Reproducer Test Tapes: Evolution and Manufacture*

ROBERT K. MORRISON

Ampex Corporation, Redwood City, California

Reproducer test tapes (also called alignment tapes or standard tapes) are used to standardize the azimuth, frequency-response characteristics, and recorded levels of magnetic sound recording systems. Informal working standards and formal standards are discussed, with emphasis on changes in standards and possible resulting confusion. The manufacture of reproducer test tapes is described, including special requirements for heads and blank tape, and the methods for determining the azimuth and the flux vs frequency response characteristic. Handling techniques which minimize the chance of damage are also described.

INTRODUCTION Recorded material must reproduce satisfactorily, not only on the machine which made the initial recording, but also on all other similar equipment. Thus, each reproducer must be adjusted to the same specified standard reproducing flux characteristics and operating level. The purpose of reproducer test tapes is to make possible the practical measurement and adjustment of magnetic tape reproducers.

The reproducer test tape is used to adjust the reproducing head azimuth as well as the reproducing amplifier equalization and gain ("operating level"). Other types of test tapes (not further discussed here) are the flutter test tape, used for measuring flutter to the NAB Standards[1] (it is also used according to American Standard Z57.1-1954); and the recorder adjusting or reference medium test tapes, which are unrecorded tapes of average characteristics used for adjusting the bias current and recording equalization of a recorder.

EVOLUTION OF REPRODUCING CHARACTERISTICS

Standardizing organizations have been almost as prolific in their recommendations as the industry has been in developing hardware. The one-of-a-kind custom equipment of a few years ago has often created a working standard simply by usage, and formal standards have then followed. In the beginning there was only full track, ¼ in. (6.25 mm) tape width, and one or two tape speeds. Now sixteen different reproducer test tapes are available from a single manufacturer (Ampex). Adding the proposed test tapes according to the new NAB Standard, plus proposed changes in International Standards, this number will soon rise to twenty-seven, and this does not even include tapes for every track configuration,[2] or cartridge tapes, or the flat sheet medium for spot announcements called CUE-MAT™.

Experience has shown that old standards cannot be simply dropped when a new standard is adopted by one, or for that matter by all, standardizing organizations. Even if the old "standard" became so only by virtue of popular usage, it does exist, libraries of tapes made to agree with it exist, equipment exists, and the manufacturer has to provide the corresponding test tapes for many years. A good example of this is the 3.75 ips (9.5 cm/sec) situation, where three different standards[3] are now in use in the United States and one more internationally: *viz,* high-frequency equalization time constants t_2 of 200, 140, 120 and 90 μsec, with or without bass equalization t_1 of 3180 μsec.

THE NAB STANDARDS

In 1953 the National Association of Broadcasters published a description of a standard reproducer for 15 ips (38 cm/sec) use, based on an idealized ferromagnetic reproducing head and an amplifier of specified response. The reproducing flux characteristic had time constants of $t_1 = 3180$ μsec and $t_2 = 50$ μsec (transition frequencies of $f_l = 50$ Hz, $f_u = 3200$ Hz).

At the 15 and 30 ips (38 and 76 cm/sec) speeds then prevalent, the wavelength remained relatively long even at high frequencies—a 1 mil (25 μm) wavelength[4] (15 kHz at 15 ips) was the shortest encountered in general audio work. This meant that even without using a reproducer test tape, the error might be small if the reproducing amplifier were adjusted to the specified response, and the reproducing head assumed to be ideal. (The test tape *was* needed to adjust head azimuth and operating level.)

Experiments indicated that a 15 ips test tape suffered

* Presented October 12, 1966 at the 31st Convention of the Audio Engineering Society, New York.

very little degradation with careful use. Primary and secondary reference response tapes, carefully stored, were employed to calibrate test tape production equipment over long periods of time.

Because several different reproducing characteristics were in use for 7.5 ips (19 cm/sec) in the early 1950's, the NAB did not standardize a reproducing characteristic for this speed. Eventually the characteristic originally used for 15 ips ($t_1 = 3180$ μsec, $t_2 = 50$ μsec) also became generally accepted for 7.5 ips, thus establishing a "standard by usage".

