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Choosing and Using MRL Calibration Tapes for Audio Tape Recorder Standardization

0 INTRODUCTION

The information in this publication applies to all MRL Open-Reel Calibration Tapes for analog audio magnetic tape reproducers. It covers the topics listed in the Table of Contents below. The MRL "Publications" mentioned here are available for you to download.

We sometimes still refer to blank-tape types that are no longer available – see §1.2.9 for more information.

MRL no longer makes the NAB Broadcast Calibration Cartridges, because the lubricated tape and the cartridges are no longer available.

If you have MRL Calibration Tapes with tape shed problems, please see our Publication SHED-3 http://home.comcast.net/~mrltapes/pubshed3.pdf .

This publication "Choosing &Using" is now only available for download (http://home.comcast.net/~mrltapes/choo&u.pdf). It is in lieu of a "Handbook of Magnetic Tape Reproducer Calibration and Standardization", which we promised years ago but never completed.

For an introduction to analog magnetic recording, we recommend Rumsey and McCormick [1]; for an intermediate discussion, Borwick [2]. For a comprehensive reference on magnetic recording theory and applications, see Camras [3] and Jorgensen [4]. (Camras has more emphasis on audio recording; Jorgensen has more on data recording).

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1 GUIDE TO CHOOSING MRL CALIBRATION TAPES

This section will help you find the information that you need to find the Catalog Number of the MRL Calibration Tape that you need.

You might logically think that the make and model of your recorder would uniquely determine which Calibration Tape to use. If that were true, you could just say "I need a Calibration Tape for my Studer Model A-80" (or whatever), and the Calibration Tape would be determined. But professional analog sound recording covers a wide range of applications, from monophonic recording to 24 track (or more) tracks, and from medium quality to the highest quality. For application flexibility, most makes and models of professional analog tape recorders can be run at several speeds, and can use more than one tape width, equalization standard, and recording level. Unfortunately most tape recorder model numbers tell nothing about how a particular recorder is *actually* being used.

MRL Calibration Tapes are designed for use with various *international interchange standards*, and they have test signals optimized for use with various *measurement equipment*. We will explain both of these to help you choose the right Calibration Tape.

In case there is still doubt which MRL Calibration Tape you should use, the engineer who will use the tape should call or email MRL and ask for Technical Support to help determine the specific catalog number. Then he can give this number to his purchasing agent to order directly from us or from one of our dealers.

1.1 Interchange Standards

Imagine a situation where you *always* record and reproduce on the *same* tape recorder, and it will never wear out or need any maintenance. Then you could conceivably just set it for flat overall response, and you wouldn't have to worry about interchange standards. But you know that any practical recorder will wear out, and you will have to repair it or buy a new one. And if you have no interchange standards, how will you be able to set the repaired or replaced recorder to have the same gain and frequency response as the old one?

But this imaginary situation of using only *one* tape recorder is very unlikely — you will usually be interchanging recordings among several recorders in your own studios, and interchanging recordings with other studios. For such interchanges you must be sure to use exactly the *same standards* for all of the recorders and reproducers. These standards include not only the obvious things like tape width, speed, and track formats, but also the less obvious things like the *equalization standard* and the *reference fluxivity* (commonly called the "recording level").

Altho audio tape recording systems are standardized, many *different* standards are used. In open-reel recording, for instance, there are 5 standard speeds, 4 standard tape widths, some 2 to 5 standard track configurations for each tape width, two standard equalizations, and at least 3 standard reference fluxivities.

The international standards for analog magnetic tape sound recording are published by the International Electrotechnical Commission (IEC) as Standard 60 094, Parts 1...11, of which a few ([5], [6], [7], [8]) pertain to the interchange of open-reel and the now-obsolete broadcast cartridge recordings.

When you set up your standards for a new studio, first talk to the other studios with whom you will be interchanging, and use the same standards that they use.

If you do not yet know with whom you will be interchanging, or if you have been using a system but aren't sure what standards it was last set for, the sections below will give you general guidance.

1.2 Information Needed to Choose a Calibration Tape

1.2.1 *Tape Width*: ¼ inch (6.3 mm), ½ inch (12.5 mm), 1 inch (25 mm), or 2 inch (50 mm) [5].

1.2.2 *Tape Speed*: 3.75 in/s (95 mm/s), 7.5 in/s (190 mm/s), 15 in/s (380 mm/s), 30 in/s (760 mm/s) [5]. Speeds are usually given in "inches per second", properly symbolized "in/s", and colloquially called "ips"; or in millimeters per second, mm/s (using slightly rounded values: see §5.2.1 for the exact millimeter speeds).

MRL also makes multispeed Calibration Tapes — see §1.2.4.3. The Multifrequency Calibration Tapes of §1.2.4.1 are not available in multispeed.

1.2.3 *Equalization Standard*: For technical reasons, the signal recorded on the tape — the magnetic flux — does not inherently have a "flat" frequency response. For optimum dynamic range in recording, the recorded flux is "equalized" so that it *decreases* with *increasing frequency* in a standardized way. Therefore reproducers must have a response that *increases* with increasing frequency in a standardized *complementary* way, so that the reproduced electrical output signal will be flat with frequency. Sometimes there is also a standardized low-frequency boost in recording and complementary cut in reproduction.

This standardized response of the tape flux — the "equalization" — is commonly identified by the initials of the organization that wrote the tape recording standard:

- IEC the International Electrotechnical Commission [5] (now also called IEC1 equalization)
- NAB the US National Association of Broadcasters (now also called IEC2 equalization)
- AES the Audio Engineering Society [9] (only for 30 in/s; now also called IEC2 equalization)
- CCIR French for International Radio Consultative Committee. CCIR turned over their tape recording standards writing to the IEC in 1970. The IEC1 at 7.5 and IEC1 at 15 in/s (which are the only speeds CCIR now recognizes) have always been identical to the original CCIR equalizations — only the administering organization has changed. Around 1993 the name of the CCIR was changed to ITU-R, International Telecommunication Union — Radiocommunications.
- DIN German for German Industrial Standard, which is identical to IEC1 for Studio use, and IEC2 for Home use.

The equalizations at 3.75 in/s and 30 in/s really are *standard* — one equalization is used everywhere for each of these speeds.

At **3.75 in/s** the only equalization now used for new recordings is identified as NAB and IEC.

At **30 in/s** the only equalization now used for new recordings is identified as AES [9] and IEC2.

> Note that there is not now, and never was, an NAB standard for 30 in/s. Some machine manufacturers erroneously put "30 in/s NAB" on their equipment. We don't know what equalization they were actually using.
>
> Note also that altho the current IEC standard includes an IEC1 (= DIN = obsolete CCIR) for 30 in/s, it is only for reproducing historical mono recordings made in Europe on ¼ inch tape before 1955: it is never used for new recordings.

At **7.5 in/s** two equalizations are used, but the usage is fairly uniform:

NAB = IEC2 is mostly used in US; and
IEC = IEC1 (= CCIR = DIN Studio) is mostly used in Europe.

At **15 in/s** — the most commonly used professional speed — the equalizations are the most confusing:

8-track recorders on ½ inch tape, and 16- and 24-track recorders on 1 inch tape ***almost always*** use IEC = IEC1;
for all other widths and track configurations,
NAB = IEC2 is mostly used in US, and
IEC = IEC1 (= CCIR = DIN Studio) is mostly used in Europe.

The NAB 15 in/s equalization, while standard, is not optimum. We have proposed two non-standard equalizations for 15 in/s [10], [11]

The standardized "equalization", which is the flux level versus frequency mentioned above, $L_\Phi(f)$ in decibels, is described by the formula below, in terms of two transition frequencies F_{low} and F_{hi} in hertz:

$$L_\Phi(f) = 10\log\frac{1+(F_{low}/f)^2}{1+(f/F_{hi})^2}\ [\mathrm{dB}]$$

The different equalizations identified above all use this same response formula, differing only in the values of the transition frequencies. The original standards speak of "time constants" τ, where $\tau = 1/(2\pi F)$. We prefer the transition frequencies, since they are more obviously related to the frequency response of the flux. The current standard transition frequencies and time constants are summarized in **Table 1**, below, taken mainly from [5]. Some older (obsolete) values are given in [12].

Note that this formula describes the standard tape flux, *not the response of an equalizing network.* In addition to providing the equalization for the standard flux response shown above, one must provide an integrator (response falling 6 decibels per octave) to compensate for the differentiation inherent in the inductive (Faraday's Law) type of heads used in essentially all audio reproducers; and one must also compensate for the "non-ideal" (non-flat) frequency and wavelength response of most practical reproducing heads. This last compensation can be provided either by providing a separate equalizing network, or (more commonly) by slightly "misadjusting" the standard tape flux response network. This "misadjustment" is usually done by reproducing an appropriate Calibration Tape, and setting the reproducer's equalizers to give the best approximation to a constant output versus frequency. To quote the IEC Standard [5], "Calibration tapes shall be used to set-up the amplitude/frequency response of the reproducing chain."

In addition to the equalizations described above that are internationally standardized by the IEC, there are several proprietary equalizations that have been used:

Ampex used "Ampex Master Equalization" (AME) [13] at 15 in/s only on some ½ inch mastering recorders introduced in 1958 and sold for several years following. This equalization does not follow the formula above. For information on the AME curve and Calibration Tapes for it, see http://home.comcast.net/~mrltapes/pubame.pdf .

