ANALOG TAPE RECORDER ELECTRONICS

A Road Map For Maintenance Engineers

BY GREG HANKS

The process of reproducing sound from a recorded tape is very similar in function to the operation of a hydroelectric generator. They both operate on the principle that when a magnetic field cuts across a wire, current flows in the wire. The recording process works using the inverse of the principle: when a current flows in a piece of wire, magnetic lines of flux are created around that wire. Magnetic tape is composed of very fine particles of magnetizable material glued onto a long chunk ofplastic. In the recording process (where analog audio is concerned), these particles are magnetized along the plane of travel of the tape. They are stacked perpendicular to the plane of travel across the face of the gap that contacts these particles. When these stacks of horizontally polarized bar magnets travel across the face of the reproduce head, the lines of magnetic flux that surround them are carried by the head across a winding inside the head, and a current flows in that winding. That current is our audio signal, and getting it on and off the tape with the least amount of destruction is our goal.

HOW HEADS WORK

Reproduction

The playback head is a transducer that changes the magnetic flux reversals of particles on tape moving past it into electrical signals. This can be viewed simplistically as a transformer that uses magnetic tape in motion across the core gap (pole pieces) as the primary winding. The head is an inductive source. This means that with a constant flux level presented to the pole pieces, the frequency response rises at 6 dB per octave. The output of the head is similar to that of a miniature generator, and it is important to note that the voltage generated not only is proportional to the amount of flux, but also to its rate of change. This results in the same response curve as you get with a capacitor in series with a load, but with a major difference. With a capacitor in series, you have 90 degrees of phase shift, but with the head, there is no accompanying phase shift. Because of this response, all tape reproduce pre-amplifiers start with a falling 6 dB per octave response, which mandates an included 90-degree phase shift. The equalization curve necessary to accomplish conformance to the appropriate standard is then applied to this falling 6 dB/oct. curve. Seems simple enough, right? See the sidebar on EQ curves for an explanation of why **most** published curves look the way they do. If the output of the head is rising at 6 dB/oct., then why is there high frequency boost applied to the record signal, and why are the EQ curves so different for different speeds? Well, the reasons are based in trying to over come the "losses" that are an integral part of the record/reproduction chain, Among these are: gap loss, azimuth loss, spacing loss, thickness loss, head bump loss and eddy current loss.

Gap Loss: This is probably the most widely comprehended loss in the reproduce chain. The head responds to the changing magnetic pattern on the tape as it is moved across the head. When thewavelength is equal

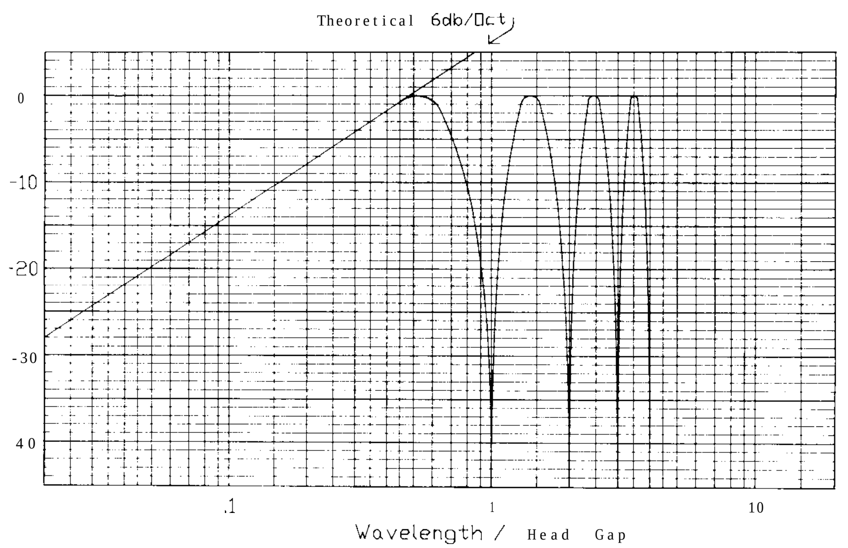

Figure 1

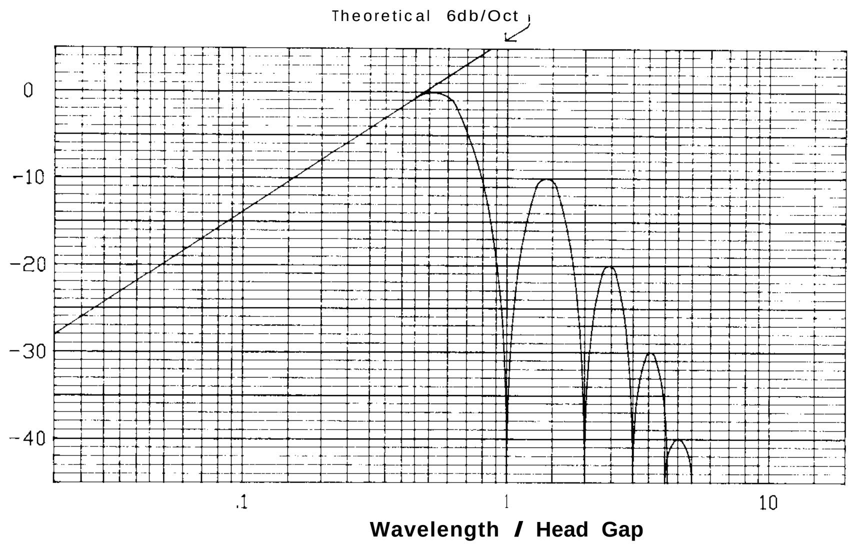

Figure 2

to the gap size, the output of the head is zero. This is the familiar function:

$$\frac{\sin X}{X}$$

The response that accompanies gap loss is shown in Fig. 1.

Azimuth Loss: It is well known that the high end will get a bit muddied when the playback head is on a tilt. This is known as azimuth loss. The reason the top end disappears is that this is a wavelength-sensitive loss. The mechanism of the loss is best explained by remembering that the amount of current which flows in the head winding is proportional to the amount of flux differential which appears across the gap. When the head is not perpendicular to the plane of travel of the "line" of magnetism (remember, there is a line of magnetic particles perpendicular to the travel of the tape), then there are fewer particles contributing to the differential of flux at the gap. The amount of loss is greater when the track width is larger. It also is greater when the wavelengths are shorter. The formula that describes this loss is:

Alignment Loss (in dB) =

$$20 \log \frac{\sin \frac{\pi \times \text{width} \times \tan \text{angle}}{\text{wavelength}}}{\frac{\pi \times \text{width} \times \tan \text{angle}}{\text{wavelength}}}$$

See Fig. 2

Azimuth error makes itself obvious with wider track widths, such as half-inch 2-track format. With a 24-track machine, the azimuth can be out as much as 360 degrees between tracks one and 24, and high-frequency attenuation due to that error is negligible.

Thickness (of Coating) Loss: Thickness loss is the primary deficiency that reproduce equalization is meant to overcome, and to understand it, we first must explain spacing loss.

