transducer attached to one end of the cell) acoustically energizes a polished optically transparent cell. The light beam to be frequency-shifted passes through the cell in a direction at right angles to the axis of the acoustic propagation. The moving wave fronts of acoustic compression and rarefaction (resembling a moving "Venetian blind") cause diffraction of the light. This diffraction of light is manifested by an array of exiting beams, all resembling the input beam, but all traveling in different directions. These are called "orders" of diffraction, and the angles of the orders tend

to be equally spaced. The extension of the input beam on the output side is called the "zero" order, where the "first order" of diffraction (which is the diffracted beam closest to the zero order) is shifted by an amount equal to the acoustic excitation. This effect is due to a Doppler shift imposed by the moving acoustic grating, and one only needs to create an aperture that will pass the first order, and block the other orders to obtain the desired frequency-shifted reference (or signal) beam.

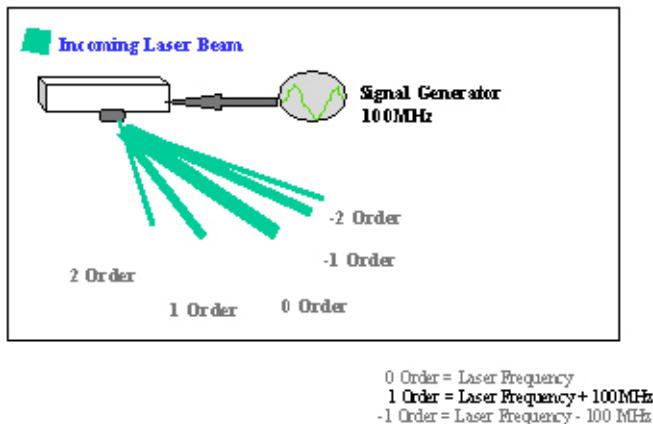


Figure 11: Acousto-optic cell.

In the *Radius* system architecture, all optical connections are guided by fiber within in a monostatic interferometer sub-system (see [Figure 12](#)). Frequency shifting occurs in the signal leg to minimize spurious signals generated by cross talk between the acousto-optic generator and the detector circuit.

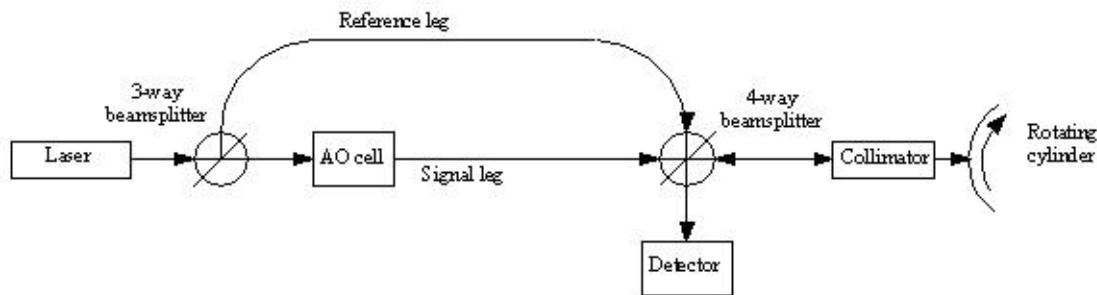


Figure 12: Radius monostatic interferometer diagram.

Radius signal demodulator sub-system

As noted earlier, since the electronic carrier frequency obtained from the optical detector (which is also the acoustic excitation frequency) is 100 MHz — the center of the FM radio band — the simplest demodulator is an ordinary FM radio. The frequency demodulation provided by the electronic discriminator found in every FM radio is precisely the process needed to recover the molecular velocity signal. The virtual stylus velocity provided by the acoustically modulated cylinder groove is exactly proportional to the Doppler frequency shift imparted to the optical signal beam by the modulation. Therefore, the desired modulation signal comes to the

demodulator as a frequency modulation of the 100 MHz carrier frequency.

For reasons of radio frequency isolation, and accurate demodulation, the *Radius* technical team constructed an electronic "phase locked loop" for use, instead of an ordinary FM radio. The linearity and isolation of the phase locked loop is superior to other discriminator designs (see [Figure 13](#)).