Nagra tape recorders use a special equalization at 15 in/s only, known as the Nagra Master Equalization (see MRL Publication 108, http://home.comcast.net/~mrltapes/pub108.pdf). It follows the standard response formula, with values of F_{low} = 50 Hz and F_{hi} = 11.8 kHz (time constants 3150 and 13.5 µs).

MRL has proposed a non-standard "Studio Master" equalization described in a paper available at http://home.comcast.net/~mrltapes/mcknight_proposed-mastering-eq.pdf , with Calibration Tapes at http://home.comcast.net/~mrltapes/pub101sm.pdf .

1.2.4 *Test Signals*: The best test signals to use for calibrating your tape reproducers will depend on several factors: the measurement equipment that you have (vu meter on the reproducer? digital multimeter? oscilloscope? a rd-octave real time analyzer? Audio Precision or Sound Technology Analyzer? etc?); how long it takes you to make the adjustments and read out the results on your tape reproducers; and the level of service work that you are doing — that is, whether you are verifying the performance of a reproducer that is in good operating order, or doing a major overhaul including replacing or relapping the heads. The different test signals are described below briefly, and in detail in the referenced MRL Publications, which can be downloaded from the MRL website http://www.mrltapes.com .

1.2.4.1 *Multifrequency Calibration Tapes* (Publication 101) http://home.comcast.net~mrltapes/pub101.pdf : These are the most commonly used Calibration Tapes. They contain a series of voice-announced recorded sine-wave signals which can be monitored with the program level meter on the tape reproducer, or on an external voltmeter. They contain a 1000 Hz section for setting the reproducer gain, an 8 kHz and a 16 kHz section for setting head azimuth and preliminary frequency response adjustment, and a series of frequencies at octaves from 32 Hz to 8 kHz, and one-third octaves from 10 kHz to 20 kHz, for calibrating the reproducer frequency response. Total duration ranges from 6 minutes for ¼ inch tape to 16 minutes for 2 inch tape. You can also special order Multifrequency tapes with *any* of these timing programs an *any* of the tape widths.

1.2.4.2 *Short Calibration Tapes with Chromatic Sweep* (Publication CHROM) http://home.comcast.net/~mrltapes/pubchrom.pdf are also for monitoring on the reproducer's own program level meter. They contain a 1 kHz and a 10 kHz tone (and optionally a 100 Hz tone) for making adjustments, and musical-semitone steps from 32 Hz to 20 kHz in 105 s, announced at the octaves, to verify the response over the entire audio frequency range. They provide more information, in less time and at less cost, than the Multifrequency Calibration Tapes. Total durations are 4 minutes or 8 minutes. They are also available in two-speed (15 and 30 in/s) versions.

1.2.4.3 *"Minimalist" Calibration Tapes*: For routine calibration of reproducers, many of our customers use "minimalist" calibration tapes with just a few tones. Out of the many possibilities, certain ones are so commonly requested that we have created the Publications below listing the part numbers and prices for 4- and 8-minute durations, at 250- and 355-nWb/m reference fluxivities, for all speeds and equalizations.

Publication 560 : 1kHz single frequency
http://home.comcast.net/~mrltapes/pub560.pdf .

Publication 580: 10 kHz single frequency
http://home.comcast.net/~mrltapes/pub580.pdf

Publication 611: 1 kHz and 10 kHz, ½ each.
http://home.comcast.net/~mrltapes/pub611.pdf

Publication 644: 1 kHz, 10 kHz, 100 Hz, a each
http://home.comcast.net/~mrltapes/pub644.pdf

Publication 673: 1 kHz, 10 kHz, 16 kHz, 100 Hz, ¼ each
http://home.comcast.net/~mrltapes/pub673.pdf

Other "minimalist" tapes are for multi-speeds:

Publication SMS1: White Noise, 500 Hz, 10 kHz, 1 kHz; 2, 3, or 4 speeds with NAB and AES equalization, at 250 nWb/m only, http://home.comcast.net/~mrltapes/pubsms1.pdf .

Table 1 Current Standard Equalizations Per IEC, NAB, and AES Standards
Transition Frequencies, F_{low} and F_{hi}, (and Transition Time Constants, $\tau = 1/(2\pi F)$)

TAPE SPEED	Professional			Commercial Tape Records and Home Recorders IEC, RIAA, & EIA
	Open-Reel		Broadcast Cartridge IEC & NAB (obsolete, no longer available)	
	IEC1 (IEC)	IEC2 (NAB)		
95 mm/s 3.75 in/s	Not Used Professionally	[NAB only] 50 Hz, 1800 Hz (3150 µs, 90 µs)	[Commercial-*not std*] [50 Hz, 1800 Hz] [(3150 µs, 90 µs)]	50 Hz, 1800 Hz (3150 µs, 90 µs)
190 mm/s 7.5 in/s	0 Hz, 2240 Hz (∞, 70 µs)	50 Hz, 3150 Hz (3150 µs, 50 µs)	0 Hz, 3150 Hz (∞, 50 µs)	50 Hz, 3150 Hz (3150 µs, 50 µs)
380 mm/s 15 in/s	0 Hz, 4500 Hz (∞, 35 µs)	50 Hz, 3150 Hz (3150 µs, 50 µs)	[Commercial-*not std*] [0 Hz, 6300 Hz] [(∞, 25 µs)]	Not Used for Tape Records and Home Recorders
760 mm/s 30 in/s	[IEC1 is *obsolete*] [0 Hz, 4500 Hz] [(∞, 35 µs)]	AES-1971 (no NAB) 0 Hz, 9000 Hz (∞, 17.5 µs)	Not Used in Cartridge	Not Used for Tape Records and Home Recorders

Publication SMS2a: Several different programs of tones at two speeds: at 7.5 in/s NAB and 15 in/s NAB; at 15 in/s IEC and 30 in/s AES; and at 15 in/s NAB and 30 in/s AES. All of the these are available in 250- or 355-nWb/m reference fluxivity, and 5.5- or 11-minute durations, http://home.comcast.net/~mrltapes/pubsms2a.pdf .

1.2.4.4 *Fast Swept-Frequency Calibration Tapes* (Publication 313) http://home.comcast.net/~mrltapes/pub313.pdf : Alignment of a magnetic tape recorder-reproducer requires such mechanical adjustments as head-height, vertex angle, azimuth angle, etc., and such electronic adjustments as gain and multiple equalizer responses across the frequency pass-band. Most of these adjustments interact with each other.

The usual Multifrequency Reproducer Calibration Tapes contain a series of discrete frequencies. Often, in order to perform the adjustments, one must rewind and replay the Calibration Tape several times in order to obtain proper mechanical adjustment and optimum frequency response.

The alignment procedure is much simpler and faster if you use a Calibration Tape containing a repeating fast-swept frequency. This signal, viewed on an oscilloscope, gives the appearance of a continuous display of all frequencies at once. Thus the effect of the adjustments and their interactions is immediately apparent because the display is updated 6 times per second. Note that the display update on the "high-tech" analyzers such as Sound Technology and Audio Precision is much slower: more typically once every second or two. The Fast Swept-Frequency is not fancy, automatic, computerized, etc., etc., but it is *FAST*, and therefore much more useful for adjusting a tape reproducer, especially if it is badly out of adjustment.

Fast Swept-Frequency Calibration Tapes contain a repeated sweep (actually, since 1994, 1/6th octave steps) from 500 Hz to 20 kHz in 100 ms, with a 65 ms blanked interval between sweeps — that is, 6 sweeps per second. This signal must be read out using an oscilloscope with an MRL Graticule. The first cycle of each sweep is at triple amplitude for synchronizing the oscilloscope. Finally, after the sweeps, there is 30 s of 1000 Hz for setting the reproducer gain.

Because various oscilloscope sizes are commonly used, the GRATICULES ARE NOT INCLUDED WITH THE SWEEP TAPES, but are sold separately.

1.2.4.5 *Slow Swept-Frequency Calibration Tapes* (Publication 402) http://home.comcast.net/~mrltapes/pub402.pdf : If you have an automatic level recorder, you can use the Slow Swept- Frequency Calibration Tapes to produce a complete written record of the frequency response of an adjusted reproducer. The signal on these tapes is suitable for readout on the United Recording Electronics Industries (UREI) Model 200 Series Level Recorder, with either the Model 2000 Automatic Response Plotting Module, or the Model 2010 Level and Frequency Detector Module; or with the Bruel and Kjaer Level Recorders, with or without the Model 4409 or 4416 "Response Test Unit".

The MRL Slow Swept-frequency Calibration Tapes contain a number of repetitions of the following 60-s sequence: 1000 Hz for 8.33 s, for level set and for the B & K automatic start system; 20 Hz for 1.67 s, for the UREI Frequency Detector to lock in on the starting frequency; then a sweep from 20 Hz to 20 kHz in 50 s. This sweep rate may be expressed as 1.67 s per a rd octave, or 16.67 s per decade of frequency.

