Authentication of Forensic Audio Recordings*

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A detailed description is given of the procedures of the Federal Bureau of Investigation (FBI) to determine whether an investigative or other forensic tape is an original or a duplicate, and whether there have been any alterations to the recording. Information is provided on contributor submitted material, the playback of recordings, an analysis overview, critical listening, physical inspection, magnetic development, instrumental analyses (waveform, narrow-band spectrum, and spectrographic), miscellaneous techniques, examination examples, training of examiners, evidence handling, and testimony.

0 INTRODUCTION

On 1973 November 21 White House lawyers advised Chief Judge John J. Sirica, U.S. District Court, Washington, DC, that an 18½-min segment had been effaced from a 1972 June 20 tape recording between President Richard M. Nixon and his former Chief of Staff, H. R. Haldeman [1]. To study the integrity and authenticity of the recording, Judge Sirica appointed an advisory panel of six scientists,[1] jointly nominated by the White House and the Special Prosecution Force. On 1974 May 31 the advisory panel's final report found that the tape, other than the specified section, was consistent with an original recording made on a Sony 800B open-reel tape recorder, and showed no indications of splicing, tampering, or copying. The 18½-min section, according to the report, was probably the result of five or more keyboard-produced overrecordings, using a particular Uher 5000 tape recorder, that erased any previously recorded information on the tape. An audible buzz present in this portion was characteristic of electric power line leakage from the Uher recorder; however, the panel reached no conclusions with regard to who made the overrecordings and why it was done [2]. On 1974 August 9 President Nixon became the first President to ever resign from office. On 1974 September 8, President Gerald R. Ford granted him an unconditional pardon.

These historical proceedings during the so-called Watergate Affair first brought about public awareness of examining tapes for authenticity. Such analyses have been conducted by the Federal Bureau of Investigation (FBI) since the 1960s, but in relatively small numbers. However, after the Watergate technical report was released, the requests submitted to the Engineering Section of the FBI have slowly increased over the past 16 years with the expanding use of investigative recordings.

The FBI's Engineering Section, which is part of the Technical Services Division, has developed a formal authenticity program to handle the chain of custody of evidential tapes, recorders, and associated equipment, to play back forensic tapes accurately, to make full use of listening and instrumental analysis techniques, and

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[1] The six scientists and their affiliations at the time were Richard H. Bolt, Chairman of the Board of Bolt Beranek and Newman, Inc.; Franklin S. Cooper, President and Research Director of Haskins Laboratories; James L. Flanagan, Head of the Acoustics Research Department at Bell Laboratories; John G. McKnight, consultant and Vice President of Engineering for Magnetic Reference Laboratory; Thomas G.

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ward “cookbook” or artificial intelligence approach, since every case is at least somewhat different from any preceding it. The examiner is trained through a lengthy apprenticeship and appropriate schooling to view all submitted recordings suspiciously, to develop and discard hypotheses, to make full use of listening and instrumentation tests, to take a scientific, but “don’t miss the forest for the trees” approach, and to draw systematic/analytical approach using the required laboratory processes, erroneous conclusions are often reached by these individuals.

2 CONTRIBUTOR SUPPLIED MATERIALS

Since an authenticity examination is based on allegations of tape alteration, equipment misuse, chain of custody deficiencies, illegal monitoring techniques, and so on, it is necessary for the contributor to supply particular information and equipment to properly conduct the examination, including the following, as appropriate:

1) Sworn testimony or written allegations by defense, plaintiff, or government witnesses of tampering or other illegal acts. The description of the problems should be as complete as possible, including exact location in the recording, type of alleged alteration, scientific tests performed, and so on.

2) The original tape. Copies of a recording cannot be authenticated and are normally not accepted for examination by the FBI.

3) The tape recorders and related components used.
begins, the evidence is marked for identification using a permanent-ink pen with the assigned specimen number, laboratory number, and the examiner’s initials. The FBI normally uses consecutive Q designations for each tape and K designations for tape recorders and other related equipment, for example, Q1, Q2, Q3, . . . and K1, K2, K3, . . . . The laboratory number includes receipt date in the Laboratory Division’s Evidence Control Center and designators for the particular forensic section and examiner.

3 PLAYBACK OF RECORDING

The proper playback of all evidence and test tapes is critical, since it provides the optimum output for listening and signal analysis. The procedures include inspection of the evidence tapes for damage, determination of track position and configuration, azimuth alignment adjustment, playback speed correction, and the use of a high-quality reproducer. A general inspection of the evidence tape is conducted, as appropriate, of the cassette or cartridge housing, the reel, and the magnetic tape itself to ensure that the safety tabs in the housings have been removed, no parts are defective, the transport is smooth and without obstruction, and the tape is not obviously torn, wrinkled, or damaged. If there are housing or reel problems, retrieval begins, the evidence is marked for identification using a permanent-ink pen with the assigned specimen number, laboratory number, and the examiner’s initials. The FBI normally uses consecutive Q designations for each tape and K designations for tape recorders and other related equipment, for example, Q1, Q2, Q3, . . . and K1, K2, K3, . . . . The laboratory number includes receipt date in the Laboratory Division’s Evidence Control Center and designators for the particular forensic section and examiner.

\[ A = 20 \log_{10} \left| \frac{\sin x}{x} \right| \]  

where

- \( A \) = amplitude loss, decibels
- \( x = \pi FW \tan a \)
- \( V \)
- \( F \) = frequency, hertz
- \( W \) = width of record track
- \( a \) = misalignment angle, degrees or radians
- \( V \) = tape speed.

The vertical lines in Eq. (1) are for absolute value. (The computed value inside the lines is always made positive.) The approximate azimuth misalignment can be computed, if needed, from the graph in Fig. 1(b) by determining the exact frequency at which the spec-
transmitter/receiver system. The laboratory playback unit is then adjusted to allow the tones to play back at the correct values, thus ensuring the same transport speed as the original recorder. The smaller motors and lower speeds of the recorders used in many forensic applications produce greater transport discrepancies than encountered in professional units. A further problem that has to be considered when analyzing such recordings is that the speed error may not be constant, but vary considerably over the length of the tape [6], [7].

Playback to correct the azimuth, positioning, and speed errors utilizes standard professional and consumer decks, modified professional reproducers with specialized head stacks and speed controls, and special format units. Professional reproducers are used for the playback of standard open-reel and cassette evidence tapes when azimuth and track placement are correct, or nearly so, and to produce laboratory copies. Many of these units have speed-variable controls to change the playback speed, some have been modified to non-standard and very slow transport speeds, and most have easily accessible head alignment screws. Consumer-type recorders are used for reproduction when professional decks are not available, such as for miniature cassette or 8-track cartridge formats. Since different manufacturers of miniature cassette recorders place the combination record/reproducer and erase heads through different gaps in the housing, care is taken to ensure that the very beginning and end of such evidential recordings are fully played back with laboratory equipment. Professional open-reel tape reproducers with specially fabricated head stacks are used to play back tapes with major azimuth and track placement problems. These units include ¼-, ½-, and 1-in (6.4-, 12.7-, and 25.4-mm) capability and have speeds ranging from 15/32 to 7½ in/s (11.9 to 190.5 mm/s) to allow the playback of standard open-reel formats and logging tapes, which can have up to 60 channels, each containing 24 hours of radio traffic and/or telephone calls. The specially fabricated head stacks allow for generous azimuth adjustment and placement of the reproduce head anywhere on the tape surface. Fig. 2 is an example of a modified professional deck for 1-in (25.4-mm) logging tapes that has transport speeds of 15/32 and 15/16 in/s (11.9 and 23.8 mm/s), speed corrections of greater than ±20%, and azimuth adjustments of greater than ±5°. Special reproducers include old and obsolete devices, such as wire recorders, magnetic dictation disk and belt units, and short-lived or specialized cassette and cartridge formats. Many of these units have been modified for improved fidelity and to add or update the output connections.

4 ANALYSIS OVERVIEW

The analyses to conduct an authenticity examination are separated into the following seven general areas, based on the different types of instrumentation and procedures: 1) critical listening, 2) physical inspection, 3) magnetic development, 4) waveform analysis, 5) narrow-band spectrum analysis, 6) spectrographic analysis, and 7) miscellaneous techniques. At least some of these analyses are used in the examination of every evidence tape submitted to the FBI for an authenticity examination.

The first overall consideration, in many examinations, is whether the recording in question is an original or a duplicate, since copies cannot be authenticated. This is because it is difficult to detect some alterations when a recording is digitized into a computer system or copied onto a professional recorder, physically or electronically edited, and then recopied onto another tape. However, editing of an investigative tape is appreciably more
complicated, compared to a professional studio recording, since the submitted recordings usually contain high-level background sounds, limited signal-to-noise ratios, varying degrees of distortion, artifacts from the transport and power systems, and so on. These factors, and others, greatly complicate such an editing process, making it difficult, or even impossible, to add or delete words in many portions of forensic tapes without producing an unnatural effect, audible even to a naive listener. For example, an individual answers “yes” to a question posed by another in a noisy investigative recording in a bar room while rock music is being performed by a live band. If someone then wished to edit in a “no” for the “yes” response, consideration would have to be given not only to imitating the particular environment, background talkers, ventilation sounds, recording characteristics, and so on, at that particular time, but also the exact music and lyrics. Indications of originality in the laboratory include the observation of erase-head-width marks and/or offset recording-head marks at record events, and the lack of multiple environments, dropouts consistent with editing, unnatural speech interruptions, phase discontinuity, and discrete frequency tones produced by a duplication process.

