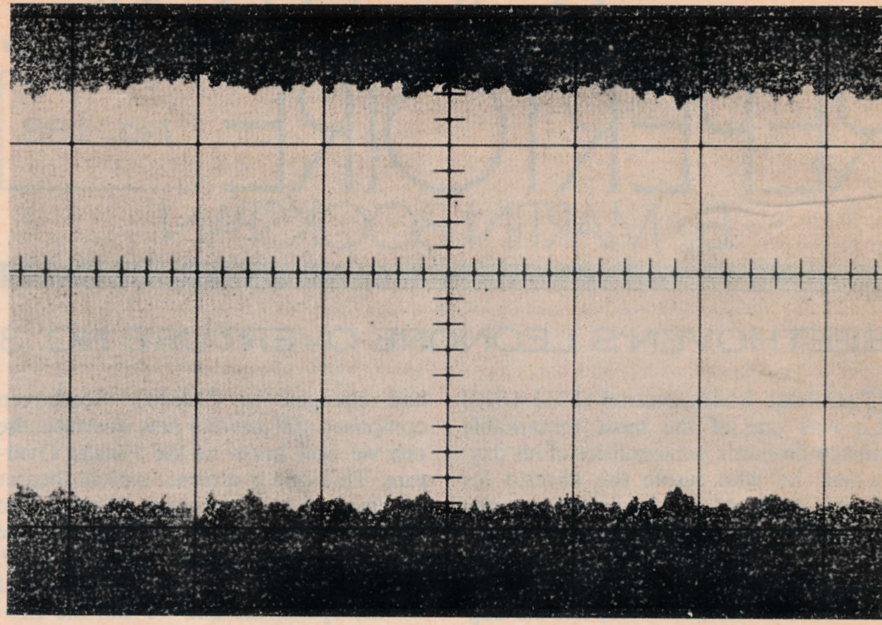
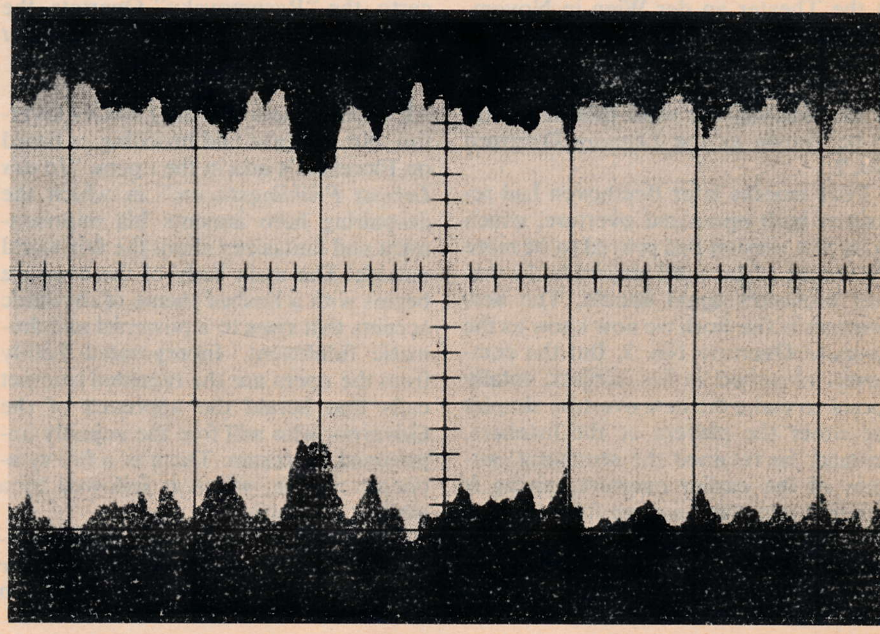


TAPE PERFORMANCE AND TAPE RECORDER BIASING

Getting the best performance out of any given recording tape depends on a delicately balanced compromise between a number of factors that are affected by the recorder's bias setting

By Michael B. Martin

The oscilloscope photos on this page illustrate the magnitude of the problem presented by improperly biased tape. The upper photo shows the playback of a high-frequency signal from a tape recorded with proper bias. The lower photo shows the same tape, recorded with improper bias. Here the tape-to-head contact variations, which had little effect on the properly biased tape, cause momentary but audible signal losses.



BY now, most owners of high-quality tape equipment are aware that for optimum results—or sometimes even acceptable results—the machine and the tape that is used with it must be matched to each other. Or, to put it another way, there is no single, universal "best" tape type for all machines. And considering the wide variety of tapes and recorders available today, choosing a satisfactory tape for use in one's recorder appears at times to be a task as difficult as selecting the right wine for a gourmet dinner guest. A survey of the various tests and reviews of tape types frequently only adds to the confusion, and in many instances even the recommendations of the manufacturer of the recording equipment are not entirely helpful.