1.2.4.6 *Signals for Use With Sound Technology 1500 Series* (Publication 211) http://home.comcast.net/~mrltapes/pub211.pdf : Special test signals designed to be used with the Sound Technology 1500 Series Tape Recorder/Audio Test System.

1.2.4.7 *Signals for Use With Audio Precision "System One" Program 2HD-FREQ* (Publication 423) http://home.comcast.net/~mrltapes/pub423.pdf : 1 kHz reference fluxivity, 16 kHz and 10 kHz for azimuth and high-frequency equalization, 100 Hz for low-frequency equalization, then two a rd octave step tone series of signals designed to be used with the Audio Precision "System One" Program 2HD-FREQ.

1.2.4.8 *Broadband White- or Pink-Spectrum Random Noise* (Publications 702 http://home.comcast.net/~mrltapes/pub702.pdf and 802 http://home.comcast.net/~mrltapes/pub802.pdf): Broadband random noise (20 Hz...20 kHz) of either "white" spectrum or "pink" spectrum.

The white spectrum is especially suited to analysis by a constant-bandwidth filter. Because of its large high-frequency amplitude, it is also very useful for adjusting the azimuth of full-track reproducers, or for adjusting multitrack reproducers for minimum intertrack time displacement ("phase error").

The pink spectrum is especially suited to analysis by a frequency-proportional bandwidth (for example, a rd octave) filter.

Finally, there is 30 s of 1000 Hz tone, for setting the reproducer gain.

1.2.4.9 *3150-Hz Flutter and Speed Test* (Publication 570) http://home.comcast.net/~mrltapes/pub570.pdf : A 3150-Hz test frequency is recorded, in accordance with current standards of IEC, AES, CCIR, and DIN.

The weighted peak flutter of the recordings ranges from ±0.02 % at 30 in/s (760 mm/s) to ±0.10 % at 3.75 in/s (95 mm/s).

This tape may also be used for "tape speed" measurements. The wavelength recorded is ±0.1 % of the true value.

1.2.4.10 *Polarity Calibration Tapes* (Publication 203) http://home.comcast.net/~mrltapes/pub203.pdf : A full-track recording of a truncated sawtooth according to the specification given by Lipshitz and Vanderkooy [14]. This polarity convention has been adopted as an AES Standard [15], as well as being standardized by the European Broadcasting Union (EBU) and the Society of Motion Picture and Television Engineers (SMPTE).

1.2.4.11 *Special Test Signals*: We can make for you Multifrequency Calibration Tapes similar to those of §1.2.4.1 in any standard width, speed, and equalization, in a wide range of fluxivity levels in 1 dB increments, using the frequency sequences and durations shown in Pub. 101. In other words, you could order a ¼ inch wide tape with the durations and sequence usually used for a 2 inch wide tape. Or a 2 inch-wide tape with the 8-minute program usually used for ½ inch tape, with a considerable cost saving.

MRL's recording system is computer controlled, and programmed in the Forth language. Therefore we can easily make almost any sequence of frequencies, levels, and durations that you need. Contact us with the details of your requirements for special test signals, including the frequency, level, and duration of each signal, the duration of blank leader (if any) between tones, whether or not you want voice announcements, and the quantity of tapes that you will need.

The prices for specials depend on the width, speed, and duration of the recordings. They are shown on the back of our price list, Publication PL http;//home.comcast.net/~mrltapes/pubpl2008.pdf .You will have to contact us for a part number — there are too many possibilities to give all of the numbers in a catalog.

1.2.5 ***Levels***: All Multifrequency Calibration Tapes (as described in Pub. 101 http://home.comcast.net/~mrltapes/pub101.pdf) have a 1 kHz tone at 0 dB (that is, at the reference fluxivity itself) at both ends;

3.75 and 7.5 in/s Multifrequency Calibration Tapes have all other tones at 10 dB below the reference fluxivity in order to avoid tape saturation at the short wavelengths;

> The 10 dB level reduction is a historical artifact of the 1950s. At that time, the short-wavelength losses of tapes required a 10 dB level reduction at 16- to 20-kHz in order to prevent saturating the tape. Also, the US voltage level meters of that day had a 10 dB per step range attenuator. With modern tapes, a reduction of 5 dB would be sufficient, and would allow one to make accurate readings on the scale of a vu meter. We can do this, if you request it. But old habits are hard to change.

15 and 30 in/s Multifrequency Calibration Tapes have all tones at 0 dB *except for G320 nWb/m IEC tapes* (see § 5.2.4.2 for G320).

The Multifrequency Tapes with G320 nWb/m reference fluxivity are in conformance with the customary European studio practice, where peak-reading program meters (PPMs) are used. The test signals are recorded on these tapes at -10 dB, in conformance with the customary European studio practice developed before the existence of high output mastering tapes. Because the PPMs have a long linear level scale, they can accurately read the test signal levels at -10 dB.

Most reproducers in the US use a "Standard Volume Indicator" (vu meter) which is only accurate for test signals in the range +3 dB to -6 dB. If you have a vu meter, it is *not* accurate at -10 dB, and in order to use these Multifrequency Tapes you will have to either use an external level meter with 10 dB more sensitivity, or else you will have to increase your reproducer gain by 10 dB each time you want to use these tapes. **We therefore recommend using the 250- or 355-nWb/m**

Multifrequency Tapes rather than the G320 nWb/m Multifrequency Tapes on all systems with vu meters.

1.2.6 ***Reference Fluxivity*** is a signal of known magnetic magnitude, such as 250 nanowebers per meter [nWb/m], usually at 1000 Hz. In practical sound recording it is used to calibrate the gain of the reproducer so that the program level meter (vu meter or PPM) reads some standard level, usually 0 dB (the "reference deflection" of the meter). Since the recorder is subsequently set to record this same fluxivity, the reference fluxivity is thus used indirectly to set the program levels recorded on tape.

If all of the elements of analog tape recording could be standardized, a single standard reference fluxivity could be used. Unfortunately, the elements are not standardized, nor — because of continuing improvements in analog recording media and systems — is it even possible or desirable to completely standardize them. Therefore several values of reference fluxivity are commonly used. The following sections give our practical recommendations.

1.2.6.1 *Choosing a Reference Fluxivity*

The reference fluxivity value and usage is interconnected with the entire subject of optimal signal level control of the audio system. It is a more complicated subject than we can discuss fully here, so we will give a few highlights and recommendations.

To our knowledge, there are *no published engineering standards for analog sound recording system that tell how to choose the reference fluxivity, nor for what reading on the program level meter corresponds to the reference fluxivity*. Therefore you will be given advice on "the correct reference fluxivity" by the tape recorder manufacturers in their manuals, by the tape manufacturers in their literature, by references to standards organizations, and by us. Unfortunately some of this advice is based on obsolete blank tape and equipment types, and on misunderstandings about standards and operating practices. *If you know of a published engineering standard, please send us a copy to reference in this publication.* (We first published this in 1992, and in 2010 we're still hoping for a reply!)

There are four particular sources of **conflicting requirements** that you will have to balance in establishing the reference fluxivity to use:

The **first conflict** is caused by progress in tape development — the maximum output level (MOL, at which the third-harmonic distortion becomes 3 %) of the newest tapes (Quantegy 499 and GP9, RMGI 900) is some 10 dB greater than that of the old reference tape (3M 111) on which many practices are based. How should this increased MOL be used? Should the reference fluxivity be kept constant, which will reduce the non-linear distortion due to tape saturation? Or should the reference fluxivity be increased, which will reduce the relative background noise?

The **second conflict** is caused by the use of two very different kinds of program level meters — one is the "peak program meter (PPM)", a voltmeter with active circuitry that averages the signal over about 5 to 10 ms, and so reads about 3 dB below the signal peak levels; and the other is the "vu meter", a passive ac voltmeter that averages the signal over roughly 200 ms, and so reads about 10 dB below the signal peak levels. If the two meters read the same on a steady-state signal such as a sine wave, they will read from 3 to 15 dB different on programs — "typically" about 8 dB.

Furthermore, altho the level monitoring meters — the vu meter in the US, and the PPM in Europe — *are* standardized, *the way they are used is not standardized*. To appreciate the situation, we recommend that you read "Three-Level Test Signal for Setting Audio Levels" by A. N. Thiele [16]. Note that the IEC has standardized three different scale markings for the PPM: one with full-scale level marked as +5 dB, one marked as +13 dB, and one with unnamed 4 dB divisions marked 1 to 7, with full scale at 7.25 [17]. Also, the DIN PPM is faster (5 ms integration time) than the IEC (10 ms integration time).

At one time the PPM was used in Europe and the vu meter in the US. But now both are being used more often in both places. How should the reference fluxivity be set to accommodate this difference in scale markings and averaging times?

The **third conflict** is the conflicting goals in level controlling: One is to produce *uniformity of recorded level* on recordings on all blank tapes, even tho the tapes may have different recording sensitivities and different maximum output levels. The other goal is to *get maximum dynamic range of the medium* by recording at the highest possible level without distortion on each different kind of blank tape. Since the maximum output levels of open-reel tapes now cover a range of about 10 dB, if you use different kinds of blank tape stock, it is clearly not possible to achieve both goals at the same time with all kinds of blank tape.

