BIASING IN MAGNETIC TAPE RECORDING

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How to select the optimum bias for best low-level response, high output, and reduction of dropouts. Bias frequencies, circuits, and problems are included.

WHEN a magnetic field is applied to certain kinds of materials—such as the coating on a piece of tape—some of this magnetic energy is *stored* on the tape. In other words, the tape coating becomes a permanent magnet. The surface flux from this "magnet" can be detected without in any way changing the stored energy. This particular attribute of detecting without changing is what makes magnetic tape recording possible.

Why "Bias"?

When we look at the relationship between the magnetizing (recording) field and the stored magnetization (Fig. 1A), a defect immediately becomes obvious—there is a tremendous non-linearity. This would cause unbearable harmonic and intermodulation distortion of recorded speech or music signals.

The earliest attempts to reduce this distortion involved applying a d.c. bias to the tape so that the linear portion of the curve from *A* to *B* could be used. Here only about one-third of the curve is used and the presence of the large d.c. magnetization made the recording noisy, thus the signal-to-noise ratio was poor.

A better d.c. biasing scheme was discovered. The tape can be magnetized to saturation in one polarity and the recording head can carry a d.c. bias which *counteracts* this original saturation, bringing the magnetization back to approximately zero. When an a.c. field is added, the magnetization is approximately proportional to this added a.c. value, and linear recording is achieved. However, it is difficult to exactly balance out the d.c. and some noise is left.

A much better method is that of a.c. biasing. The tape is automatically left in a demagnetized state and the full potential signal-to-noise ratio can be achieved. The principle of a.c. biasing was described (but not used for magnetic recording) by Steinhaus and Gumlich in Germany in 1915. A.c. biasing for magnetic recording was discovered but never used practically by Carlson and Carpenter in the USA in 1921, and again by Nagai, Sasaki, and Endo in Japan (1938). Practical utilization came with the re-discovery by Braunmuehl and Weber in Germany in 1940.

Early papers and books on magnetic recording attempted to explain the effect of a.c. biasing through mathematical models, analogies with a class AB push-pull amplifier, and graphical models considering major and minor hysteresis loops of the magnetic material. These explanations are all somewhat magical and of doubtful value. A much clearer visualization of the effect of a.c. biasing can be gained using the process of "ideal magnetization" (also called "anhysteretic magnetization").

For simplicity's sake, let us consider a flexible "bar magnet" made by cutting off a length of blank tape, say 4 cm long. The "bar" can be magnetized in a solenoid carrying a known amount of direct current; the resulting permanent magnetization left after the current is removed can be measured by means of a fluxmeter. When we perform this experiment, and plot the permanent magnetization resulting from various magnetizing currents, we get a curve as in Fig. 1A, showing the great non-linearity.

Suppose that while the direct magnetizing current is applied we add an *alternating* magnetizing current, which we then reduce to a zero value before turning off the direct current. The resulting permanent magnetization is shown in Fig. 1B for different values of the alternating current. Clearly we have accomplished two things: we have greatly increased the sensitivity (the magnetization for a given d.c. magnetizing current), and we have made the magnetization a linear function of the d.c. magnetizing current. Thus, with this system, an undistorted recording can be made. In this experiment, the d.c. represents the signal to be recorded and the a.c. represents the a.c. bias. There is only one major difference in an actual tape recording. In our experiment, the a.c. field decreases while the d.c. field remains constant. If we were to use a magnetic ring-core head on a tape recorder to magnetize a piece of tape pulled past the head, we would find that the a.c. and d.c. fields would die out *together*.

If we go back to our solenoid system and repeat our experiment, but now with both fields decreased simultaneously, we would find the curves of Fig. 1C. Increasing the a.c. up to a certain point has the same effect as before but beyond this point the magnetization decreases.

This magnetization process is exactly equivalent to what actually happens in a tape recorder at low frequencies. At high frequencies, on the other hand, the process becomes very complicated, because the d.c. (signal) field is changing while a particle of tape passes across the recording gap. Fig. 1D demonstrates the 1000-Hz output of a tape recorder at 38 cm/s (15 in/s). Increasing bias current increases the output up to the point of maximum sensitivity (also called "peak bias"), then further increases in bias current *decrease* the output.