The nature of magnetic recording is such that potential improvements in performance usually can be realized only if the recording equipment is specially set up for any new tape to be used. The most obvious example of this is provided by the introduction of chromium-dioxide cassette tape a few years ago. It is now well known that, for optimum use of chromium dioxide tape, the recorder requires special bias and equalization. What is *not* so well known is the fact that to achieve the optimum performance from *any* magnetic tape, a recorder should be adjusted for that tape. It is fortunate that, within types of ferric oxides, the deviations in frequency response, dynamic range, and signal-to-noise ratio caused by the use of a different brand may have no greater effect than the error caused by manufacturing variations *within* a brand. However, not all iron-oxide tapes use the same type of oxide particles. The particles used in iron-oxide tapes today can be broken down into four categories, all of which are wholly or mostly gamma ferric oxide, for which the chemical designation is Fe_2O_3.

1. The "low-noise/high-output" particle .... pure Fe_2O_3
2. Very small particles .... pure Fe_2O_3
3. Chemically modified particles . . Fe_2O_3 with a small percentage of cobalt or magnetite (Fe_3O_4)
4. Improved-shape particles ..... pure Fe_2O_3

Generally speaking, the low-noise/high-output particles are those used by the majority of manufacturers for cassettes up to the end of 1972, and they are still used for second-line cassette products, high-quality reel-to-reel tapes, and cartridge tapes. Subsequently, tapes using the very small unmodified iron oxides and the so-called "cobalt-doped" and "magnetite-doped" oxides became available. Early in 1973, the first tapes using pure ferric-oxide particles of perfected shape (Memorex MRX_2, for example) reached the market, and for the first time the performance of an iron-oxide cassette tape approached that of chromium dioxide.

Proprietary arguments aside, it is clear that all of the above oxides can be made into a tape capable of high-fidelity performance. However, the problem from the *user's* viewpoint is that the potential of such tapes can be realized completely only when the recorder is adjusted accurately for the specific tape being used. This involves complications, because the playback characteristics of the tape machine must conform to internationally agreed-on standards that enable a tape made on any standard machine anywhere in the world to be played back with reasonable accuracy on any other machine. So (usually), only the recording characteristics of the machine can be adjusted, and these must be adjusted to complement both the performance capabilities of the tape used *and* the playback characteristics through which the tape will be heard. (Some cassette decks have switches that also modify their playback characteristics for optimum results.)

THERE are two aspects to a tape machine's adjustable recording characteristics: the recording equalization and the recording bias. The *equalization*, in effect, adjusts the frequency response of the signal going on the tape. The recording *bias* is a steady signal of very high frequency (usually 50,000 Hz or above) that is generated within the tape machine and applied to the tape along with the signal to be recorded.

It is beyond the intent of this article to discuss the *theory* of magnetic-tape biasing. It is a very complex subject, and there are still some technical disagreements about the exact way in which a.c. bias works. However, it can be readily demonstrated that incorrect biasing (that is, employing a bias signal that is too strong or too weak for the tape being used) can change the performance of an excellent tape to no better than average. Incorrect bias adjustment will cause poor frequency response as well as high harmonic and intermodulation distortion, and it can even aggravate the effects of dropouts and errors in head-to-tape contact. Incorrect equalization, on the other hand, will not always seriously impair the performance of a tape, since it can often be at least approximately corrected for by using the tone controls of a high-fidelity system.

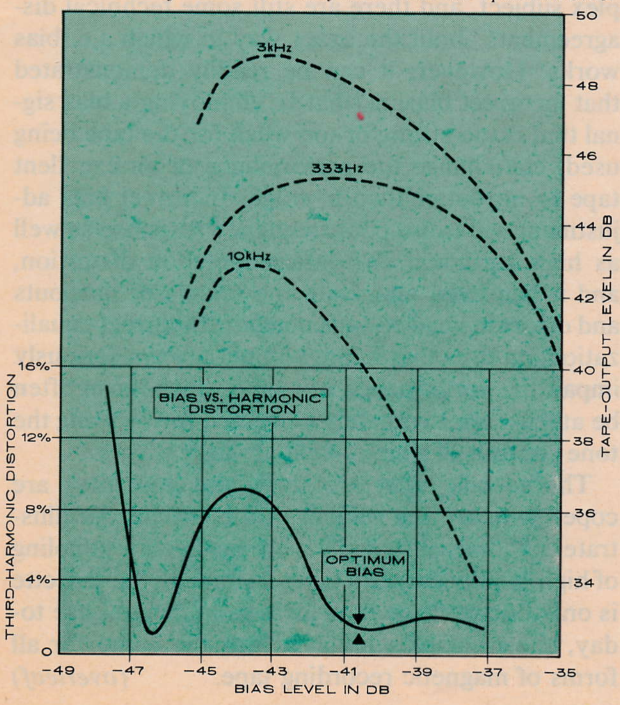
The specific *effects* of bias and how they are coped with are the subject of this article. To illustrate each, measurements were made on a sampling of high-quality cassette tapes. Although the cassette is only one of three tape formats in general use today, the principles involved are the same for all forms of magnetic recording tape. *(overleaf)*