Spacing Loss: Spacing loss occurs when the magnetic oxide of the tape is not in contact with the gap of the head. This loss is wavelength dependent. For a given separation distance, the shorter the wavelength, the greater the loss. Consider the case of the cassette-the tape speed is slow and the high frequencies have short wavelengths, so a spacing of 25 micro inches (.000025) will produce 11 dB of loss at 15 kHz. The formula for calculating this loss is:

Spacing Loss (in dB) =

$$55 \times \left(\frac{\text{distance}}{\text{wavelength}}\right)$$

Spacing loss probably is the most significant element that a techie will deal with. It rears its ugly head in many forms. Most of the time, spacing loss occurs because of incorrect head rotation coupled with wear of the head at the gap. This can be corrected "in the field," whereas the majority of other types of losses mentioned here are a function of head manufacture. Spacing loss appears in other ways, such as registration error. The manner in which this usually distinguishes itself is in "meter bounce," although this also occurs with racking error mentioned above. Registration error is the same thing as head height errors between the recorded track and the reproduce head gap location. Registration error common to all tracks in a multi-track head can be corrected by changing the height of the head, whereas the situation where only a couple of tracks are off can be corrected only by head replacement. When the reproduce head track width is not centered on the recorded track, there is less total flux available to the reproduce head, and the overall signal level is reduced.

Thickness Loss (Revisited): When the tape is recorded, the oxide coating depth is completely penetrat-

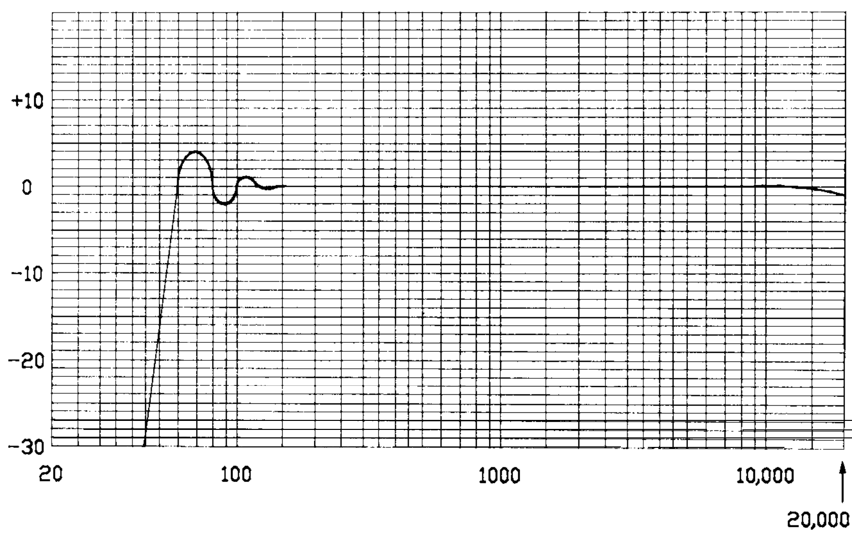

Figure 3

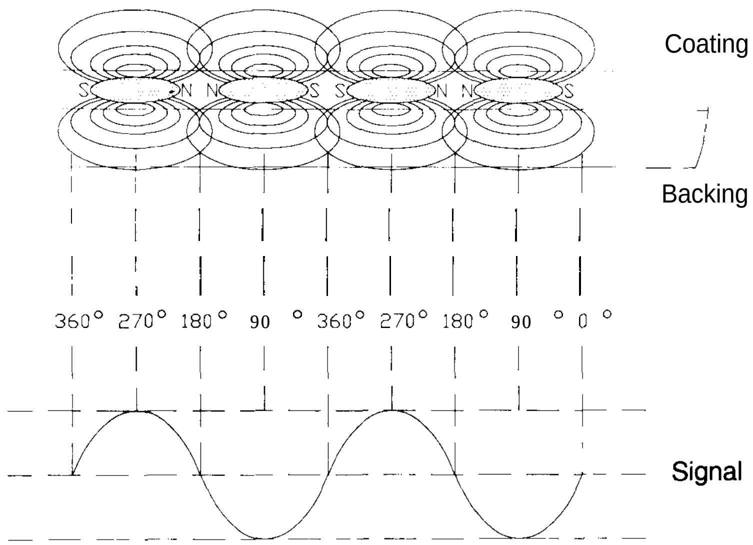

Figure 4

ed by the bias field. Thus, the entire depth of the tape is recorded. When the tape is played back, the flux field(s) of all the "layers" of the magnetic particles that comprise the tape contribute unequally to the reproduced signal. Because of the spacing loss phenomenon noted above, only the longest of wavelengths fully contribute to the reproduced signal, with only the surface layers of magnetized particles contributing to the high frequency reproduction. This gives us a falling frequency response that is tape speed-dependent, It is this high frequency loss that both reproduce and record equalization are meant to overcome. The slower the speed, the shorter the wavelengths and the more thickness loss we have. The above loss illustrates why newer chrome tapes have better top end. The tape surface is now much smoother than older tapes, and this means the oxide can have much more intimate contact with the head.

Eddy Current Loss: In the reproduce chain, this loss probably contributes the least to the difficulties of getting quality reproduction of music. Eddy currents are created by the lines of flux generated by the windings of the head. When the flux from the tape is converted into electrical energy, this generates a current flow in the winding. The current flow in the windings of the head causes lines of flux to be generated around the winding, and these are coupled into the core, and around and around it goes. The net result is that the flux (at high frequencies) is confined to the surface of the core. Modern heads consist of many laminations of core material. This reduces eddy current losses by increasing the number of surfaces, thus increasing the amount of available flux. The net result: the slope of the rising response of 6 dB/oct. is reduced to 5½+ dB/oct. Typically, this results in ¼ to ½ dB loss at 2OkHz. This is a frequency-dependent loss, so is unnoticeable at lower speeds, while observable at 15 and 30 ips.

Head Bump Loss: When the recorded wavelength on tape approaches the overall dimensions of the two head pole pieces, the pole pieces begin to act as a second gap. This leads to a rise in the output of the head. When the wavelength is twice the length of the contacted pole pieces, there is a maximum addition of available flux. Conversely, when the wavelength is equal to the combined "second gap," we have a cancellation of output because the additional flux output is zero. The resulting curves can be seen in **Fig.** 3.

Recording

Getting the signal back off the tape is much more difficult than getting it on there in the first place. The recording process operates on the principle that when a current flows through a winding, lines of flux are generated around that winding. These lines of flux are carried by the pole pieces of the head to the surface of the tape. There is a gap perpendicular to the travel of the tape, and this gap has a magnetic field across it that is polarized along the plane of tape travel. Being that we are glossing over the basic physics principles of the recording process, I will simply state that obviously we are all well aware of the non-linearities of tape, and thusly are cognizant of the role of bias in the recording process. Recording takes place at the trailing edge of the gap, and not across the gap itself. The above mentioned phenomenon is what accounts for the drastic phase shifts that occur in multi-track machines with their bias aligned at 1kHz or below.