The choice of the "best" bias current for practical operation of a tape recorder depends on several factors, because the bias current affects not only sensitivity but also the frequency response and the distortion of the recording process.

One extremely important fact must be pointed out here: all of the relationships in biased recording depend on the relative dimensions of the tape-coating thickness, the recording head gap length, and the recorded wavelength.

1. The tape-coating thickness ranges from about 5 μm (0.2 mil) for triple-play tape through 12 μm (0.5 mil) for standard tape, to about 22 μm (0.87 mil) for high-output tapes. The ratio of the thickest to the thinnest is 4 to 1.
2. The recording head gap length ranges from 1.5 μm

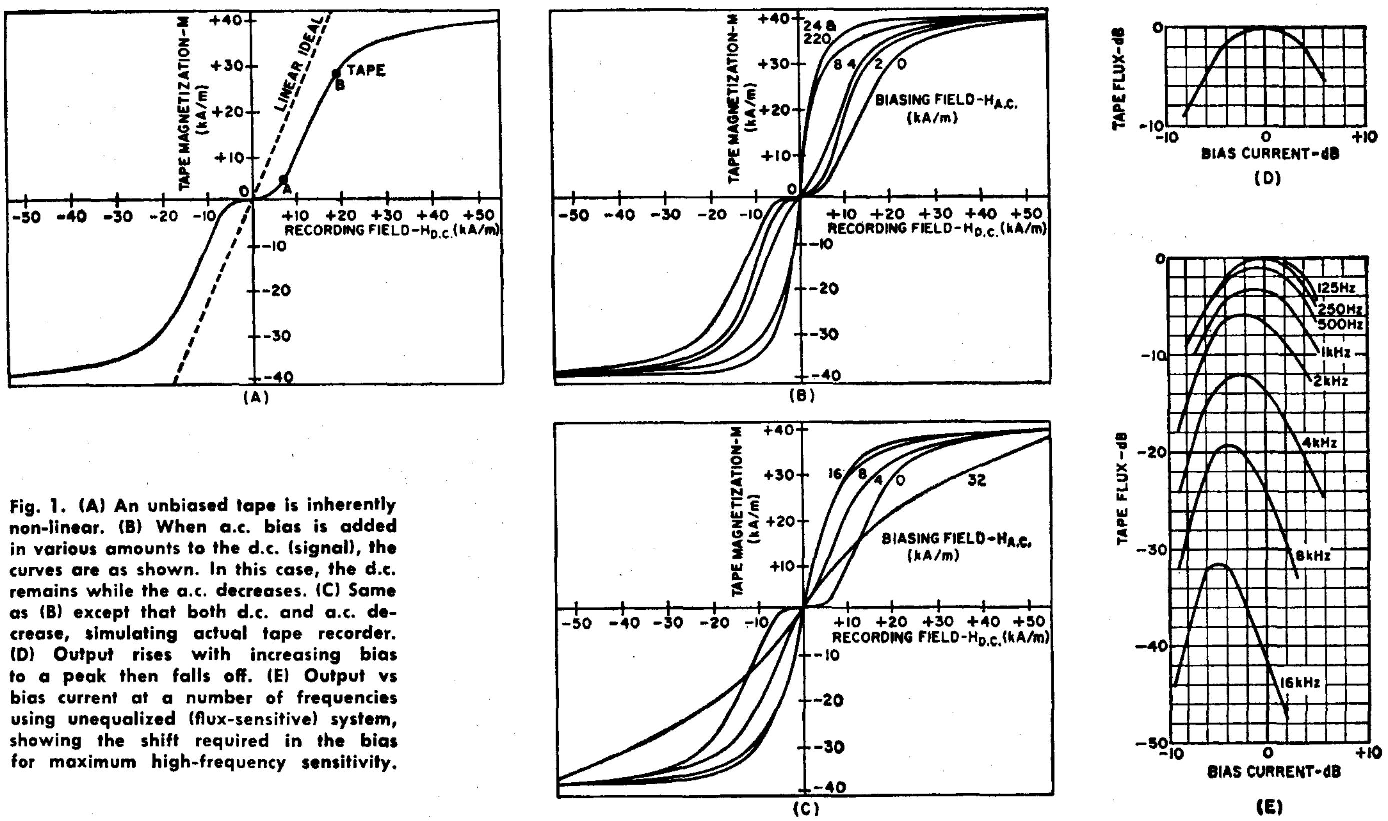


Fig. 1. (A) An unbiased tape is inherently non-linear. (B) When a.c. bias is added in various amounts to the d.c. (signal), the curves are as shown. In this case, the d.c. remains while the a.c. decreases. (C) Same as (B) except that both d.c. and a.c. decrease, simulating actual tape recorder. (D) Output rises with increasing bias to a peak then falls off. (E) Output vs bias current at a number of frequencies using unequalized (flux-sensitive) system, showing the shift required in the bias for maximum high-frequency sensitivity.