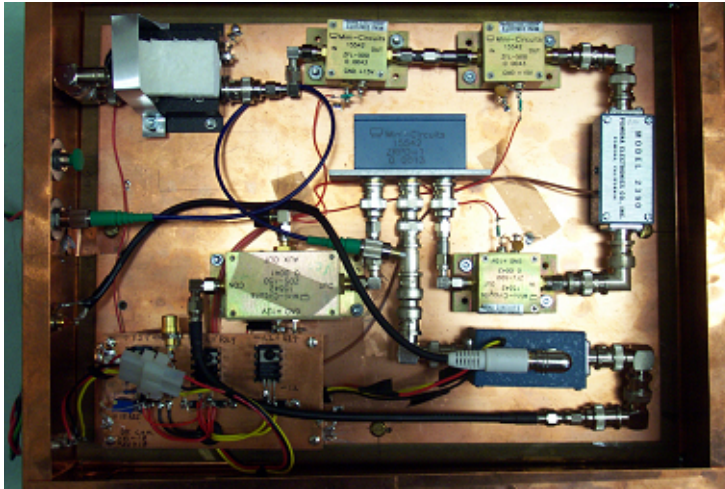


Figure 13: Completed *Radius* "phase locked loop" signal demodulator.

Radius tracking sub-system

The system must provide a way to steer the laser beam into the center of the groove during the playback process. [Figure 14](#) is a microphotograph of a typical area on an Edison cylinder recording. It exposes five grooves, where the second groove from the top shows a relatively high audio-recorded frequency and the fourth groove down displays a lower frequency. Groove spacing is 250 microns center-to-center.

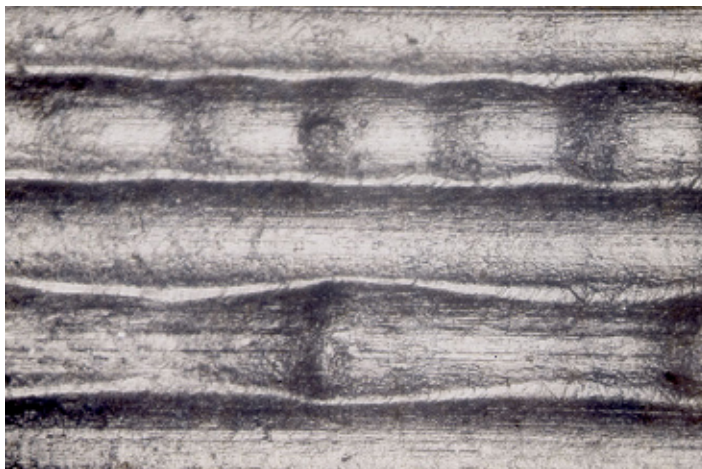


Figure 14: Microphotograph of cylinder grooves.

The tracking is based on a comparison of the strength of scattered light in directions to the left and right of the main reflected signal beam. [Figure 15](#) shows groove cross sections and how the light is directed in reflection, as a function of beam position. In the left two diagrams the beam is shown aligned with the groove center. In the upper right diagram the beam is too far to the right (left) and thus the scattered light is predominant to the left (right).

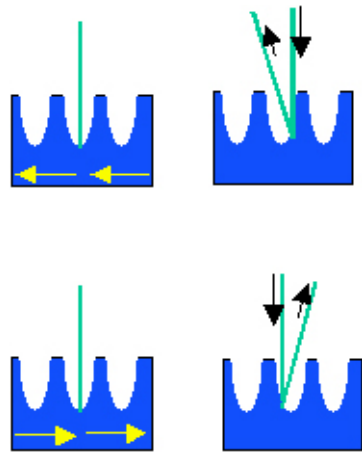


Figure 15: Groove cross-sections — How light is directed in reflection.

[Figure 16](#) illustrates how these two components are intercepted by the right and left auxiliary detectors that have been seen in the picture of the optical head in [Figure 8](#), and described in that previous section of this discussion. [Figure 16](#) also suggests how the two detector outputs are subtracted to produce a tracking error signal.

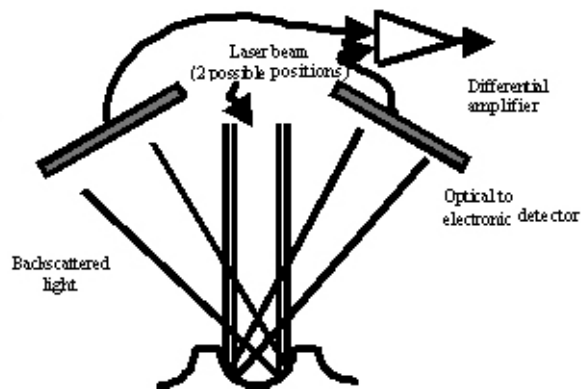


Figure 16: Tracking error detection.