Let me move into a discussion of the losses that affect the recording

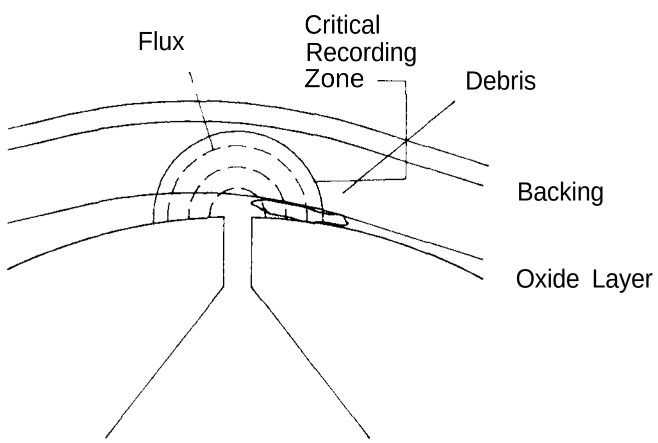

Figure 5a

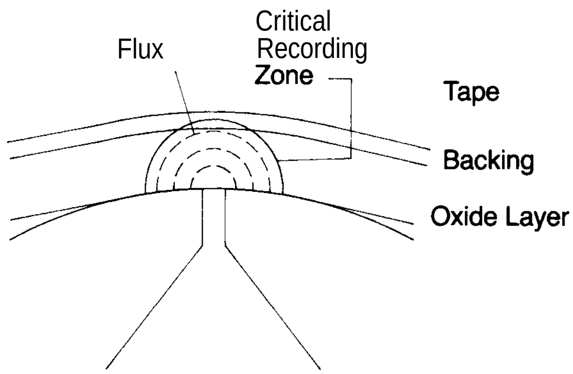

Figure 5b

process, to better illustrate the reasons for the equalization that we apply.

There are a number of losses that occur in recording as well as reproduction, including demagnetization, bias erasure, eddy current (revisited) and spacing (revisited).

Demagnetization: When recording takes place, we are orienting and magnetizing the magnetic particles (rust) that are glued onto the tape. Refer to **Fig. 4** for a simplistic picture of a representative magnetic flux pattern on tape. Upon inspection, we see the patterns from one group of particles interact with adjacent groups of particles. This occurs in both longitudinal and perpendicular magnetization. The result is a reduction of the flux available to the head. The demagnetization loss for longitudinal orientation is greater at short wavelengths, and perpendicular losses are greater for long wavelengths. A bell-shaped curve is the result. Modem tapes use longitudinally oriented particles, so the predominating loss is at shorter wavelengths. Low frequency boost is the result of demagnetization losses. The formulae that describe this loss are lengthy, and can be found in the IEEE transcripts authored **by** Shun-Ichi and Neal Bet-tram.

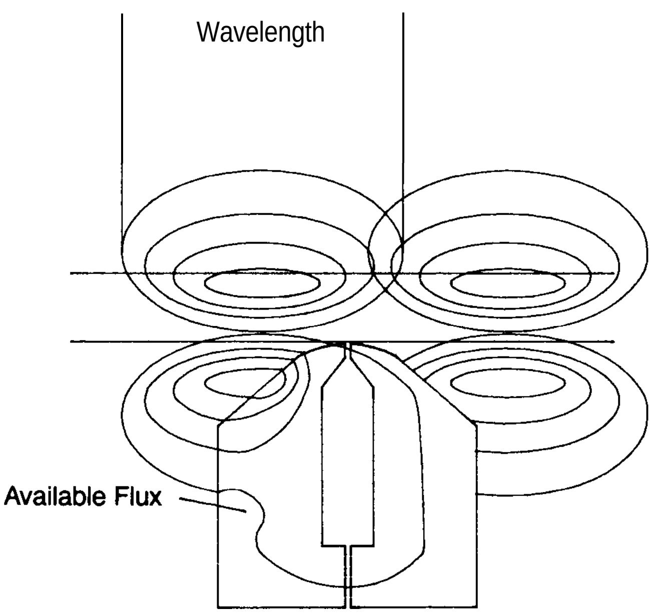

Figure 6

Bias Erasure: This is the phenomenon whereby the short wavelength signals (top end) are reduced in level more rapidly than the long wavelength signals with increasing bias current. There are a number of different explanations for this occurrence. Some early investigations explain the process by mapping the geometry of the bias field at the gap, and state that the shape of the bias field at the "trailing edge" of the head (or "transition zone") is responsible for the reduction in high frequencies.1 Let me take a step back, and note that the recording process takes place as the tape exits the head where the bias field is decaying past the remnance point of the tape. There is a zone where the bias level is at a flux level which no longer will re-orient the magnetic domains of the particles of the tape. This is called the recording zone. If the bias field is of a geometry that allows this zone to be large in relation to the wavelength of the recorded signal, then the resultant flux is reduced to zero. It has also been said that it can be viewed as though the short wavelengths are being pushed into the tape coating, and that thickness loss prevents the signal from being available to the reproduce heads.[2]

Eddy Current Loss (Revisited) and Core Permeability Loss at High Frequencies: Eddy currents can be defined as the circulating currents within the core of a magnetic head. They flow in the same direction as the core windings and, if permitted to circulate unhampered, would behave as if there were a number of short ed turns within the core. Such a short circuit would dissipate a considerable amount of energy and decrease the head's efficiency. It can be said that these losses are best visualized as a reduction in the cross-sectional area of the pole pieces, which reduces the amount of flux-carrying area, resulting in a loss of signal. Eddy currents limit the penetration of flux lines into the core center and the flux lines are confined to the core surface. As the frequency increases, this sheath of flux carrying material is no thicker than the skin depth of the core material. A laminated structure is used in most magnetic heads to increase the number of flux-carrying sheaths.3 Eddy currents increase with frequency. In the recording process, eddy currents limit the amount of current available to the windings, because of the increasing impedance of the head. This results in a loss that increases with frequency. Core permeability loss at high frequencies is not as well-known as eddy current loss, but contributes to its effect. In practice, the permeability of metal heads changes with frequency, partially due to eddy current losses, and partially due to core permeability loss. This results in the head changing inductance as the frequency increases. The slope of the high frequency losses is increased by the coupling of these two losses combined. (Ferrite heads do not show decreasing permeability at high frequencies, and the eddy currents are negligible, which illustrates why there are often difficulties in the simple exchange of ferrite heads for metal heads in the record chain.[4]) The end result is 15 to 20 kHz being down in record, all other factors being equal. The only corrective action possible is the replacement of the head with a different type showing lower losses. Modern studio recorder heads do not usually demonstrate this property, and if they do, the integrity of their manufacture is suspect.

Spacing Loss (Revisited): The geometry of the bias field is one of the determinants of the high frequency response of the recording chain. Spacing loss in the record side of the system, whether caused by debris or a film of air, results in a dynamic change of the shape of the recording zone. The effect of this change is the same as "under-bias," which results in an increase in distortion, and an elevation of the high frequencies. See Fig. 5.

