THE B.A.S.

SPEAKER

The Boston Audio Society
P.O. Box 7
Boston, Mass. 02215

July
1973

July meeting. Chuck Ange will host the next meeting of the B. A. S. at the recording studio of Renaissance Inc. at 2:00 p. m. on Sunday July 22. The principal activity will be a live-versus-recorded experiment; vocal and instrumental musicians will perform and be recorded, and the recordings will be played back through various loudspeakers for comparison with the live sound. There may be a shortage of chairs, so feel free to bring a folding chair if you have one.

Renaissance is at 63 Main Street in Maynard, on the second floor above Woolworth's five-and-ten-cent store. A map is enclosed. From most places the easiest path is west out Route 2 from Route 128, then south (left) on Route 27, and when entering Maynard a very sharp right onto Main St. If you need a ride call one of the following: Dave Letterman (266-2231), Dennis Boyer (783-0920), Al Foster (353-6114), Peter Mitchell (242-4542), or a member near you in the BAS phone list. Those who can't make prior arrangements will be picked up at B. U. 's Marsh Chapel plaza at 735 Commonwealth Avenue (directly across from Radio Shack) at 12:45 pm.

Bulk tape purchase. About $400 worth of tape was ordered at the June meeting. We hope to deliver the tape at the July meeting, so if you placed an order, bring money or a checkbook.

Advent tour. The first BAS tour of the Advent factory has been set up. Those who signed up for it in June will be notified of the time and date by mail or phone.

Sign-up sheet. Since many members did not get to the June meeting, we are including in this mailing the sign-up sheet for outside activities. If you want to participate in BAS activities outside of the monthly meetings, bring the form to the July meeting or mail it in before July 25 so that the group listings can be included in the August newsletter.

Membership list. As announced last month, the BAS membership phone list is enclosed. This list includes all current BAS members except (1) those who requested that they not be listed and (2) complimentary and institutional memberships. The phone list will start becoming useful next month when lists of special-interest groups are printed.

BAS Publications. In this month's featured BAS article, Al Southwick provides an introduction to the physics of magnetic tape recording. This discussion is preparatory to Al's planned article on procedures for biasing and equalizing tape recorders.

Publications policy. In case we haven't made it perfectly clear, the Publications Committee invites all BAS members to write for this newsletter. The BAS Speaker should be a vehicle for communication of ideas and facts among members -- not only from the executive committee to members. Anything from a one- sentence hot tip to a full-length article will b e welcomed for consideration. We ask only that contributions (1) be of general interest to members and (2) be clearly presented, typed if possible. As for style, brevity and clarity are hallmarks of all good nonfictional writing. The BAS Publications Committee includes members who have moderate-to-extensive professional experience in writing and editing, and we prefer to maintain professional standards in the BAS publications. So both authors and the reading membership should recognize that all BAS publications have been, and will continue to be, thoroughly edited to maximize clarity and to minimize verbosity. So don't be deterred from contributing just because your writing lacks polish; if you have something interesting, the polishing will follow.

June meeting. About 40 members attended the BAS greeting on June 17 at MIT. The National 381A preamp ICs were delivered. Interested members signed up for an Advent factory tour, for a group purchase of recording tape and cassettes, and for proposed activity groups. The preferred time of the July meeting was discussed. Keith North provided a data sheet giving addresses, subscription info, etc. on the major noncommercial hi-fi magazines (The Stereophile, The Absolute Sound, The Audio Amateur, The Hi-Fi Newsletter), and he donated sample copies to the BAS library-to-be. Chip Atwood's proposal for a BAS record-rating service (see the June newsletter) was approved by vote and will be set up. A suggestion to make recordings of the BAS meetings available through the Dubbing Committee was disapproved. Jim Brinton reported that we now have over 20 paid out-of-state members, some as far away as Texas, California, and Canada, resulting from Audio's favorable notice.

For the featured part of the meeting, Mark Davis introduced Mr. "Ed" Nakamichi, founder of Nakamichi Research and principal designer of the Tri-Tracer 1000 deck, and his son "Ted" Nakamichi, USA marketing manager. Nakamichi Research was the first company to develop a practical Dolby-B circuit (after Henry Kloss and Ray Dolby conceived it), so nearly all of the first-generation Dolby-B tape recorders were partly or fully made by Nakamichi (KLH 41, Advent 200, Fisher RC-80, Harmon-Kardon CAD-5, and others).