Frequency Response and Distortion

Figure 1 illustrates some of the relationships between the applied bias, recorded signal strength, and distortion. The upper three curves show the output levels for three frequencies—333, 3,000, and 10,000 Hz—that have been recorded on a high-quality iron-oxide tape at a constant input-signal strength, but with changing bias-signal strength. The bottom curve shows the amount of third-harmonic distortion in the output for one of the test frequencies—333 Hz. Note that, for the upper curves, as the bias is increased the signal output level of the tape rises to a maximum and then begins to decrease. The distortion level also changes with changing bias, declining steeply at first, then rising to a broad peak, and finally dropping back down to a relatively moderate 2 per cent or so.

Obviously, maximum output-signal strength and minimum distortion are both desirable characteristics for any tape-recording system. But, unfortunately, in the case of this tape or any other, these characteristics do not occur at the same bias-signal strength. For example, maximum output at 3,000 and 10,000 Hz is achieved at about a −44-dB bias, while the lowest distortion is at just below 40 dB. It therefore quickly becomes clear that any fixed bias setting is going to have to be a compromise between several conflicting goods and evils. For this particular tape, the above factors and a number of other considerations (some of a very practical nature) dictate that the optimum bias point is just below −40.5 dB. This happens to correspond rather closely with the bias settings for minimum distortion and maximum output at 333 Hz, but it doesn't always work out this way.

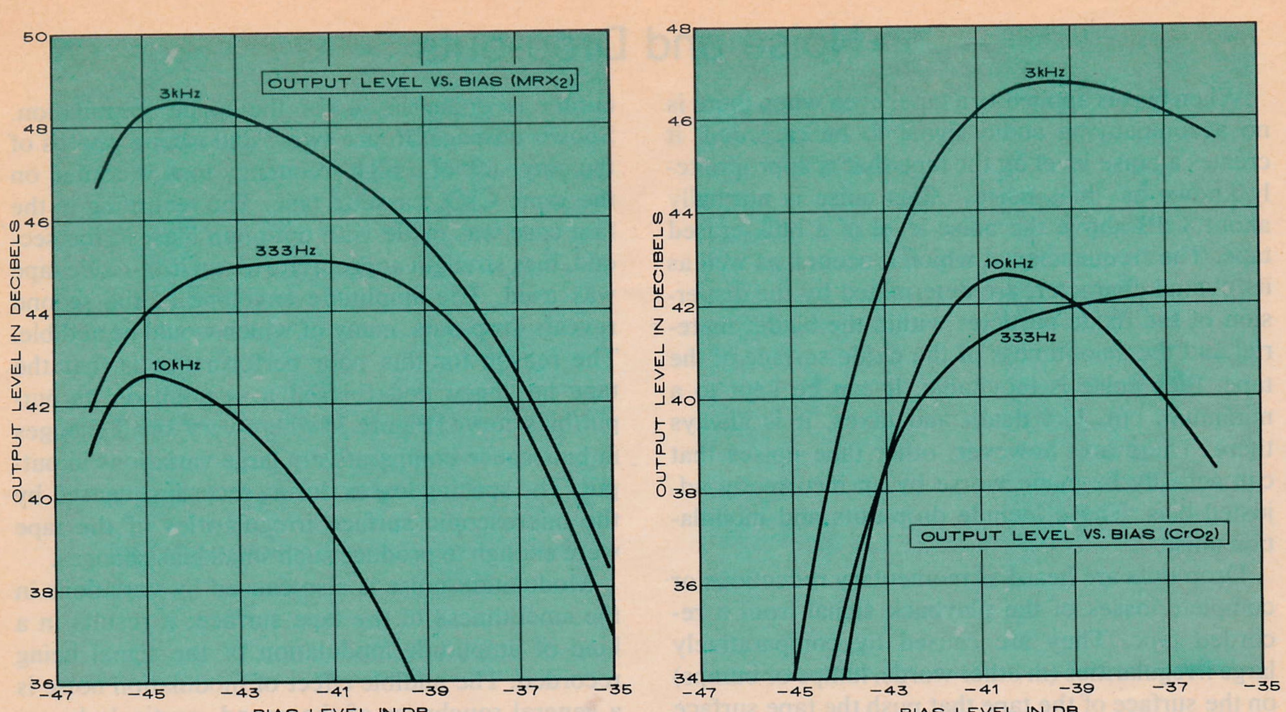
Fig. 1. The effect of bias strength on the output (at three frequencies) and distortion of a high-quality iron-oxide tape. These and other factors ultimately determine the optimum bias.