So now you see how difficult it is to get audio on tape, and how much more difficult it is to get the stuff back! Enough about losses. Let's get into some of the meat and potatoes issues that we face every day.

Operating level

One of the more confusing aspects of studio life for the aspiring "Techie" is the mathematical relationships of "standard operating level." I am frequently asked why the 250 nW/m² test tape is called a +3 operating level, when the standard operating level is 200 nW/m². Also, is "+6" 6 dB above 200, or +3 above 250, or is it based upon a European reference level? Well, I hope that the following list and explanations of the most commonly used reference levels will explain some of

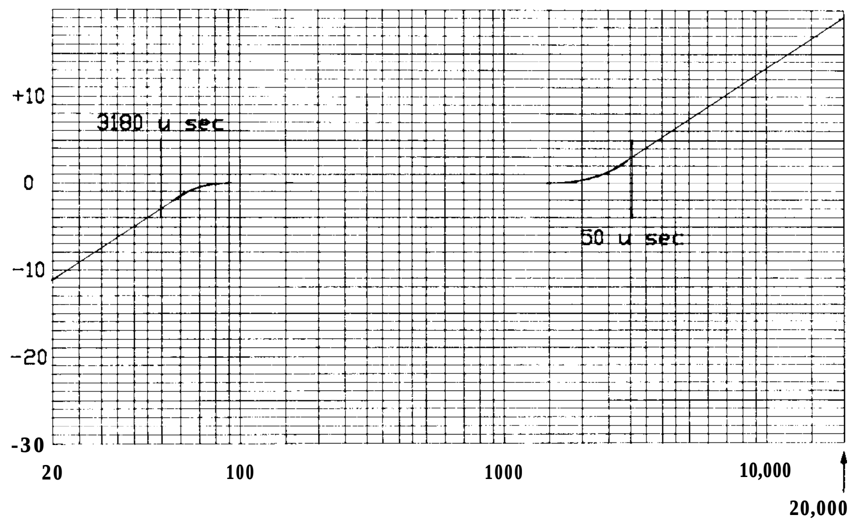

Figure 7

the confusion. There are a number of standards adhered to, including:

NAB: The NAB operating level was specified as -8dB below 3% distortion using an "appropriate tape" (such as Scotch 111). There was no fluxivity specified, but it generally fell in the 160 nW/m² range. This has evolved into the current I60 nW/m² specification used by the NAB for the tape cartridges commonly used in broadcasting. (Most broadcasters are now using 200 to 250 nW/m² as their "in-house" operating level.)

185 **nW:** This is the original "Am pex operating level," established as the amount of flux per unit area that was **-6dB** below the 3% distortion level of the tapes in common use at that time. This fluxivity refers to a 700 Hz tone recorded at 7½ or 15 ips where the playback head pole pieces cover the full recorded track Mono machines were the norm, and this operating level and the test tapes utilizing it were fully sufficient for the purposes of alignment. This level has also been adopted by the NAB for the purposes of 7½ and 15 ips open-reel formats. There are no compensations employed in the test tapes that use this level.

200 n\w: Magnetic Reference Iaboratories introduced this as a means of conforming the reference fluxivity of their test tapes to the ANSI preferred number series. There is much consternation and argument about the relationship between 185 and 200 nW/m². It's said that this differential is due to the differences of "open" and "closed' magnetic measurements. But, according to Magnetic Reference Laboratories' J. McKnight, who is the person responsible for the introduction of this level, the move to 200 nW/m² was only for the purpose of number reconciliation. These tapes employ fringing compensation and use 1 kHz as the reference frequency.

250 **nW** This was the first **"+3"** or "elevated level" reference fluxivity. The reference frequency was 1 kHz and was first introduced by Standard Tape Laboratories. This number was +2.85 above 180 nW/m² which is the fluxivity of a 1 kHz tone from a 185 nW/m² tape referenced to 700 Hz at 7½ or 15 ips. This is rounded to +3 for convenience. MRL also introduced a 250 nW/m² test tape, because this number finally conforms to the ANSI standard number sequence. The level differential between the STL and MRL tapes is due to the fringing compensation incorporated in the MRL tapes. This has become the DIN standard for cassette operation, using 333 Hz as a center frequency. The Japanese have adopted this standard for cassette production, with the reference frequency conforming to the ANSI preferred number of 315 Hz.

320 **nW:** This is the DIN standard level for 19 to 76 cm/s (7½ to 30 ips). First established as "peak recording level" way back when, this level was to correspond to "0" on a peak program meter. This is, curiously enough,+6dB over the approximate level of the original NAB standard. These days, this level often is referenced to "0" VU or -6dB on a peak reading meter. This level is referenced to 1 kHz.

"+6": Ambiguous as it may seem, this number actually makes more sense than trying to refer to the other numbers above. The preceding begs the question "+6 relative to what?' and that is what makes this reference sensible. The use of "+6" requires contemplation of the reference level in use, and choosing either to go to twice that fluxivity, or to match an arbitrary level that is recorded on the tape. What this reference generally means in the U.S. is to align the reproducing circuitry of the tape machine to read -3 VU at the reference frequency of 1 kHz when reproducing a 250 nW/m² test tape conforming to the equalization standard in effect for the chosen operating speed. This number corresponds to an actual flux level of 353.13 nW/m², or +5.85 dB above the original Ampex operating level of 185 nW/m².

510 **nW/m²**: This 510 nW/m² is a somewhat newer reference, used to align DIN or CCIR reproducers to "0" on a peak reading meter. This level corresponds to +9 dB above 180 nW/m², which you will recall is the effective flux of a 1 kHz tone referenced to a 700 Hz 185 level. This effectively represents a +3 dB increase over the original Ampex level, or roughly corresponds to our "+3" level of 250 nW/m².

"Dolby Level": Not to confuse things any more than they are already, Dolby labs attempted to influence operating levels on machines that employed their noise reduction system. The reasoningwent something like: If we tell 'em to use 185 nW/m², then they won't be limiting the signal with the tape itself, and our compandor system will work within its proper dynamic law; and with the improvements offered by our noise reduction system, the reduction of operating level will not be negatively intrusive. Well, as it works out, what in fact happens is that "Dolby Level" refers not to the fluxivity, but rather to the operating level of the facility. When the tape recorder reads "0," then the Dolby is aligned to read in the center of the Dolby dot. They had the right idea, but studio personnel are forever going to do it their own way anyway!

What falls out of the above discussion is the determination that operating level must be tied to the volume units in use, and the alignment method must be specified if true tape interchangeability is to be fully realized.

Thus, a master reel with tones should include a note indicating what meter type should be used, such as VU or peak reading, and what the reference level should be set to.

OK, so now you understand where some of the confusion about operating level comes from, and why losses play such a prominent role in the recording/reproduction chain. So at this point you can seewhywe have equalization, applied both to the playback and record systems. Let's discuss some of the details. . . .

