

PHASE DISTORTION IN AUDIO MAGNETIC RECORDING

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This paper reviews some of the important factors influencing the overall phase non-linearity of magnetic recording as applied to audio usage, and the effect of these non-linearities on multiple generation copying. A new record equalizing scheme is described which provides a considerable degree of inherent phase correction and which produces a recording whose phase characteristics are compatible with normal reproducing equalizing standards.

Introduction

The fundamental aim of any audio magnetic recorder or any storage media for that matter, is to retain an accurate representation of an input signal applied to it, and later reproduce this signal exactly. This may seem obvious, but the implications of the more obvious statement can be overlooked.

Virtually all professional audio recorders are characterized by their amplitude response, distortion, and noise. It therefore is not surprising that under suitable conditions, A/B comparisons between two supposedly equal machines, reveal more subtle differences, which obviously can not be ascribed to differences in the conventional methods of characterization.

This same statement can and has been made, about virtually every other element in the audio chain; from microphones through amplifiers to loudspeakers.

In recent years, considerable effort has been expended in attempting to explain and understand why, notwithstanding the apparent similarities in performance, there still remain considerable differences between similar elements of the chain when subjected to critical listening tests. To date most of the differences have been found to be due to differences in time domain response. Sometimes these differences are quite large. The effect upon the design of amplifiers, loudspeakers and other elements in the chain, has been a concerted reduction of some of the now most obvious time domain irregularities.

Naturally enough, this activity serves to highlight some other offenders in the chain as being the "new" limitation on the "perfect" sound. (This is often referred to as the "onionskin" effect).

The magnetic audio recorder may well be the next candidate!

Apart from any interest due to improving the quality of sound recording, there is a second and also significant reason for becoming concerned about the time domain response of a magnetic audio recorder. In the professional recording industry, most original recording is done on multitrack recorders, the final mix being committed to a two or four track recorder. This master will be copied, sometimes through several generations. Clearly, for the minimum degradation of this final mix, the overall performance in both the frequency and time domain of the machines used, is very important.

In video technology it is now possible to compare a first generation tape with a 10th generation tape, and see only very slight impairments.

The same is not true for audio recorders.

Requirements

In any amplifier or transducer, the basic requirement is to be able to transmit a wide range of frequencies with no relative amplitude distortion. This is the frequency domain response, and is really only a measure of the ability of the system to transmit any frequency without changing its amplitude relative to any other frequency.

The second factor comes into play when we consider applying a transient to the input of this system. The transient may, in general, by Fourier analysis, be resolved into a number of sine waves, of different amplitudes and frequencies and also with amplitudes varying as a function of time in many cases; if there is to be an accurate representation of the transient at the system output, then the various component frequencies must retain a specific timing relationship to one another. If this is not the case, then for example, the leading edge of the transient will become "smeared" in time.

The basic ability of a system to transmit such transient signals without time distortion, is described by the time domain response. The simplest way of thinking of this response is to look at the relative delay in transmission of the various frequencies. (This is often referred to as the group or envelope delay of a transmission system). The ideal requirement is then that the system transmit all frequencies with equal delay. The time delay of any system will be a constant over its bandwidth, if the phase response changes linearly with frequency; over the same bandwidth.

Since most electronic systems have high and low frequency limits in bandwidth imposed by RC type time constants, they will not have linear phase response at their bandwidth extremes and thus will suffer, to greater or lesser extents, from non linear time delay.

An important fact to remember is that since the magnitude of the delay depends upon the rate of change with frequency of the phase response, then the values of group delay of low frequencies in the region of the lower frequency amplitude response limit, will be much larger than those at high frequencies when in the region of the upper frequency amplitude response limit.

There is thus some merit in having a low frequency response greatly in excess of that required. Unfortunately this sometimes is just not feasible, or may be undesirable due to other more objectionable side effects.

