Tape Reproducer Response Measurements With a Reproducer Test Tape*

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The reproducer test tape affords the most satisfactory field means of standardizing magnetic sound recording systems. This method is nevertheless susceptible to numerous errors of measurement due to inappropriate test tape (wrong speed, equalization, track format, or test frequencies), and mechanical misadjustment of the reproducer (head height; azimuth and zenith adjustment; and poor tape-to-head contact due to dirt on heads, inadequate tape tension or wrap around the heads, improper vertex adjustment, worn heads, and improper tape guiding). These errors are described, in order that they may be avoided.

INTRODUCTION The measurement, adjustment, and standardization of the frequency response of a magnetic tape reproducer,[1] and the setting of gain and head azimuth are usually performed in the field by the use of a reproducer test tape.[2] For example, Section 2.05 of the 1965 NAB Standard[3] defines the response of a reproducer as the output voltage of the reproducing amplifier *vs* frequency when reproducing the appropriate test tape. In general, this method is quite satisfactory, and is the best one known for this purpose. However, in order to avoid measurement errors during the use of a test tape, it is essential to observe certain special precautions, in addition to the use of ordinary good engineering practices. High- and low-frequency errors of measurement amounting to 3 to 6 dB (or more) are a likely result of improper procedures or the failure to observe needed precautions. Common errors of procedure cause an apparent rise of low-frequency response or a decrease of high-frequency response, or possibly both at once. Therefore, when measurement errors occur, the response will almost always fall with increasing frequency.

Although a new test tape is subject to certain small errors[2] and a used test tape is subject to much larger errors[2] most complaints about defects in the test tapes are in fact caused by errors in the use of the tape. This paper discusses measurement errors resulting from the use of an inappropriate test tape and errors resulting from mechanical misadjustments in the reproducing head.

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INAPPROPRIATE TEST TAPE

Test tapes may be inappropriate for use on a given system in any of the following areas: rated tape speed, flux characteristic (equalization), track format, and/or recorded test frequencies.

Tape Speed

It is obvious that a 38 cm/sec (15 ips) reproducer must be tested by use of a 38 cm/sec test tape. It is not so obvious that a multiple-speed reproducer must be tested and adjusted at *each* of the speeds; a response measurement at one speed guarantees nothing about the response at the other speeds. It is commonly assumed that, since the NAB equalization curve is identical for both 19- and 38-cm/sec tape speeds (7.5 and 15 ips), an adjustment at one or the other tape speed suffices for both. This is only approximately true because of the 1:2 ratio of wavelengths involved. Accurate response measurements require the use of both 38- and 19-cm/sec test tapes.

Test Tape Flux Characteristic (Equalization)

A number of equalization time constants are used in the USA and elsewhere.[1] Although the 19- and 38-cm/sec (7.5- and 15-ips) tape speeds most commonly used in the USA are nearly always used with the NAB characteristic (t_1 = 3180 μsec, t_2 = 50 μsec), recent USA changes in 9.5 cm/sec (3.75 ips) equalization, coupled with recent changes in international standards for 9.5 and 19 cm/sec (3.75 and 7.5 ips), require that the user specify not only the name of the standardizing organization and the tape speed, but also the date of the standard. There is the least chance for error if the actual time constants desired are specified.

While this paper is not concerned with the absolute recorded level, one should be aware that the Reference Level of the proposed NAB Standard Tapes may be lower than that traditionally used on the Operating Level section of Ampex Test Tapes. The flux for the NAB Standard Reference Level has not yet been definitely established. Also, the DIN Test Tapes have a *Bezugspegel* (reference level) that is 1.5 to 3.5 dB higher than the Ampex Operating Level, depending on the intended tape speed. This is because the German volume indicators and equalizations are different from the USA ones.