Uniformity of level is usually most important where a large library of recordings is to be used, and they must all play at the same level with a minimum of attention from an operator — for instance, in a broadcasting station that plays many different tape recordings on the air. In this case a standard reference fluxivity is chosen and used for all kinds of recording tape.

On the other hand, obtaining the maximum dynamic range of the medium is usually most important where the dynamic range of the program material is large, or the dynamic range of the recording system is reduced because of narrow recording tracks on tape, many re-recordings of the program, etc.; and the operator is available to control levels individually — for instance, in a sound recording and record mastering studio. In this case a different reference fluxivity is used for each of the various kinds of recording tape.

The **fourth conflict** has to do with maximizing the dynamic range of a given tape recording system. The dynamic range is limited at high levels by the distortion produced by compression of the signal as the tape approaches saturation; and at low levels by the tape noise, which is just another kind of distortion.

Originally the only way to maximize the dynamic range of a recording system was to record such a high level that 1 or 2 dB of tape compression would occur on the peak levels. This corresponds to a recording level increase of about 3 to 6 dB above that for which no compression occurs. The distortion due to the tape compression is nearly inaudible in practice, but the effective noise level reduction of 3 to 6 dB is very audible.

Modern companding noise-reduction (NR) systems were introduced by Dolby in the mid-1960s, and later by others (dbx, etc.) Because these NR systems increase the dynamic range by 10 dB or more, it is not necessary to record at levels so high that they produce tape compression. In fact, if there is tape compression it will seriously degrade the performance of the NR system.

Therefore if maximum dynamic range is required and NR is not used, the reference fluxivity can be 3 to 6 dB higher than when NR is used.

1.2.6.2 *Common US Practice* is to monitor the recording level with a Standard Volume Indicator (vu meter). The *reference fluxivity* is usually used to set the reproducer gain so that the vu meter reads 0 dB. Different reference fluxivities are used as shown in**Table2** below, according to the remanence fluxivity (saturation output) of the blank tape to be used for recording, and whether or not noise reduction (NR, such as Dolby, dbx, etc.) will be used.

> If you experiment with different tapes, keep the same headroom during a test: if you use Quantegy 456 at 250 nWb/m, then try Quantegy 499 at 355 nWb/m (not 500 nWb/m). Otherwise you will not be able to tell whether any change you get in performance — better or worse — is due to the change of tape, or due to the change of headroom.

If you expect to use the very-high output tape (Quantegy 499 or GP9, or RMGI 900) without NR, but you might also sometimes use NR or other tapes, we recommend using the 355 nWb/m (+6 dB) reference fluxivity. With this, a ±3 dB offset on a vu meter will let you set up for reference fluxivities in the range 250...500 nWb/m (+3 to +9 dB). See §2.3.1 for details. If you are sure that you will be using *only* the very-high output tapes, the 500 nWb/m reference fluxivity is available on request, even tho it is not specifically mentioned in our "Publications". For the multifrequency tapes of Pub. 101 at 500 nWb/m, use "5" for the fourth character of the catalog number.

1.2.6.3 *Common European Broadcasting Practice* is to monitor the recording level with a Peak Program Meter (PPM), and to use a reference fluxivity of G320 nWb/m for mono recordings, and G510 nWb/m for stereo recordings. (See §5.2.4.2 for more information on G320 nWb/m.)

1.2.6.4 *Fluxivity Level* in decibels [dB] is sometimes given instead of the fluxivity in nanowebers per meter. **Table 3** gives the commonly used fluxivities and corresponding levels.

The fluxivity level L_Φ was calculated using the formula: $L_\Phi = 20 \log_{10} (\Phi/\Phi_{ref})$, where Φ_{ref} is the reference fluxivity, which in this case is the old "Ampex Operating Level" of 185 nWb/m at 700 Hz (corresponding to 180 nWb/m at 1000 Hz — see §5.2.4.1). The fluxivities listed above are conventionally rounded to the R 20 "Preferred Number" values of the ISO Standards [18], which correspond to 1 dB increments of level. You may also see slightly different values that are unrounded conversions between fluxivities and levels.

1.2.7 *Track Configuration and Fringing Compensation*: All MRL Calibration Tapes are recorded full track in order to provide the most uniform flux and time alignment across the tape width.

When full-track tapes are reproduced on multi-track heads, a small low-frequency measurement error called "fringing" occurs. Unless otherwise requested, we apply an approximate correction for fringing while recording ½ inch, 1 inch, and 2 inch width tapes, but not ¼ inch tapes. See §2.2 and §5.1.1 for details.

1.2.8 *Packaging*: Unless otherwise specified, MRL Open-reel Calibration Tapes are supplied on a reel, in a box.

¼ inch tapes are usually supplied on 7 inch (180 mm) diameter plastic reels with a 4 inch (100 mm) hub and a 0.319 inch (8 mm) mounting hole. Lengths too great to fit these reels are supplied on a 10.5 inch (270 mm) plastic reel with a 4.5 inch (115 mm) hub and 3 inch (76 mm) mounting hole.

Wider tapes are supplied on 8 inch (200 mm) or 10.5 inch (270 mm) diameter metal reels with 3 inch (76 mm) mounting holes.

1.2.9 *Blank Tape Stock*: The manufacturers of professional analog audio tape have been — how should we put it? — in a state of flux. 3M sold its pro audio products to Quantegy, and left the pro audio analog market completely. Ampex Recording Media Corp was sold to Quantegy Inc, now bankrupt. The German tape manufacturer AGFA was sold to BASF, and it in turn was sold to Emtec, in turn sold to Recordable Media Group International, B.V. of the Netherlands (RMG International, or RMGI) http://www.rmgi-usa.com/index.html , who is currently (2010) manufacturing the AGFA/BASF/Emtec tapes under their original type numbers. Another new manufacturer of high-output studio tapes is ATR Magnetics http://www.atrtape.com/ . MRL Calibration Tapes are available on ATR tape at a slightly higher price http://home.comcast.net/~mrltapes/pubpl2008-atr.pdf

Our standard stock for Open-reel Calibration Tapes for 200- and 250-nWb/m fluxivity is RMGI Studio Master 911, which we identify by a red dot on the box spine).

Many studios use higher-output tapes such as Quantegy 456, 499, or GP9, or RMGI 900. We do not always use these tapes, because they are more expensive and do not provide any benefit for a Calibration Tape. With very few exceptions *the blank tape stock doesn't make any difference for a Calibration Tape, because the test signals are standardized independently of the blank tape, and the test signals are not recorded at the peak levels used for programs.* Also, for instance, RMGI uses the same base materials, binders, and processing equipment to make SM900 and SM911. The only difference is in the oxide particles — the oxide in SM900 has better dynamic range and is therefore better for recording programs, but it is not better for making a Calibration Tape, nor does it guide differently, nor last longer.

You can avoid the delay for special production by using the standard blank tapes – talk to MRL Technical Support if you believe that you need one of these high-output blank tape stocks.

The one exception is for Calibration Tapes recorded at fluxivities of 500 nWb/m and greater. These require tapes with higher saturation flux than RMGI 911. For 500 nWb/m reference fluxivity, we use RMGI 900 (lite blue).

Since there are lots more tape types than dot colors, we have had to reuse the colors when tape types have been discontinued. If you have a calibration tape with a red, orange, or blue dot made before 1994-06, call us with the serial number of the tape, and we can tell you what kind of blank tape type was used.

Table 2 Blank Tapes and Reference Fluxivities Commonly Used

Blank tapes (typical)	3M 111 Quantegy 642	3M 206 Quantegy 406	Quantegy 456, RMGI 911 or 468	Quantegy 499 or GP9, RMGI 900
Tape Sat. Remanance Fluxivity	~1000 nWb/m	~1400 nWb/m	~2300 nWb/m	~2900 nWb/m
For Systems **with NR** (Low Ref Flux)	—	200 nWb/m	250 nWb/m	355 nWb/m
For Systems **without NR** (Medium Ref Flux)	200 nWb/m	250 nWb/m	355 nWb/m	500 nWb/m

Remanence values are from the tape manufacturers' "magnetic properties" in their data sheets.

2 TAPE REPRODUCER ADJUSTMENT TECHNIQUES

2.1 Preliminary

Before using any Calibration Tape, the heads and tape guides should be cleaned and demagnetized. See [19] for detailed demagnetizing techniques. Heads should be visually checked for "lips" at the edge of tape travel, and for wear-through at the gaps. While running a blank tape, look to see that it is tracking properly and that the heads are not obviously misadjusted. The relative height of the tape guides and heads should be such that the tape is symmetrically located over the head faces. That is, the distance from the edge of the tape to the next outside shield should be the same at both edges of the tape. See [20] for detailed head-height adjusting techniques.

If the tape is wound unevenly on the reel, it is easily damaged in handling and storage. MRL Open-reel Calibration Tapes are supplied "tail out" for best storage. Mount them on the takeup side, with the label facing up, and rewind them immediately before use. (If the voice announcements sound like some really weird foreign language, you probably forgot to rewind the tape.) After use, leave them in the "tail out" position again for removal and storage. All tapes should be stored in the "played" (tail out) position, since fast rewinding usually produces an uneven tape pack.