Different tapes can require significantly different bias settings for best performance. Considering just output level for the moment, let us look at Figures 2 and 3. Figure 2 shows the bias/output curves at three frequencies for a high-quality iron-oxide tape—Memorex MRX_2. Figure 3 graphs similar data for chromium-dioxide (CrO_2) tape. Comparing the two sets of curves shows that the maximum CrO_2 output at both 333 and 10,000 Hz occurs at (at least) a 4-dB higher bias than for the iron-oxide tape. If the bias of a cassette recorder were adjusted to optimum for the iron-oxide tape (about −41 dB), it can be seen that the signal output at 333 Hz would be very close to maximum, while the 10,000-Hz output would be approximately 3 dB *below* maximum. This would result in the best performance of which the tape is capable. However, if the CrO_2 tape were recorded with the same bias setting, its output at 333 Hz would be considerably below maximum, while at 10,000 Hz it would be almost at its peak. The final recording would therefore have a greatly exaggerated high-frequency response—and, incidentally, too much distortion at 333 Hz because of underbiasing effects. Reversing the situation (recording the iron-oxide cassette with a bias optimized for CrO_2, about −37 dB) would so overbias the tape that its output would be reduced by at least 10 dB at 10,000 Hz and by about 3 dB at lower frequencies.

WHILE chromium-dioxide and iron-oxide cassettes require drastically different bias adjustments for best performance, there are lesser (but still significant) differences between various iron-oxide tapes. The four types of iron-oxide tapes listed above have optimum bias points that differ over a range of 20 per cent. Recording them all with a bias adjusted for one (the "improved-shape particles" of MRX_2) would result in the frequency-response differences illustrated in Figure 4.

Distortion is at least as important as frequency sensitivity in determining a tape's optimum bias point, and it should be taken into careful account by tape-recorder designers. Unless there is some flaw in the recording equipment, the distortion generated by the tape-recording process consists exclusively



Figs. 2 and 3. The effect of bias-strength variations on the output of Memorex iron-oxide tape (left) and chromium-dioxide tape (right) at three frequencies. In terms of output, chromium dioxide requires a markedly higher bias than iron oxide, which is why so many cassette recorders have tape-type switches. Bias requirements for different iron oxides also vary, though not so drastically.

of odd-order harmonics—that is, the third, fifth, and seventh harmonics, etc. (The maximum usable output of a tape is normally defined in terms of a reference level of odd-harmonic distortion.) Distortion at lower frequencies is significantly more audible than at the higher frequencies. As the distortion curve of Figure 1 shows, the application of a relatively small amount of bias has a rapid distortion-reducing effect on the tape *at first*. Then there is a tendency for distortion to increase again as the bias approaches its optimum. This is caused by phase effects acting throughout the thickness of the tape's oxide coating.

When a tape recorder is rated at such-and-such a distortion percentage for a 0-VU recording level (usually 1, 2, or 3 per cent, depending on the practice of the individual manufacturer or sometimes on the recorder's country of origin), this specification is very much a function of the tape used in adjusting the machine. It follows, therefore, that the purchaser is not likely to be able to duplicate it exactly with any other type of tape. On the other hand, when the tape for which the machine was adjusted *is* used, the figure should be precisely duplicable. If the distortion measures more—or even less—at the level and test frequency specified, it indicates that the bias is not optimum; this might well result in higher-than-normal distortion levels at other frequencies, and it could also produce frequency-response errors.