Test Tape Track Format

All of the proposed NAB Standard Test Tapes, and all Ampex Test Tapes with one exception, are recorded across the full width of the tape.[4] When these tapes are reproduced by narrower-track heads (e.g., half-track, stereo, or multiple-track heads), a low-frequency measurement error occurs because of the "fringing effect": at long wavelengths (low frequencies) the reproducing head core receives effective flux from the recorded track area outside of the area actually contacted by the reproducing head core. This error is a function of the recorded wavelength (which equals the tape speed divided by the recorded frequency), the particular design of the head shielding, and the geometry of the tape wrap over the head face. For example, Fig. 1 illustrates the rise of

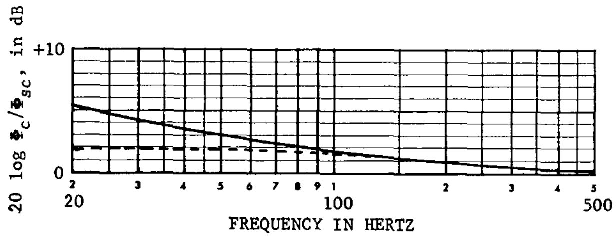

Fig. 1. "Fringing" response rise when reproducing a full-track recording with a half-track reproduced **(solid curve)** and a stereo reproducer **(dashed curve)** at 38 cm/sec (15 ips), where Φ_c is the flux in the head core, and Φ_{sc} is the short-circuit tape flux.

response at 38 cm/sec (15 ips) caused by the fringing when a full-width recorded track is reproduced by a half-track head (*solid curve*), and by a stereo head (*dashed curve*). (The response would be flat if the appropriate half-track or stereo recording were used.) The response rise due to fringing at 50 Hz (wavelength = 3.8 mm, or 150 mil) is +3 dB for the half-track head and +1 dB for the stereo head. The difference between these responses is caused by the difference in the shielding arrangements of these heads; the actual head cores and track configurations are essentially identical. Thus we see that an all-purpose correction curve cannot be found even for one particular track configuration.

In the instance of a four-track head, fringing response rises of 1 to 5 dB, depending on the particular head design, have been observed.

A really satisfactory solution to the problem of producing test tapes for all of the various multi-track configurations of reproducers is yet to be found. Table I below lists eight of the track configurations most commonly used with the three common tape widths. But it should be remembered that at least 11 "standard" (but different) flux characteristics are used for four common speeds. If each flux characteristic were produced in each track configuration, a catalog of 88 reproducer test tapes would be required. And one could add 4.75 cm/sec (1.87 ips), Ampex Mastering Equalization at 38 cm/sec (15 ips), and undoubtedly others too! It is just not possible to manufacture, catalog, and distribute reproducer test tapes for every track configuration, because to do so would make their cost prohibitive. Therefore, reproducer test tapes are made only in the full-track configuration, plus the one frequently required 6.25 mm (¼ inch) four-track tape for the 19 cm/sec (7.5 ips) tape speed.

TABLE I. Commonly used track configurations.

Tape Width *mm*	*in.*	*Number of Tracks*
6.25	0.246	1, 2, 4, 8
12.7	0.50	3, 4
25.4	1.00	6, 8

One means by which fairly accurate data on multi-track reproducers could be determined even though using a full-track test tape would be for the tape recorder manufacturer to include in the instruction manual of each model of multi-track reproducer the response of that reproducer to a *full-track* test tape, when the response is flat with the correct track-configuration of the test tape.

In lieu of this, anyone desiring really accurate low-frequency response measurements of multi-track reproducers (other than with the previously mentioned four-track ¼ in. tape) must make his own low-frequency test tape. This is feasible; although the making of accurate test tapes for high frequencies (short wavelengths) is rather difficult, and not at all recommended to the general user, a low-frequency test tape is not too difficult to make accurately if one has accurate general-purpose electronic measuring equipment. The method is described in the Appendix.

Frequencies on the Test Tape

Reproducer test tapes can be made with a sweep-frequency tone, or with a succession of discrete ("spot") frequency tones. Since a graphic level recorder is required to realize the benefits of the sweep-frequency tone, and since such a recorder is not commonly available to tape recorder users, the spot frequency method is used in making test tapes. The use of spot frequencies assumes that the frequency-response of the reproducer is smooth and continuous throughout the whole frequency range. This assumption is usually valid—but not always. If the reproducing head is unshielded, and the corners of the pole pieces are rectangular, the true long-wavelength (low-frequency) response will be as in Fig. 2; if the reproducing head gap is perfect, the short-wavelength (high-frequency) response[6] will be as