(60 μin) for slow-speed, combination-head recorders, through 3 μm (120 μin) for normal combination-head recorders, to 25 μm (1 mil) for professional recording-only heads. The ratio of longest to shortest is 16 to 1.

3. The recorded wavelength (= tape speed in recording/frequency in recording) ranges from 4 μm (160 μin) to 500 μm (200 mils) at 4.76 cm/s (1⅞ in/s) for a frequency range from 12 kHz to 100 Hz and from 25 μm (1 mil) to 10 mm (0.4 in) at 38 cm/s (15 in/s) for a frequency range from 15 kHz to 40 Hz. Altogether the ratio of wavelengths is 2500 to 1!

In the day when recording was primarily professional, that is, 38-cm/s (15 in/s) speed, with 12-μm (0.5-mil) tape coating, and 25-μm (1-mil) recording-head gaps, one could show general relationships and draw general conclusions for optimum operation. Things are not now so simple. We shall have to be content to show specific trends for specific conditions, and simply realize that other conditions will yield different data and conclusions.

The particular magnetic properties of the tape coating are also important and they affect the frequency response, distortion, and the signal-to-noise ratio that is obtained.

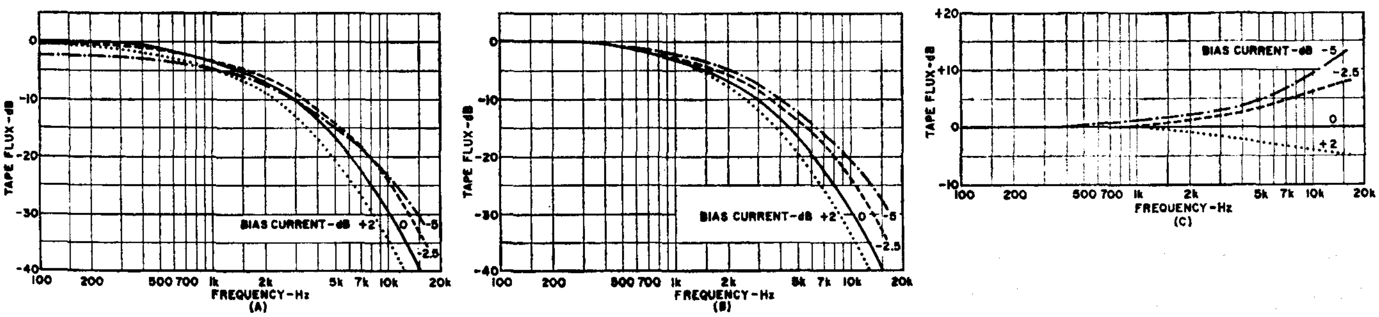
Effect of Bias on Frequency Response

A basic unequalized experimental recorder would use constant recording head current *vs* frequency to produce a constant recording field *versus* recording frequency. A basic unequalized experimental reproducer would have an output proportional to the flux on the tape. For instance, by means of a loss-free short-gap ring-core reproducing head plus an integrating amplifier with constant flux, the head voltage rises 6 dB per octave. But the integrating amplifier response falls 6 dB per octave. Therefore, the two effects compensate and the output voltage is flux-proportional.

Suppose we draw the output *versus* bias current curve at a number of frequencies, as in Fig. 1E. We would see these things: 1. At all frequencies, the output rises with rising bias current, then falls off. 2. The current for maximum sensitivity is the same over a wide range of *low* frequencies (long wavelengths), then, as frequency increases (wavelength becomes shorter) the maximum sensitivity occurs at lower and lower currents.