Equalization

An important item of note: the current equalization standards are applied to *reproduction only.*

The equalization applied to the recording and reproduction system is designed to overcome the above mentioned losses, as well as to provide an improvement in the signal-to-noise ratio of the system. This task is broken into pre-equalization, applied during recording, and post-equalization, applied during reproduction. The division of the quantities of equalization used between recording and playback should not be an arbitrary one. The trade-off that occurs is between high frequency headroom and high frequency noise. Unfortunately, these two goals are mutually exclusive. The reproduce equalization is mandated by the various standards that are in place, and the equalization applied to the recording chain is that correction required to create recordings that reproduce in conformance to the above mentioned standard. This means that the record EQ is tailored to the machine, tape and head characteristics of the recorder and tape used. (See sidebar).

Remember when we were talking

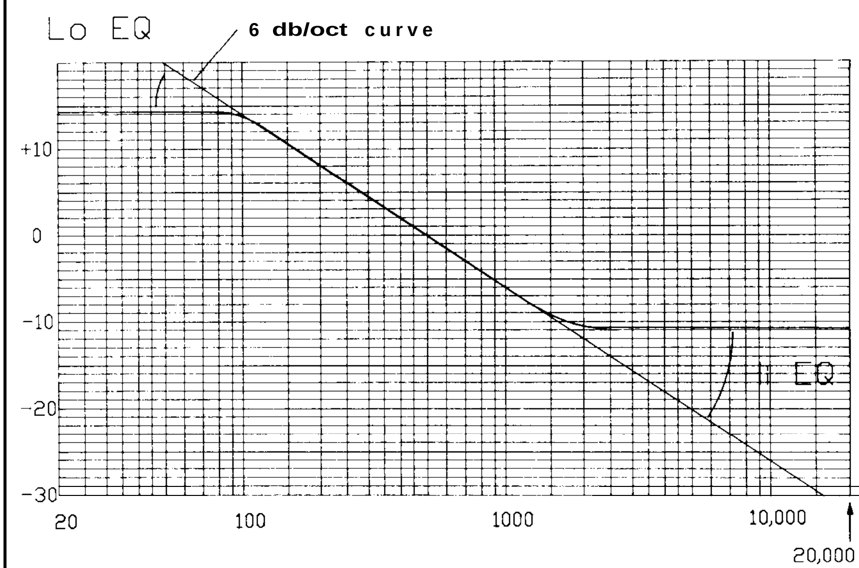

Figure 8

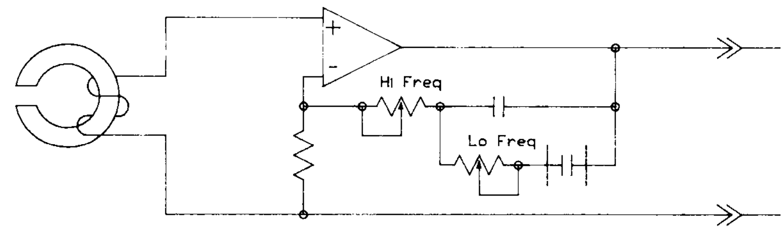

Figure 9

about the reproduce head having a response that rises at **6** dB/oct. with a constant flux? Well, to get a constant flux level, we need a constant current in the record head. Remember eddy currents, and the other losses of the record head that deprive the head of available flux? The rising response of the record equalization is intended mainly to overcome the rising impedance of the record head with frequency, to provide us with the ability to drive the record head with a constant current. Because some of the losses of the system are frequency-dependent, while others are wavelength (operating speed)-dependent, the EQ requirements change with the operating speed. The trade-offs between headroom and noise were made long before we had the need to adjust or repair our equipment, so I won't belabor the philosophies involved in the decision as to where boosts and cuts belong, but rather will try to illustrate where they are, and how to look at the system when we have response problems to address. Equalization standards are expressed most often as two different time constants, such as 3,180 and 50 μsec. These numbers refer to the time constants of the combination of resistors and capacitors comprising the filters that accomplish the equalization (for example, T=RxC). Therefore, for the NAB 15 ips standard, T=50 μsec., and C= .01μF, R=5 kΩ. Since the **-3dB** point of 5 kΩ in series with .01μF is calculated with the formula:

$$F = \frac{1}{2\pi RC}$$

Therefore, F= 3183 Hz.

The low frequency EQ point is calculated with the resistor and the capacitor in parallel. The following time constants provide the appropriate operating EQ standards:

Remember, the **frequency** response of the reproduce pre-amplifier starts at a falling **6 &per** octave, and the above time constants refer to break points on this curve. This means the low frequency EQ results in a flat response from the pre-amp, but this translates to low frequency attenuation. The high frequency response also is flattened out with EQ, but this translates to high frequency boost. We also have a boost requirement in record; so, we have high frequency boost in both record and reproduction. This overcomes all those losses we described earlier.

Much of what we're discussing deals with fixed EQ. We have adjustments in our machines, both for playback and record. The playback adjustment control has the affect of changing the "short" time constant, or high frequency turn-over point of the equalizer. Since most of the high end problems we encounter in a studio environment deal with spacing loss, if we crank up the high end EQ to make up for dirt on the heads, gap loss, or resonance losses, we end up bringing the mid-band up in level as well.

Remember that the turnover point of the standard for **15** ips is 3,180 Hz. The result of the turnover frequency being so low, coupled with the variable element changing the turnover point, means that turning up the equalizer for +3 dB at **16 kHz** can end up bringing 4 kHz up about 1½ as well! The net result of all this is that we must find out which one of the many losses is responsible for the problems we face. For example, I have encountered machines that, when new heads were put on them, you could not turn down the top end. Upon inspection I found there was an EQ limiting resistor in series with the high frequency control. By lowering its value by half, we could bring the machine into alignment.

Most machines also incorporate some form of circuitry to overcome the effects of gap loss. The simplest form of compensation is head damping. You often will find that the head is terminated in a transformer, and the secondary of that transformer will have an "R" and a "C" in parallel across it. These elements provide "critical damping" of the head, and may be varied for optimal flat response in the 12 to 20 kHz area.

There are many benefits in optimizing this area of the circuitry, not the least of which is the phase response of the machine. When the reproducer is made flat, the transient response of the machine sounds better. Take care when doing this change, for the damping elements on the front end of the repro pre-amp correct for gap loss, which is a wavelength-dependent phenomenon, in a manner that is frequency-dependent. This results in the optimization being valid only for one operating speed. If this optimization is to be performed, do it at the highest operating speed where the losses are at a minimum. Otherwise, the extreme top end will take off, and "brittleness and hiss" will result.

If you think about it, you can see why the high end at 30 ips sounds so much better than 15 ips, because the wavelength-dependent losses are half as great, there is much less high frequency boost in the playback equalizer. But this gain is not without payment, and that occurs in the bottom end.

Low end problems at higher tape speeds are caused by a number of things, including head bumps, secondary gap effect and recorded wavelength versus pick-up size.