The 1953 NAB Standard made no mention of the recorded level. The Ampex "operating level"[5] was originally determined by measuring distortion, and would thus be a function of the particular tape used. A 15 mil (380 μm) wavelength signal producing 1% third harmonic distortion on a selected batch of then-current 3M-111 tape became the flux reference for the "Ampex operating level". It was recognized very early that the operating level of the Ampex Test Tapes had to be held at a constant absolute flux level rather than at a constant distortion, in order to produce practical compatibility of levels in the recording industry. Thus, although tape has changed, the operating level flux of test tapes has remained extremely constant to the present time. Fortunately, the tape selected in the original determination of long wavelength operating level had greater distortion at a given flux than present-day tapes; therefore the amount of distortion experienced today with most available tapes at operating level is less than the original 1%. The Ampex operating level recording has a short-circuit flux of approximately 210 nanowebers per meter of track width (= 21 millimaxwells per millimeter, or 130 mM for a tape 246 mil wide).

In 1965, the NAB published a new Standard which reaffirmed the reproducing flux-characteristic time constants for 15 ips ($t_1 = 3180$ μsec, $t_2 = 50$ μsec), and recognized past industry usage of this same reproducing characteristic for 7.5 ips. The new NAB Standard does call, however, for a change of the reproducing characteristic time constant t_2 at 3.75 ips from 120 μsec to 90 μsec. This represents a 2.4 dB reduction of high-frequency response in the reproducer, which in turn necessitates a corresponding increase of 2.4 dB of the recording pre-emphasis in order to maintain a flat overall response. This in turn suggests that a recording level reduction might be desirable at this speed. On the other hand, it would be confusing in practice if the NAB Reference Level were different from the existing Ampex Operating Level. Also, among recording companies and broadcasters there exists a great variety of methods for mixing and for reading program levels: some recording companies record in the "RED" at all times, and others make it a practice never to allow meter readings to exceed −3 on the vu meter. It seems doubtful that many will want to change their long-established level practices. Therefore it would seem advantageous for the NAB Reference Level to be the same as the presently accepted Ampex Operating Level.

Since the NAB Standard specified the Reference Level in terms of a "vault reference recording" rather than in terms of flux in standard units, one must await the availability of the approved NAB Test Tapes in order to find out what the new NAB level will in fact be.

MANUFACTURING REPRODUCER TEST TAPES

In order to manufacture reproducer test tapes, one must obtain high quality heads and tape; determine the correct head azimuth; and calibrate the reproducing system which is used to measure the reproducer test tape flux characteristic.

Magnetic Heads

A chief requisite in the production of reproducer test tapes is the availability of a good source of custom-built recording and reproducing heads. Without a facility such as a head development laboratory, it would be difficult (if not impossible) to obtain the necessary calibration and production hardware.

Heads must be selected for greatest possible edge straightness, gap regularity[6,7] and consistency of pole-piece depth. In the case of full-track tapes, the recording head cores must be wider than the tape in order to assure recording across the entire width of the tape. Gap depth of the recording head must be constant across its entire width in order to insure even flux distribution across the tape. Reproducing heads for calibration work should be of the high density type (that is, with very thin layers of bonding material between laminations). For 0.5 mil (= 12 μm) wavelength recording the bonding material should be less than 0.5 mil in thickness; any thicker material will cause noticeable unrecorded "tracks" where the tape is contacted by the non-magnetic bonding material, which in turn will cause amplitude variations when adjusting overall response and thereby increase the possibilities of error.

Head gaps must be microscopically examined, lamination by lamination, and deviations from the average center of the gap measured at both the leading and trailing edges. Imperfect heads are rejected.

Selection of Tapes

Blank tape for test tape production must exhibit even coating thickness and a good degree of surface polish, in order to have amplitude stability of the recorded tones.

Other very important requirements are precise straightness of the tape edge, and accurate tape packing on the reel. Otherwise, the recorded azimuth will vary to the point where the "azimuth" section on the test tape will be unsuitable for adjustments. By carefully selecting properly slit tape, one can hold average azimuth variation to about ±1′; amplitude variation caused by this amount of azimuth disagreement will then be less than ±0.5 dB with a 12 μm (0.5 mil) wavelength full-track recording.

Azimuth Determination

Correct head azimuth is obtained when the head gap is exactly at right angles to the edge of the tape; this in turn produces a recorded track which is exactly perpendicular to the tape edge. (This assumes that the tape *has* a straight edge which can be referenced. If the tape is improperly slit, wound, and/or stored, the edge will be wavey and relative azimuth will vary.)