This data can be re-plotted as a frequency response (Fig. 2A). The generally drooping characteristic shows that the system must be equalized to compensate for short-wavelength losses. Fig. 2B shows the relative responses if the recording field were changed to give the same tape flux at low frequencies for each bias current. We see that low bias current gives the *least* high frequency losses, and therefore would require the least amount of equalization. Therefore,

Fig. 2. (A) Frequency response with different bias currents showing the need for equalization. (B) Same as (A) but with outputs at low frequencies adjusted to same level. (C) Same as (A) but with the system equalized for a flat response when the bias has been adjusted to provide the maximum sensitivity at low signal frequencies.



from *only* a frequency-response standpoint, biasing for maximum sensitivity at the highest frequency would be best. When the system is equalized for the maximum low-frequency sensitivity bias point, changes of bias would change the equalized response as shown in Fig. 2C. Lowering bias increases high-frequency response and *vice versa.*

Effect of Bias on Distortion

Fig. 1B shows that at low bias the curves are non-linear and with increasing bias they become more linear. The measured harmonic distortion at low frequencies shows this effect (Fig. 3A).

Harmonic distortion measurements above one-third of a recorder's bandpass are, of course, meaningless since the distortion (primarily third harmonic) is eliminated. High-frequency non-linear distortion can be measured, however, by the CCIF intermodulation method. Two equal-amplitude high-frequency tones, say f and $f + \Delta f$, are used. If we let $f = 300$ Hz, then the frequencies could be 10,000 Hz and 10,300 Hz. In the output, we look for the second-order intermodulation frequency component at $f - \Delta f$, which would be 9700 Hz in this case. This frequency is caused by the same non-linear phenomenon which causes third-harmonic distortion, but this frequency is *inside* the system bandpass. Fig. 3B shows the output for 2% IM distortion *versus* bias current, for 500-Hz, 2500-Hz, 5000-Hz signals, using a 9.5 cm/s (3¾ in/s) tape speed, standard tape, and a 5-μm (200 μin) combination recording head gap length. The 0-dB bias current is that which gives maximum sensitivity at 500 Hz.

This data shows the difficulty of improving the high-frequency response by lowering the bias current. The response at lower levels is improved (see Fig. 3B), but the maximum output for a given distortion at mid-frequencies is greatly diminished. Operation at −3 dB bias, for instance, increases the 5-kHz maximum output by almost 3 dB, but decreases the 500 Hz maximum output by 4 dB, thus the mid-frequency signal-to-noise ratio is compromised in order to gain improved high-frequency performance. With separate recording heads, the problem still exists, but is not so severe.

Effects of Bias on Dropouts

When recording, a tape nodule or a dust particle causes the tape to be lifted away from the recording head, the biasing field is, in effect, decreased. If the system is underbiased (say at −2 dB in Fig. 1D), then a small loss of bias causes a large loss of recording sensitivity, and a large dropout of the recorded signal at all frequencies. If, on the other hand, the system were operated in the overbiased condition (say at +2 dB of Fig. 1D), the loss of contact would decrease the biasing field, but this would result in a compensating *increase* in recording sensitivity, thus the dropout would be reduced.

Hence, we have a conflict—best response at low levels dictates low bias current, greatest output for a given distortion dictates a medium bias current, and reduction of dropouts dictates a high bias current. In professional recorders, high-speed recorders with separate recording heads, there is little problem. Best operation comes from biasing at 0 to +2 dB *re* bias for maximum sensitivity at low frequencies. In home recorders—slow-speed recorders with combination recording heads—there is a real conflict and some compromise must be made. Different equipment manufacturers do this differently and extended frequency response may mean high distortion.