Head bumps and secondary gap effects affect us just as much at 15 ips as they do at 30, but at **15** the frequencies

Time Constant Low Freq	Tape Speed High Freq	Standard	Tape Speed
3180	90 μsec	NAB and IEC	3.75 ips
∞	70 μsec	IEC and CCIR	7.5 ips
3180	50 μsec	NAB	7.5 and 15 ips
∞	35 μsec	IEC and CCIR	15 ips
∞	17.5 μsec	AES	30 ips

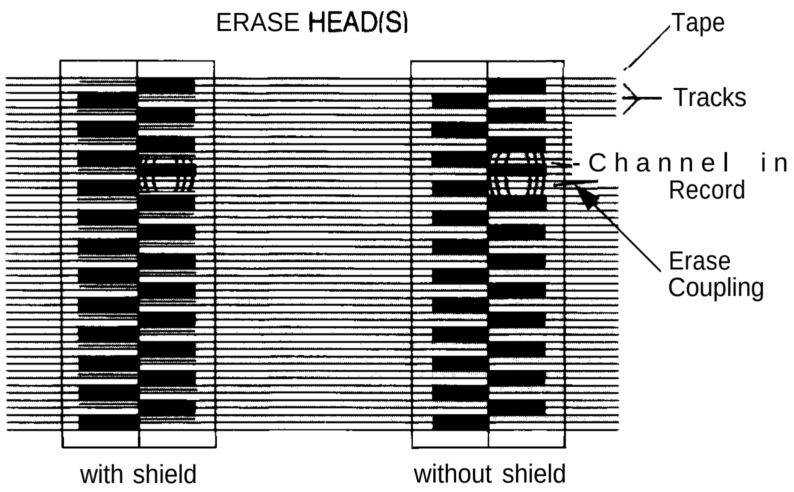

Figure 10

of disturbance are an octave lower than at **30,** and usually fall below the lowest frequencies of interest. But at 30, these gremlins tend to jump out at the 50 to 125 Hz region, and the extremely long wavelengths at the frequencies below this make reproduction extremely difficult to achieve.

Consider this: we are able to extract the maximum signal from tape as long as the pickup transducer dimensions are greater than the wavelengths to be reproduced, and the gap is smaller than the shortest wavelengths of interest. When the wavelength of the reproduced signal is greater than the overall length of the pickup transducer, then we only are able to retrieve the maximum differential available at the transducer contact points. See **Fig.** 6. The signal we retrieve from a playback head is directly proportional to the rate of change of the magnetic field, as well as the strength of the field. Since a 30 Hz signal at 30 ips is over one inch in length, the wavelength is longer than the head dimension and therefore the response falls. Thirty Hertz at **15** ips has a wavelength of one-half inch. This usually is within the width of the "secondary gap" of the reproduce head, and the response is still robust.

Coupling the loss of wavelength resolution to the attenuation we provide to correct for head bumps and fringing, we see a rapid fall-off in the low frequency response of the reproducer. Methods for improving head bumps include increasing the width of the head, making the incoming and outgoing wrap angle of the tape nonsymmetrical about the gap, decreasing the wrap angle of the tape-to- head contact area, and ensuring that all of the angles of the head around the face of the head are radius'd curves and not sharp angles.

If the head penetration is not field-adjustable, there is not much the screwdriver-wielding maintenance person can do about these low-end problems, other than taking the heads to a service facility that can change the geometry of them. There are a few things that can be done electronically to improve the very low frequency response of a reproducer, and one of them was put forward by J. M&night in a paper presented at the 1976 AES convention. MCI took him up on this one, and incorporated this change into their JH- **114** and JH-24 series machines. (This change is responsible for the problems associated with the LF con trol affecting the wide band gain when it is at the end of its attenuation range.) See **Fig. 9.**

Bias and Related Arguments

Let's re-examine some knowns. The mechanism aiding the transfer of the current that's an analog of our audio signal to the strip of iron oxide we call "tape" familiarly is termed bias. This is a high-frequency, high-amplitude signal added to the audio signal. The benefits of employing bias are well-known and many. Some of them include: increased recording efficiency, reduced noise residual, reduced signal distortion and improved high frequency response.

The bias current causes a high-frequency magnetic field to exist about the vicinity of the recording head gap. To effectively function as an aid to recording, the bias field must fully saturate the oxide as it passes over the record head gap. As the tape enters the flux zone, it alternately is saturated in both polarities by the bias field. The tape then proceeds to the "critical recording zone," which contains a field intensity below the tape saturation level corresponding to the linear magnetization characteristic of the oxide. Our audio signal is amplitude modulating the bias field in this region. When the dimensions of the wavelength of the modulating signal are significantly longer than the size of the recording zone, the magnetic undulations representative of the amplitude modulation of the bias field (our audio signal, in other words) remain on the tape as it leaves this zone. Signals that modulate the bias field whose wavelength is shorter than the length of the critical recording zone will not remain on the tape as it passes out of the recording zone, and will be of significantly lower level. This, in a nutshell, is how and why recording takes place on the trailing edge of the gap.

When we set the bias on a machine, it is common practice to set it while observing the playback monitor and recording a 10kHz signal at **15** ips. We then set the bias so that we "overbias" the tape by 3 dB. Or, when operating at 30 ips, we over-bias the same amount with a 20 kHz signal, or 10 kHz overbias **1%** dB. This method best establishes the size and shape of the critical recording zone, for if the bias level is established (say at the maximum 1kHz sensitivity level), minor reproduction level variations represent major variations in the shape and size of the recording zone. Any variations in the size of the recording zone represent a shift in time for the signal recorded. This results in an apparent phase shift of the recorded signal, and will result in high-frequency losses of the summed reproduction of the recorded signals.

The above mentioned phenomenon may be put to use in determining the accuracy of manufacture of the record head in a multi-track machine. If we set the record head azimuth using the summing method in sync playback, we have aligned the center-line of the gaps to be perpendicular to the recorded field on the test tape. When we then inspect the azimuth of the record signal on the same machine and find that the azimuth has shifted slightly,

—CONTINUED ON PAGE 200

go to record, good places for pressing. Everybody should start a label!" Evelev exclaims; in fact, Evelev's own Icon label was picked up for national distribution by the prestigious Nonesuch label. Among his projects have been records by Daniel Lentz, the Javanese "pop" group Group Gapura and an elaborate setting of music by Ennio (*The Good, the Bad and the Ugly)* Morricone by John Zorn. But it was no easy feat for Evelev to launch Icon. "I should know enough *not* to do it. You need the funding to start, and then you have to figure how to issue records and get money back quick enough, or spend little enough so that you can issue more records, and that's always been a problem. Any time you have a successful record, you're going to strain your resources; you'll never have enough money to keep it in print because the money won't come back quick enough. If you have an unsuccessful record, then you have a problem too, because you have all these records lying around and no one's paying for them. ***So*** you've got to hit this middle ground, a weird way of looking at things."

One unique side effect of NMDS's continued, albeit modest, success is that its very existence serves as encouragement to outcast musicians whose chances in a conservative record industry are next to nil. "When it started, there weren't many musicians making their own records," Evelev reports. "We showed that if **you** can make your own record and there's a place to take it, it doesn't have to sit in your living room propping up your coffee table. ***You*** can take it here; we'll send it out to stores, to press people, to radio people, try and promote it in some limited way and try and help you sell the records."