Sometimes a tape machine's bias adjustment will be resorted to when it is desired to alter the frequency response of a tape. While this is often effective (a slight reduction of bias will, for example, cause an increase in high-frequency output), it is not recommended practice, since the bias reduction will also have its effects on distortion and on the tape's output capabilities at lower frequencies. *(overleaf)*

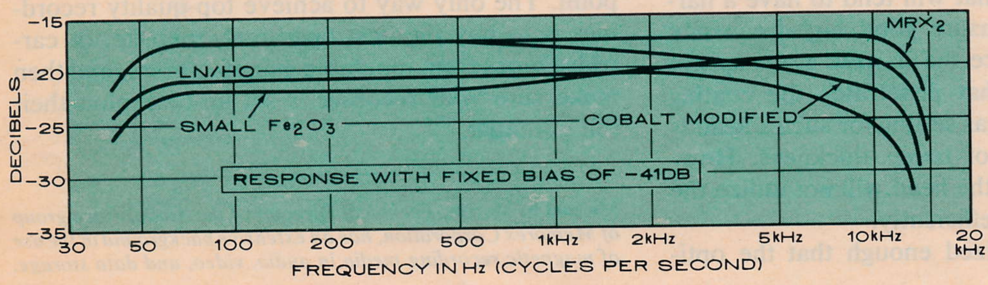


Fig. 4. Typical record-playback frequency-response variations when different tape types are used on a machine with fixed bias. Bias is correctly adjusted for the MRX_2 tape-oxide formulation.

Noise and Drop-outs

When bias is applied to a tape, even when there is no accompanying audio signal to be recorded, it creates a noise level on the tape that is appropriately known as "bias noise." Bias noise is normally about 3 dB above the noise level of a bulk-erased tape. The frequencies at which it occurs, as well as its overall character, are determined by the dispersion of the oxide particles within the binder material and the smoothness of the oxide surface of the tape. Bias noise is inevitable; it can be kept to a minimum, but, like death and taxes, it is always there. There are, however, other tape noises that can actually be made worse by an incorrectly adjusted bias. These include drop-outs and modulation noise.

Drop-outs are heard as momentary reductions or complete losses of the playback signal from a recorded tape. They are caused by comparatively large irregularities (in other words, lumps or bumps) on the surface of the tape that push the tape surface away from the head as they pass over it. Because the strength of magnetic fields diminishes rapidly with distance, even a small space between tape and head will often result in an audible loss of signal.

One solution to drop-outs is smoother tape surfaces. But even good tapes can give rise to audible drop-outs introduced during recording if the recorder is underbiased for the oxide formulation. Shown on page 56 are two oscilloscope photos of the playback of a high-frequency tone recorded on the same CrO_2 cassette tape. The recording in the first case was made with optimum bias; in the second, bias strength appropriate for an iron-oxide tape was used. The amplitude envelope of the second reveals drop-outs, many of which would be audible. The reason for this poor performance is that the tape has been underbiased to a point on its output/bias curve (Figure 3) where very small changes in bias cause comparatively large variations in output. The spacing losses during recording caused by the microscopic surface irregularities of the tape were enough to produce such small bias changes.

Modulation noise is also caused by variations in the smoothness of the tape surface; it results in a kind of amplitude modulation of the signal being recorded. The audible effect of modulation noise is a general roughness of the sound, particularly noticeable on transients. In bad cases, an instrument such as a piano can sound as though each note is accompanied by a "fizzing" sound. In general, surface irregularities smaller than those producing drop-outs are responsible for modulation noise, but the basic mechanism is the same, and the noise is similarly aggravated by underbiasing of the tape.

Summary

It is frequently impossible to state a single "optimum" bias value for a given tape, simply because the particular tape recorder used introduces additional variables. For example, a good three-head recorder will have a recording-head gap with a width that may be twice the thickness of the tape's oxide coating. Such a head will generate a well-shaped bias field that will penetrate the coating thickness fully at low frequencies. While this is desirable, it does mean that the correct bias setting will depend on the thickness of the tape coating—and on any variations in that thickness. On the other hand, most cassette recorders use a dual-purpose record/play head that will tend to have a narrow gap in order to ensure good high-frequency playback response. Since the narrow gap may not produce a bias field that penetrates the coating thickness entirely, the bias setting for such a head is relatively independent of oxide thickness. However, it is also true that the head will not utilize the full potential of the tape efficiently.

It cannot be emphasized enough that the optimum bias for any tape is a *compromise* setting that tries to strike a happy balance between a number of variables without necessarily being ideal for any one. While there are several procedures used by manufacturers of tape and recorders to determine correct bias adjustments, a procedure that takes *all* the variables into account will almost always produce better results than one that considers only a few of them.

Improper bias can degrade the performance of even the best tape shockingly. However, the most painstaking bias adjustment cannot improve the performance of a mediocre tape beyond a certain point. The only way to achieve top-quality recordings is to buy the best open-reel, cassette, or cartridge tapes from reputable manufacturers, and then make sure your recorder is set up to exploit their full potential.

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