Once the examination of the evidence tape has revealed no indications of duplication, then critical listening, physical inspection, and appropriate instrumentation are used to continue the analysis. Critical listening encompasses four major steps to ensure that all questionable events in the designated area are cataloged and also allows for a smooth transition to the other tests. The physical inspection identifies splices, tape damage, improper tape length, housing alterations, and other visual defects. The magnetic development process shows the higher amplitude magnetic fields present on the tape that can visually reveal record events, track widths and configurations, record and erase head artifacts, and so on, and allows comparisons with test tapes prepared on submitted tape recorders. The waveform graphs are high-resolution representations of recorded sound in a time-versus-amplitude display, that reveal record events, dropouts, questioned transient-like events, sequences of pertinent occurrences, and similarities and differences with test recordings. Narrowband spectrum displays are useful for analyzing background sounds, discrete tones, wow and flutter, transport speed errors, and general frequency characteristics, found quickly and generally facilitates further work.

Spectrographic analysis shows changes in frequency versus time versus sound pressure, which assists when examining certain types of record events and discontinuities. The miscellaneous techniques include phase continuity, statistical determinations, and other tests that are helpful with certain evidential material. After all the necessary tests are performed, the examiner, with input from appropriate staff engineers and technicians, reaches conclusions regarding the authenticity of the recording based upon the examination of the evidence tape, comparisons with test recordings, review of manufacturers’ literature, and prior experience gained from similar recording systems.

As previously mentioned, authenticity examinations cannot always be quantified into a standard set of analysis procedures for a particular case. The examiner, instead, conceptualizes possible hypotheses for each questioned event or claim of duplication, and then through the laboratory process determines which, if any, of the explanations are correct. This is repeated until the examiner is satisfied that the conclusions are directly supported by scientific tests and tape recorder theory. Following are descriptions of many of the techniques used by the FBI in forensic authenticity examinations, but the interrelationships between them are too numerous and complex to be completely set forth.

4.1 Critical Listening

After the preliminary procedures, the first examinations conducted on a questioned tape are listening tests using the original tape or a direct open-reel or digital copy prepared in the FBI laboratory. These aural evaluations, though not conclusive, provide considerable direction to the examiner in locating areas requiring specific instrumental or physical inspection. Listening tests are always performed without filtering using high-quality playback systems and headphones of the “over-the-ear” style; if needed, additional reviews are conducted with appropriate enhancement procedures [8].

The critical listening analysis has four separate, but overlapping areas of interest: 1) preliminary overview, 2) record events, 3) background sounds, and 4) foreground information. In the preliminary overview the entire tape is reviewed, except for formats that contain an extensive amount of recorded material, such as police department logging tapes with multiple channels of information, each lasting 24 hours. In this review, a time log, or chronology, is begun in order to list pertinent events that will be of assistance in other examinations. Events often noted include obvious record stop and start occurrences, environmental changes, unrecorded portions, sudden transport speed differences, and other audible variations in the character of the recording that will require further study. This preliminary aural overview is an important first step, since it often limits the portions of the tape that have to be further examined, allows obvious record events to be

The three remaining aural tests are conducted at various times and in no particular order, both before and after other appropriate analyses, depending upon the information developed in the overview, the type of alterations alleged, instrumental analysis findings, and the preference of the examiner. The record events examination requires prior listening to known stops and starts on the evidence tape, and test recordings prepared on the submitted tape recording equipment. Substantial experience in examining such signals from a wide variety of other tape recorders is also essential, since the evidence tape could contain record signatures from unsubmitted recorders. This critical listening test and many
of the transientlike signatures left by most nonprofessional tape recorders, when starting and stopping in the record mode. These events, produced by both the record and the erase heads, are the result of activation and deactivation of the bias signal, the energizing and collapse of the electromagnetic head fields, and other electronic switching in the recorder circuitry. Signatures vary considerably in amplitude, shape, and duration, not only between different formats and recorder brands, but often between identical units. As a general rule, record stops produce a cessation of recording followed by a short unrecorded area, equal to the distance between the record and erase heads on the particular unit, and then the sound of the erase-head deactivation; record starts often have a low-level transient, an unrecorded area, and then the beginning of the recording; record stop/stops usually leave a short unrecorded portion, depending upon the distance the tape moves after the stop button is pushed and before the recording process is restarted; pause stop/stops produce short-duration, or even inaudible, dropouts; and voice-activated starts usually have a rapid frequency decrease, or chirplike sound, at the beginning of the recording. Any complete dropout or nonenvironmental transientlike signal, whether consistent with a record event or not, is listed on the chronology for further study, unless it has previously been shown to be innocuous.

Analyses of background sounds include documenting unnatural sounding changes in the environment, repetitive noise sources, music, recorder and tape noise, and so on; the presence of unexpected transientlike signals [9], multiple environmental characteristics, dropouts [10]–[12], inappropriate microphone-handling sounds, 60-Hz hum on battery-operated tape recordings, and the like; and the absence of expected environmental or transmission channel effects, reverberation, and so forth. Examples of possible problems that would be noted are a rock song that only lasts 1 min on a radio playing in the background, an abrupt change in the level of the tape hiss, a series of unexplained clicks in a quiet room environment, no ringing, hang-up, or other telephone signals and noises on an alleged telephone recording, and, conversely, telephone switching sounds on a supposed room recording made on a miniature concealed tape recorder.

The last general area of aural review is a detailed examination of the foreground information, including pertinent voices, various high-level sounds, pre- and postconversation narratives by the operator, contextual information, and overriding RF transmissions. Examples of aural events requiring further instrumental analysis include sudden, unnatural, or linguistically peculiar changes in an individual’s voice or cadence, inconsistency between the beginning and ending times given by the operator and the actual length of the recording, an abrupt and unexplained change in the topic of conversation, and interrupting radio transmissions that could be masking a tape alteration.

The critical listening examination provides unique information in an authenticity determination due to the ability of human beings to identify pertinent sounds in the midst of extraneous signals and noise. The examiner’s experience of having reviewed numerous investigative recordings and test tapes, in general and for the particular case, provides insight and direction for the various instrumental analyses. In addition, during the waveform and narrow-band spectrum examinations, the examiner can both listen and view the real-time displays for direct aural-to-visual correlations.

### 4.2 Physical Inspection

The physical inspection of a magnetic tape and its housing or reel is concerned with three general areas: finding indications of alterations, cataloging damage produced by normal wear or improper handling, and determining tape length. Obviously, only the original evidence tape can be used for these examinations. The first two concerns include the following tests, as needed:

1. Examining the outside of the housing for indications of tampering, such as pry marks on welded construction or damage to the screws.

2. Inspecting the reel or housing to determine whether it is consistent with the magnetic tape present, including size, label, and leader type.

3. Inspecting the splicing of the magnetic tape to the leader, if present, to determine consistency with normal manufacturing processes.

4. Locating any physical splices, other than connections to the leader tape, that could reflect either an obvious alteration or the repair of damage.

5. Identifying any damage to the tape, including loss of oxide, tears, deep creases, and edge stretching.

6. Comparing the alleged date of the recording to when the tape itself was manufactured, which is determined by either lot number, when present, or brand name.

Locating splices and identifying damage is normally conducted on a submitted reel tape by playing back the evidence on a horizontally aligned recorder at a transport speed of 1.25 in/s (3.28 mm/s) or less, and viewing the tape with a high-intensity cold light source. The tape is not only examined on both sides, but on thinner tapes a translucent inspection is possible through the tape. For cassettes and cartridges, the magnetic tape is carefully pulled out of the housing and then transported slowly, by hand, on a special jig, using the same lighting. All anomalies are cataloged on the chronology and, as appropriate, photographed for future reference.

Examples of the use of these first two tests in actual FBI cases include: identification of a cassette tape with Maxell nonmagnetic leader in a TDK cassette housing; determination that allegations of “editing” by a defense “expert” were caused by oxide losses on the tape; and finding that a recording provided by a cooperating witness was on a type of Maxell cassette not manufactured until at least 6 months after the alleged conversation took place. In another case, involving a civil aircraft accident, an examination of the designated portion of
a 10½-in (266.7-mm) reel of ½-in (12.7-mm)-wide tape from a 24-hour logger revealed that the tape had broken and been repaired by office adhesive tape. One of the explanations provided was that the tape had broken on playback and had been poorly repaired by non-technical personnel without loss of tape; but low-power microscopic examinations refuted this claim, since the cleanly cut ends did not match each other and there was no evidence of appreciable tape stretching.

The third physical examination is a measurement of tape length, where either a special pulley device directly determines the footage, or the tape is played back on a calibrated laboratory tape recorder for cassettes and reels, and on recorders whose speed accuracy is known for other formats. The results are then compared as to the expected length for a particular format and size; for example, a 1200-ft (365.8-m) length of reel tape would be expected to run from 16 to 19 min at 15 in/ s (381 mm/s) [1200–1425 ft (365.8–434.3 m)] and a C90 cassette from 45 to 49 min a side at 1¾ in/s (47.6 mm/s) [422–460 ft (128.6–140.2 m)]. This physical test will usually only identify gross changes, such as when the tape from a C60 cassette is placed in a C45 housing.

4.3 MAGNETIC DEVELOPMENT

A preliminary magnetic development examination was described in Sec. 3, where general track characteristics were inspected to ensure optimum playback of questioned tapes and test recordings. Originality and alteration determinations of evidential submissions require more detailed analysis using various ferrofluids, micro- and macroscopic systems with a selection of lighting, photographic and video imaging components, appropriate photographic film and video printer devices, and measurement stages (Fig. 3). The freon- and water-based ferrofluids applied to the original tape, with ferric particles ranging in size from approximately 0.01 to 3.0 μm, are thoroughly tested to ensure that they do not damage the magnetic tape or affect the recorded information [13]. After applying the ferrofluid with a small plastic squeeze bottle for freon-based solutions or a cotton swab for water-based, the tape is usually elevated on an absorbent surface until the carrier liquid evaporates, leaving the ferric particles aligned with the higher magnetized areas on the oxide side of the tape. This ferric "residue" produces a light-colored, visible pattern that is contrasted against the darker tape surface. Recorded sounds are seen as parallel vertical lines, perpendicular to the tape edge, whereas artifacts from head laminations and edges of record- and erase-head gaps produce horizontal marks. Record stop and start signatures will have patterns in a variety of shapes and styles, depending upon the type of heads in a particular tape recorder.