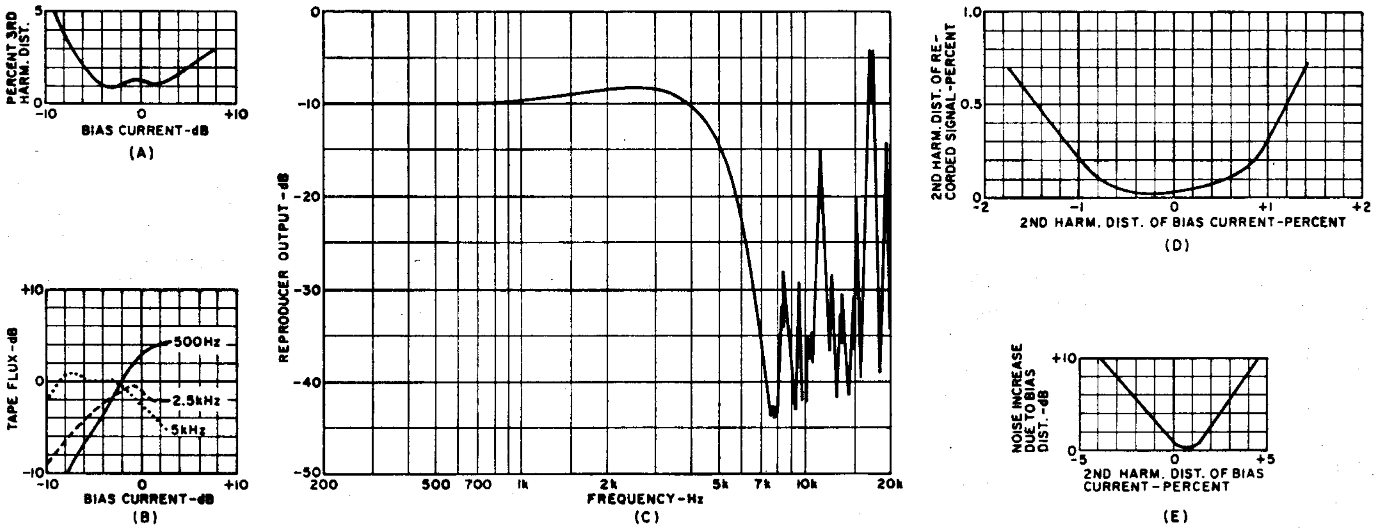
The Bias Frequency

The bias frequency should be as high as possible for two reasons. First, lower bias frequency causes the background noise to increase: at 19 cm/s (7½ in/s) tape speed, the use of bias frequency of about 100 kHz (or more) reduces this noise to nearly the minimum amount. Second, at high recorded frequencies, the harmonic distortion which is created at high recording levels by the tape and recording amplifiers produces audible beats with the bias frequency and these beats are recorded on the tape. A frequency-response run at high levels may look like Fig. 3C. The response above about 8 kHz is, in fact, a series of bias beats. This 4.75-cm/s (1⅞-in/s) recorder uses a 67-kHz bias frequency.

This problem may be especially troublesome when one attempts to make tape recordings from an FM-multiplex tuner. Both 19- and 38-kHz signals are present in the multiplex unit and may get through to the tape recorder. If these are of large magnitude, the bias beats will occur. Several solutions are possible including better filtering of the multiplex carrier in the tuner and low-pass filtering in the tape recorder input circuit. If the multiplexer is well-balanced, so that only the 38-kHz is of concern, the choice of a 95-kHz bias frequency will place the beats above the audible frequency range.

If the bias waveform has even-order harmonic distortion, a d.c. signal is recorded on the tape. This has the bad effect of causing second-harmonic distortion as shown in Fig. 3D. A tape noise is also added, as shown in Fig. 3E. The noise consists of "cracks and pops" *(Continued on page* 75)

Fig. 3. (A) Low-frequency third-harmonic distortion. (B) Maximum output for 2% second-order CCIF IM distortion. Reducing bias for improved high-frequency output results in reduced low-frequency output. (C) High-level frequency response showing "bias birdies"—spurious outputs above 8 kHz in this 1⅞ in/s recorder with 67-kHz bias frequency. (D) Second harmonic distortion due to bias distortion in current. (E) Noise in recording also due to bias distortion in bias current.



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caused by irregularities in the tape coating; it is therefore very much a function of the tape quality.

When the bias is a.c.-coupled to the recording head, any *average* d.c. is eliminated. Unfortunately, the *peak* bias amplitude may still be asymmetrical and this leaves a d.c. flux on the tape.

The bias oscillator circuit shown in Fig. 4 is a common astable multivibrator circuit with a center-tapped transformer, in place of the normal collector resistors and a capacitor, added to complete the parallel resonant circuit with the transformer. This tuned circuit not only sets the frequency of oscillation but also makes the signal sinusoidal. Because the circuit is push-pull, the even-order harmonics, which will cause distortion and noisy recordings, are greatly reduced. The emitter resistors are added to balance the gain in the two transistors to further reduce the generation of even harmonics. ▲

Fig. 4. A typical bias-oscillator circuit using transistors.