Causes

In magnetic audio recording, a great deal of pre and post emphasis is used to create a system which has an overall flat, amplitude response (see Figure 1). However, care must be exercised when applying these amplitude corrections since they may create unnecessary anomalies in the delay time response which may be objectionable. To understand how this can occur we should first consider what amplitude and phase response non linearities occur in the process of recording and reproducing a tape, and consider how they are normally corrected.

In the reproducing process, the following amplitude errors occur:

- a) Reproduce gap loss
- b) Thickness scanning loss
- c) Spacing loss
- d) Reproduce head resonance
- e) Reproduce head core losses
- f) Azimuth errors.

The first three are amplitude loss effects which do not have any phase shift effects accompanying them. The fourth, being a function of the head inductance, head, lead and amplifier stray capacity, and damping, certainly does produce phase shift effects.

In cases where the reproduce head resonance is deliberately used to correct for gap loss effects for example, then, since the gap loss has no phase non linearity associated with it, overall phase distortion and non constant group delay will occur.

Azimuth errors are also not accompanied by phase effects and can be reduced by proper alignment of the reproducing head.

The reproduce head core losses, being caused by the complex permeability of the head core material, will have phase effects associated with them. (However in modern reproducing heads, core loss is a very small factor up to quite high frequencies).

The dominant type of non linearity in phase response

in a reproducing system, is undoubtedly the effect of under damped reproduce head resonance, particularly if this resonance is only just outside the audio band.

In the recording process, the principle causes of amplitude errors are:

- a) Tape demagnetization losses
- b) Record head core losses
- c) Relative geometry of record head gap and oxide thickness.

Record head core losses are, as with reproduce head losses, low with modern head construction. However, if present to any significant degree, they would be accompanied by phase shift effects.

Tape demagnetization losses are not accompanied by any phase effects, and are determined by the tape itself, in conjunction with the value of biasing used.

The relative geometry of record head gap and tape oxide becomes influenced by the value of bias used, and manifests itself on playback by the thickness loss. Figure 2 shows a simple model of the fringing fields around a magnetic record head. The curvature of the critical recording zone will depend upon the relationship between the record head gap and oxide coating thickness and upon the method of biasing. At long wavelengths the reproducing head "sees" all of the flux recorded through the depth of tape, thus when the tape is biased for maximum output, the critical zone just reaches the farthest layers of oxide from the record gap. Under these conditions, the critical zone nearest to the record gap, will be displaced mechanically from its position in the farthest layers of oxide.

On playback, the short wavelength signals deep in the tape, as well as being subject to greater demagnetizing fields, also can not be "seen" as well by the reproduce gap. There is thus an apparent phase shift, (high frequency leading), whose magnitude depends very strongly on the bias field.

It is incidentally, this fact which makes it very important on multichannel machines, to bias each channel in exactly the same manner and with some accuracy. Failure to do this results in apparent intertrack phasing errors at shorter wavelengths which have nothing whatever to do with the intrinsic gap scatter of the head. (Typically at 10 KHz and 15 in/s a 1 dB difference in overbias between two channels can cause 15 to 20 degrees of phasing error). Since this

effect is wavelength dependent it will be twice as bad at the same frequency at 7.5 in/s.

The effect of the head gap/tape oxide/bias field geometry also can cause an effectively lowered recording sensitivity for shorter wavelength recordings. This occurs because of the reduced rate of change of bias field in the direction of tape motion.

Fortunately the above amplitude effect is not severe at the tape speeds, tape oxide thickness and record gap lengths commonly used for professional audio recorders.

Of all the above listed amplitude losses, demagnetization losses are the largest proportion.

Effects of Record Equalizers

In order to ensure interchangeability of recordings, a number of standards both national and international, have been agreed upon. In every case, for audio recording the standards are based in part or wholly, upon the concept of the "ideal reproducer" reproducing an ideally recorded tape.