The macro- and microscopic systems, as a group, are able to display full-frame images of fields from 2 mm upward, to allow wide latitude in the examination of the various magnetic marks. The lighting used, depending upon the ferrofluid, application, and type of recorded sound, is either incident from a professional electronic flash unit or a cold-light source positioned at a 30–45° angle from the tape surface, axial or ring from a cold-light source circling the bottom of the ob-
jective lens, or coaxial, which is parallel to the viewing path in the microscope. Fig. 4(a) shows an erase-head event with incident lighting and Fig. 4(b) is the same event with coaxial lighting, which produces a reverselike image since the metallic smooth surface of the tape reflects the light back to the lens like a mirror, causing the ferrofluid particles to be silhouetted. Using a 35-mm or larger format camera, exposures are taken of appropriate events on the evident and test tapes using a slow-speed, technical panchromatic, black-and-white film. The film is developed to an elevated contrast for improved clarity and then printed into 8- by 10-in (203-by 254-mm) or larger photographs for viewing. High-resolution video cameras and printer units are also used, allowing almost immediate hard-copy images. Due to the light losses from magnification factors, higher f-stop settings, and the slow-speed film, short-duration electronic flash exposures or a vibration-damped table are utilized to eliminate camera shake. Built-in automatic exposure systems with manual override are used to ensure correct negative density. Often a finely ruled glass plate or other scaling device is placed under the tape specimen for reference. For determining azimuth, track width, track position, and so on, calibrated stages provide digital measurements and readouts with an accuracy of ±1 μm.

As an example of the information available using the magnetic development technique, Fig. 5 is a drawing of a typical stop/start record event on a nonprofessional recorder. A stop/start is a sequence where a recorder is stopped while recording and then subsequently restarted in the record mode without moving the tape between the stop and the start. This figure, which for increased clarity is not drawn to scale, shows a recording represented by the evenly spaced parallel lines, progressing from right to left. This is consistent with most reel and standard cassette formats, where the tape is transported left to right, which causes the information to be recorded in a right-to-left orientation; or, stated in another way, the current (new) input signal is at the recording gap, and the “older” recorded material is to the right of the record head toward the take-up reel. It should be noted that microcassette recorders and some other consumer formats have the supply reel on the right instead of the left, with the tape thus being transported right to left. On this figure, the recording is stopped at $R_1$, which produces a signature mark there, and at $E_1$, which is the location of the erase-head gap. This record-to-erase-head distance can vary from approximately 0.8 mm in a combination record/erase head to over 50 mm, depending upon the format and the recorder manufacturer’s design. The erase-head mark

![Fig. 4. Magnetic development of erase-head event. (a) Using incident lighting. (b) Using coaxial lighting.](image)

![Fig. 5. Drawing of record stop/start event (not to scale).](image)
is always ahead of the recording process to allow erasure of previously recorded material on the tape; if reversed, the erase head would delete the information just after it was "written" by the record head. It is also apparent on the figure that the erase-head mark has a wider track than the record head, which is a standard manufacturing practice to allow the complete erasure of previously recorded material, even if the record track is offset somewhat toward the middle of the tape. The horizontal distance between \( R_1 \) and \( R_2 \), and concurrently \( E_1 \) and \( E_2 \), represents the slight movement of the tape by the fore using these specified visual differences and others across the lines, since they are usually partially or completely erased by the recording process of the record head.

Three authenticity areas in which magnetic development assists the FBI examiner are determining originality, analyzing record event signatures, and measuring general record characteristics [2]. For originality considerations, important magnetic mark indicators occurring at record events are offsets, head edge line discontinuities, and the existence of the wider erase-head signatures. Fig. 6(a) is a developed, original record-head stop/start event, with the right-hand band of striations representing the sounds up to the record-head stop and the left-hand band the sounds after the startup. The record-head start track is offset toward the middle of the tape in Fig. 6(a) of the original recording, but the offset is not present in Fig. 6(b), which is a copy of the original tape back onto the same tape recorder. This comparison shows that the offset caused by the recording discontinuity on the original tape is not transferred to a copy, since the gap on the reproducer head cannot directly "read" this information. Fig. 7(a) is an original stop/start that leaves a record-head edge discontinuity at the event. This again is not transferred to the copy, shown in Fig. 7(b), which has a continuous line between the record-head stop and start marks. Fig. 8(a) shows the marks by the erase head in an original recording event, which are wider than and partially erased by the narrower record head. Fig. 8(b) is a copy on the same tape recorder, where the top parts of the erase-head marks are not duplicated due to the inherent width limitations of the reproduce head, and the record-head-wide marks are now barely visible. Fig. 9(a) shows the two obvious erase-head marks in another original record stop/start, which have been completely erased except for the section that is wider than the record-head gap. Fig. 9(b) is a copy of the same area, and there is no evidence of any erase-head activity. Therefore using these specified visual differences and others between developed tracks on originals and copies, the examiner can often determine whether a questioned record event is an original or a duplicate.

A second application of magnetic development is the pictorial identification of original record events and their comparison to test recordings prepared on moving tape slightly before the electronic start of the recording process. \( R_2 \) and \( E_2 \) are the start signatures of the record and erase heads, respectively, as the recorded information continues in the right-to-left direction. The bottom portions of the erase-head stop and restart marks \( E_1 \) and \( E_2 \) are represented by dashed lines, since they are usually partially or completely erased by the recording process of the record head.

Lines \( R_1 \) and \( E_1 \) are magnetic artifacts of the top edges of the record- and erase-head gaps, which are often present on investigative recordings. The last major items of interest in Fig. 5 are the vertical offsets toward the center of the tape at \( R_2 \) and \( E_2 \), which can occur as the tape is pressed against the heads at the onset of the recording process and does not immediately achieve correct gap-to-tape alignment (The offsets are somewhat exaggerated in Fig. 5 for illustrative purposes.)

Fig. 6. Magnetic development of record-head stop/start event, (a) Original recording. (b) Copy made on same recorder. (0.16-in (0.4 mm) marks at bottom.)
from the record head, but in general the handwriting of head, then.

These measurements can include such parameters as track width, track distances from edge of tape, tape width, etc.

Fig. 7. Magnetic development of record-head stop/start event. (a) Original recording. (b) Copy made on same recorder.

Fig. 8. Magnetic development of erase-head stop/start. (a) Original recording. (b) Copy made on same recorder. [0.01-

(a) Original recording. (b) Copy. [0.01-in (0.25-mm) marks at bottom.]
of erase-head events, spacing of head laminations, and azimuth misalignment. Generally the procedures to determine distance on a tape are:

1) Application of an appropriate ferrofluid to the oxide side of the evidence tape in the higher amplitude portions of the recording, where transientlike signals, loud voices, and record events occur. Whenever possible, ferrofluids with smaller particle sizes are used for better resolution.

2) The tape is held down by a thin, clear glass plate or by placing the tape backing against a solid, non-metallic, flat surface with a temporary-type adhesive that is not harmful to the tape.

3) The flattened tape is carefully set on top of the microscope stage with its edges reasonably in line with the x-axis measurement coordinate. This is accomplished by visually sighting on a reference point in the microscope’s eyepiece reticle and aligning it with the edge of the tape. The x and y coordinates of the measurement stage are then set to (0, 0), and the point of reference is moved to the edge of the tape approximately 20 or 30 mm away. If the tape is properly situated, this y0 value will be quite small compared to the x0 value; if the y0 value is high, the tape support is moved appropriately and a new set of readings are taken. Once reasonable stage versus tape alignment is obtained, the small angular error is computed to allow adjustments to the subsequent record events measurements. The angular error \( \Phi \) is then determined by the equation

\[
\Phi = \arctan \left( \frac{y_0}{x_0} \right)
\]  

As an example, if \((x_0, y_0) = (20,081 \pm 4 \, \mu m, 404 \pm 4 \, \mu m)\), then \(\Phi = 1.15 \pm 0.01^\circ\).

4) As a reference, the width of the tape is often measured in several areas by aligning the reference point in the eyepiece reticle on one edge of the tape, setting the stage transducers to (0, 0), determining the y-axis value for the opposite side of the tape with the x-axis value at zero, and then computing the width \(W\) of the tape using the y coordinate value \(y_w\) and the known angular error \(\Phi\) by the following equation:

\[
W = y_w \cos \Phi
\]

For example, using the \(\Phi\) value computed in step 3 and letting \(y_w = 6351 \pm 3 \, \mu m\), then \(W = (6351 \pm 3)[\cos(1.15 \pm 0.01)] = 6350 \pm 3 \, \mu m\), which reflects that, in this case, the tape alignment error affects the tape width results only slightly.

5) Eq. (3) can also be used to compute the distance for any information that produces a line parallel to the tape edge, such as track width, track distance from the tape edge, width of the head edge marks, position of head laminations, and so on. However, the equation is not appropriate to measure the length of single marks, such as individual transients and record event sounds. For such signals, the Pythagorean equation for the distance \((x_2, y_2)\) is used:

\[
D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}
\]  

This equation simplifies when one point is set to \((0, 0)\):

\[
D_0 = \sqrt{x_1^2 + y_1^2}
\]

For example, if the measurement transducer of the stage is set to \((0, 0)\) when the reticle is aligned with one end of a mark, and the other end reads \((414 \pm 3 \, \mu m, 2110 \pm 3 \, \mu m)\), then \(D_0 = \sqrt{(414)^2 + (2110)^2} = 2150 \pm 3 \, \mu m\).