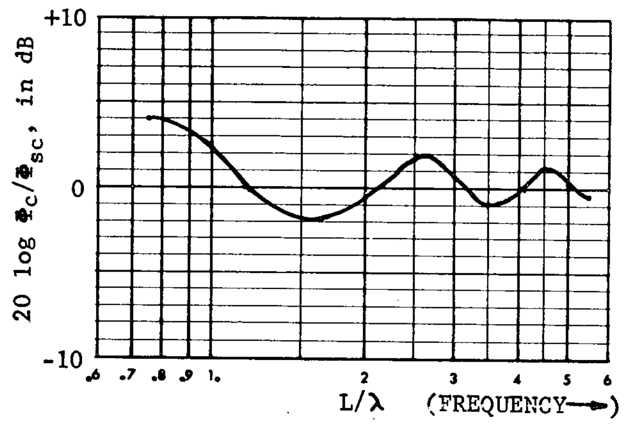

Fig. 2. Theoretical long-wavelength response of an unshielded reproducing head with rectangular pole pieces, where L is the length of the head core face and λ is the recorded wavelength.

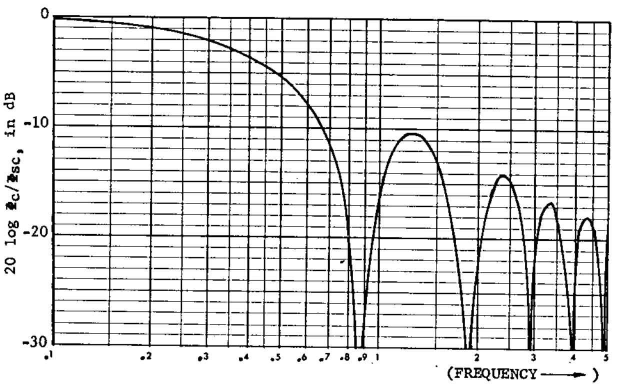

Fig. 3. Theoretical short-wavelength response of a reproducing head with a long gap, where l is the mechanical gap length.

in Fig. 3. Thus, the response at both very long and very short wavelengths may show large undulations.

A practical example of an extreme case is given by the measurements made on an 8-track, 6.25 mm (¼ in.), 9.5 cm/sec (3.75 ips) reproducer: in Fig. 4 the solid line shows the response of the reproducer to a full-track test tape; the data points are connected by the usually assumed smooth curve, and the response looks satisfactory. Next (dashed line) the response was measured at the same spot frequencies with an actual 8-track test tape; having removed the fringing effect by using the correct track width, the response fell 4 dB at 50 Hz; the usual smooth curve was again drawn. In Fig. 5, the solid line shows the true response, as measured with a sweep-frequency test tape; the dashed curve shows the response assumed on the basis of the spot frequencies on the test tape. The error due to using spot frequencies instead of a sweep frequency is seen to be ±3 dB over much of the range from 50 to 500 Hz, and 7 dB at 130 Hz. This shows that a complete and accurate measurement of reproducer low-frequency response may require a sweep-frequency test tape, since spot-frequency measurements may be grossly in error in some cases. The method which is described in the Appendix may be used to establish the response for making such a sweep tape.

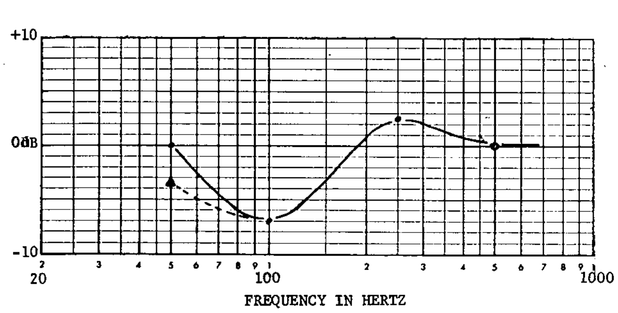

Fig. 4. Frequency response measurement of an eight-track reproducer, 6.25 mm (0.25 in.) tape, showing fringing error of 4 dB at 50 Hz with a full-track recording. **Solid curve:** full-track recording, spot frequencies. **Dashed curve:** one track only of eight recorded spot frequencies. Data points are connected with assumed smooth curves.

MECHANICAL MISADJUSTMENT OF THE REPRODUCING HEAD

The gapped reproducing head is a "flux collector" which gathers the flux from the recorded track. Proper flux collection depends on having intimate contact and correct alignment between the recorded track and the gap area: any imperfection of this alignment or contact will result in losses at some or all frequencies. In principle, errors of contact and orientation can be corrected in the reproducing equalization. The practical problems are:

1. A system with faulty contact and/or alignment is usually unstable, i.e., the response is variable during the measurement, and from one measurement to another.