While the standards are principally concerned with amplitude response, the statements of the standards contain implied phase relationships in the recorded signal.

If we start with the hypothetical assumption that the tape performance has advanced to the point where the Recording amplitude losses are negligible, then no record boost would be required. In fact, we would, in order to record a tape to the standards, be required to roll off the record current at some high frequency, dictated by the equalization standard (Figure 3).

The implication of this is that the phase response of the recorded tape would be as shown in Figure 3.

In reproducing this "ideally" recorded tape with an "ideal" reproducer, the reproducing head would produce an output rising at 6 dB per octave, where the recorded flux is constant with frequency, and then a constant output where the recorded flux is falling at 6 dB/octave. (Mathematically the reproduce head open circuit voltage output is the negative differential of the flux on the tape).

This voltage response from the reproduce head is corrected with an amplifier which provides the inverse voltage response to the head output (see Figure 4). In addition

the relative phase response of the amplifier is the inverse of the flux phase/frequency response, and the combination will have a flat amplitude and phase characteristic. (The -90° at low frequencies in the reproduce system is effectively cancelled by the head differentiating response).

Thus we can assume that if there were a "perfect" tape and it were recorded "ideally" and reproduced "ideally" then a constant amplitude and phase response would occur.

In a real tape however, the actual overall losses in amplitude are corrected partially with the reproduce equalization and partially with record pre emphasis.

If the record pre emphasis is applied with conventional RC, or worse RLC, equalizers, then the phase response (Figure 5) will lead with increasing frequency. This is exactly the opposite of the desired phase lag (see Figure 3) which is implied in the equalization standard.

In professional audio recorders, the main reason for needing amplitude correction is due principally to tape demagnetization losses, which are not accompanied by any phase response non linearities, and hence the record pre-emphasis will cause an overall undesirable phase response, leading strongly at high frequencies.

Anyone who has ever attempted to record a square wave on an audio recorder will have seen the effect of the resulting phase non linearity. The leading edges of the reproduced waveform have a large amount of overshoot. In addition, if the reproduce head resonance were not adequately controlled, the high frequency "ring" after the leading edges will be very evident.

Much has been written about the audibility of non linear phase effects, however, most of the conclusions that can be drawn from such discussions usually overlook the fact that:

- a) Several other elements in the system may contain similar types of non linearities, which effectively mask those due to the object under test.
- b) The effect of cascading several systems is additive, and usually the end result of any recording has several such cascaded systems to pass through before reaching the average listeners ears.
- c) The average listener does not have actual access to the original signal in the control room to

make an A/B comparison, and even if he could, it is likely that other differences would be more readily obvious.

However, it is certainly very obvious that if a recorded transient is reproduced with excessive overshoot, then upon successive copying, the transient edge will become further degraded and if the overshoot is severe, will suffer additional high frequency amplitude limiting, due only to the limitations in high level high frequency performance of the tape.

Cures

Some attempts in the past have been made to provide corrections for phase non linearities in audio recorders. However, the methods used for correction have principally been applied to the reproducing side of the system. When adjusted correctly, they certainly produce excellent square wave and transient response. This however, is only true with the same type of tape, biassed identically. In other words, this approach does not yield a recording implicitly compatible with the equalization standard. If such a recording were reproduced on our "ideal" reproducer, there would no longer be an accurate time domain representation of the recording.

Additionally it is an unfortunate fact of life that any necessary adjustment to any system, is inevitably eventually set incorrectly, sometimes with disastrous results.

A New Equalizer

The Ampex ATR-100 system incorporates a record equalizer, which while possessing several other important properties, mainly to do with covering the required equalization range, from 3.75 in/s standards to 30 in/s standards, with one adjustable control, also has the novel feature that the phase response is opposite to that expected from a circuit providing high frequency boost.

Figure 5 shows the typical effect upon the phase response, of a conventional record equalizer providing needed amplitude boost to the record current. The boost required will be that needed to leave the tape with a flux amplitude/frequency response as required by the standards.