This tracking error signal is applied to two control actuators. The low frequency component of the error signal is filtered out and used to control, after appropriate power amplification, a motor drive lead screw that drives the optical head hub (the previous tone arm hub), which positions the entire optical head so that it approximately follows the "drift" of the precessing groove on the rotating cylinder. The high frequency component of the error signal is used to position the tracking mirror that was also described in the earlier discussion of the optical head, and this tracking mirror is also visible in the photograph of the optical head shown in [Figure 8](#). In that photograph, the tracking mirror will be located as the nearest device to the slit between the front pair of tracking detectors. It is this mirror that accomplishes the precise quick-reacting tracking function. Thus, the overall tracking system is a two-tiered system to provide drift and fine tracking functions.

Testing *Radius* system performance

A meaningful test of *Radius* system performance required confirmation of the interferometer concept. To this end, the *Radius* technical team substituted a small mirror for the cylinder groove as the reflecting target. This mirror was driven by a speaker coil with a signal equivalent to that found in a rotating cylinder — that is, the motion of the mirror was made to emulate the groove motion of a cylinder recording. In [Figure 17](#), the small mounted mirror is located in the right side of the photograph and the objective lens is situated in a mount in the center. The receiving telescope located in the left side of the photograph is the same telescope

used in the optical head (it was removed and relocated for use in this simulation). The remaining components of the *Radius* system were undisturbed.

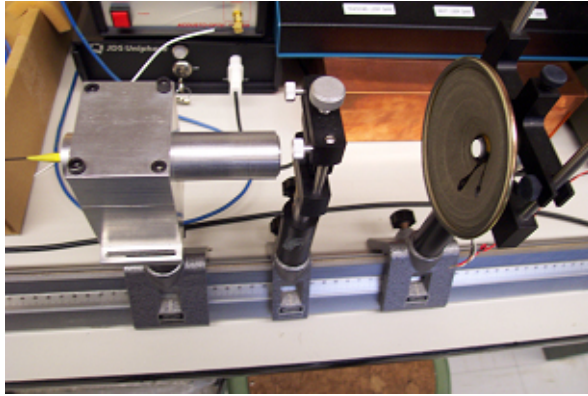


Figure 17: Speaker simulation set-up.

The team used two types of signals for testing the interferometer. Music served as the first signal, and the sound recovered by the *Radius* system was subjectively judged by the *Radius* technical team to be of quite high fidelity. Serving as the second signal was a pure electronically generated tone (sine wave) for which the frequency was 250 hertz. Again the amplitude of motion of the driven mirror was made equivalent to typical motion amplitudes found on recorded cylinders. [Figure 18](#) shows a computer-calculated spectrum of FM pre-demodulated spectrum produced by such a tone, using light wavelength as the basis of the calculation.

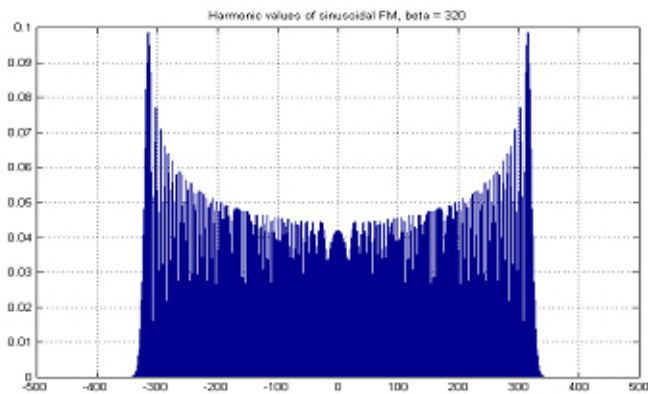


Figure 18: Speaker simulation calculated spectrum.

[Figure 19](#) is a photograph of an actual spectral display obtained during the second test on a laboratory spectrum analyzer. The excellent agreement between the calculated and measured spectra is evident.

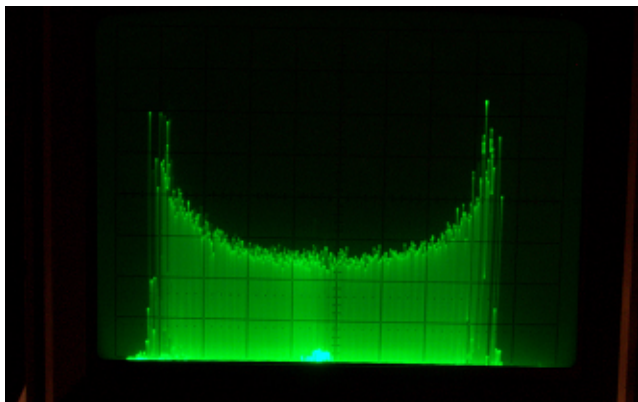



Figure 19: Speaker simulation measured spectrum.