Play the Calibration Tape, and check (without adjusting) the

Table 3 Fluxivities and Fluxivity Levels

Fluxivity at 1 kHz	Fluxivity Level re 185 nWb/m at 700 Hz
180 nWb/m = 185 nWb/m at 700 Hz*	0 dB
200 nWb/m	+1 dB
224 nWb/m	+2 dB
250 nWb/m = 260 nWb/m at 700 Hz*	+3 dB
280 nWb/m = G320 nWb/m**	+4 dB
315 nWb/m	+5 dB
355 nWb/m = 370 nWb/m at 700 Hz*	+6 dB
400 nWb/m	+7 dB
450 nWb/m = G510 nWb/m**	+8 dB
500 nWb/m	+9 dB

* See § 5.2.4.1 on page 10.
** See § 5.2.4.2 on page 10 on G320 and G510.

reproducer gain, the head azimuth, and the high and low frequency response. ***If the reproducer was in adjustment previously, but now shows an incorrect azimuth, sensitivity, or response, check the mechanical alignment of the transport and heads before adjusting the electronics. Mechanical errors cannot be properly compensated by electronics adjustments.***

Then, if adjustment of the reproducer is required and possible, set the high- and low-frequency equalization controls according the tape recorder manufacturer's instructions in order to obtain the most uniform frequency response.

The following sections give advanced topics that may not be covered in the recorder manufacturer's manuals.

2.2 Low-Frequency Response Calibration

Calibrating the frequency response of a magnetic tape reproducer is usually a simple process: play a reproducer calibration test tape, and write down the output level versus frequency, or adjust the reproducer equalizers for as nearly as possible constant output voltage level versus frequency.

However, at medium to low frequencies — below 500 Hz at a tape speed of 15 in/s (380 mm/s) — there are several important sources of error that make this approach inaccurate:

1) The equalization standards below 50 Hz are often not followed exactly in practice.

2) Some head core widths, and therefore track widths, are not standardized in practice, and although fringing response calculations exist, they are only approximate (see §5.1.1 below).

3) There are too few frequencies on the usual Multifrequency Calibration Tapes to characterize accurately the undulating low-frequency response of most reproducing heads.

If you want all of the details, download the paper "Low-Frequency Response Calibration of a Multitrack Magnetic Tape Recording and Reproducing System" by J. G. McKnight [21]. That paper points out that some of these errors can be avoided by using the *recording* section of a system to calibrate the low-frequency response of the *reproducing* system. (This method can *not* be used for high-frequency calibration.)

This method of setting the reproducer response against the recorder response is recommended by most professional recorder manufacturers in their instruction books. Despite the availability of this information, many users are neither aware of the sources of error, nor of the methods for avoiding the errors.

The best practical solution for many casual users may simply be to ignore the problems entirely. The audibility of the differences in tape recording and reproducing system responses below 125 Hz may often be obscured by differences in response between various loudspeakers and their associated room acoustics. The meticulous users will surely object: the response errors in one generation of recording might be inaudible, but they will certainly cause problems in multiple generations through the same recording and reproducing system. Furthermore, the errors of response will be increased by companding systems (noise-reduction systems such as Dolby, dbx, etc.) And finally, systems using low-frequency control tones will have problems. Can a practical solution be found to eliminate all these errors at once? Yes — and it is summarized as follows:

1) Decide exactly what low-frequency recording equalization you want to use, and modify all recorders to this equalization.

2) Standardize the widths of the head cores, and thereby the widths of the recorded and reproduced tracks in all of your recorders and reproducers. Also, be sure all head heights are correctly set, so the tracks will be correctly located. (See [21] if you want to modify the equalization or standardize core widths.)

3) Calibrate the reproducers against the now-calibrated recorders by recording and reproducing. Slowly sweep the frequency to determine the maxima and minima of response, and set the reproducer low-frequency equalization for the flattest average response.

2.2.1 *Calibrate the Reproducer*: To calibrate a reproducing system against a recording system, record and reproduce simultaneously on *one* track; sweep the frequency slowly down from 1000 Hz to the lowest frequency of interest (16 Hz?? 32 Hz??). Find the frequencies and amplitudes of the response maxima and minima; then adjust the reproducing low-frequency equalizer for "optimum flatness." We personally prefer to set the low-frequency maximum to be not more than +1 dB and let the minima fall where they may.

2.2.2 *Calibrate the Calibration Tape*: Now that you have adjusted one track of the reproducing system to the optimum response, you should reproduce your MRL Reproducer Calibration Tape and read and write down *its* response on that same adjusted track. These readings constitute a custom calibration table for this Calibration Tape on your particular reproducing system, to correct for all the effects we have discussed: variations in the standard equalization, track width, and fringing, and the response at the test frequencies on the Calibration Tape. In other words, your custom calibration table describes the way the MRL Calibration Tape should play on your system when it is properly adjusted.

Now you can use this custom calibration table with the Reproducer Calibration Tape to adjust all of the other tracks on this reproducer, and all of the tracks on any other identical type of reproducer. You can also use it in the future to readjust the original reproducer, in case someone changes it.

Some systems utilize machines which reproduce *only*, and do not record at all. In this case record a low-frequency slow sweep on whatever recorder is normally used to make the recordings which this reproducer plays. In this case an automatic level recorder is almost a necessity for plotting the reproducer's response.

2.3 In Case You Don't Have the Right Calibration Tape

You should have a Calibration Tape for each speed, equalization, and reference fluxivity that you use regularly. A full set of Multifrequency Calibration tapes may be too expensive. A *Short Calibration Tape with Chromatic Sweep* (§1.2.4.2 above), a *"Minimalist" Calibration Tape* (§1.2.4.3), or a *Special Test Signal* (§1.2.4.11), can give you more flexibility at lower cost.

Even then you may have an unexpected call for a speed, equalization, or reference fluxivity that you don't ordinarily use. In this case you can use a correction table to make do with the tape you already have.

2.3.1 *Shifting the Reference Fluxivity*: Use **Table 4** below to determine the offset for setting to one reference fluxivity, given a Calibration Tape with another reference fluxivity. Suppose you have a 250 nWb/m Calibration Tape, and want to set your reproducer for 500 nWb/m reference fluxivity. Find the box along the left side that corresponds to the tape you have: e. g.. "250 nWb/m". Then find the line in the box to the right for the desired fluxivity: e. g.. "500 nWb/m". On the same line in the next box to the right read "-6 dB". This means to play your 250 nWb/m Calibration Tape and set the reproducer gain so that the program level meter on your reproducer reads -6 dB.

After setting the reproducer gain this way, remove your Calibration Tape, put on a roll of your blank tape, and adjust the recording level so the signal plays back at 0 dB. This recording is thus recorded 6 dB above 250 nWb/m, which is the desired 500 nWb/m.

2.3.2 *Shifting the Equalization Standard*: In general, you will need a separate Calibration Tape for each different speed and equalization.

The exception is the following group, whose members are identical on a wavelength basis: that is, you can play any of these Calibration Tapes at any of these speeds, set the reproducer equalizers for flat response, and have a correct calibration:

7.5 in/s IEC (IEC1)   15 in/s IEC (IEC1)   30 in/s AES (IEC2)

Of course the frequency range scales with speed, and the playing times scale inversely with speed.

For some other speeds and equalizations, the subtables in **Table 5** on the next page give the frequencies and corresponding level offsets for substituting a Calibration Tape that you have for one of another speed, equalization, or both. The complete set for all combinations is at http://home.comcast.net/~mrltapes/eq-shift-tables.pdf .

In the captions of Table 5, "Calibration Tape" identifies the speed and equalization of the Calibration Tape that you *have*, and "Desired Playback" identifies the speed and equalization that you want your reproducer to be set for. For example, if you have a 15 in/s NAB Calibration Tape, and want to set up a 30 in/s AES reproducer, you will find this combination in Table 5-3. Play the tape at 30 in/s, and set the reproducer gain control so the 1 kHz recording — which plays as 2 kHz — reads 0 dB on the level meter; then set the high-frequency equalizer so the 8 kHz recording — which plays as 16 kHz — reads -2.33 dB on the level meter, as shown in the table.

Some of the tables are for the Calibration Tape and the playback at the same speed. For those tables *only*, you can reverse the Calibration Tape and the playback equalization conversion just by inverting the sign of the Playback Level column. For example, suppose you have a 15 in/s IEC Calibration Tape, and you want to set the Playback for 15 in/s NAB equalization. Use the Table 5-4, but, where the table shows -2.51 dB at 10 kHz for the NAB to IEC conversion, use +2.51 dB for the IEC to NAB conversion.

In the captions of Table 5, "Calibration Tape" identifies the speed and equalization of the Calibration Tape that you *have*, and "Desired Playback" identifies the speed and equalization that you want your reproducer to be set for. For example, if you have a 15 in/s NAB Calibration Tape, and want to set up a 30 in/s AES reproducer, you will find this combination in Table 5-3. Play the tape at 30 in/s, and set the reproducer gain control so the 1 kHz recording — which plays as 2 kHz — reads 0 dB on the level meter; then set the high-frequency equalizer so the 8 kHz recording — which plays as 16 kHz — reads -2.33 dB on the level meter, as shown in the table.