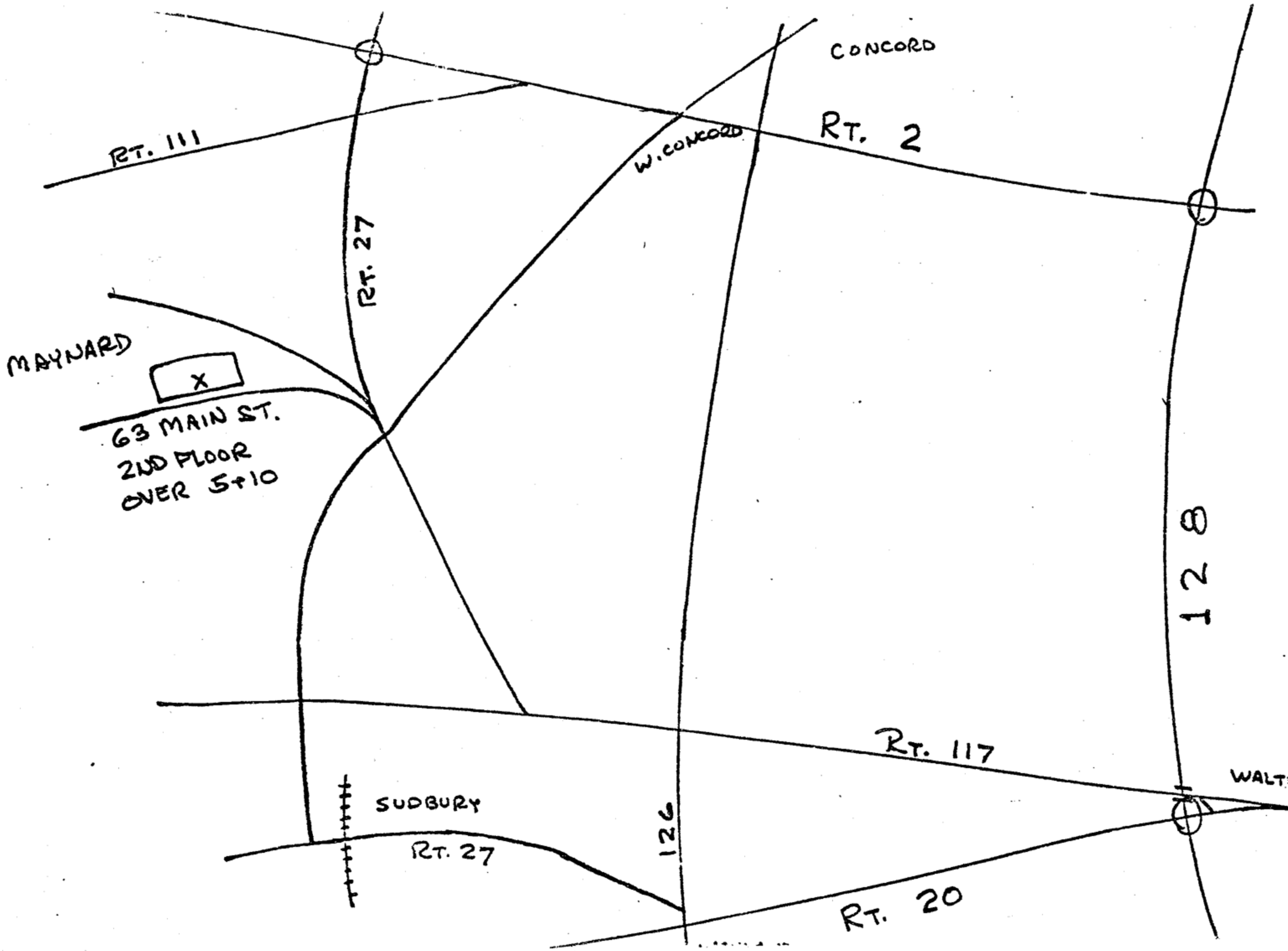
The senior Nakamichi noted that the Tri-Tracer 1000 was developed as an industrial machine for use by manufacturers to certify the performance characteristics of cassette tapes. Among the machine's features the following are particularly noteworthy. (1) Both Dolby- B and Philips DNL noise reduction systems, the Dolby for general use and the DNL for additional hiss reduction especially with non-Dolbyed material. (2) Three-head design, which (with the separate input-output pairs of Dolbys) permits off-the-tape monitoring while recording. The record head has a 5-micron gap, which permits higher saturation levels than the usual 1-micron combo record/play head. The playback head has a 0.7-micron gap to obtain flat response to 20 kHz. (3) A record-head alignment beacon which senses the interchannel phase difference, to reduce skew errors due to cassette-to-cassette variations in mechanical assembly. This also ensures that the machine can record matrixed 4-channel (SQ or QS) without loss of rear-channel directionality - a common problem in recorders as last October's BAS Recorder Clinic revealed.

(4) A dual-capstan differential-tension drive system which minimizes wow, flutter, and skew due to mechanical imperfections in cassettes. (5) Solenoid-control logic-operated tape motion controls which are noiseless, immune to tape jamming, and easy to use.

The Nakamichi 1000 was demonstrated, with a stereo system supplied and set up by Clayton Anderson, manager of Minuteman Radio in Cambridge and exclusive Nakamichi dealer in the Boston area. Source tape comparisons were made while dubbing pop selections from records and from a Revox. It made perfect copies except for (1) a subsonic rolloff (not audible, but the elimination of subsonic rumble was visible in the improved woofer cone motion), and (2) a slight dulling of the extreme highs apparently due to tape saturation (the recorded level was quite high and the meters are not equalized to reflect the recording pre-emphasis). The demo also illustrated the effectiveness of the DNL in reducing hiss from non-Dolby source material with only a slight loss of highs in the music.

The Nakamichi 700, a consumer version of the machine with essentially the same performance and features except for the DNL and auto-rewind, will be introduced in the fall for about $700.

The BAS owes thanks to Mark Davis both for inviting the Nakamichis to Boston and for providing the meeting room.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BOSTON AUDIO SOCIETY

Name ______________________________________

Phone number _______________________

Please indicate below the group activities in which you would actively participate.

Opera (discussion and listening)

_____ Symphonic music (" " ")

_____ Chamber music (" " ")

_____ Modern music (" " ")

_____ Electronic music (" " ")

_____ Folk music (" " ")

_____ Jazz (" " ")

_____ Rock music (" " ")

_____ Kit construction/repair

_____ 78-rpm records

_____ Tape dubbing/swapping

_____ Live recording

_____ Equipment test clinics

_____ Evaluating cartridges

_____ " tuners

_____ " recorders

_____ " amplifiers

_____ " speakers

_____ " accessories

_____ Other (specify below)

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A Publication of the B.A.S.