In essence, NMDS has helped generate a Warholian utopia: everyone, once authorized, has a shot at 15-minute celebrity. In addition, NMDS has admirably bucked the monolithic record industry and shown that independence and artistic self-sufficiency are possible.

Carla Bley writes: "Until the recent unruly springing up of musicians' labels began in defense (against corporate impenetrability), the selection of interesting new music available to the listener was limited by a scandalous set of rules. . . better suited for raising poultry, these standardswere responsible for practically annihilating an already endangered species-the creative musician."

(For further information and a catalog, write to New Music Distribution Service, 500 Broadway, New York, NY 10012, or call (212) 925-2121.) ■

—FROM PAGE 44, ANALOG ELECTRONICS

we can conclude that the trailing edge(s) of the record head gap(s) are not in perfect vertical alignment. This may be caused by gap scatter or gap width differentials that are symmetrical about the gap center-line. Gap scatter is easily identified in playback, whereas varying gap width is not. The net result is that the optimization of the record process may be at the expense of sync reproduction, and vice versa.

Distortion vs Levels: The amount of bias current that is applied to the record head will affect distortion, high frequency response, "biased tape noise" and recording sensitivity. Many assume that these characteristics are tied together and that setting the bias current for minimum biased tape noise puts you at minimum distortion, and near maximum record sensitivity. This is not so-it only will put you at the operating point of minimum bias tape noise. The formulations of various tapes often cause the minimum noise point and the minimum distortion points to overlap at the same bias current, but you can't take it for granted.

Examination of each parameter affected by bias current, as specified on the manufacturers' data sheets, provides a much clearer picture, hopefully. Something missing on most spec sheets is the variability of bias current for minimum distortion vs operating level, and the effects of "self-bias."This phenomenon has been studied recently[5, 6, 7] and has resulted in products that appear mostly in cassette and home equipment, such as the Dolby'" HX system. Applying this to professional recorders requires looking at the study that was done by T. Staros of MCI[8] and relating his curves (See **Fig. 11)** to your operating level.

Bear in mind that music has a dynamic envelope that the VU meter does not see. If we are operating at "+6," then we have to assume that most of our signal content will actually have a flux density of anywhere from 370 to 1,100 nW/m². We therefore would like our minimum distortion point to be about 3 dB above our chosen test tape and sine wave operating point. Generally this falls at around 3 dB over, at 10 kHz at 15 ips. By the way, the over-bias point is wavelength-sensitive, therefore it is very important to note that 3 dB over at 10 kHz at 15 ips is not the same bias point as 3 over at 30. It is much closer to 1½ over.

Bias symmetty (or lack thereof) is

Why EQ Curves look the Way They Do

Most of the time, when we see the response of the reproduce section of a tape recorder illustrated graphically, as in the case of test tape curves, or in the back pages of the service manual, these curves look like those in **Fig.** 7.

What you are seeing in these curves is what response would be if there were a constant flux of changing frequency present in an ideal reproduce head. However, if you disconnect the head and attach a signal generator that has a constant output and sweep it, you will see a curve similar to the one in **Fig. 8.** This is due to the rising 6 dB/oct. curve mentioned in the accompanying article. Since all magnetic reproduction systems exhibit this basic curve, it is assumed in all literature and equalization discussions. It seems obvious now, but how many of us believed that the low frequency EQ differences between CCIR and NAB were in fact a low frequency roll off in NAB that requires a boost in recording?

Recording curves do not exhibit the inverse of the 6 dB/oct. response. In fact, there is only a slight rise in the high end and low end, (for the NAB curve), on the order of +2 at 10 kHz and +5 at 40 Hz. Whenever we look at reproduce equalization curves, unless it is otherwise stipulated, assume that the curve is the result of the difference between a falling 6 dB/octave line and the result of the equalization.

-G.H.

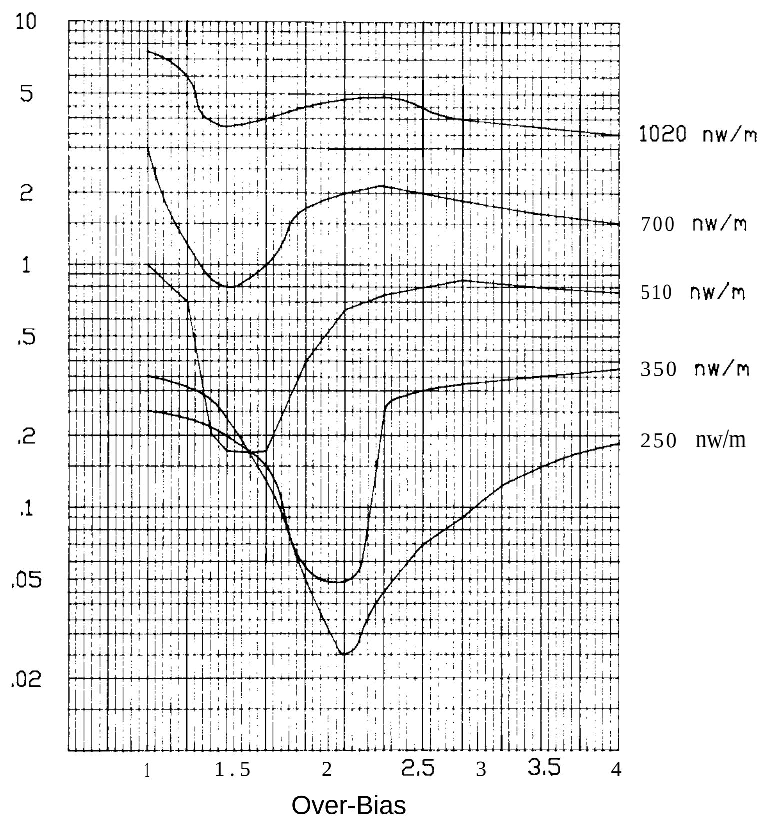

Figure 11

something that is rarely mentioned but often causes grief. Distortion in the bias waveform is not a bad thing in itself, because the bias waveform is not reproduced. However, any even order harmonic distortion results in the recording of "random" noise. When there is any non-symmetry in the signal, the even order distortion products yield the equivalent of a DC signal that will offset the reproduced zero axis. This means that all drop-outs and surface irregularities become modulation elements resulting in "pop-corn" and "bias rock." We often see the same result with a magnetized erase head. (The ***cogniscenti*** in my audience are familiar with the sound, and it is not pleasant.)

Symmetry problems are most often traced to problems with electronic clipping or magnetic saturation. In almost all newer tape recorders, there exists some form of adjustment to care for (or cause) this problem. The various stages that require inspection, correction and alignment are: master oscillator, master bias bus, master erase bus, individual channel bias outputs and individual channel erase outputs.