Some very early test tapes were made with incorrect azimuth. The error was not too serious (especially at the then-current 30 and 15 ips speeds), but was corrected because it was quite noticeable at the slower speeds.

Azimuth loss is plotted[8] in Fig. 1; the loss is seen to increase with increasing angle, track width, and frequency, and with decreasing speed. This curve is shown again in Fig. 2, this time plotted *vs* tape speed, with the other conditions fixed: the loss is seen to increase as speed decreases, from about 0.4 dB at 15 ips to 5.5 dB at 3.75 ips. Similarly, Fig. 3 shows the loss *vs* track width with other conditions fixed: an unmeasurable loss with 20 or 40 mil tracks increases to a 5.5 dB loss with full track heads. Thus, for a given tape speed and frequency, the wider the track, the more critical the azimuth adjustment becomes. From this, it follows that high-frequency amplitude variations due to misalignment, poor tape slitting or winding, or poor guiding will generally be worse with wide-track systems.

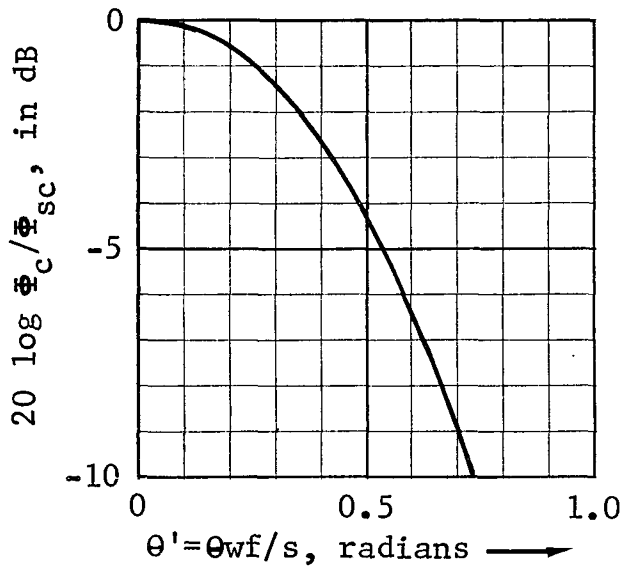

Fig. 1. The azimuth loss, $\Phi_c(\theta')/\Phi_{sc} = (\sin\pi\theta')/\pi\theta'$; or, in dB directly, $\Phi_c(\theta')/\Phi_{sc} = 20 \cdot (\theta')^{2.82}$, where $\theta' = \theta wf/s$, in radians, θ is the angle between the recorded track and the reproducer gap, in radians (3440 minutes of arc = 1 radian), w is the track width, and s the reproducing speed (w and s in the same units), and f the reproduced frequency in Hz.

A number of methods have been used to determine the azimuth of a recorded track. The simplest in principle is to make the recorded track visible by means of carbonyl iron powder,[9] by softening the binder with amyl acetate,[10] or by using a tape viewer.[11] The visible track can be checked for perpendicularity to the tape edge by means of a toolmaker's microscope.[12] The major difficulty is that tape with a perfectly straight edge does not exist; therefore many measurements are required in order to determine the average angle. (This method is also helpful in demonstrating edge curl, which may happen when imperfect tape winding allows the tape to rest against one reel flange.)

If tape is simply turned end-for-end, the azimuth error will be in the same direction—it does not reverse. Therefore some means is needed for producing a "mirror image". The first and most satisfactory method is shown in Fig. 4. It consists of the following steps:

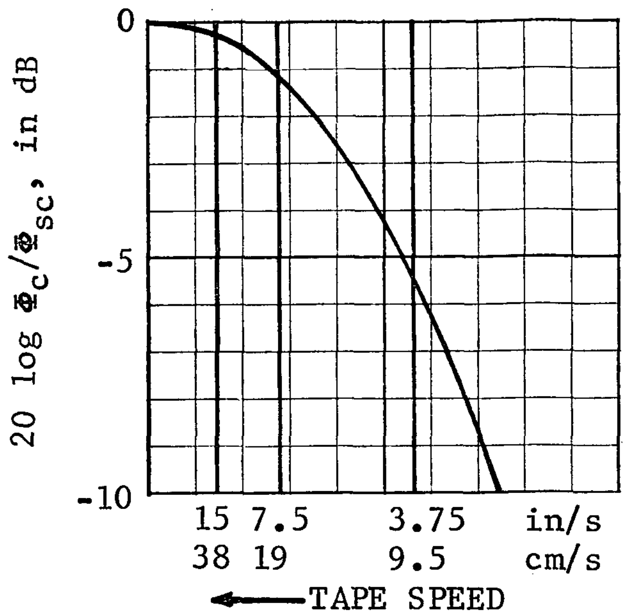

Fig. 2. Azimuth loss vs tape speed for $\theta = 2'$, w = full-track ¼ in. tape (6.25 mm), f = 15 kHz.