YOUR TAPE RECORDER
PART 1: HOW MAGNETIC RECORDING WORKS

by Alan E. Southwick

To anyone seriously involved with magnetic tape recording or anyone contemplating the purchase of a tape recorder, it is essential to understand the behavior of the medium and the physics of its operation. This is the topic of Part I. Part II of this article, to be published later, will investigate the setup and alignment of several available tape recorders. An understanding of the limitations inherent in magnetic tape recorders and recording helps in obtaining more enjoyment, satisfaction and respect far the wide variety of entertainment which magnetic recorders can deliver when utilized with knowledge, imagination, and creativity.

Just about everyone of us who has used a tape recorder has had to face eventually the problem of a failure which has impaired the quality of an irretrievable recorded document.

Why these innumerable frustrations? We can squarely place the blame on a Danish gentleman, Valdemar Poulsen, who in 1893 managed to create the first functional magnetic recorder/reproducer. This device encountered many difficulties among which were poor frequency response, poor signal-to-noise ratio, and high distortion. These setbacks only served to increase enthusiasm and success for Mr. Edison's wondrous talking machine.

Basically, Poulsen noted that certain materials would "conduct" magnetism through them and retain a certain amount of residual magnetism after being placed near a strong magnet, while other materials, though attracted to the strong magnet, would not retain magnetism afterward. Poulsen reasoned if one could control this residual magnetism, a record of events might be recorded and reproduced for future reference. All this creative thinking took place less than 100 years ago!

Magnetism, as presently understood, has its origins within the structure of the atom and is the result of the motion of charged particles in the atom's outer electron shells. All atoms have some magnetic properties, even atoms of elements such as oxygen.

Magnetism has the distinctive property of "reaching out" beyond the physical boundaries of the magnetic material and creating an area of proximity, or a field, which can affect other magnetic materials. A magnetic compass demonstrates the results of this behavior. Although there is nothing visibly in

-
contact with the compass needle, it still swings about and directs one end toward the north polar region of the Earth. The planet's enormous but relatively weak magnetic field is at work here.

It is the combination of these -- physical magnets and the fields created about them -- that creates a medium to record events and a method to reproduce these recorded events.

In any material atoms tend to cluster into specific groupings called molecules; occasionally this clustering is carried even further, creating large ordered arrays of atoms known as crystals.

Domains

In magnetic materials, these crystals tend to form very tiny magnets (some lees than a billionth of an inch across). In general, these tiny magnets are randomly oriented throughout the mass of material, canceling each other's fields so that the material exhibits no net magnetism at a11. If a strong magnetic field is brought near this material, however, some of these small crystals, called magnetic domains, alter their magnetic alignment to coincide with that of the applied field. As the applied field is increased in strength, more and more domains align themselves to the field direction until at last almost no randomly oriented domains exist and the material "saturates;" there is no measurable increase in the possible magnetization of the material.

But how is this applied magnetic field created? Recall that magnetism results from electric charges in motion and note that if one passes electricity through a wire, charges are set in motion within the wire and a magnetic field is created. Varying the flow of electricity in the wire varies the strength of the magnetic field; changing direction of flow changes polarity.

Iron is one of the most commonly used magnetic materials for many reasons. Depending on fabrication techniques, iron-based materials can be made into permanent, or "hard," magnets which retain their magnetism long after the removal of an applied magnetic field, or "soft" magnets which retain little residual magnetism. Both types of materials are used in magnetic recorders and reproducers.

First are permanent magnetic materials like iron oxide (Fe_2O_3) --- the basic material used in magnetic tape (Chromium Dioxide is a relatively new material which holds great promise for slow-speed recording). Fe_2O_3 has properties which make it very useful as a magnetic recording medium: fairly low residual noise coupled with a relatively high saturation level permit good signal-to-noise ratio and good retention of "recorded" information. It is somewhat difficult to "erase," has very fast response time for good high frequency retention, and manufacturing and production are relatively easy.

Second are the "soft" magnetic materials, such as "permalloys," through which a magnetic field finds an easier pathway than through air. This behavior, plus very low residual magnetization, helps to "channel" a magnetic field through or around the material and focus the field at a particular point. "Soft" materials find extensive application in magnetic recording and playback heads.

Heads

Magnetic record and playback heads are the actual input-output elements of the recording process. A magnetic record head's job is to convert electrical impulses into a magnetic field through which a magnetic tape passes. This process is greatly complicated by the nature of the tape itself, but basically, a coil of wire is wrapped around a ring of "soft" magnetic maternal, which channels the field created by passing electricity through the coil. At some point in this ring there is a break, or gap, usually filled with mica, glass, or copper -- materials which do not channel magnetic fields very well. If a magnetic recording medium is placed on or near this gap, the magnetic field will bridge the gap, passing through the magnetic tape in contact with the gap and magnetize it. If the tape is moved past the gap while the field is varied, the tape will retain a "record" of the magnetic variations -- a sequential recording of past events.

Playback

If the recorded information is moved past a similar "head" (which has no current source attached to it) a small flow of electricity will be induced in the coil by the varying magnetic field recorded on the magnetic medium. Amplification of this weak signal provides playback of the recorded information.