6) The azimuth misalignment angle is computed, using the magnetic development procedure, by first choosing a suitable transientlike signal, setting the measurement stage to \((0, 0)\) at one end of the mark, and then determining the coordinates \((x_a, y_a)\) at the other end. Then the azimuth misalignment angle \(\theta\) can be computed directly by

\[
\theta = \arctan \left( \frac{x_a}{y_a} \right)
\]

For example, if \(x_a = 10 \pm 3 \, \mu m\) and \(y_a = 1998 \pm 3 \, \mu m\), then \(\theta = \arctan(10/1998) = 0.29 \pm 0.09^\circ\).

Another method of measuring distances of magnetic marks is to photograph the events and areas in question.
Then by using the reference scale above or below the tape on the photograph to determine the magnification factor, measurements can be made of the marks with a calibrated ruler. This technique cannot provide the resolution of the previously described method, but its accuracy is sufficient for most applications.

4.4 Waveform Analysis

A waveform display reflects graphically the relationship between the time and amplitude of recorded sounds, and allows the identification and comparison of record events on evidence and test tapes, provides minute scrutiny of suspicious dropouts and transientlike sounds, times complex sequences of events, determines electronic signal return times, and so on. These waveform plots can also clearly reveal low-amplitude sounds not observable with magnetic development. As examples of waveform displays, Fig. 11(a) is a record stop event on a cassette tape recorder over a 0.85-s time frame, Fig. 11(b) is an expansion of just the record-head signature over 40 ms, and Fig. 11(c) is the same expansion of the erase-head information.

The FBI presently produces waveform graphs on three different types of instrumentation. The first is a scientific computer system with an array processor, precision four-channel analog-to-digital/digital-to-analog converter, mass magnetic storage, a high-resolution color monitor, specialized software, and an engineering plotter with adjustable paper widths of 11, 24, and 36 in (279.4, 609.6, and 914.4 mm). Since transientlike events of relatively wide frequency bandwidths are encountered in investigative recordings, a 50-kHz or higher sampling rate is used for digitizing. The plots produced are not limited to the ANSI standard engineering lengths, but a continuous plot to over 50 ft (15.2 m) can be graphed at a number of effective paper speeds, from below 10 mm/s to over 20 000 mm/s. The 11-in (279.4-mm)-wide paper is used for most single-channel analyses, with the larger sizes reserved for multiple channel, specialized signal analysis projects, instructional uses, and courtroom exhibits that can be easily seen by the jury panel and court officers. The capability of expanded plot lengths allows excellent detail resolution of both time and signal on one continuous graph.

The second general type of waveform graph production is on long, continuous light-sensitive or thermal paper using optical and thermal-array printheads, with either real-time analog inputs or dedicated digital-to-analog converters and digital storage. These systems allow bandwidths of up to 1 MHz for specialized work, the display of eight simultaneous channels of information, numerous effective paper speeds, and the rapid production of quality graphs. The third type of waveform analysis devices produce “single-shot” graphs, usually on the standard engineering sizes of ANSI A through E [8.5 by 11 in (215.9 by 279.4 mm) to 34 by 44 in 863.6 by 1117.6 mm], by digitally sampling and storing the sound information and then allowing user-selected portions to be plotted. Not included in this last group are digital-storage oscilloscopes, which perform appreciably better on repetitive, rather than constantly changing, signals. For example, a typical digital-storage oscilloscope with 4000 points of storage, sampling at 200 μs, will display a record event of 800 ms with a frequency response of better than 2 kHz for a repetitive signal, but only up to about 250 Hz for a nonrepetitive signal.

High-resolution waveform analysis assists the examiner in numerous ways, including accurate measurement of closely spaced record signatures and other events of interest, determination of signal return times, and detailed inspection of record-mode stops and starts. Measurement of a sequence of events on an evidence tape is a straightforward use of waveform analysis, which provides accurate timing of occurrences too rapid to catalog aurally and whose temporal relationships are important to an examination. As an example, Fig. 12 is a series of five record-head stop/start signatures that take place over a 2.24-s period on playback, labeled 1R through 5R, respectively. Since the sounds of these events occur so rapidly, they could not be accurately timed in the critical listening tests or with magnetic development, but are easily measured on the computer monitor or plot. When needed, the spacing on the evidence tape between any two events can be calculated.

Fig. 11. Waveform plot of record stop event on cassette tape recorder. (a) Entire event over 0.85 s. (b) Only record-head signature over 40 ms. (c) Only erase-head signature over 40 ms.
from the waveform, using the equation

\[ D_T = \frac{D_p T_R}{S_p} \]  

(7)

where

- \( D_T \) = distance on tape between events
- \( D_p \) = distance on plot between events
- \( T_R \) = transport speed of playback recorder
- \( S_p \) = plotter scaling (distance/time).

As an example, using a microcassette tape, with \( D_p = 10 \) mm, \( S_p = 5000 \) mm/s, and \( T_R = 12 \) mm/s, the physical distance on the tape would be 0.024 mm.

The waveform measurement of the signal return time (SRT) reveals how long certain tape recorders have been turned off, prior to the beginning of a recording. This is based on the circuit characteristics in many recorders that produce a record-head start signature when the record button is pressed, but a short time delay before actually recording the input signal. This delay can be directly affected by the length of time the recorder was turned off, with the longest delays for extended deactivation. The time difference between the record-head start signature and the beginning of the recording is called the SRT. Fig. 13(a) shows the record stop/start waveform of a commonly utilized cassette deck that has been turned off for 10 min, and Fig. 13(b) shows the same event, except that the recorder has been off for only 5 s, which reflects graphically the shortened SRT and even the changes to the record-head stop and start signatures. To conduct this examination, SRT tests are conducted on the known tape recorder and measurements taken from the evidence tape of all known record start events. It is also useful if some of the evidential start events have known tape recorder power-off times. Since SRTs are usually affected by the power line voltage, the choice of record input jack (telephone inputs on some recorders are designed to produce reduced SRTs compared to the microphone and line inputs), type of recorder, tape drag, keyboard pressure, and other factors, the results are normally limited to fairly general characterizations, except when extensive testing is conducted [14]. An example of the usefulness of this SRT technique would be on an evidence tape with three recorded telephone conversations, each made more than an hour apart. Examinations determine that there is an original record start before the first conversation, an original stop/start event between the first and second conversations, two original stop/start events between the second and third conversations, and an original stop after the third conversation. The SRTs of the beginning start, the start between recordings 1 and 2, and the first start after the second conversation are found to range from 798 to 830 ms, but the second start after the second recording is 405 ms. This would probably reflect, based on appropriate tests, that this last start occurred very shortly after the previous start. This could be consistent with the operator having pushed down the record key, but...
not completely locking it into position, and having it return to the original "up," or "off," position after moving the tape slightly forward; the operator then may have quickly pushed the record button a second time to restart the recording.

A third general use of waveforms is the identification of record-mode events on evidence tapes and comparing them with test recordings [2]. Some of the applications include the measurement of the record-to-erase-head distance, determination of the spacing between gaps in multiple-gap erase heads, inspection of the signature shape and spacing of various record event signals, detailed analysis of questionable dropouts, transientlike events, and other sounds, and identification of duplicate record events reflecting a nonoriginal recording. The record-to-erase-head gap distances vary considerably with recorders using different head stacks and usually at least slightly between identical models of nonprofessional recorders. The time difference can be measured directly on the engineering plot or by cursors on the computer graphics terminal, and the physical distance of the tape computed with Eq. (7). The same method is used to determine the distance between multiple erase-head gaps. Previously described Fig. 11 shows the time spacing between heads of a record stop and the expansions of the individual record- and erase-head signatures. Test recordings prepared on submitted recorders can then be compared to the evidence tape for similarities and differences in gap distances and signature shaping.

Record events produced on consumer-type recorders vary considerably among different manufacturers, models, and formats, and sometimes between units with consecutive serial numbers. Even identical record-mode operations will, at times, result in slightly different waveform shaping on the same recorder, though gap distances will not vary unless the magnetic heads are not firmly attached to the head stack piece or recorder frame. Fig. 14 illustrates the following keyboard record events on a standard cassette recorder used by some law enforcement agencies: stop with no input, stop with high-level input, start with no input, start with high-level input, stop/start with low-level input, stop/start with high-level input, pause stop/start with high-level input, an overrecording stop over previously recorded high-level information, and finally an overrecording start over previously recorded high-level information. These nine record events, which represent only some of the possible keyboard operations, all have markedly different characteristics that help the examiner determine whether questioned sounds represent a record event and, if so, what type.

Waveform analysis is also useful for inspecting dropouts, transientlike sounds, and other suspicious noises. For example, Fig. 15 is a plot of a physical splice reflecting a momentary loss of signal lasting about 4 ms, whereas Fig. 16 is a 100-ms dropout caused by a partial loss of input signal from a faulty connection to the recorder. Fig. 17 is a 50-ms dropout caused by system anomalies of a miniature transmitter/receiver.
(Fig. 14 continued) (d) Start with high-level input. (e) Stop/start with low-level input. (f) Stop/start with high-level input. (g) Pause stop/start with high-level input. (h) Overrecording stop over previously recorded information. (i) Overrecording start over previously recorded information.
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unit, and Fig. 18 is an overrecording start on a professional reel recorder. Waveform analysis alone cannot always determine whether an unrecorded occurrence represents an alteration or not, but in combination with other analyses it is a powerful examination procedure.

Another use of waveform graphs is the determination of whether a known record event on an evident tape is original or copied. If a duplication process is conducted by a nontechnical individual who uses a loudspeaker-to-microphone arrangement, the shaping of the record signatures is often changed and distorted, especially when using built-in tape recorder loudspeakers and microphones. Fig. 19(a) is an original record-head stop signature, and Fig. 19(b) is a tape-recorder-loudspeaker-to-microphone duplication with relatively inexpensive equipment in a quiet room of the same event; Fig. 19(b) has obvious shaping changes and increased noise. If a tape is copied from line output to line input or acoustically, as described, using two recorders, there is often a slight rise in the noise floor or the addition of hum and other artifacts in the unrecorded areas of the record events, such as between the record-head signatures in an original stop/start event, and Fig. 20(a) is a plot of the noise floor in the area between the stop and start record-head signatures in an original stop/start event, and Fig. 20(b) is the same area duplicated via an inexpensive recorder-loudspeaker-to-microphone acoustical coupling. As can be readily seen, Fig. 20(b) graphically reflects increased noise compared to the original stop. Care is always taken in such analyses to use test tapes with similar signal-to-noise ratios and other pertinent tape characteristics.