1. A full-track, short-wavelength signal is recorded, using a combination recording and reproducing head with an arbitrary azimuth setting. An indicator and an angular scale should be added to the azimuth adjustment screw of the head assembly to show the relative azimuth settings: the angle for this first recording should be noted.

2. After the signal is recorded, the full-track tape is rewound with the oxide surface in contact with a blank piece of tape.

3. The two tapes are then run through the machine, with a small amount of bias current applied to the head. This causes a "mirror image" of the original signal to be printed on the adjacent blank piece of tape.

4. The "printed tape" is reproduced, the head adjusted for this new azimuth, and the new setting noted.

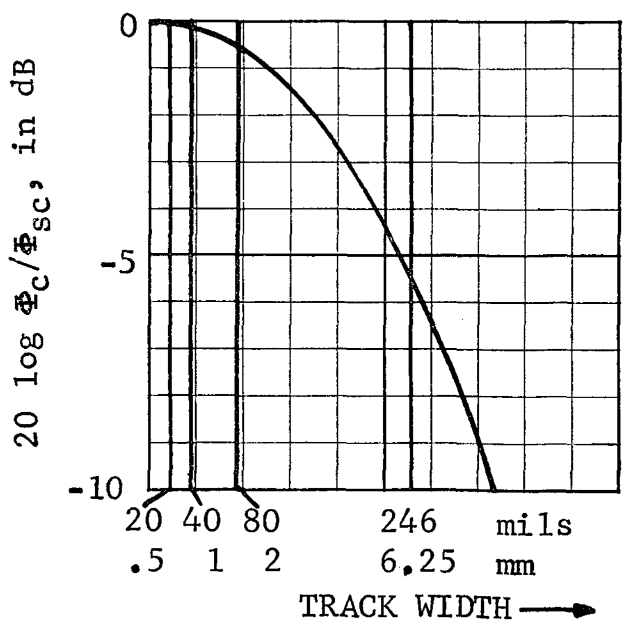

Fig. 3. Azimuth loss vs track width for $\theta = 2'$, f = 15 kHz, s = 3.75 in./sec (9.5 cm/sec).

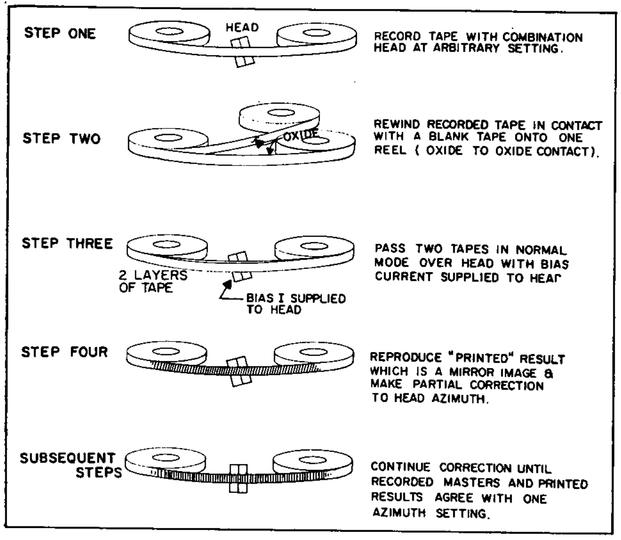

Fig. 4. Azimuth determination by the master and transfer print method.

5. The azimuth is set halfway between the two azimuth angles measured in steps 1 and 4.

6. Steps 1-5 are repeated until "masters" and "prints" both show maximum response at the same setting—this indicates perpendicularity of the head gap to the guided tape path.