This is the fundamental operating principle of record and reproduce heads when appropriately "interfaced" with a recording medium. A few fine points are in order: a recording head is designed to project as much magnetic field as possible out of the gap in order to reach as deeply as possible into the tape's oxide coatings; a playback head must gather as much magnetic information as possible from the tape. Good high frequency response demands a head gap width which depends on the highest frequency to be reproduced and the speed of the tape past the reproduce head. For example, a cassette machine requires a head gap of 0.0001 inches or smaller to reproduce a 15 kHz signal from a tape moving at 1-7/8 inches per second; in comparison, a human hair is about 0.003 inches in diameter.

Needless to say, this is very small, and when one takes into account that two such gaps, placed one exactly above the other, are required for stereo, head tolerances must directly affect manufacturing cost. These dimensions and tolerances create further difficulties as well: debris between the tape and the head markedly reduces performance. A fleck of dust a few thousandths of an inch in diameter between head and oxide can cut signal level to 1/100 of the intended amplitude. Thus clean heads are indeed very important for accurate information transfer.

Unfortunately, a record head is not an ideal reproduce head, and when a single record/play head is utilized, as in almost all cassette machines, a compromise must be struck between the needs of recording and reproduction. For a given gap width either record or playback performance must suffer, or both. Thus separate heads with appropriate head gaps are used for most quality reel-to-reel recording.

The Medium

A magnetic recorder would be useless without a good recording medium like Fe_2O_3. Hence the recorder is dependent upon this material and must match or complement the magnetic characteristics of the medium. A so-called transfer characteristic curve illustrates some of the peculiarities of Fe_2O_3 as a recording medium. Figure One illustrates a linear transfer curve, detailing input and output. What goes in, comes out; a power amplifier has essentially a linear transfer characteristic.

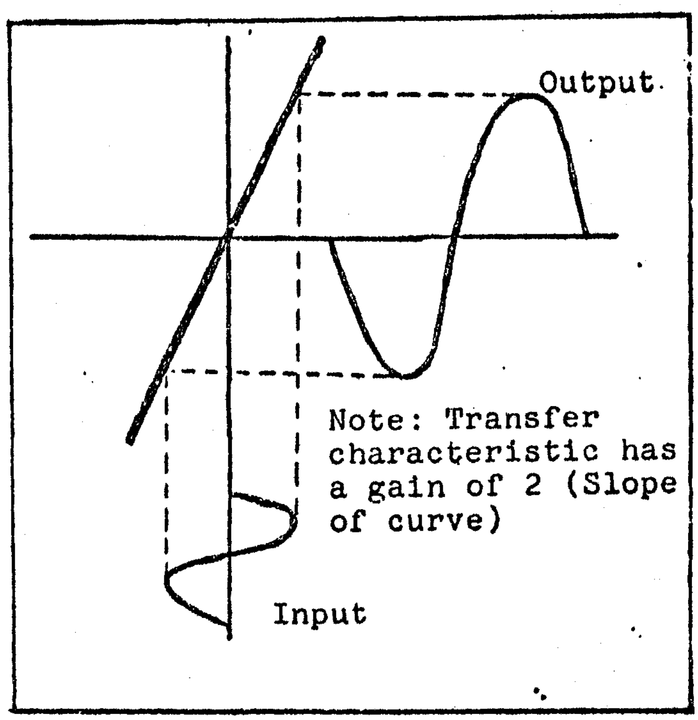


FIGURE ONE: LINEAR TRANSFER CHARACTERISTIC

Figure Two shows the transfer characteristic of iron oxide, Fe_2O_3, derived from the applied magnetic field (Br) versus the residual magnetism (Hc). Notice that this curve really is a curve and pretty far from linear except off the center of the axes. Until the late 1920's, the crossover "bump" at the origin in the middle of the curve was not completely recognized and early machines had very high distortion, as indicated in Figure Three. In 1927, the Naval Research Laboratories discovered a way to avoid this bump in the middle of the Fe_2O_3 transfer curve and to join the linear portions of the characteristic curve. This greatly improved signal-to-noise ratio and lowered distortion.

Up to this time the bump had been removed by using a fixed magnet to first "erase" the recorded signals by magnetic saturation, then just enough current was applied to the record head to displace the input onto the straight part of the curve. This produced a fairly linear input/output characteristic, but