An additional waveform test that assists in determining originality is the playback of the evidence tape on a special recorder with a narrow-gap-width reproduce head, which has been raised to a position just above the record track. Only the information from the wider erase-head track (see Fig. 5) is then sensed and can be plotted or displayed. Since this waveform analysis is more sensitive than magnetic development, the pro-

Fig. 15. Waveform plot of physical splice dropout lasting 4 ms.

Fig. 17. Waveform plot of dropout from miniature transmitter/receiver unit over 50 ms.
procedure is useful when a recorder’s erase head leaves low-amplitude signatures.

4.5 Narrow-Band Spectrum Analysis

Narrow-band spectrum examinations utilize FFT analyzers, or appropriate software on high-speed computers, to produce frequency-versus-amplitude (FA) and frequency-versus-amplitude-versus-time (waterfall) displays of chosen frequency ranges. Fig. 21 is a dual graph of a 60-Hz square wave, showing in Fig. 21(a) a time-continuous waveform over 400 ms and the corresponding FA display in Fig 21(b). The FA display has a range of 0 to 2 kHz on the horizontal axis and an amplitude of 80 dB on the vertical axis, with the square wave’s spectrum represented as a series of separate peaks consisting of the 60-Hz fundamental and its harmonics. Fig. 22 is a sweeping square wave varying from 200 to 1800 Hz, displayed in a waterfall format, where the time history is shown by the 88 individual FA spectra in a slanting parallel array.

A FFT spectrum analyzer converts a signal from the time to the frequency domain through a mathematical relationship discovered by Baron Jean Baptiste Joseph Fourier in 1807, but not published until 1822 in his book, The Analytical Theory of Heat (see [15]). This transformation is based upon the periodicity inherent

Fig. 19. Waveform plot. (a) Original record-head stop signature. (b) Inexpensive recorder-loudspeaker-to-microphone duplication of same signature in quiet room.

Fig. 20. Waveform plot of noise floor in area between stop and start record-head signatures in stop/start event. (a) Original recording. (b) Recorder-loudspeaker-to-microphone acoustical duplication with inexpensive equipment.

Fig. 21. Dual graph of 60-Hz square wave. (a) Time versus amplitude waveform of 400 ms. (b) Corresponding frequency versus amplitude display from 0 to 2 kHz.

Fig. 22. FFT waterfall graph of sweeping square wave. varying from 200 to 1800 Hz, displayed in a waterfall format, where the time history is shown by the 88 individual FA spectra in a slanting parallel array.
in sine and cosine functions, which allowed him to define in the frequency domain any continuous, periodic signal as a summation of these trigonometric functions. This Fourier transform was later adapted to the discrete operation of modern computers with an incremental form called the discrete Fourier transform (DFT). This DFT was, in turn, optimized into the FFT, which requires fewer computations, thus providing an appreciable increase in processing speed. A detailed description of FFT theory is beyond the scope of this paper, but many excellent texts are available on the subject [16]-[20].

The FBI uses a variety of FFT analyzers and software, with most providing at least 800 lines of resolution, two or more separate channels, 4-kHz or better real-time processing rate, linear and exponential averaging, adjustable frequency ranges of 40 kHz or higher, interactive cursor controls, digital plotter outputs, and high-resolution monitors (Fig. 23). The lines of resolution of these instruments are directly related to the size of the transform with, for example, a 2048-point transform producing approximately 800 usable lines of resolution. The lines refer to the total number of evenly spaced frequency increments that the FFT can display, with the actual frequency resolution determined by dividing the length of the frequency range by the number of lines selected. For example, using the 800-line mode, a 0–1000-Hz range will have a resolution of ±1.25 Hz (1000 ÷ 800), but a 150–250-Hz range will be accurate within ±0.125 Hz (100 ÷ 800). FFT frequency resolution is also inversely related to time resolution, so that increasing one decreases the other. Using the previous examples, when frequency resolution improved from 1.25 to 0.125 Hz, the display range decreased by 90% and the time segment necessary for the frequency transformation increased 10 times. A typical FFT analyzer using the 1-kHz range requires a 0.8-s time block for a complete transformation, but on the 100-Hz range it increases to 8.0 s.

Multiple-channel FFT operation permits direct and statistical comparisons between separate tracks on investigative and test recordings to reveal important similarities and differences in frequency components. Linear averaging allows a selected number of frequency spectra to be combined as an aid to identifying low-level discrete frequency components, to reflect the general characteristics of the recording and transmission systems, to increase the signal-to-noise floor of steady-state information, and so forth. Exponential averaging is the same type of display, but with a constantly updating spectrum. Fig. 24 is a dual display reflecting the instantaneous spectrum of the air flow sounds from a room ventilation system from 0 to 1 kHz in Fig. 24(a) and the same sounds averaged for 30 s in Fig. 24(b). This shows that averaging gives an improved picture of the long-term frequency characteristics of the noise. Adjustable frequency ranges permit the examiner to look at the complete spectrum of the information on an evidence tape, and then zoom in on a particular area of interest. Fig. 25 is a dual display of an averaged telephone recording with 0 to 4 kHz in Fig. 25(b) and a zoom spectrum from 984 to 1016 Hz in Fig. 25(a),

Fig. 23. Typical FFT instrumentation used by FBI. (Photo courtesy of Dave Zimmerman, Spectral Dynamics Division, Scientific Atlanta.)
which clearly reveals two separate discrete tones at 998 and 1001 Hz, instead of only the one resolved in Fig. 25(b). Interactive cursor controls allow a direct reading of the frequency and amplitude of any point displayed, plus all of its harmonics.

Authenticity examinations using narrow-band spectrum analysis show the general frequency characteristics and discrete tonal signals recorded on evidence and test tapes. Examinations include analysis of flutter, transport speed errors, questioned signals, background sounds, convolutional and transmission characteristics, bias signals, and multiple power line hum components for indications of duplication.

Mechanical imperfections in analog tape recorders cause periodic (and transient) speed variations, or flutter, which modulate discrete tones recorded on an evidence tape and produce sidebands. The originally recorded tone and these added sidebands form a flutter spectrum, which can be analyzed and compared to test recordings [2], [7], [21]. Aurally this flutter is heard as a wavering of the information recorded on the tape, especially during sustained signals containing discrete frequencies. Every mechanical imperfection produces its own set of sidebands; for example, if a slightly out-of-round pinch roller has a circumference of 1.57 in and the tape transport speed is 1.875 in/s, the roller will make a complete circle 1.19 times per second (1.875 + 1.57 = 1.19), producing a modulating frequency of 1.19 Hz. Thus the modulating frequency for simple eccentricity, when the component is in direct contact with the tape, is determined by

\[ f_m = \frac{S}{C} \]  

(8)

where

- \( f_m \) = modulating frequency, hertz
- \( S \) = tape speed
- \( C \) = circumference of a circular component.

As derived from frequency-modulation theory [22], the effect actually produces two sideband tones, each distance \( f_m \) from the center frequency of the tone, which for small modulation indexes is [23]

\[ e = A \left\{ \sin 2\pi f_0 t + \left( \frac{m_l}{2} \right) \sin 2\pi (f_0 + f_m) t \right\} - \sin 2\pi (f_0 - f_m) t \]  

(9)

where

- \( e \) = instantaneous value of waveform at time \( t \) (original tone and sidebands)
- \( A \) = arbitrary constant
- \( f_0 \) = frequency of tone, hertz
- \( m_l \) = modulation index.

According to Eq. (9), the first sideband frequency is at \( (f_0 + f_m) \) and the second is at \( (f_0 - f_m) \). Using the pinch roller example, where \( f_m \) was determined to be 1.19 Hz, and letting \( f_0 = 60.00 \) Hz, there would be sidebands at 58.81 and 61.19 Hz. If the component also exhibits ellipticity, there would be additional sidebands at \( (f_0 + 2f_m) \) and \( (f_0 - 2f_m) \). Every transport part that rotates can add its own pair of sidebands, which includes the pinch roller, capstan, supply reel, take-up reel, pulleys, motor shaft, gearing, and so on, with the amplitude of each pair of sidebands being directly proportional to the degree of mechanical imperfection in the particular component. Fig. 26(a) is an FFT chart from 985 to 1015 Hz of a 1-kHz input tone, Fig. 26(b) is the sideband flutter spectrum from an expensive cassette tape recorder, and Fig. 26(c) is the spectrum of a typical inexpensive cassette recorder.

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Fig. 24. Dual FFT graphs from 0 to 1 kHz of room ventilation sounds. (a) Instantaneous spectrum. (b) 30-s averaged spectrum.

Fig. 25. Dual FFT graph of telephone recording. (a) 0–4-kHz averaged spectrum. (b) 984–1016-Hz averaged zoom spectrum.

all over an 80-dB amplitude range. These figures reflect that the highest level sidebands are down better than 28 dB for the professional deck, but only 11 dB on the types of units often encountered in the forensic world. The flutter spectrum analysis is useful whenever a fairly stable, high-amplitude tone is present on a questioned recording, which can then be compared to test tapes from submitted recorders for similarities and differences in component parameters.