2. The usual equalizer is incapable of correcting for faulty contact and/or orientation, i.e., the range and shape of equalizer responses do not generally match the response of the system in which there are contact and/or orientation losses.

3. Although faulty contact and/or orientation reduces the signal and the tape noise by approximately the same amount, the head and amplifier noises remain constant, so that the signal-to-noise ratio is usually degraded.

Because of these reasons, the contact and orientation should be mechanically adjusted in order to prevent errors in respect to a number of variables.

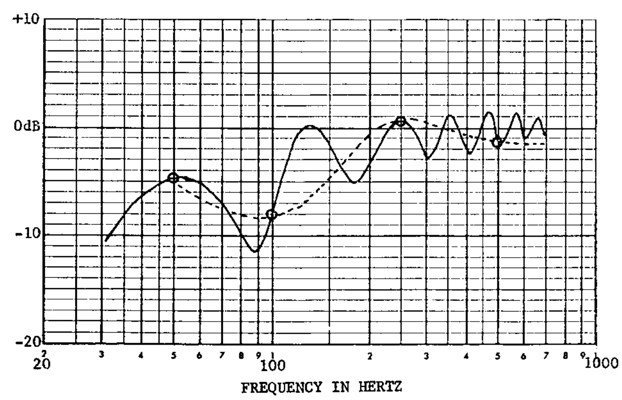

Fig. 5. Frequency response measurement of an eight-track reproducer, 6.25 mm (0.25 in.) tape, showing error of up to 7 dB due to measuring 4 points and assuming a smooth response between these points. One track of eight recorded. **Dashed curve:** assumed response from four spot frequencies. **Solid curve:** true response with sweep frequency.

Head Height

The height of the reproducing head should be adjusted accurately so that the reproducing head cores will coincide with the recorded tracks. This is particularly critical with narrow tracks (e.g., four- and eight-track systems). A misalignment of the reproducing head, causing the recorded test tape track to contact only a portion of the reproducing head core, will cause a reduction of the reproducing core flux at medium and short wavelengths, but, due to the fringing effect, not at long wavelengths. Thus one has both a level-setting error, and a frequency response error. Misadjustments of recording and reproducing heads may also cause recorded levels which are too high or too low, depending on the nature of the misalignment. Too high a recording level will in turn cause high distortion.

Azimuth Angle

The gap of the reproducing head should be parallel to the gap of the recording head. Standard practice is to make both of these gaps perpendicular to the edge of the tape. These relationships will be affected by the azimuth and zenith adjustments, and the tape guiding.

Azimuth Adjustment.—Practical azimuth adjustment is made by reproducing the "azimuth adjustment" section of a reproducer test tape.[2] As the azimuth angle of the reproducing head is changed, the signal output will rise and fall, as shown in Fig. 6. The adjustment must

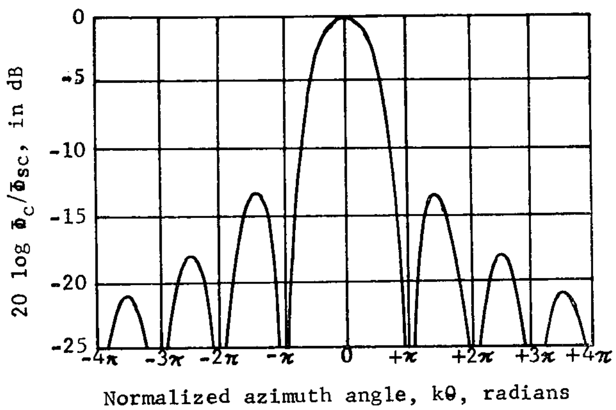

Fig. 6. Output vs azimuth angle, where θ = azimuth angle in radians, $K = \pi w/\lambda$, w = track width, λ = wavelength (in the same units), and $\Phi_c/\Phi_{sc} = (\sin K\theta)/K\theta$, for $\theta < 0.2$ radians (11°).

be made to the peak with the *maximum* output ($\theta = 0$). If, before adjusting the azimuth from the test tape, the reproducing head is visually adjusted so that the edge of the head is approximately parallel to the edge of the tape, the chances of setting to the wrong peak are greatly reduced.