A second method for producing the "mirror image" involves turning the tape over and reproducing the signal through the base of the tape. The adjustment method is similar to that just explained. The problem here is that, at the short wavelengths necessary for accurate azimuth adjustment, the loss of signal through the backing of the tape is so large that it is difficult to find the signal at all. Evans has described[13] a means for making this principle of azimuth determination practical: A two-track combination head is used. (An important requirement not mentioned by Evans is that the two gaps must be exactly coplanar, that is, there must be no gap scatter.) Phase of the two signals is compared, rather than seeking maximum amplitude. If the two signals are combined out of phase, the position of correct alignment results in a very sharp null of output even when a mid-frequency signal (say 3 kHz at 15 ips) is used. Therefore the signal amplitude can be large enough even when reproduced through the tape back.

Finally, experiments have been conducted on a third method for determining azimuth, using heads with a gap at the front and another at the back, and special guides for the tape (see Fig. 5). The front and back gaps of the head must be parallel to one another, and both surfaces must be lapped for good tape-to-head contact. The tape is recorded at the front of the head, rewound oxide-out (B wind), then reproduced by the back gap of the same head. The head rather than the tape thus produces the "mirror image". Adjustments are made as described above until perfect agreement is achieved between the back and front gaps. Guiding problems have made this method unsatisfactory.

DETERMINING THE REPRODUCING FLUX CHARACTERISTIC

The calibration of the reproducing channel used in making reproducer test tapes generally follows the procedures detailed in the 1965 NAB Standard. First one determines the response of the reproducing head plus electronics from a constant flux input: a flux-inducing loop is attached to the front gap of the head, and a constant current signal *vs* frequency is applied through the loop. The amplifier can then be adjusted to provide the correct response for an ideal head. (In this measurement, resonance effects of the head and cable are included. It simplifies matters if the playback head resonates well outside the band of interest; this requires a low inductance head, with fewer turns of wire than usual.) When using this flux-inducing method, a de-emphasis network can be used after the reproducing amplifier to produce a flat reading on a vtvm when the reproducing flux response is correctly adjusted to the appropriate standard. A different response is of course needed for each of the many standard curves in use.

A practical head will also have wavelength response errors which must be measured and taken into account. Gap losses and contour effects are measured as outlined in Annex C of the 1965 NAB Standard. These measurements are somewhat involved, and it is best to double-check them. As a further check, one should measure several known heads for later cross reference.

After the losses inherent in the reproducing head are determined, a curve may be drawn showing the deviation from ideal of a particular reproducing system. A recording can then be made which will reproduce in agreement with the calibration curve; in other words, the recording should play back with the same response as the reproducing system.

Once a system is calibrated, a tape may be made for use in adjusting other test tape production machines, for test tape production on a comparative reference basis. Each such machine must produce tapes which have recorded flux identical to that of the tape made on the calibrated system. In production practice, several tapes are made on the calibrated reproducer and used as setup tapes. However, it should be noted that setup tapes do not last long, and must be recalibrated frequently on the original test setup or else replaced entirely.

These techniques all center around the calibration of the reproducing system. Recording current can be varied to compensate for differing tape characteristics.

Production practice at Ampex has shown that each test tape must be made individually: each tape is an original recording, it is not a copy. Of course, the voice announcements are dubbed, but the test signals are

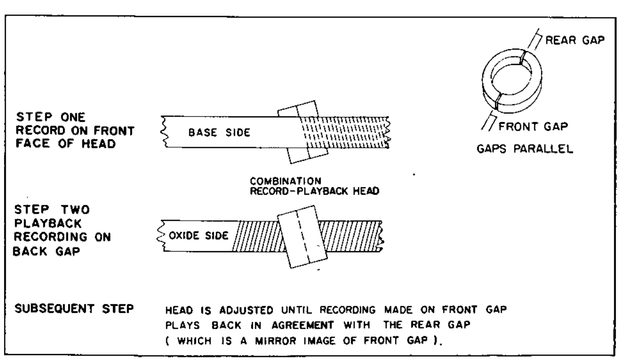

Fig. 5. Azimuth determination by the front/back gap method.

supplied directly to the recording amplifiers from a specially constructed oscillator having pre-set switchable frequencies. The voice track is reproduced backwards, and the announcements, along with the tones from the oscillator, are recorded in reverse order. This provides a smooth tape pack since the reel is ready for packaging, with no need for rewinding.

TEST TAPE ACCURACY

Accuracy of Manufacture

Table I lists the usual maximum errors which can be expected for Ampex Test Tapes. These include the uncertainties of the basic measurements in addition to the deviations allowed in manufacturing.