An oscilloscope is necessary for all of this work, as is a low capacitance probe. The specifics **vary** from machine to machine, but the concept remains the same. We must insure that the bias and erase signal(s) that are getting to the head are as free of even order distortion as possible.

While we're on the subject of saturation, it is a good time to discuss bias and erase frequency. We need the bias signal to be at least five times greater than the highest audio frequency of interest. This is obvious, for any fifth order harmonic of the highest frequency will produce a beat frequency with the bias signal, and this beat product will become an integral part of our recorded signal. Whistles do not agree with flutes or drums. In practice, this has resulted in most machines using a frequency of 120 kHz or greater. The higher the bias frequency, the higher the audio frequency response can extend.

There are practical limits on how high we can get the bias frequency, and one of them is eddy current. Eddy current losses result in heat, which lowers the permeability of the head resulting in lowered magnetic efficiency. Newer head designs using extremely thin laminations, and the entire ferrite family, exhibit very low eddy current loss. This has enabled modem recorders to utilize bias frequencies of up to 500 kHz, with 240 kHz being quite common. The frequency of the erase signal, on the other hand, is kept much lower. We desire a frequency which will have negligible eddy current loss and a stable permeability with a consistent inductance. Most newer designs incorporate a divider in the master bias oscillator section to achieve an erase signal that is 1/3 or ¼ of the bias frequency.

We need to develop some significant erase current to fully erase a track on a multi-track machine, and we are constrained by the amount of area that we have available to us to accomplish that task. Modem erase heads are built in a checkerboard type of pattern to allow for extra area in which to wind the wire and house the pole pieces. This has given us levels of erase previously unobtainable with conventional "inline" erase heads. Incorporated in almost all erase heads are multiple gaps which, in effect, erase the signal twice.

When we align the erase drivers, we want as much signal as possible to get to the head, without saturating the pole pieces or clipping the driver amplifier. Care must be taken with some of the checkerboard type heads because early versions did not include a guard band between vertically adjacent tracks, which can result in transformer coupling of the erase signal to the winding(s) of the tracks above and below the track that is in record. This results in partial erasure of the high frequency signal on the tracks that are two tracks above and two tracks below a track that is in record. See Fig. 10 for a graphic illustration of what I'm trying to relate.

Another concern to be aware of when doing the erase alignments is heat. Most modem erase heads require the presence of tape on the front of the head while it is energized, because the head utilizes the tape as a "heat sink' to help keep the internal temperature of the pole pieces within operational limits. If the head gets too warm, the inductance of the pole pieces shifts. As almost all recorders are designed to resonate the erase head for maximum signal, when the inductance changes, so does its resonant frequency. This can result in an alignment that is incorrect for the

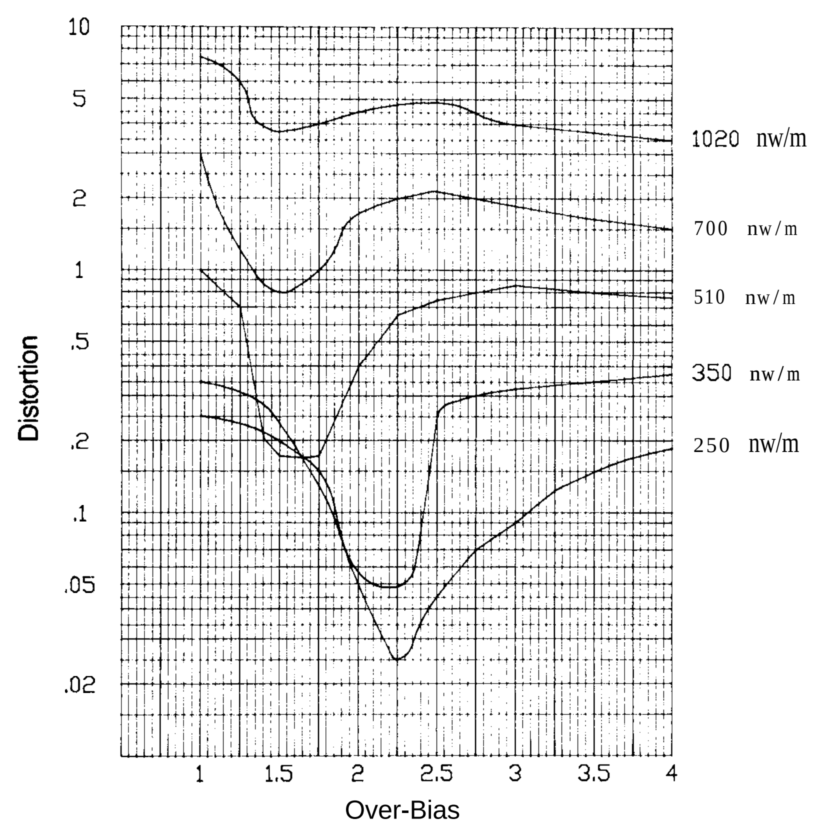

Figure 11

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—FROM PAGE 37, MAINTENANCE EXPERTS

ment should be cool and dry, around 40% relative humidity The deck should be on all the time. The danger in this would be AC power line disturbances caused by the electric company or heavy loads from nearby industrial facilities, but you should have a line monitor/ conditioner on the power supply line, because in one fell swoop, much damage can be incurred.

Forman/Tekcom: Starting out with a properly aligned tape deck ensures that you won't have to relap or replace the heads prematurely. If the studio doesn't have a maintenance tech who does daily alignment and calibration, they should purchase a series ofalignment tapes so they can check that and do any minor level adjustments needed to keep it running properly. If it's a 4- or 8-track format, check the alignment every week or two. If it's a larger format being used heavily, check it on a daily basis.

Garrett/Studioworks: I always suggest that all new machines be used for about a month, to let the electronics settle down and stabilize. Tweak it whenever you want, then after that, it's starting to stable out, it holds its setting, *then you* align it. After that, every day the engineer should clean the machine, demagnetize it, tweak it up; but *learn* about it before diving in. Keep the service manual handy, along with service bulletins, and any spare parts necessary to keep it running — silly little things that cost three, four dollars. Voltage regulators, pinch rollers, lightbulbs, springs, small items that can put the whole. thing out of commission. And keep track of how much time you have on a pinch roller.

Once a month or every two months, clean the relays and belts. Keep every connection and switch contact as clean as possible. Many machines have edge connectors that are alwaysgoing bad, so keep a pencil eraser handy to shine 'em up. Cramolin is a product that's good to put on all edge connectors, contacts, anything else you can get.

—CONTINUED ON PAGE 204

standard operation of the machine.

As can readily be observed from the preceding, it is a wonder that we get audio on and off tape at all, let alone as well as we do. It is a tribute to the art and skill of the design engineers of today's recording equipment that we obtain, in the analog realm, results that can be so artistically satisfying. I hope that this article has armed you with a few tools with which you can optimize your recording system, and give continued life to the analog recording domain. Happy tweaking! ■

*Formerly chief **engineer** at Wally Heider Studios (L.A. and SF) and technical director of Audiotechniques, Greg Hanks now heads New York! Technical Support.*

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