Some of the tables are for the Calibration Tape and the playback at the same speed. For those tables *only*, you can reverse the Calibration Tape and the playback equalization conversion just by inverting the sign of the Playback Level column. For example, suppose you have a 15 in/s IEC Calibration Tape, and you want to set the Playback for 15 in/s NAB equalization. Use the Table 5-4, but, where the table shows -2.51 dB at 10 kHz for the NAB to IEC conversion, use +2.51 dB for the IEC to NAB conversion.

Table 4 Reference Fluxivity Conversions

Reference Fluxivity of the Calibration Tape ***That You Have***	Desired Reference Fluxivity	Set Reproducer Gain So Volume Indicator Reads
180 nWb/m at 1000 Hz = 185 nWb/m at 700 Hz*	185	0 dB
	200	-1 dB
	250	-3 dB
	G320	-4 dB
	355	-6 dB
	500	-9 dB
200 nWb/m at 1000 Hz	185	+1 dB
	200	0 dB
	250	-2 dB
	G320	-3 dB
	355	-5 dB
	500	-8 dB
250 nWb/m at 1000 Hz = 260 nWb/m at 700 Hz*	185	+3 dB
	200	+2 dB
	250	0 dB
	G320	-1 dB
	355	-3 dB
	500	-6 dB
G320 nWb/m at 1000 Hz**	185	+4 dB
	200	+3 dB
	250	+1 dB
	G320	0 dB
	355	-2 dB
	500	-5 dB
355 nWb/m at 1000 Hz = 370 nWb/m at 700 Hz*	185	+6 dB
	200	+5 dB
	250	+3 dB
	G320	+2 dB
	355	0 dB
	500	-3 dB
500 nWb/m at 1000 Hz	185	+9 dB
	200	+8 dB
	250	+6 dB
	G320	+5 dB
	355	+3 dB
	500	0 dB

* See §5.2.4.1 on page 10.

** See §5.2.4.2 on page 10 on G320 and G510.

2.4 Levels in a Tape Recorder/reproducer

There are three important but different kinds of levels involved in setting up a tape recorder: The first is the magnetic fluxivity level in decibels on the magnetic tape itself. The second is the electrical voltage level in decibels at the input and output connectors, commonly called the "line level". The third is the level in decibels indicated by the program level meter (we assume a vu meter in this discussion).

Since all three are "levels in decibels", it is easy to confuse them. So we have occasional calls from a puzzled tape recorder owner who says he needs a Calibration Tape made "for a -10 dB recorder", or "for a +4 vu recorder".

Perhaps the easiest way to clear the confusion is to go back from the levels in decibels to the fundamental quantities: the magnetic fluxivity in nanowebers per meter; the electrical line voltage in volts; and the sensitivity of the meter in volts for the "reference deflection" (0 dB reading). Let's look at each of these quantities.

2.4.1 *Reference Fluxivity*

MRL Calibration Tapes are made with several different values of "Reference Fluxivity". Each is designed to be used for setting up for a particular kind of blank tape which will be used later for recording. The Reference Fluxivity is intended to be used to set the reproducer gain so that the vu meter reads Reference Deflection (0 dB).

2.4.2 *Reference Output Voltage*

Two reference output voltages are commonly used in the US for the line levels on recorders with vu meters. In each case the "reference output voltage" (usually called "standard line level") corresponds to the "reference deflection" (0 dB reading) of the vu meter.

One standard line level is "+4 vu", which is the de facto "professional" recording studio standard used by many tape recorder makers, including Ampex starting around 1948. The original vu meter system is based on a passive ac voltmeter designed so that the reference deflection of the meter (0 dB) corresponds to a line voltage of 1.25 V. This voltage corresponds to 2.5 mW dissipated in a 600 Ω load resistor, which in turn corresponds to a power level relative to 1 milliwatt of +4 dB (abbreviated +4 dBm), and this is called a "+4 vu" line level. These systems are usually balanced.

> Altho the original audio systems of the 1920s to 1940s actually had 600 Ω input and output impedances, and were designed to be used with 600 Ω source and load impedances, most systems designed since the 1940s are 600 Ω in name only, having a lower output impedance and a higher input impedance. For more information, see [22].

The other standard line level is "-10 dBV", which is the de facto"semi-professional" standard used by several makers, including Tascam and Fostex. The metering system is designed so that the reference deflection of the meter (0 dB) corresponds to an output voltage of 315 mV, which corresponds to a voltage level relative to 1 volt of -10 dB; this is commonly called a "-10 dBV" line level. These systems are usually designed to work into a load impedance of 10 kΩ or more, and are usually unbalanced.

For interchangeability of line input and output levels, it is important that this voltage actually be 1.25 V for a "+4 vu" system, or 315 mV for a "-10 dBV" system. It is of course also important that, if "professional" and "semi-professional" systems need to be interconnected, an interface circuit be provided to convert the voltage, the impedance, and the balance/unbalance.

2.4.3 *Program Level Meter Sensitivity*

To calibrate the meter sensitivity, you measure the line voltage with an accurate voltmeter, adjust the line voltage to be its standard voltage (1.25 V for +4 dBm in a nominal 600 Ω system), then adjust the rheostat associated with the vu meter so the meter reads 0 dB.

Table 5 **Conversions for Different Speeds and Equalizations, Normalized to the 1000 Hz Fluxivity**

Table 5-1 For *any* Calibration Tape and *any* Desired Playback among the following three speeds and equalizations, there is NO correction required: the response is flat. You can play any of these Calibration Tapes at any of these speeds, set the reproducer equalizers for flat response, and have a correct calibration.

30 in/s AES (IEC2)
15 in/s IEC (IEC1)
7.5 in/s IEC (IEC1)

Table 5-2 Calibration Tape: 30 in/s, AES (IEC2) Equalization
Desired Playback: 15 in/s, NAB (IEC2) Equalization

Recorded Frequency/ [Hz]	Playback Frequency/ [Hz]	Playback Level/ [dB]
32	16	-10.33
63	32	-5.48
125	63	-2.16
250	125	-0.65
500	250	-0.17
1000	500	0.00
2000	1000	0.18
4000	2000	0.66
8000	4000	1.61
10000	5000	1.95
12500	6250	2.24
16000	8000	2.51
20000	10000	2.69

Table 5-3 Calibration Tape: 15 in/s, NAB (IEC2) Equalization
Desired Playback: 30 in/s, AES (IEC2) Equalization

Recorded Frequency/ [Hz]	Playback Frequency/ [Hz]	Playback Level/ [dB]
32	64	5.56
63	126	2.31
125	250	0.83
250	500	0.35
500	1000	0.18
1000	2000	0.00
2000	4000	-0.48
4000	8000	-1.43
8000	16000	-2.33
10000	20000	-2.51

Table 5-4 Calibration Tape: 15 in/s, NAB (IEC2) Equalization
Desired Playback: 15 in/s, IEC (IEC1) Equalization

Recorded Frequency/ [Hz]	Playback Frequency/ [Hz]	Playback Level/ [dB]
32	32	5.56
63	63	2.31
125	125	0.83
250	250	0.35
500	500	0.18
1000	1000	0.00
2000	2000	-0.48
4000	4000	-1.43
8000	8000	-2.33
10000	10000	-2.51
12500	12500	-2.64
16000	16000	-2.74
20000	20000	-2.79

Table 5-5 Calibration Tape: 15 in/s, NAB (IEC2) Equalization
Desired Playback: 7.5 in/s, NAB (IEC2) Equalization

Recorded Frequency/ [Hz]	Playback Frequency/ [Hz]	Playback Level/ [dB]
63	32	-3.01
125	63	-1.17
250	125	-0.16
500	250	0.13
1000	500	0.00
2000	1000	-0.71
4000	2000	-2.34
8000	4000	-4.19
10000	5000	-4.63
12500	6250	-4.96
16000	8000	-5.22
20000	10000	-5.37

Table 5-6 Calibration Tape: 7.5 in/s, NAB (IEC2) Equalization
Desired Playback: 7.5 in/s, IEC (IEC1) Equalization

Recorded Frequency/ [Hz]	Playback Frequency/ [Hz]	Playback Level/ [dB]
32	32	5.00
63	63	1.75
125	125	0.28
250	250	-0.17
500	500	-0.23
1000	1000	0.00
2000	2000	0.68
4000	4000	1.64
8000	8000	2.25
10000	10000	2.35
12500	12500	2.42
16000	16000	2.47
20000	20000	2.50

Table 5-7 Calibration Tape: 7.5 in/s, NAB (IEC2) Equalization
Desired Playback: 15 in/s, NAB (IEC2) Equalization

Recorded Frequency/ [Hz]	Playback Frequency/ [Hz]	Playback Level/ [dB]
32	64	2.25
63	126	0.45
125	250	-0.55
250	500	-0.84
500	1000	-0.71
1000	2000	0.00
2000	4000	1.63
4000	8000	3.48
8000	16000	4.51
10000	20000	4.67

Table 5-8 Calibration Tape: 7.5 in/s, NAB (IEC2) Equalization
Desired Playback: 3.75 in/s, NAB & IEC Equalization