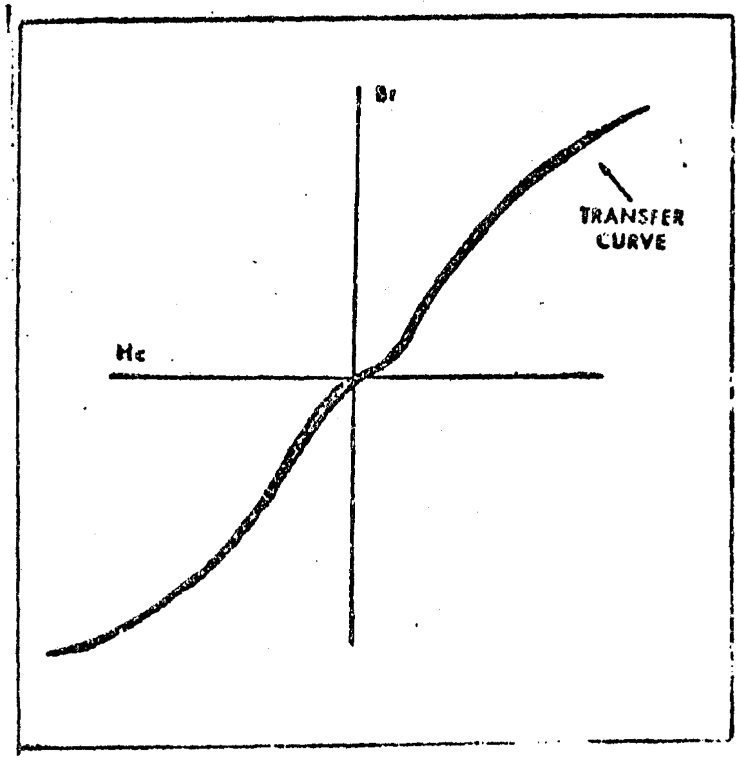


FIGURE 2. TRANSFER CURVE DERIVED FROM A FAMILY OF HYSTERESIS LOOPS
(From Sound Talk, Vol.: 1. No. 2, 1968)

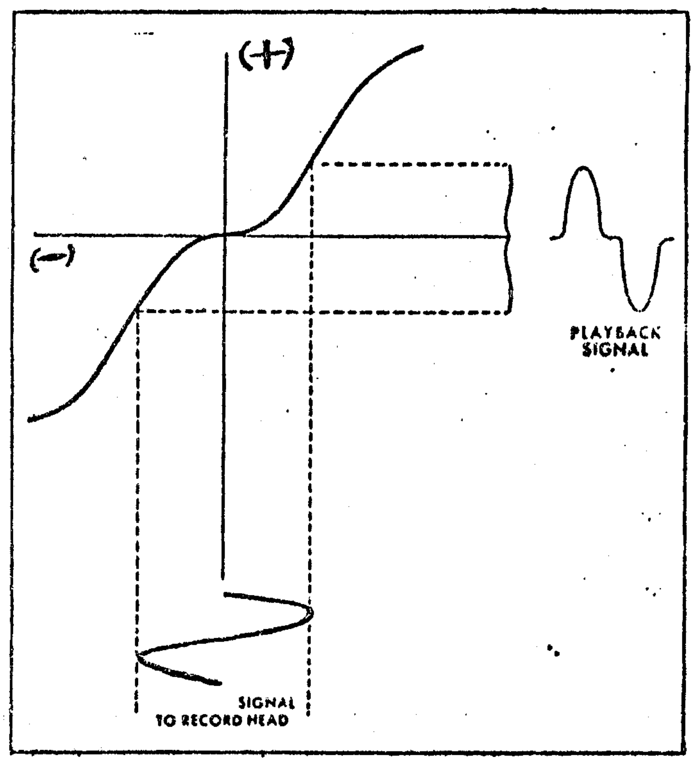


FIGURE THREE: NO BIAS CONDITION

only over a limited dynamic range and necessitated hairline adjustment of the fixed amount of current for bias at the record head for lowest distortion. This method was called the Direct Current Bias method (See Figure Four)- and produced a signal-to-noise ratio in the vicinity of 20 dB before saturation of the magnetic medium occurred.

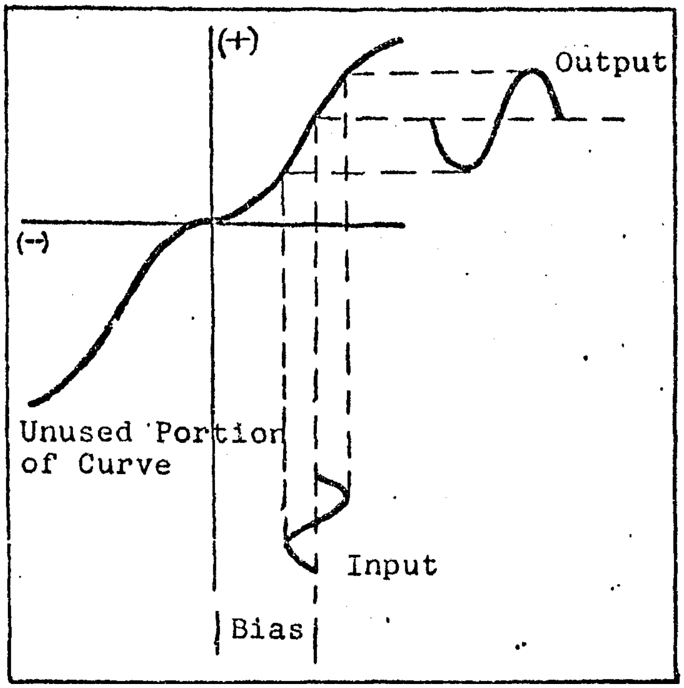


FIGURE FOUR: D. C. BIAS CONDITION

The Navy scientists instead applied an alternating current which produced both North (+) and South (-) magnetic polarization to traverse the bump and allowed the input to span the two linear portions of the curve. This used more of the transfer curve and so doubled dynamic range. The way this alternating magnetism was applied in conjunction with the signal to be recorded also reduced distortion by an order of magnitude.