Transport speed errors are not constant on investigative recorders, varying at least slightly from one end of the tape to the other due to drag, transport anomalies, tension variations between take-up and supply reels, and so on [6], [7]. This variability can be measured on the FFT analyzer by manually determining the actual values of a known discrete tone, at incremental times, when the evidence tape is played back on a calibrated professional reproducer. The waterfall mode of the FFT analyzer can also be used to present this variance pictorially. Fig. 27 shows the changes on a small cassette recorder of a 60-Hz tone for a 44-min period over a 54–66-Hz frequency range. This procedure is then repeated using a laboratory oscillator on the submitted tape recorder with a tape of the same general characteristics, and the results of the variability are compared to the evidence tape.

Analysis of questioned signals, background sounds, and convolutional and transmission characteristics is conducted by comparing the frequency spectra of events occurring on the evidence tape to known sounds and system features. If a particular signal or background sound in a recording is a point of contention, test tapes of the equipment or the site can be made and compared. Convolutional and transmission characteristics are normally revealed by long-term spectrum averaging, which minimizes the effect of voice and other dynamic signals, and then are compared, in a general way, to the known effects of such systems. For example, a long-distance telephone conversation whose far-party voice information exceeds 7 kHz would be considered very suspicious, since such lines are normally band restricted to well below 4 kHz.

Fig. 26. FFT graphs from 985 to 1015 Hz. (a) 1-kHz tone. (b) Sideband flutter spectra of expensive cassette recorder. (c) Sideband flutter spectra of cheap cassette recorder. All over an 80-dB range.
The bias signal of a few inexpensive recorders is comparatively low in frequency and can be identified on evidence tapes; the results can then be compared to the bias signal of a submitted recorder. Fig. 28 shows the bias tone of such a recorder averaged on an FFT, which is characterized by a band of frequency components due to the instability of the signal and the recorder flutter.

If the power line frequency of 60 Hz or one of its harmonics is recorded by a recorder that is off speed, and then played back on a laboratory unit at the correct speed, the frequency will be reproduced at a new value, given by the equation

$$F_p = \frac{F_a}{S}$$  \hspace{1cm} (10)

where

- $F_p$ = measured frequency on playback, hertz
- $F_a$ = actual frequency of original tone, hertz
- $S$ = speed accuracy of first recorder (1.00 = correct speed).

For example, if a 60-Hz tone is recorded on a tape recorder running 4.0% slow, or at 96% of the correct speed, and then played back on a laboratory deck at the correct standard speed, $F_p = 60 \times 0.96 = 62.5$ Hz. In a multiple duplication process the situation becomes more complicated, since each copying step can add its own set of 60-Hz or other frequencies, which are then modified separately by the different tape recorder speed errors. If the original tape is played back on one recorder and a copy is prepared on a second recorder that has a different speed error, while also contributing, for example, a set of 60 Hz and harmonics (usually from ac power leakage), then two sets of frequencies will be present. The two frequency sets both began as 60 Hz plus harmonics, but have now been modified by the separate speed errors of the tape recorders involved in making the original recording, playing the tape back, and rerecording the audio information. Going one step further, if an additional copy is made from the recording in the same manner (producing a third-generation copy), but with a different recorder, a third set of frequencies will be produced. A general equation that defines the actual frequencies produced is [24]:

$$T = \left[ F_1 \left( \frac{S_{1p}}{S_{1r}} \right) \left( \frac{S_{2p}}{S_{2r}} \right) \cdots \left( \frac{S_{np}}{S_{nr}} \right) \right]$$

$$F_2 \left( \frac{S_{2p}}{S_{2r}} \right) \left( \frac{S_{3p}}{S_{3r}} \right) \cdots \left( \frac{S_{np}}{S_{nr}} \right), \cdots, F_n \left( \frac{S_{np}}{S_{nr}} \right)$$

(11)

where

- $T$ = complete set of discrete frequencies produced in copying process, hertz
- $F_1, \ldots, n$ = discrete frequencies introduced at each copying step, hertz
- $S_{np}$ = speed accuracy for nth playback recorder
- $S_{nr}$ = speed accuracy for nth recording unit
- $n$ = total number of copying steps or generations.

In other words, the speed accuracy of the original recording unit is $S_{1r}$, the recorder used to play back the original recording has an accuracy of $S_{1p}$, and so on.

If the same frequency $F$ is introduced at each recording step and the final playback is on a calibrated laboratory reproducer with no speed error ($S_{np} = 1.0$), then Eq. (11) simplifies somewhat to

$$T = F \left[ \left( \frac{S_{1p}}{S_{1r}} \right) \left( \frac{S_{2p}}{S_{2r}} \right) \cdots \left( \frac{1}{S_{nr}} \right) \right]$$

$$\left( \frac{S_{2p}}{S_{2r}} \right) \left( \frac{S_{3p}}{S_{3r}} \right) \cdots \left( \frac{1}{S_{nr}} \right), \cdots, \left( \frac{1}{S_{nr}} \right)$$

(12)

**Fig. 27.** FFT waterfall graph of transport speed variance of recorded 60-Hz tone over a time period of 44 min.

**Fig. 28.** Averaged FFT graph of bias signal from inexpensive tape recorder centered near 25 kHz.
As an example, the following values are given for a third-generation copy: $F = 60$ Hz, $S_{1p} = 0.995$, $S_{1r} = 0.997$, $S_{2p} = 1.002$, $S_{2r} = 1.005$, and $S_{3r} = 1.012$. Substituting into Eq. (12), $T = [58.984$ Hz, $59.102$ Hz, $59.289$ Hz], reflecting the three discrete tones that should be present on the third-generation copy.

The use of the preceding theory relates to the analysis of submitted tapes to determine originality, since a recording containing multiple power line frequencies around 60 Hz, 120 Hz, 180 Hz, and so on, is often a direct indication of a duplication process. Fig. 29 is an FFT plot from 57.4 to 60.6 Hz with three discrete peaks at 58.984, 59.102, and 59.289 Hz, reflecting a multigeneration copying process, as described. A dc-powered evidential recording containing no ac power line frequencies does not preclude a copying process, since the duplication process may have been done with battery-powered units or with the ac information masked by low-frequency noise. If a set of ac frequencies are observed on the FFT monitor and the original recording was battery powered with neither strong electromagnetic fields nearby nor ac components in the input signal, then this is a strong indication of a duplication process.

If more than one set of ac frequencies are displayed, then it is usually conclusive of duplication. FBI examiners ensure that the displayed 60 Hz plus harmonics are neither laboratory ac artifacts, separate tones produced by the recording system, nor the effects of speed drift. This analysis and others are based on the stability and accuracy of the power line frequency, which was found in one experiment to rarely vary more than

$$2\Delta = 0.060 \text{ Hz} = 0.010\%$$

for time periods of 15 s or longer [25–29]. Everything else being equal, the time-versus-frequency filter settings are therefore the time-versus-frequency filter settings.

Substituting into Eq. (12),

$$\Delta T = [58.984 \text{ Hz, 59.102 Hz, 59.289 Hz,}$$

and the 60-Hz or other discrete tone does not show a direct indication of a duplication process. Fig. 33 shows a spectrogram of a speaker saying "audio engineering," with the horizontal axis representing 1.25 s, the vertical axis frequency from dc to 6 kHz, and the gray scaling the sound pressure through a scanning 300-Hz-wide bandpass filter. The highest energy areas are represented by the blackest shades, the lowest by white, and the middle levels by varying shades of gray. The dark bands are called formants and graphically represent the resonances of the speaker’s vocal tract; the close vertical striations are the pitch of the voice.

Spectrograms are usually produced on one of three types of instrumentation: a computer system with appropriate software, a completely analog spectrograph, or a hybrid system with digital storage, but an analog printer. These systems extract the sound information from either a loop of open-reel tape or digital storage, perform a frequency analysis with a variable bandpass filter, and then produce the results on a monitor or printer. User-selected parameters include different analysis filters and frequency ranges, adjustable display contrast, frequency and time markers, hi-shaping circuits to correct for the normal high-frequency roll-off of speech, and gating functions to remove unwanted signals. The different analysis filters are especially important in authenticity examinations, since increasing frequency resolution decreases time resolution (like narrow-band spectrogram analysis), and vice versa.
Fig. 30. Spectrogram of male speaker saying “audio engineering.”

Fig. 31. Spectrograms of change in low-level hum during pause stop/start. (a) Using 22.5-Hz analysis filter. (b) Using 5-Hz filter.

Fig. 32. Spectrogram of constant hum during pause stop/start reflecting a duplication process.
this voice-activated event often produces an audible "zip" sound, the spectrogram provides a hard-copy graph of the event, as the voice formants are seen to rise in frequency when the recorder stops and fall when it restarts. Fig. 34 shows the effect of the slight change in hum when a 300-ms section of tape is spliced into a recording, with the spectrograms showing frequencies from 30 to 300 Hz using a 37.5-Hz analysis filter. In these examples, narrow-band spectrum analysis can often provide confirming information.

Spectrographic analysis provides a graphic representation which clearly illustrates certain types of record events and tape alterations, but its uses as a substitute for waveform and narrow-band spectrum analyses can produce misleading or even false examination results. Fig. 35 shows waveforms of stop/start record-head events from two different types of tape recorders, with the differences in shaping quite obvious. Fig. 36 shows the same events on spectrograms, which unfortunately reflect nearly identical representations.

4.7 Miscellaneous Techniques

Critical listening, physical inspection, magnetic development, and signal processing with waveforms, narrow-band spectra, and spectrograms are the most common laboratory procedures in authenticity determinations. This section will include some examples of other techniques that do not fall neatly into the previous six areas, but are useful in some submitted forensic cases. A complete list cannot be compiled, since the number of potential signal analysis procedures is large; examination methods are constantly being improved and expanded by the FBI, other governmental forensic laboratories, and the appropriate scientific community; and unique tests will constantly have to be developed for particular forensic problems. Included in this section are descriptions of phase continuity, convolutional filtering, azimuth determination with calibrated test tapes, and statistical analysis.