Recorded Frequency/ [Hz]	Playback Frequency/ [Hz]	Playback Level/ [dB]
63	32	-3.24
125	63	-1.40
250	125	-0.37
500	250	-0.04
1000	500	0.00
2000	1000	-0.14
4000	2000	-0.43
8000	4000	-0.67
10000	5000	-0.71
12500	6250	-0.75
16000	8000	-0.77
20000	10000	-0.78

The original vu meter system consists of a generator with a 300 Ω source impedance (formed by a 600 Ω source terminated by a 600 Ω load), a "bridging" or "build-out" resistance of 3600 Ω (so the 300 Ω source plus 3600 Ω build-out totals 3900 Ω), and the actual vu meter itself, which is a passive ac voltmeter with 3900 Ω input impedance. The basic sensitivity in this configuration (meter plus 3600 Ω build-out resistor) is 1.25 V to deflect the pointer to 0 dB on the scale. An optional 3900 Ω "T" attenuator can be inserted between the build-out resistance and the meter, to reduce the meter system's sensitivity, so it reads 0 dB for a higher line voltage. The 3600 Ω build-out resistance was normally split into a 2800 Ω fixed resistance and a 1600 Ω rheostat; at mid-resistance (800 Ω) the build-out resistance was its standard value, 3600 Ω. The 0 to 1600 Ω adjustment gave a ±1 dB adjustment for variations in the basic sensitivity of the ac voltmeter. Some tape recorders (most or all Ampex') omitted the rheostat, and just put in a fixed 3600 Ω resistor. This means that the line voltage for 0 dB on the meter would be something in the range of about 1.18 ... 1.32 V; or, put the other way, if the line voltage were 1.25 V, the meter would read something in the range ±0.5 dB. To set this for exactly 1.25 V requires replacing the 3600 Ω resistor with either a custom-determined resistor, or with the 2800 Ω fixed resistor plus 1600 Ω rheostat. This is worth doing if you need to have consistent levels in your system.

On many modern recorders, a dedicated meter driving amplifier with its own gain control is used. In this case the line output voltage is set to 1.25 V, and the meter gain control is set so the meter reads 0 dB.

On the "-10 dBV" systems, a separate meter amplifier is always necessary to drive the vu meter, and a meter gain control is usually provided to set the meter to read 0 dB when the line output voltage is 315 mV.

Note that the relationship between the *program level meter indication* and the *reproducer output voltage* ("line level") is actually quite arbitrary: 0 dB on the vu meter usually corresponds to either 315 mV or 1.25 V, but it *could* be anything, since it is set by the meter's sensitivity control.

2.4.4 *Setting the Levels*

In summary, to coordinate between the tape flux, the vu meter reading, and the line voltage:

Feed a 1 kHz tone from an oscillator thru the recorder (or, if a reproducer only, play a 1 kHz tone); measure the line output voltage with an accurate ac voltmeter; adjust the recording (or reproducing) gain control so the line output voltage is appropriately exactly either 315 mV or 1.25 V; then adjust the vu meter gain control (or meter trimming rheostat) so the vu meter reads 0 dB. This adjustment should only be necessary once in the lifetime of the system.

Then play a Calibration Tape with a reference fluxivity that is appropriate to the tape you will subsequently be recording onto, and set the reproducing gain control so the vu meter indicates reference deflection (0 dB). Now the reference fluxivity corresponds to reference deflection on the program level meter, and also to the reference output voltage ("standard line output level").

Thus we see that the relationship between the *fluxivity on tape* and the *reproducer output voltage* can be anything, since it is set by the "Reproducer Gain" control.

It follows that the choice of Calibration Tape is completely independent of the line output voltage of the reproducer.

3 CONFORMANCE TO STANDARDS

The equalizations and other characteristics of MRL Calibration Tapes conform to the applicable parts of the IEC Standard [5] as well as the standards published by the US National Association of Broadcasters (NAB), and the Audio Engineering Society (AES).

The format and tolerances of MRL Multifrequency Calibration Tapes conform to applicable parts of the IEC Standard [6].

4 CALIBRATION GRAPHS

Each MRL Calibration Tape is accompanied by a Calibration Graph made on a level recorder that simulates a Standard Volume Indicator (vu meter), as that tape is reproduced on MRL's calibrated reproducing system while the recording is being made. The Graph assures our operator and you that our recording system is recording the standard level, and that level fluctuations are within tolerance.

When you play the MRL Calibration Tape on your reproducer, if you observe flux level variations that are greater than those shown on the graph, check your tape tracking and the tape-to-head contact.

5 SPECIFICATIONS

5.1 Track Configuration

With the exception of some NAB Broadcasting Cartridge tapes which have the "cue track" erased, *all* of the MRL recordings are *"full track"*, that is, recorded across the full width of the tape.

5.1.1 *Fringing Effect*

When any full-track tape (for instance one of these Calibration Tapes) is reproduced on any multi-track reproducer, the recording is wider than the intended reproducing head, and this causes a measuring error called *fringing*. This causes both an apparent rise in the low-frequency response of the reproducer, and also increased undulations of the low-frequency response ("head bumps").

The MRL ¼ inch (6.3 mm) width tapes are suitable for use on full-track mono players. When they are used on stereo or multi-track reproducers, the low-frequency response will be in error by 1- to 2-dB because of fringing. The corrections for a 2-mm track width are shown in **Table 6**.

We compensate the ½ inch (12.5 mm) and wider tapes for fringing by reducing the recording level at low frequencies by the amounts shown in Table 6.

For very wide tracks (e.g. two tracks on ½ and 1 inch tape and eight tracks on 2 inch tape), however, you should NOT use the usual MRL Calibration tapes with fringing correction. On request, we will make any of our Calibration Tapes *with* or *without* fringing compensation.

Be aware for all cases that the fringing response calculations are only approximate, especially at the lowest frequencies. Also, they assume a center track; the corrections for an edge track are somewhat less. If you need exact measurements of the low-frequency response, use the method described in §2.2, Low Frequency Response Calibration.

The announcements on older MRL Multifrequency Calibration Tapes referred to specific numbers of tracks, for instance 16 tracks on 2 inch width tape, 8 tracks on 1 inch tape, and 4 tracks on ½ inch tape. Since the calculated fringing compensation is approximate at best, it is also usable for 24-, 16-, and 8-track recorders respectively. The reference to specific numbers of tracks is unnecessary, and has now been deleted.

5.2 Tolerances

Unless otherwise specified, all MRL Calibration Tapes conform to the following tolerances, when measured by the methods described below.

5.2.1 *Accuracy of Recorded Frequencies*

The deviation of the recorded frequency from its stated value is measured when the tape is reproduced at its standard speed (a binary submultiple of exactly 30 in/s = 762 mm/s), with a tape tension into the head assembly of 0.8 newtons (N) for ¼ inch (6.3 mm) tape width (1 newton = 3.6 ounces = 100 grams-force); 1.3 N for ½ in (12.5 mm) width; 2 N for 1 in (25 mm) width; or 3 N for 2 in (50 mm) width, and a tension increase at the reproducing head of about 25 %, due to the friction of the tape over the heads and guides.

Tolerance on the frequency:

for 3150 Hz Speed & Flutter Tapes (see Pub. 570). . . . . ±0.1 %

for all tones above 32 Hz on all other MRL tapes. . . . . . ±0.5 %

5.2.2 *Harmonic Distortion of Tones*

The total harmonic distortion is the root sum square of the individual harmonic components as measured with a wave analyzer.

Maximum distortion at 1 kHz. . . . . <1 %

Table 6 Fringing Level Corrections for a 2-mm Trackwidth

Frequency/ [Hz]	Tape Speed			
	95 mm/s **3.75 in/s**	190 mm/s **7.5 in/s**	380 mm/s **15 in/s**	760 mm/s **30 in/s**
32	1.1 dB	1.3 dB	1.4 dB	1.5 dB
63	0.9 dB	1.1 dB	1.3 dB	1.4 dB
125	0.6 dB	0.9 dB	1.1 dB	1.3 dB
250	0.4 dB	0.6 dB	0.9 dB	1.1 dB
500	0.2 dB	0.4 dB	0.6 dB	0.9 dB
1 k	0.1 dB	0.2 dB	0.4 dB	0.6 dB
2 k	0 dB	0.1 dB	0.2 dB	0.4 dB
4 k	0 dB	0 dB	0.1 dB	0.2 dB
8 k	0 dB	0 dB	0 dB	0.1 dB

5.2.3 *Mechanical Azimuth Angle*

All signals are recorded with the tape flux parallel to the longitudinal axis of the tape.

Tolerance on mechanical azimuth angle. . . . ±300 µrad (±1 min)

5.2.3.1 *Conversion of Mechanical Angle to Electrical Angle*

The more common measure of azimuth error is the *electrical* phase angle between edge channels on a multi-track reproducer. This electrical phase angle depends not only on the mechanical azimuth error, but also on the tape width, tape speed, and test frequency used for the measurement. With the specified mechanical azimuth angle error (±300 microradians, equivalent to ±1 minute of angle), and a 10 kHz test signal, the electrical phase angle between 2-mm-wide edge tracks will be as shown in **Table 7** below. If a different test frequency is used, the electrical phase angle will be directly proportional to the ratio of the actual test frequency to 10 kHz.

5.2.4 *Fluxivity Measurement at Medium Wavelengths*

The short-circuit fluxivity at medium wavelength is measured according to AES7-2000(r2005) [23].