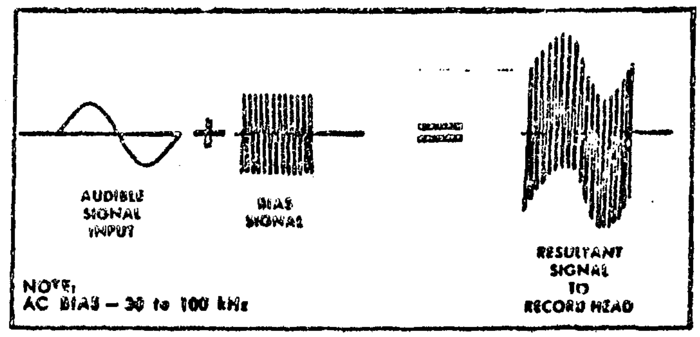
<u>How AC Bias Works</u>

If a sinusoidally varying input is applied to a record head to produce a similarly varying magnetic field, interesting things happen to the Fe_2O_3 transfer characteristic.

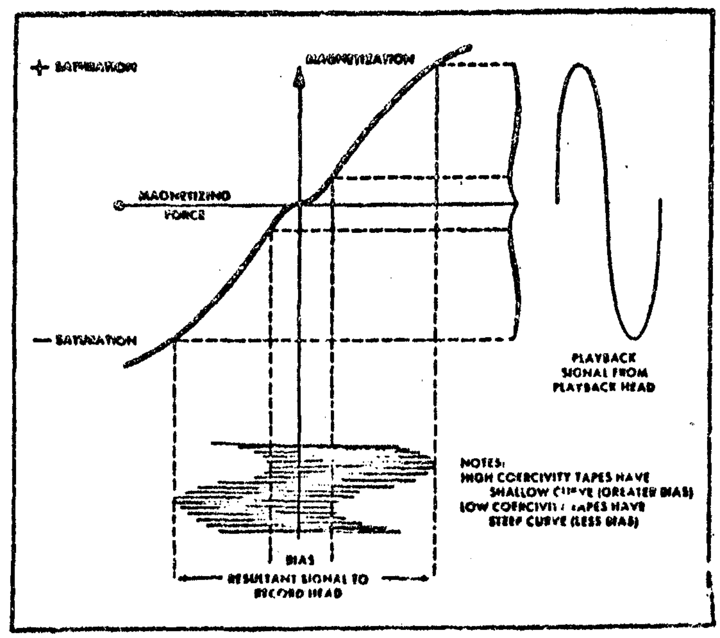
First, both sides of the curve are effectively joined together and the bump is masked, allowing for more signal room and lower distortion. Second, the more nearly sinusoidal is this applied current, the less distorted is the recorded audio signal (superimposed upon the bias).

Experiments show that if the AC bias signal is a pure single-frequency ultrasonic tone, noise and distortion can be minimized. If the bias waveform is not a pure "sine" wave, i.e., if it contains two or more frequencies, then the input audio signal can interact with the non-linear part of the transfer curve, increasing noise and distortion. (See Figure Five.)

To "bias out" the Fe_2O_3 transfer bump correctly, several factors have to be considered, for example, the frequency response of the iron oxide used. This may sound odd at first since Fe_2O_3 is a chemical compound. How can one "type" of Fe_2O_3 vary from another? Magnetic oxide characteristics do indeed vary from one tape to another even within the lines of given manufacturers. Domain particle size, thickness of the oxide coating, special additives such as cobalt (which may "beef up" certain parts of the frequency spectrum), and binder mix (the stuff that holds the oxide to the plastic tape), all create differences among various tapes. And tapes are intended for different purposes; some with extended life are used in language labs, while others are utilized for audio mastering and require extended dynamic range and extremely uniform oxide coatings.



PRODUCTION OF RESULTANT SIGNAL



A.C. BIAS CONDITION
FIGURE 5

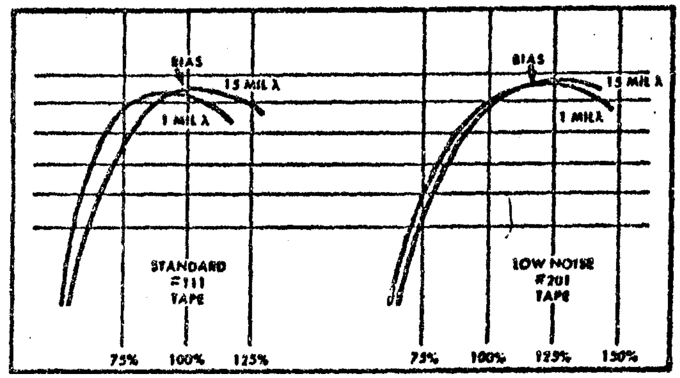
(From Sound Talk, Vol. I, No. 2, 1968)

The bump in the oxide's transfer curve may vary in width with frequency; varying magnetic saturation at certain frequencies compounds the problem. All these variables force compromises in oxide manufacture and make bias adjustment for each type of tapes critical for best performance.

These factors are primary reasons why each recorder must be adjusted for the tape chosen and used exclusively with that tape for optimum and consistent performance.

Tape

Figure Six details the variations in two types of Scotch brand recording tape with respect to the recorded frequency and bias amplitude. The frequencies are expressed in terms of wavelength (λ)-- a high frequency (1 mil wavelength) and a lower frequency (15 mil wavelength). The curves show playback signal level versus the record bias current used. Note that type 111 tape varies its maximum bias point widely with frequency. Type 203 can be more easily optimized at both frequencies. And these are just two formulations from a manufacturer who produces more than seven different oxide formulations for audio tape alone.



BIAS CURRENT

FIGURE 6. BIAS CURVES

(From Sound Talk, Vol. I, No. 2, 1968)

Bias is among the most critical parameters in magnetic recording. When bias is properly adjusted for a particular oxide formulation, maximized signal-to-noise ratio, optimum "flat" frequency response, and minimized harmonic distortion result.