Determination of phase continuity involves the direct comparison of a high-amplitude discrete tone on a questioned tape recording to a test tone from a laboratory oscillator. This is accomplished through the use of a phase meter, which displays a constantly updating value of the angular difference between the two signals, or a digital waveform analyzer that gives various direct and statistical comparisons [2]. To provide meaningful results, the discrete tone on the evidential tape has to be relatively stable, of high amplitude, and band-passed through steeply sloped filters (usually 48 dB per octave or greater).

The deconvolutional filter is a digital processor used in enhancement examinations to reduce the level of certain correlated noises via a linear predictive algorithm. This software has a transversal filter that is automatically adjusted, according to past values of the input signal, to predict future audio information; thus its effectiveness is highly dependent upon the time correlation of the signals in the recording. For example, random noise is uncorrelated, pure sine waves are per-
fectly correlated (repeating themselves every cycle), and voice information can be correlated in short segments but becomes uncorrelated in periods longer than a few hundred milliseconds. A more detailed description of this device is set forth elsewhere [8], [30]. In enhancement examinations, the device’s output which contains the original signal less the correlated noise ("residue") is used, due to the improved intelligibility when correlated noise is reduced. In authenticity determinations, the information removed in the filtering process ("predicted") is often of greater interest. This signal contains the stable discrete tones on the tape, the room reverberation, slower moving music sounds, and so on, which can be analyzed further by critical listening and instrumentation. For example, the general reverberation characteristics on a submitted tape can be compared with test recordings prepared at the recording site, if that should be a point of contention.

Azimuth determinations with test tapes involve playing back the evidential recording with optimum reproduce-head alignment, as previously set forth in the section on playback. A "difference method" azimuth adjustment test tape is then substituted for the questioned reel tape to determine the actual azimuth alignment angle of the playback head. This calibration tape contains a medium-frequency discrete tone that has been alternately recorded at two equal, but opposite azimuth angles symmetrically displaced from true azimuth [31]. If the reproduce head has perfect alignment, the output level in decibels will be identical. However, if the alignment is off even slightly (less than 4 min of arc for most applications), there will be a 1-dB or larger difference. This alternating change in level can then be used to determine the actual azimuth misalignment by readings on a laboratory level meter, and computing the angular error from the sensitivity (dB/deg) listed for the calibration tape. For standard cassette evidential tapes, a calibration tape with a high-frequency tone is utilized; and for miniature cassette formats, a cassette test recording is manually inserted into the smaller housing. Eq. (1) is then used to determine the azimuth angle. The results can then be compared to test tapes prepared on the submitted recording equipment.

Statistical analyses reflect trends in voluminous information gleaned from evidential recordings to detect events needing further examination, to draw best fit curves from experimental laboratory data, and so on. Fig. 37 is a "scatter" chart of the SRTs (see Sec. 4.4) of the record starts on eight cassette tapes involved in a wiretap operation, with the SRT times on the vertical axis in milliseconds, counter numbers of the tape on the horizontal axis, and the different tapes represented by separate symbols. This graph shows the examiner two readily apparent pieces of information: the SRTs decrease toward the end of the tapes and three SRT values are appreciably shorter than the rest. The decreased values toward the end were determined to be caused by increased drag inside the housing, as more tape was wound on the take-up reel, due to the poor-quality construction of the inexpensive cassettes. The three lower SRT values were found to occur only at the times on the investigative logs when a short recorder "off" operation was noted.

Fig. 35. Waveform plots of stop/start record-head events from two different tape recorders.

(a) (b)

Fig. 36. Spectrograms of same stop/start events as Fig. 35.
5 AUTHENTICITY EXAMPLES

To give some general understanding as to how actual authenticity examinations are conducted, two examples are described. To allow them to be meaningful, without being too lengthy, some analysis steps have been summarized or not included. Fictitious names are used, and the examples listed are not specific cases, but rather compilations that represent the flavor of FBI-conducted analyses.

The first case begins with a telephone call from the State Attorney's Office in Los Angeles, CA, regarding a chain-of-custody problem with an important tape in the murder prosecution of Jennifer R. The cassette in question contains three telephone conversations recorded by an acquaintance of the defendant, Eric K., on or about the date of the crime. The killing is not mentioned on the tape, but the defendant discusses her recent activities in the Los Angeles area, which contradict her sworn statement that she was in San Francisco at the time of the crime. The evidence came into police custody just prior to the trial of Jennifer R., when Eric K. was arrested for bank robbery and provided the tape in an attempt to improve his plea-bargaining position. According to Eric K., the cassette had been in an unlocked desk drawer in his apartment for the past year, and numerous individuals could have had access to the tape. The defense attorney representing Jennifer R. does not question the custody of the evidence, once in police hands, or that there are three recordings of the defendant on the tape, but that the cassette could be a copy which may have been altered. The defense attorney can provide no assistance as to where on the tape any alterations may have occurred. The Assistant State Attorney does not know whether the three recordings are original or not.

The prosecuting attorney, after discussing the matter with the FBI examiner, forwards the cassette, recorder, and microphone used, a transcription of the conversations, and a statement from Eric K. The statement reflects that the recordings were made in his fairly quiet living room with a newly purchased tape; he used keyboard record and stop buttons for all operations; the cassette, after being inserted in the recorder, was not removed until after the third conversation; no additional information was recorded on the tape; the recorder was powered by four C cell batteries, and no known maintenance or repairs were conducted on the equipment. After being logged in through the FBI's Evidence Control Center, the submitted materials are assigned to the examiner and given appropriate laboratory and specimen numbers. The examiner marks the specimen and laboratory designations on the cassette, recorder, and microphone with an indelible ink pen, and then describes them in the work notes.

The examiner magnetically develops a loud portion of each of the recordings on the tape and determines that a 1/4-track stereo configuration is present, but only
the right channel is recorded. Placing the cassette in a professional deck, the azimuth alignment is adjusted for maximum high-frequency output using the FFT analyzer; also using the analyzer, but on a lower frequency range, the tape speed is determined to be accurate based on the 60-Hz tone (an artifact of the telephone system) found during the conversations. A listening test is then performed on both sides of the C60 cassette, while simultaneously a direct open-reel copy is prepared for laboratory use. This preliminary review reveals that side A contains three conversations lasting 3:20 (minutes:seconds), 4:15, and 8:16, respectively, with the first recording starting on the nonmagnetic leader. There are various transientlike sounds after each separate conversation and then constant, low-level, nonvoice information after the last conversation, that continues for the remainder of side A, out to 31:58. No sounds, other than the inherent tape hiss, are heard on side B. Test recordings are made on the submitted cassette recorder, first by short-circuiting the microphone input jack and then by using the suction cup microphone attached to a telephone handset. Various keyboard stops, starts, stop starts, and overrecordings are made for comparison with the submitted tape using a comparable-quality C60 cassette. The areas between the telephone conversations and after the last one, plus many of the test recordings, are developed with an appropriate ferrofluid, and a macrophotographic system is used to produce high-contrast 8- by 10-in (203.2-by 254-mm) black-and-white photographs. Concurrently, waveform graphs are run of the same events on a computer system with an effective plot speed of 1250 mm/s.

A visual review of the magnetically developed data reveals offset record- and erase-head marks between the conversations, along with wider erase-head signatures, consistent with the original stop starts made on the submitted tape recorder. However, after the last conversation, where a stop event should occur, there is an original overrecording start with no high-amplitude information. The erase-head edge mark of the overrecording start continues for the entire duration of side A. Waveform analysis confirms the three record events and their consistency with the test recordings, and shows a higher noise floor at the end of side A compared to side B. Narrow-band spectrum analysis reveals low-level hum, with only one set of frequencies, which is present only when the telephone system is on-line and then disappears both when the telephone instrument is hung up and during the overrecording at the end of side A. There is little information above 3 kHz for the defendant’s voice, but Eric K.’s voice easily exceeds 7 kHz during all three telephone conversations, which is consistent with normal telephone system high-frequency losses.

Before additional tests are conducted, the prosecuting attorney is advised that there is an overrecording after the last telephone conversation, which may have erased other originally recorded information. The attorney then confronts Eric K. with the results, and he concedes that several other conversations with the defendant had been erased, in which the actual crime is discussed. The prosecutor advises Jennifer R.’s defense attorney that the tape will not be used at the murder trial. The governmental attorney telephonically advises the examiner to discontinue the authenticity testing. The examiner prepares a final report and sends it, along with the submitted evidence, to the contributor. The work notes, plots, photographs of the magnetic patterns, and so on are sealed in a box and placed in long-term secure storage.

The second example is initiated by a telephone call from an Assistant United States Attorney (AUSA) in Miami, FL, regarding a heroin importation prosecution. She advises that the tape in question was produced from a miniature transmitter secreted on the body of an undercover Drug Enforcement Administration (DEA) special agent and recorded by a second agent two blocks away with a receiver and cassette recorder. In the taped conversation, the defendant agrees to supply the undercover agent with five million dollars worth of heroin. The recording occurs in the Little Havana section of the city, and there is a considerable number of very short dropouts, presumably, according to her, caused by trucks and other vehicles disrupting the low-powered transmitted signal. The custody of the tape has been maintained by the DEA and there are no chain-of-custody problems. The defense has hired a scientist, a professor of speech science from an out-of-state university, who claims the tape has been altered in hundreds of areas, but does not identify any specific incidences. The AUSA is advised by the examiner that the exact locations of the alleged alterations are needed, and the various other materials that should be submitted for an authenticity examination.