TABLE I. Maximum errors of Ampex Test Tapes.

"Operating Level" Flux	±0.25 dB from one test tape to another; absolute value, 210 nanowebers per meter of track width, ±10%.[14]
Uniformity of Flux Across Tape Width	±0.25 dB of specified value.
Azimuth	±2′ of perpendicularity to edge of tape.
Frequency Response	The short circuit flux is ±0.6 dB of specified response for wavelengths greater than 0.75 mil (19 μm) (frequencies of 10 kHz at 7.5 ips, 5 kHz at 3.75 ips, and 2.5 kHz at 1.87 ips). Accuracy at shorter wavelengths (higher frequencies) may be ±1.2 dB of specified response.
Accuracy of Recorded Wavelength	±2%.

Other studies, made by European test-tape manufacturers, have yielded very similar accuracies.

In practice, test tapes checked at time of manufacture do not show variations of this magnitude. The quoted figures include instrumentation error and 3 months' storage with temperature cycling variations of approximately 60°F to 80°F (15° to 27°C). There are several sources of error in each measurement in calibrating the reproducing system, and in making the test tapes. One would expect these to add in a root-sum-square manner most of the time, but it is possible that all of the errors could be in the same direction, and therefore add directly.

Errors in Test Tapes Arising after Manufacture

Accidental Damage.—Mechanical and/or magnetic damage which will destroy the accuracy of test tapes may occur in playing, rewinding, or storing them. The shorter wavelength (high-frequency) recordings are most easily damaged.

Mechanical deformation of the tape will usually damage the edge of the tape, causing uneven tracking and a constantly changing relative azimuth of the recorded tone. Contact of the tape pack with one reel flange may result in irreparable edge damage. Mechanical distortion due to uneven wind of the tape on the reel is aggravated by high temperatures, and by temperature and humidity cycling.

Magnetic damage (erasure) may occur if tape is stored in areas of high magnetic field (e.g., certain loudspeakers, meters, motors, microphones, etc.). Partial or complete erasure of the tape may occur if it is reproduced on a transport which has magnetized heads or guides, or if the recording and/or erasing heads are accidentally energized while reproducing the test tape.

Normal Wear and Tear.—The effects listed under Accidental Damage may be small enough to cause damage that is not apparent from one use of the tape, yet that with repeated usage will result in a gradual loss of accuracy. The tape surface will also wear (lose oxide), even if the tape transport is perfect. Also, loose oxide may become "welded" to the tape surface, causing increased spacing loss.

When the tape passes around small radii, the mechanical bending may cause some loss of magnetization, especially at short wavelengths. This loss depends on the tape used, but is usually about 0.5 dB at 0.5 mil (12 μm) wavelength.

For example, a test tape which has been carefully handled and played 50 times will have a loss of 0.5 to 2 dB at 0.5 mil wavelength (15 kHz at 7.5 ips). For 100 plays, the loss may be about 3.5 dB at short wavelengths. With more playings and/or slightly defective reproducers, the loss will approach 5 dB or more.

In order to prolong the useful life of the test tapes, Ampex practice is to compensate for some of the losses experienced in normal usage by recording the shortest wavelengths at a level slightly higher than that prescribed in the Standard: a boost of 1.25 dB is used at 0.5 mil (12 μm).

Conclusions about Tape Wear and Damage.—From this information we must conclude that *it is absolutely necessary that test tapes be recalibrated or replaced periodically, no matter how carefully the tapes are handled.*

This experience with test tapes also leads to a practical conclusion about the frequency response of systems working at wavelengths of 0.5 mil (12 μm) or less (e.g., at and above 15 kHz at 7.5 ips, or 7.5 kHz at 3.75 ips, etc.): namely, that, even though a system at these short wavelengths may be adjusted to have flat overall response, true flat response on an interchangeability basis may be difficult to obtain due to errors in the test tapes. Further, even when a system *is* set up to be flat on an interchangeability basis, the short wavelengths recorded on the tapes are fugitive, just as those on the test tapes, and a tape recording at slow speed (3.75 ips or less) which is flat today may well be lacking high frequencies after storage or after a number of playings.