Zenith Adjustment.—Proper guiding requires that all tape guides and the front faces of the heads be parallel to the axes of the tape reels. These, in turn, are usually perpendicular to the top plate. This adjustment of the heads is called the zenith adjustment—all axes should "point up". If any of these elements are not parallel, any change in tape tension[7] will cause the tape to "bow", producing an apparent azimuth change; since in this case the azimuth depends on the tension, unstable high-frequency response results. A simple technique will aid in setting the zenith adjustment:

1. Paint the face of the head with dye, using a red felt-tip marking pen. (Wax pencil may be used, but is messy; a layout fluid such as Dykem is also usable, but it takes too long to wear off.)
2. Play a piece of scrap tape until the dye is worn off the head face where the tape runs.
3. Observe the wear pattern of the dye on the head face. If the zenith adjustment is correct, the right and left edges of the wear pattern will be parallel; if they form a *V*, the zenith is incorrect.

Location of the Edge of the Tape.—Changes of position of the edge of the tape will also usually cause the tape to bow, resulting in the apparent azimuth changes mentioned above. If the tape guides are too wide, the tape edge will wander. If guides or heads have a slot worn in them, then different widths of tape will lie in them differently. This is especially noticeable if heads are re-adjusted after having been allowed to "wear in" in an incorrect adjustment.

Head-to-Tape Spacing (Poor Contact)

Response loss due to spacing between tape and head in reproducing is found from the formula: *loss* (in dB) $= 55\ s/\lambda$, where s is the tape-to-head space, and λ is the recorded wavelength. Very small spacings cause large losses: the slope is not "6 dB/octave", but expotential, i.e., the *slope* increases with frequency. Unintentional spacing may come from any of several sources, including:

Dirt on the Heads.—Material (usually loose tape oxide, or loose scraps of oxide and base material from the slitting process) may accumulate on the head face in use, causing spacing loss. Heads should be cleaned carefully before measurements and/or adjustments are performed.

Tape Tension Adjustment.—Tape-to-head force which causes tape-to-head contact is commonly obtained in professional recorders by having the heads deflect the tape path between two guides. In this case the force which holds the tape in contact with the head is proportional to the hold-back tension. Low contact force may therefore be caused by a hold-back tension that is too low because of improper adjustment, or because of the use of large reels[8] with the *Reel Size* (tension) switch set for small reels[9] (low tension). This low force again allows separation of head and tape.

Inadequate Wrap Angle.—In the design of a head assembly or in replacing heads in an adjustable head assembly, it is possible to have too little wrap of the tape around the heads. For a given tape tension, head-to-tape force is a function of the wrap angle; angles of less than about 12° total deflection of the tape at each head are unlikely to give adequate contact force for the elimination of the spacing loss.

Vertex Adjustment.—In the machines described above which obtain tape-to-head force by having the heads deflect the tape path between two guides, the *gap* of each head must be at the *vertex* of the angle so formed in order to have best tape-to-gap contact. This is shown in Fig. 7: misadjustment again causes spacing loss.

Worn Heads.—Mention was made earlier of guiding

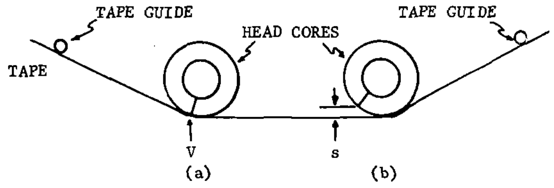

Fig. 7. Vertex adjustment. **a.** Gap of the head at the vertex of the tape wrap angle V with no spacing between gap and tape. **b.** Gap of the head not at the vertex of the tape wrap angle, resulting in spacing s.

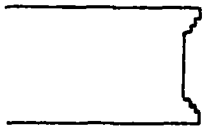

Fig. 8. Cross-section of a worn head face, showing step-shaped pattern of the wear which lifts the tape out of intimate contact with the head face.

problems due to a head which has a slot worn in it. Such a slot causes a further difficulty: when a head wears, the cross-section is usually stepped, as shown in Fig. 8. The steps often cause the edge of the tape to be lifted out of contact with the head face, with the resultant spacing loss.