Two other parameters are indirectly affected by bias considerations. Foremost is frequency response. As mentioned earlier, magnetic oxides do not have linear frequency-response characteristics. That is, the magnetic oxide will not retain a constant magnetism with variations in frequency, despite a constant applied magnetic field strength. Signal-to-noise ratio changes with frequency also.

This dilemma -- inherent in Fe_2O_3 -- is avoidable but requires contouring the input amplitude of various frequencies and thus complementary playback contouring to achieve flat record/playback frequency response. Figure Seven shows a standard reproduce equalization curve and its recording complement. Note that the curves are not really complementary; this is because the magnetic recording/ playback process adds its own frequency contouring – but it all comes out flat it all comes out flat in the end. Incidentally, a little too much applied bias causes the record head to behave like an erase head, attenuating higher frequencies as they are recorded.

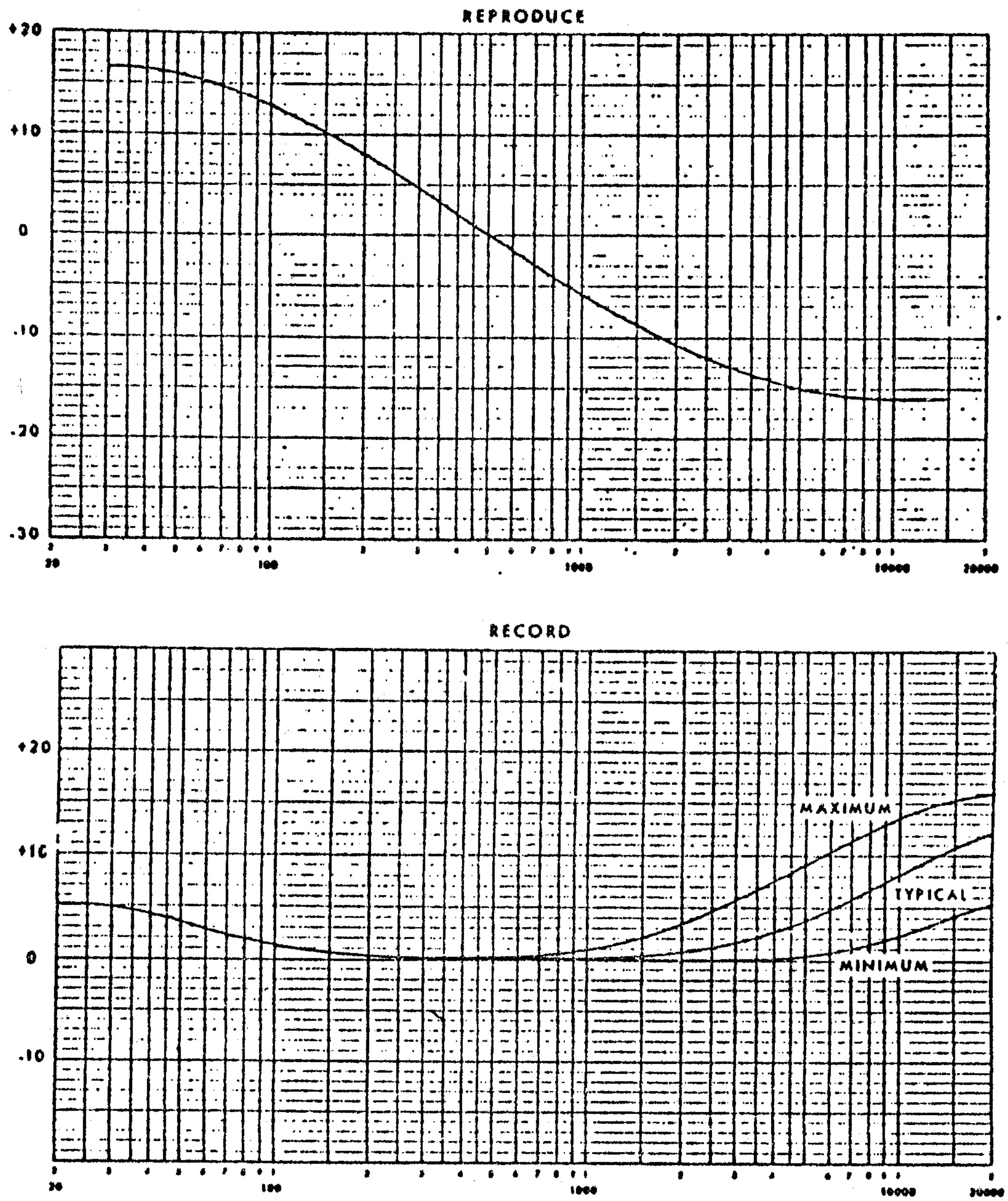


FIGURE SEVEN: N.A.B. REPRODUCE AND RECORD
EQUALIZATION FOR 7 1/2 I.P.S.

(From Ampex Corporation, AG 440 B/AG-445B Recorder/Reproducer. Operation and Maintenance Manual, revised January 1970, Ampex Part No. 4890301-02)

A lower-than-optimum bias amplitude allows higher frequencies to be recorded but at the cost of increased distortion.

Figures Eight and Nine show some of the difficulties encountered with extreme under- and over-biasing respectively. Too little bias doesn't eliminate the bump completely, creating distortion, and too much bias reduces "headroom" or maximum allowed signal before saturation, and this results in poor signal-to-noise ratio.