The simulation with the driven mirror clearly demonstrates the viability — the proof of concept — in a definitive way of the heterodyne interferometer concept for this application. At this time, however, the quality of sound generated by the *Radius* system needs substantial improvement, since optical losses in the interferometer that generates the desired playback signal, and other areas in the system, exceed original expectations. As a result, the electronic signal currently generated by the *Radius* system falls below the threshold needed for good FM discriminator action, causing the existing shortfall in quality of sound recovery. The *Radius* technical team has already identified the areas in which there is optical loss, and has developed a strategy for resolving such losses.

Conclusion

Syracuse University Library believes that it is essential to complete the development of the *Radius* system in order to preserve and enhance accessibility to its collection of 20,000 cylinder recordings. This collection represents approximately 85 percent of the total number of commercially produced two-minute and four-minute cylinders released during the 'cylinder era' of 1895-1929. The unique strategy of *Radius* system is the use of a heterodyne interferometer to generate the desired playback signal from cylinder recordings. The interferometer obtains a precise measurement of the Doppler frequency shift (the rate of change of optical phase shift) caused by the motion of the modulated groove in the cylinder, using wavelength of light as the unit of measure. This ability of the *Radius* system to measure the rate of change of optical phase shift may provide the optimal approach for reconstructing historically accurate sound from cylinder recordings.

Although the *Radius* system has recovered voice and music from actual cylinders, the quality of recovery has been poor due to losses of optical power. However, the laboratory simulation using a simulated target (an audio driven mirror) has demonstrated the viability — proof of concept — in a definitive way of the heterodyne interferometer concept for the recovery of recorded audio signals from Edison-era cylinder recordings.

Successful completion of the *Radius* system will provide Syracuse University Library's Belfer Audio Archive and Laboratory with the capability to preserve the sonic content of Belfer's previously inaccessible cylinder recordings by producing high fidelity, historically accurate analog reproductions. In turn, and as copyright permits, Belfer will also be able to meet the changing needs and expectations of twenty-first century learners by contributing high fidelity, historically accurate digitized sounds from cylinders, thereby enriching the historical content of the World Wide Web. 

About the Authors

Dr. William A. Penn is Research Professor in the Syracuse University L.C. Smith College of Engineering and Computer Science and served as Technical Coordinator for the IMLS-funded *Radius Project*.

E-mail: wapenn@syr.edu

Martha J. Hanson is Preservation Administrator at Syracuse University Library and served as Project Manager for the IMLS-funded *Radius Project*.

E-mail: mjhanson@library.syr.edu

Notes

1. The Online Computer Library Center, Inc. ([OCLC](http://oclc.org)) is a non profit membership organization that serves 43,559 libraries in 86 countries and territories around the world.
2. The term "radius" derives from the Latin *radius solis* (beam of light).
3. The term "light" is meant to include a wide spectral band including, but not limited to the spectrum of visible light. The groove dimensions and the shortest mechanical wavelength are

both on the order of 0.1 millimeters. Then the appropriate light wavelength might be anywhere in the range of 10 microns (0.01 mm), which is referred to as a "far infrared" wavelength, to the ultraviolet band (in the general region of 0.1 microns).

4. "Inventing Entertainment: the Motion Pictures and Sound Recordings of the Edison Companies," at <http://memory.loc.gov/ammem/edhtml/edhome.html>, accessed 4 April 2003.

5. "The Hoagy Carmichael Collection, 1899-1981," at <http://www.dlib.indiana.edu/collections/hoagy/>, accessed 4 April 2003.

References

William Heine, 1977. "A Laser Scanning Phonograph Record Player," Audio Engineering Society , Preprint number 125.

T. Iwai, T. Asakura, T. Kawashima, and T. Ifukube, 1986. "Reproduction of the Sounds From Old Phonographic Wax Cylinders Using the Laser-Beam Reflection Method," *Proceedings of the IEEE-IECEJ-ASJ International Conference on Acoustics, Speech and Signal Processing* (April), pp. 493-496.

Editorial history

Paper received 16 April 2003; accepted 18 April 2003.

Contents **Index**

Copyright ©2003, First Monday

Copyright ©2003, William A. Penn

Copyright ©2003, Martha J. Hanson

The Syracuse University Library *Radius Project*: Development of a non-destructive playback system for cylinder recordings by William A. Penn and Martha J. Hanson
First Monday, volume 8, number 5 (May 2003),
URL: http://firstmonday.org/issues/issue8_5/penn/index.html