The ATR-100 record equalizer, when providing the same required amplitude boost, in fact produces a lagging phase characteristic which is in the correct direction for the implied phase characteristic required by the equalization

standard; (see Figure 5).

Figure 6 shows a very much simplified block diagram of how this is achieved.

The input signal is applied to the main amplifier summing node through a resistor, and in addition goes through an active differentiating amplifier. A portion of the output of the second amplifier, adjusted by the main record equalizer, is then also applied to the main amplifier summing node. Since the differentiating amplifier effectively produces a signal whose amplitude rises at 6 dB per octave, the output of the main amplifier will be constant until a frequency is reached where the increasing contribution from the differentiating amplifier equals and then exceeds that from the direct path.

At this and higher frequencies, the output from the main amplifier will rise, ultimately at 6 dB per octave. Varying the contribution from the differentiating amplifier therefore varies the frequency at which the boost commences.

The differentiating process will normally produce a 90° phase lead. However, because the differentiating amplifier also has a 180° phase inversion, the output of the differentiating amplifier will be lagging the input by 90° , even though its output amplitude rises at 6 dB per octave.

Thus the input from the differentiating amplifier to the main amplifier lags the other, direct input, by 90° . The phase shift in the summed output will be a lagging function with increasing frequency with a limiting value of -90° .

The more record boost that is required, the greater will be the phase lag at that specific frequency up to a maximum of -90° .

Although this scheme will not necessarily give perfect phase response, it has the very real advantage that a recording made using it, will play back on any conventionally equalized audio recorder with the improved phase linearity.

Also since there is no separate adjustment for phase response, it happens automatically when adjusting the record equalizer, there is no likelihood of an incorrect setting, providing the record equalizer is set properly for amplitude response.

Finally, with modern tapes and present practice of heavily overbiasing medium to short wavelengths for minimum

distortion and modulation noise, the required increase in high frequency record boost provides, with this equalizer, even better overall linearity of the phase response and consequently a more constant group delay in the very critical medium to high frequency range.

Conclusions

The process of magnetic recording, particularly for audio usage, produces a variety of amplitude losses. Most of these are a property of the tape, and with improved tape performance less amplitude correction in record is required when recording to an existing standard.

The nature of normal record equalizers will be to produce a more rapid change in phase slope at medium to high frequencies. This is not strictly consistent with the recorded phase response implied by the prevailing national and international equalization standards.

A new and novel record equalizer has been described, which while not performing exact phase correction, has the operational advantage of providing greatly improved recorded transient performance, while not requiring any additional system adjustments.

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Note: Reference 4 has extensive references.