MEASUREMENT ERRORS IN USING A TEST TAPE

Most of the complaints of "defective test tapes" are found to be actually due to errors of measurement technique in using the tapes. A very common error is that of using a full track test tape to measure the frequency response of a multi-track reproducer. The fringing effect causes a rise of up to about 5 dB in the apparent low-frequency response of the reproducer. This error is sometimes attributed to the test tape; it is in fact due to use of the wrong tape since a multi-track test tape must be used for accurate low-frequency measurements of a multi-track reproducer.

The numerous possible errors of measurement technique are dealt with in detail in a companion paper.[2]

CARE OF TEST TAPES

Tape intended for repeated use in standardization work must be properly cared for if its full usefulness is to be maintained. Physical deformation of the tape can be a serious problem. Edge damage can be prevented by winding the tape smoothly under moderate tension and evenly spaced between the reel flanges. The tape pack should not be wound in contact with one reel flange, as this will result in irreparable edge damage if it is stored in this condition for long periods of time.

Tapes should not be stored in fields from motors or permanent magnets; for example, a tape stored in a cabinet next to a loudspeaker or microphone may be affected. Heads and tape guides should be demagnetized. When a reproducer test tape is used for continuous check-out purposes, such as in production line work, age and wear as described above often become the primary sources of inaccuracy.

ACKNOWLEDGMENT

The author wishes to thank the following Ampex Corporation personnel: Harold Lindsay, Mort Fujii, and George Goodall, for suggestions relative to this paper; and John G. McKnight for editorial revision of the paper.

NOTES

1. All standards referred to in this paper are fully described in: J. G. McKnight, "A List of Published Standards Related to Magnetic Sound Recording", scheduled for publication in the July 1967 issue of *JAES.*

2. The need for test tapes in different track configurations is discussed in the companion paper by J. G. McKnight, "Tape Reproducer Response Measurements with a Reproducer Test Tape", p. 152.

3. J. G. McKnight, "Absolute Flux and Frequency Response Characteristics in Magnetic Sound Recording", scheduled for publication in the July issue of *JAES.*

4. Wavelength = speed/frequency ($\lambda = s/f$). The recorded wavelength, in mil, equals the tape speed in inches per second divided by the frequency in kilohertz; alternately, wavelength in micrometers equals tape speed in mm/sec divided by frequency in kilohertz.

5. The operating level recording on the test tape is used to set the reproducing amplifier gain so that the vu meter reads zero.

6. See Eric D. Daniel and P. E. Axon, "The Reproduction of Signals Recorded on Magnetic Tape", *Proc. IEE* **100**, Pt. 3, 157 (1953).

7. O. Schmidtbauer, "Einfluss der Schiefstellung des Spaltes und andere Spaltfehler" (The Influence of Misalignment of the Gaps and Other Gap Defects), in F. Winckel (ed.), *Technik der Magnetspeicher* (Springer-Verlag, Berlin, 1960), p. 55.

8. The very convenient formula shown in the figure caption is good for $\theta < 0.2$ radian (11°), and loss $\lesssim$ 12 dB. It is taken from page 407 of F. Krones, "Die Theorie des Magnetspeichers" (The Theory of Magnetic Storage) in F. Winckel, ed., *Technik der Magnetspeicher* (Springer-Verlag, Berlin, 1960).

9. A commercially available form of carbonyl iron powder in volatile solvent is the Ampex Edivue Kit, 50495-01.

10. Technique described by Walter Guckenburg, in "The Process of Magnetization of Magnetic Tape", *JSMPTE* **65**, 69 (1956).

11. For example, 3M's Magnetic Tape Viewer #600.

12. B. F. Murphey and H. K. Smith, "Head Alignment with Visible Magnetic Tracks", *Audio Engineering* **33**, 12 (1949).

13. Arthur G. Evans, "The 'Null Method' of Azimuth Alignment in Multitrack Magnetic Tape Recording", *IRE Trans. on Audio* **AU-7**, 116 (Sept.-Oct. 1959).

14. The measuring method is being refined so that the absolute flux should soon be measurable with an error of only ±2%.

THE AUTHOR

Robert K. Morrison was born in 1925 in Madera, California. He received his B.A. degree from the University of California's College of Letters and Science at Berkeley in 1949. During his undergraduate years he was involved in disk and optical film recording with Picto Sound Company in San Francisco.

Following his graduation, he joined Voice of America in New York City, moving in 1953 to Central California Broadcasters, Incorporated, where he held the position of chief engineer until 1959. At the present time, Mr. Morrison is manager of the Ampex Standard Tape Laboratory in Redwood City, California.