Bias also governs the maximum undistorted high frequency recorded. Generally, when two signals or tones of slightly different frequency are combined, tones which are the sum and difference of the two are also generated. If bias frequency is low enough to "beat" or heterodyne with any recorded frequencies present, disturbing "whistles" or saturation will result. With a 50 kHz bias frequency, the 38 kHz stereo multiplex tone used in receivers or tuners can wreak tape recordings if not properly filtered out because 50 kHz bias frequency minus 38 kHz results in a difference tone of 12 kHz which is audible and will be recorded.

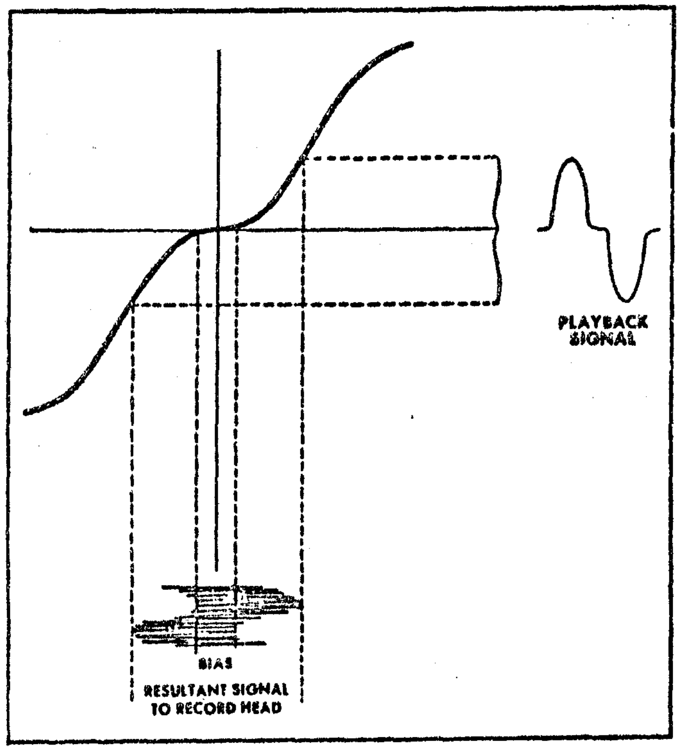


FIGURE 8 UNDER BIAS CONDITION

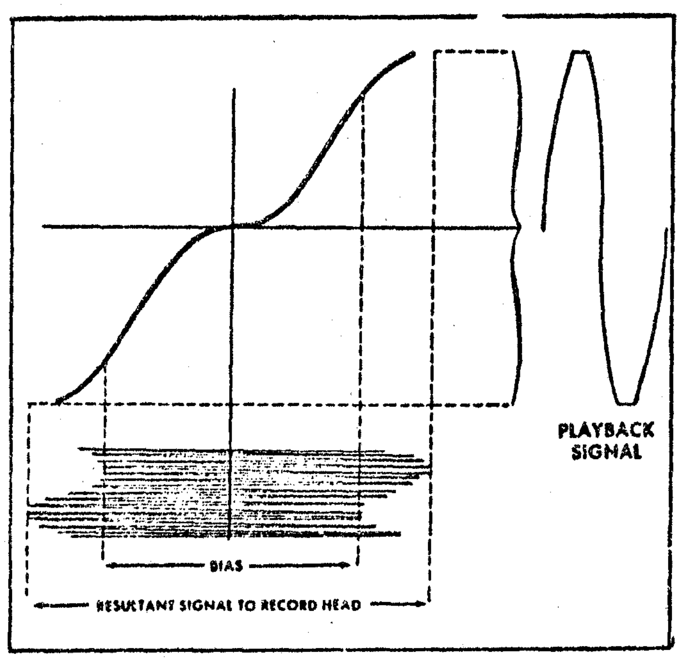


FIGURE 9 OVER BIAS CONDITION

(From Sound Talk, Vo1. 1. No. 2, 1968)

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Bias frequencies used today usually equal or exceed 100 kHz to avoid this difficulty and therefore even less expensive recorders can do justice to first rate program material when properly adjusted.

Chromium Dioxide or "Crolyn" has all the properties of Fe_2O_3 with a few exceptions. In comparison with Fe_2O_3, CrO_2 has a wider frequency response and potentially improved signal-to-noise ratio, due to increased sensitivity at high frequencies to the applied magnetic recording field. More bias is needed because the characteristic transfer bump is wider.

A11 things considered, its increased high-frequency sensitivity makes CrO_2 an ideal medium for high-quality low-speed tape recording, such as cassettes and eight-track cartridges. Prerecorded CrO_2 cassettes using electronic noise reduction are proving to be the first viable tape recordings of equal or better quality than phonograph records at competitive costs.

The author wishes to thank the Ampex Corporation and the Magnetic Products Division of the 3M Company for assistance in the preparation of this article.

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Departing from standard bibliographic style, the following items are listed by source -- where possible -- to help you obtain them.

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- c) "Test Tape Applications," reprinted from the Journal of the Audio Engineering Society, Technical Literature, 1967,

Audio Magazine, "A Tape Survey," May 1973.

db, The Sound Engineering Magazine
- a) February 1973, Vol. 7, No. 2
  "Tape Technology Today," by Norman H. Crowhurst
  "Setting Up a Professional Recorder," by Marvin Soloff.
- b) March 1973, Vol. 7, No. 3
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