CONCLUSION

Although the reproducer test tape provides the most satisfactory means known for measuring and adjusting the azimuth and frequency response of tape reproducers, there are numerous opportunities for making errors in the measurements. If care is taken in performing the measurements and these errors are avoided, measurements with a test tape should give accurate indications of the frequency response of a reproducer.

NOTES

1. John G. McKnight, "Absolute Flux and Frequency Response Characteristics in Magnetic Sound Recording: Measurements, Definitions and Standardization", scheduled for publication in the July 1967 issue of *JAES.*
2. Robert K. Morrison, "Reproducer Test Tapes: Evolution and Manufacture", *J. Audio Eng. Soc.* **15**, 157 (Apr., 1967).
3. 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.*
4. The one other Ampex Test Tape is for the four-track 6.25 mm (¼ in.) tape system.
5. K. Fritzsch, "Zur Wiedergabe grosser Wellenlaengen vom Magnetband" (The Reproduction of Long Wavelengths on Magnetic Tape). *Hochfrequenztechnik und Elektroakustik* **75**, 39 (April, 1966). Fig. 2 is taken from Fritzsch's Fig. 14a.
6. W. K. Westmijze, "Studies on Magnetic Recording", *Philips Research Reports* **8**, 148; 161; 245; 343 (1953), and Reprints R213, R214, R217, R222. Fig. 3 follows Westmijze's function $S(\pi e/\lambda)$.
7. In most professional tape transports, the tape tension comes from a constant torque supply-reel motor. Therefore the tension is inversely proportional to the diameter of the supply-reel pack. The outside-to-inside tension ratio is 2:1 to 3:1, depending on style of reel.
8. Defined as NAB Type A reels, with 27 cm (10.5 in.) diameter.
9. Defined as NAB Type B reels with 18 cm (7 in.) diameter.

APPENDIX

Calibration Method for Making Long-Wavelength (Low-Frequency) Reproducer Test Tapes

At long wavelengths* the flux is constant **vs** wavelength for a constant recording field, which is in turn produced by a constant recording current. Therefore, to produce a **long-wavelength only** reproducer test tape requires only making the recording head signal current a known response **vs** frequency.† To measure the recording head current **vs** frequency, remove the high frequency recording bias current, e.g., by unplugging the bias oscillator tube or disconnecting the oscillator power. Sense the recording head signal current by means of a current probe attached around the lead of the recording head or by inserting a resistor in series with the ground side of the recording head, and measuring the voltage across this resistor. Measure the frequency response from amplifier input terminals to recording head current. Then one can compensate the input signal for this response, so as to produce the desired head current **vs** frequency when the recording is made.

If the test tape is for use with the NAB Standard, the low-frequency flux response should rise at 6 dB/octave with a transition frequency (+3 dB point) at 50 Hz. Such a test tape should be made at reduced level to prevent over-recording and consequent distortion at the lowest frequencies, since the equalized recording current is +8.6 dB at 20 Hz re/700 Hz.

For a test tape to the CCIR Standards or for many experimental purposes, constant current **vs** frequency is used with no low-frequency boost.

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* The wavelength λ should be much greater than the coating thickness t. Since $t \cong 12\ \mu m$ (0.5 mil), λ should be greater than about $500\ \mu m = 20$ mil. Therefore frequency should be 750 Hz or less at 38 cm/sec (15 ips).

† There are "secondary gaps" at the corners of a head core. If a recording head is used which has rectangular corners contacting the tape, additional long-wavelength recording response effects could occur. A ring head whose pole face gradually sweeps away from the tape does not seem to produce any such effect.

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John G. McKnight was born in Seattle, Washington, in 1931 and received his B.S. degree in electrical engineering from Stanford University in 1952. He has been with Ampex Corp. since 1953. In 1959 Mr. McKnight became manager of the advanced audio section of the Professional Audio Division at Ampex. He is presently staff engineer with the Consumer and Education Products Division of the company in Redwood City. His work has included research and engineering on the dynamics of tape transports, magnetic recording—especially the recording of music—and tape recording standardization. He has presented and published many papers on magnetic recording.

Mr. McKnight is a member of several standards committees on magnetic sound recording. He is a senior member of the Institute of Electrical and Electronic Engineers and a member of the IEEE **Transactions on Audio** editorial board. He is also a Fellow of the Audio Engineering Society, an ex-governor and a member of the **Journal**'s editorial board.