Two months later the same AUSA calls and advises that the defense consultant refused to provide the locations until ordered by the federal judge; and that the list of alleged alterations and the other requested material would be forwarded shortly. Two weeks after this telephone conversation, the questioned tape, the miniature transmitter “bug,” the receiver, and the cassette recorder in a carrying case, a statement by the DEA agents, and two reports from the defense are received by the FBI via registered mail. The agents’ statements reveal that the recording was done on a new tape and is approximately 40 min in length. It contains introductory comments by the monitoring agent, the beginning of the pertinent conversation, a stop/start sequence approximately 10 min into the recording, when the defendant left the area for about 30 min, the second part of the recorded conversation, and a short concluding statement by the monitoring agent. The recorder was stopped and then restarted between each segment using keyboard operations. The receiving and recording systems were powered by a cigarette lighter adapter plugged into the government car, and the cassette recorder was not turned on or off, except as outlined. The defense reports reflect that the “dropouts” are not consistent with the operation of such a miniature transmitter/receiver system, and therefore must represent some type of unspecified ed-
DEA agents testify during the government’s presentation under the direction of a fully qualified examiner for at least 3 years. This training period includes full-time training, attendance at specialized schools, familiarity with some articles on authenticity and certain specialized equipment, and so on. When asked about his use of a high-speed copy and lack of testing of the transmitter/recording system, he states that the original tape and the equipment are not needed by him to conduct the examination. On the government’s redirect case, the examiner explains to the court the analyses conducted by the FBI using the magnetic pattern photographs, waveform charts, and FFT plots. Time is also spent to fully describe to the jury, in a general way, how information from an individual talking is sensed by a microphone and then recorded on magnetic tape using a recorder. The jury then has to decide whether to believe the defense witness and reject the information recorded on the tape, or accept it based on the testimony of the DEA agents and the FBI examiner.

6 TRAINING

The Engineering Section of the FBI follows rigorous procedures in qualifying individuals as examiners in the field of forensic tape authenticity. This includes screening of potential applicants, a lengthy apprenticeship, attendance at specialized schools and lectures, moot court training, and formal approval by senior examiners and supervisory personnel. Even after certification, training is continued through supervisory and peer reviews, additional schooling, and regular hearing tests.

The evaluation of applicants includes affirmation of a Bachelor of Science or higher degree from an accredited college or university, contact with past employers and work associates, and verification of excellent hearing. In addition, at least two interviews of the applicant are conducted and a Top Secret background clearance is performed, since some of the recordings analyzed are classified. Normally only applicants with physical science degrees or other degrees supplemented by a number of physics, mathematics, or engineering courses are considered. If the individual has worked in a forensic field, his or her prior testimony and laboratory work are thoroughly reviewed.

Once hired, or reassigned from other FBI duties, the trainee examiner is placed in an apprenticeship program under the direction of a fully qualified examiner for at least 3 years. This training period includes full-time

Six months later, at the defendant’s trial, the two DEA agents testify during the government’s presentation how the tape had been recorded and custody maintained.
experience on over 300 submitted tapes, many of which involve authenticity examinations, using laboratory tape recorders, macrophotographic systems, waveform display devices, FFT analyzers, general scientific computer systems, and so forth. Though the technical procedures are emphasized, other important areas such as note taking, report preparation, and evidence handling are also covered in detail. Concurrently, the trainee attends lectures, demonstrations, schools, university courses, workshops, and conventions concerning various laboratory devices, recording theory and practice, audio engineering topics, acoustics, electrical and electronic engineering, computer science, and related subjects.

When the supervising examiner is completely satisfied that the individual has a good mastery of tape authenticity techniques and equipment, moot court training is given to assess verbal responses and demeanor under courtroom conditions. The moot court exercises are made as stressful as possible, with experienced FBI personnel acting as judges, attorneys, and jury members. Wide latitude is allowed in the questioning to force the nearly trained individual to cope with difficult legal and technical concepts that are often encountered during cross-examination. With the concurrence of supervisory personnel and other examiners, the trainee is approved to receive and conduct authenticity cases, with an overview process continuing for about 6 months.

7 EVIDENCE HANDLING, WORK NOTES, AND REPORTING

Since authenticity examinations always utilize original tape recordings that may subsequently be admitted in criminal and civil proceedings, evidence handling procedures are obviously important. Every step from receipt until return to the contributor is carefully monitored and documented. Areas of concern include custody, storage, and transport of the original recordings and other submitted equipment.

The chain of custody of the evidence from date of receipt until its release to the contributor or other party is set forth in written form — ledgers, work notes, signed receipts, evidence envelopes, and so on. While under examination in the laboratory, the evidence is usually assigned to only one examiner to simplify accountability and possible future testimony. Evidence is stored at normal room temperature in a security file or sturdy lockable cabinet in an area that is secured when unattended. In addition, the laboratory is housed in a restricted-access building. Evidence handling is strictly limited to necessary personnel, and evidence is stored well away from magnetic fields produced by loudspeakers, transformers, and other devices. The transport of evidential recordings and equipment is handled in four ways: 1) registered mail, 2) overnight delivery services with signature confirmation, 3) courier, and 4) personal delivery. All, except personal delivery, are forwarded, with at least 3 in (76.2 mm) of packing between the evidence and the outside of the box to avoid the possible effects of stray magnetic fields and improper handling.

Work notes are taken on most facets of the authenticity process; this includes a description of the physical evidence, track configuration, playback speed errors, chain-of-custody changes, lists of waveforms, photographs, and spectrograms; a chronology; aural and instrumental observations; and conclusions. A formal report is sent to the contributor at the end of the examination, with information such as the FBI file and laboratory numbers, investigative title, evidence description and receipt date, results of examination, examiner’s name, and disposition of evidence.

8 TESTIMONY

After the completion of the examination, expert testimony may be needed at a deposition, hearing, or trial to explain the results regarding the authenticity questions or allegations. The FBI examiners can be confronted by paid defense “expert” witnesses who will assert strongly that their findings, favorable to the party they are retained by, are equally correct. To allow accurate and meaningful testimony, and to properly prepare the governmental or other attorneys to cross-examine the opposing witness, the FBI examiners prepare a qualification list, attend a pretestimony conference with the attorney, present a proper appearance and demeanor on the witness stand, and verbalize the important aspects of the examination and chain of custody in an understandable way to the judge and jury.

A qualification list allows the presenting attorney to ask the appropriate questions of the examiner to reflect his or her training, education, professional societies, and so forth. The list often includes the following, as appropriate:

1) Present title, organization, responsibilities, and length of service.
2) Pertinent prior employment information.
3) Formal college and university degrees and additional college courses.
4) Appropriate technical schools, lectures, and seminars.
5) Membership in professional societies.
6) Publications in the tape analysis field.
7) Number of times previously qualified as an expert in judicial proceedings.
8) Approximate number of different investigative matters in which examinations have been conducted.
9) Approximate number of different evidential recordings analyzed.

Discussion of the examination with the attorney before testimony is almost mandatory in authenticity cases due to their complexity and the need to provide assistance in cross-examining opposing witnesses. After being provided the examiner’s qualification list, the attorney is given an overview of the tape recording process and authenticity examination, a detailed description of laboratory methodology, the results of the separate analyses, and the conclusions. Explanations
of various scientific areas are repeated or presented in a different manner until the attorney is comfortable with the principles; whereupon the examiner and attorney decide on the most appropriate line of questioning for the judge and the jury to grasp an understanding of the examination. Further time is also spent with the attorney discussing the weaknesses, if any, in the opposing "expert’s" qualifications in areas of education, apprenticeship training, schools and lectures attended; and the flaws in their examination based upon inexperience, lack of instrumentation, incorrect analysis procedures, and so on. The attorney provides guidance on local court procedures, the expected questions from opposing counsel, and exactly when the testimony will be needed.

Examiners dress in proper business attire and direct explanations to the jury, when present, to allow feedback of their understanding of the answers [32]. They are trained to maintain a proper demeanor under the stress and distractions of, for example, intimidating opposing counsel, repeated interruptions by court reporters, and inattentive jury members. Although the Engineering Section cannot examine tape recording for the defense in criminal matters, the examiners will appear, when requested, for either side or the judge at judicial proceedings to testify to the results of their analyses, with all expenses paid by the FBI.

9 SUMMARY

Beginning with the careful selection and training of examiners, the FBI has formalized a procedure to authenticate tape recordings produced by law enforcement and other agencies involved in forensic investigations. Details have been provided on examination requests, contributor supplied material, training, evidence handling, work notes, reporting, and testimonial procedures; and the actual methodology used in the laboratory for critical listening, physical inspection, magnetic development, waveform analysis, narrow-band spectrum analysis, spectrographic analysis, miscellaneous techniques, and examination examples.

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11 REFERENCES


THE AUTHOR

Bruce E. Koenig received a B.S. degree in physics and mathematics from the University of Maryland in 1968, an M.F.S. degree in forensic science from George Washington University in 1977, and has taken additional courses at George Mason University, Massachusetts Institute of Technology, and the University of Utah. In 1970 he entered on duty as a Special Agent (SA) of the Federal Bureau of Investigation (FBI), and served in the Atlanta and Detroit Divisions investigating bank robberies, federal prison escapes, and other violations of Federal law. In 1974 he became a Supervisory SA in the Engineering Section at FBI headquarters and has since been involved with the analysis of magnetic tape recordings produced or collected by Federal organizations of law-enforcement agencies worldwide. These have included tapes containing undercover drug buys, political corruption, bribes, racketeer activities, and “black box” cockpit conversations of major airlines disasters.

Mr. Koenig’s responsibilities include the analysis of audio and video tapes to improve intelligibility, compare voice samples, identify nonvoice signals, authenticate recordings, etc. He has examined over 7500 separate tapes, involving over 2900 investigative matters, for law-enforcement agencies in all 50 states, the territories, and 18 foreign countries, and has qualified in court as an expert witness on over 190 occasions. He is a member of the Audio Engineering Society, Acoustical Society of America, Institute of Electrical and Electronics Engineers, and the International Association for Identification. He has authored articles on forensic tape analysis in publications including the Journal of the Audio Engineering Society, Journal of the Acoustical Society of America, Crime Laboratory Digest, FBI Law Enforcement Bulletin, and International Criminal Police Review.