Tolerance on reference fluxivity.. . . . . ±3 % (≙ ±0.25 dB)

Comments on the Reference Fluxivity

5.2.4.1 *Effect of Reference Frequency*: Because of the "standard equalizations" described in §1.2.3 , the flux on a standard Calibration Tape is not usually constant versus frequency even in the range 250 Hz ... 1000 Hz. Therefore a change of the reference *frequency* will produce a change of the reference *fluxivity*. For example, the Ampex calibration tapes used 700 Hz as the reference frequency, whereas the MRL tapes use 1000 Hz. When the 7.5 and 15 in/s NAB equalizations are used, the fluxivity on a calibration tape at 1000 Hz is 2.5 % less than at 700 Hz. So the old "Ampex Operating Level" of 185 nWb/m corresponds to approximately 180 nWb/m at 1000 Hz, 260 nWb/m at 700 Hz corresponds to 250 nWb/m at 1000 Hz, and 370 nWb/m at 700 Hz corresponds to 355 nWb/m at 1000 Hz..

For another example, the original MRL 21F101 (speed 3.75 in/s = 95 mm/s) used 500 Hz for the reference frequency. The standard equalization causes the flux level at 500 Hz to be 1 dB greater than that at 1000 Hz. Therefore when the reference fluxivity is kept constant and the reference frequency is changed from 500 Hz to 1000 Hz, the flux level of *all* signals recorded on the tape is increased by 1 dB.

5.2.4.2 *German Flux Measurement, G320*. The original tape flux measurements were made in Germany in the late 1950s, using a transfer-to-dc method standardized in German Standard DIN 45 520 [24]. These measurements are the basis for the reference fluxivity of 320 nWb/m used on German calibration tapes made by BASF and AGFA.

In the late 1960s we used the AES7 method [23] to measure the German tapes, and found that the German reference fluxivity was not 320 nWb/m, but only 290 nWb/m, which is almost 1 dB low. Recent new measurements at MRL [25] have confirmed that flux measurement by the transfer-to-dc method used in Germany gives exactly the same results as the AES7 method. So we conclude that the original (1950s) German measurement was in error by 10 %.

Table 7 Electrical Phase Angle at 10 kHz for a Mechanical Azimuth Angle of ±300 µrad (±1 min of angle)

Tape Speed	For 2 mm Edge Tracks on a Tape Width of:			
	6.3 mm **¼ in**	12.5 mm **½ in**	25 mm **1 in**	50 mm **2 in**
95 mm/s **3.75 in/s**	±45°	±110°	±260°	NA
190 mm/s **7.5 in/s**	±22°	±55°	±130°	±280°
380 mm/s **15 in/s**	±11°	±27°	±65°	±140°
760 mm/s **30 in/s**	±5°	±14°	±32°	±70°

The MRL Calibration Tapes made to conform to the old German measurements were previously identified by MRL as "320" nWb/m; we have changed this identifier to G320 nWb/m, indicating 320 nWb/m according to the original German measurement. There is also a G510 nWb/m which corresponds to 450 nWb/m.

5.2.4.3 *Effect of Track Width Mismatch on Two-track Recorders*: There are three different "standard" widths for two tracks recorded on ¼ inch (6.3 mm) tape: 1.9 mm, the Ampex Standard (the original two-track de facto standard) ; 2.1 mm, the NAB Standard (used by almost everyone else but Ampex); and 2.8 mm, the DIN "stereo" format. Put more cynically, the track widths for two tracks on ¼ inch tape are *not* very standardized.

When the recorded track is wider than the reproducing head core, the reproducer will show the low-frequency boost mentioned above due to fringing.

When the recorded track is narrower than the reproducing head core, there is no fringing, but instead an apparent loss of recorded level at all frequencies. It amounts to the ratio of 1.9 mm to 2.1 mm, corresponding to a 1 dB level shift for these head widths; or 1.9 mm to 2.8 mm, corresponding to 3.3 dB for these widths.

In conclusion: if you want standardization of recorded levels and frequency responses in exchanging two-track 6.3 mm recordings, do not trust any manufacturers' claims of "standard track widths". Measure the recording and reproducing head core widths yourself, and use only recorders and reproducers with the same core widths.

5.2.5 *Flux Level Error vs Frequency*

The flux level error vs frequency occurs because of the basic limitations to the accuracy of the calibration techniques used by MRL to calibrate its reference reproducer. It will cause an error of measurement of the flux amplitude that we call "deviation of the average recorded levels relative to the flux response curve given in the standards."

Tolerance on deviation of average recorded levels relative to the standard flux response curves:

For open-reel recordings at 3.75 in/s (95 mm/s) speed, and broadcasting cartridges at any speed:

Up to and including 10 kHz . . . . ±0.5 dB

Above 10 kHz . . . . ±1 dB

For open-reel recordings at 7.5 in/s (190 mm/s) and greater speeds:

Deviation of average recorded levels relative to the standard flux response curves:

At all frequencies . . . . ±0.5 dB

5.2.6 *Flux Level Error vs Time*

The flux level error vs time occurs at long wavelengths because of variations of the tape coating thickness, and at short wavelengths because of variations of the surface finish of the tape. It will cause instantaneous level fluctuations that we call "level fluctuations", around the average value. These level fluctuations are measured with an indicator having the dynamics of the Standard Volume Indicator ("vu meter").

Tolerance on level fluctuations about average values:

For open-reel recordings at 3.75 in/s (95 mm/s) speed, and broadcasting cartridges at any speed:

Up to and including 10 kHz . . . . ±0.3 dB

Above 10 kHz. . . . . ±0.6 dB

For open-reel recordings at 7.5 in/s (190 mm/s) and greater speeds:

At all frequencies. . . . . ±0.3 dB

6 TAPE RECORDER ADJUSTMENT TECHNIQUES

6.1 Biasing

High-quality audio recording is made possible by "high-frequency ac biasing". For information how bias works, see [26] and [27], and the graph of the effect of bias on recording performance that is in the technical data sheets from RMGI (available at http://www.rmgi-usa.com/page3/page3.html), and some of those from Quantegy.

The amplitude of the bias current affects the high-frequency response (better with less bias), the distortion (better with more bias), and the modulation noise of the recording (dependent on the tape speed and the particular tape type). Therefore the "optimum" bias depends on both the tape type and the recording speed.

The general idea is that the recording sensitivity (the reproduced output level for a fixed low recording level) is low for low bias current, increasing with increasing bias to a maximum sensitivity, then decreasing with a further increase of bias current.

At the studio mastering speeds of 15- and 30-in/s, the effect of bias on frequency response is minimal, so one often biases for minimum distortion (this of course assumes that you *have* a distortion meter). This is however not as straight forward as it sounds, because the distortion with some tape types is also dependent on the recorded fluxivity.

An old, simple, and effective method that we use for setting bias with all kinds of tape is to use a 1000 Hz test signal. First set the bias current for maximum recording sensitivity. Then, for 15- and 30-in/s recording, *increase* the bias current so that the recording sensitivity drops by 0.2 dB. For 3.75- and 7.5 in/s recording *decrease* the bias current so that the recording sensitivity drops by 0.1 to 0.2 dB.

Another method, recommended by tape manufacturers, uses a 10 kHz test signal. We find this method more complicated — you need to know the gap length of the recording head, and the amount of signal reduction for each kind of tape and each speed — and without any redeeming social value.

7 REFERENCES

Notes on the availability of references:

The **articles** by J. G. McKnight are available from the MRL website– see the links indicated.

The **international standards** of ISO and IEC are available from the IEC http://webstore.iec.ch/ (in the search box enter "IEC" and the standard number).

The **AES Standards** are available for purchase from the AES Standards Store http://www.aes.org/publications/standards/ , and are free to AES members.

The books are available (new or used) from Amazon.com http://www.amazon.com .

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[3] M. Camras, "Magnetic Recording Handbook", Van Nostrand Reinhold Co. (1988), now out of print.

[4] F. Jorgensen "*The Complete Handbook of Magnetic Recording*", Fourth Edition (1995), TAB Books/McGraw-Hill. (Much of the emphasis in this 4th edition, however, is on video, instrumentation, and digital data theory and applications.)

[5] IEC Standard 60094-1, "Magnetic Tape Sound Recording and Reproducing Systems, Part 1: General Conditions and Requirements", International Electrotechnical Commission. Includes among other things toleranced tape dimensions and speeds, and the amplitude/frequency response of the recorded short-circuit flux (standard equalizations).

[6] IEC Standard 60094-2, "Magnetic Tape Sound Recording and Reproducing Systems, Part 2: Calibration Tapes". International Electrotechnical Commission. Includes the contents, format, and tolerances of Calibration Tapes.

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[17] IEC Standard 60268-10, "Peak Program Level Meters", International Electrotechnical Commission.

[18] ISO Standard 3, "Preferred Numbers: Series of Preferred Numbers"; ISO Standard 17, "Guide to the Use of Preferred Numbers and of Series of Preferred Numbers"; and ISO Standard 497, "Guide to the Choice of Series of Preferred Numbers and of Series Containing More Rounded Values of Preferred Numbers". International Standardization Organization.

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