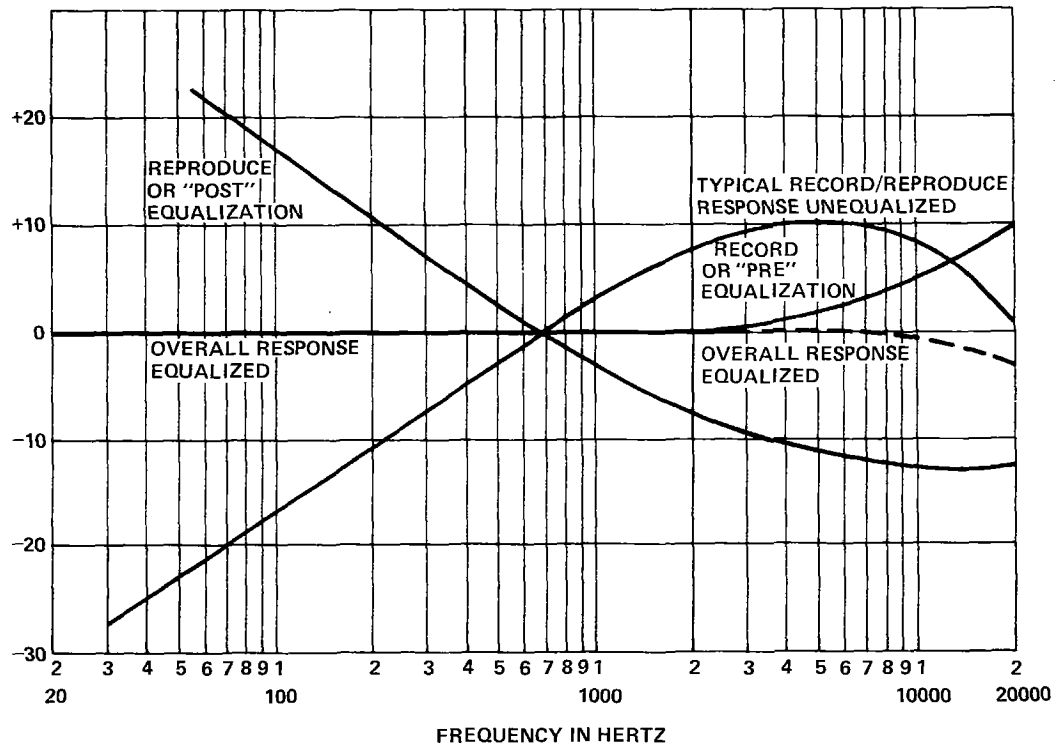
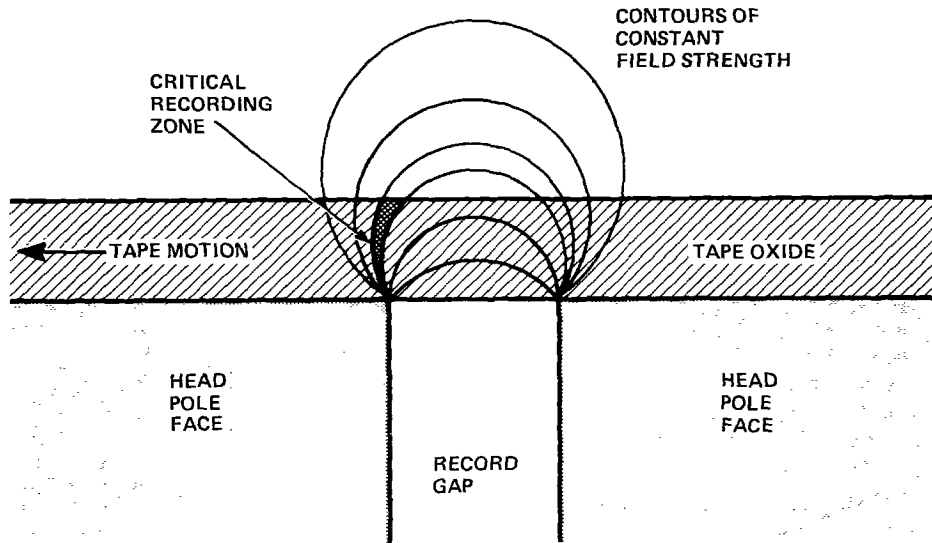


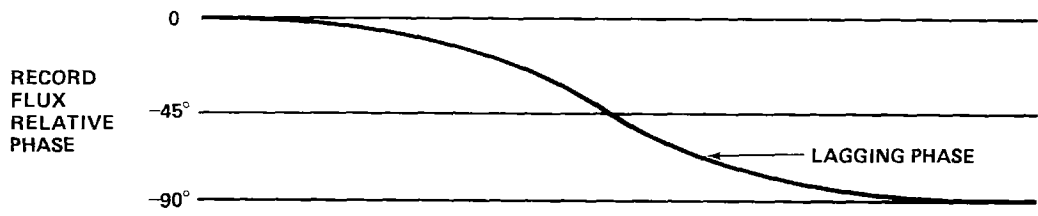
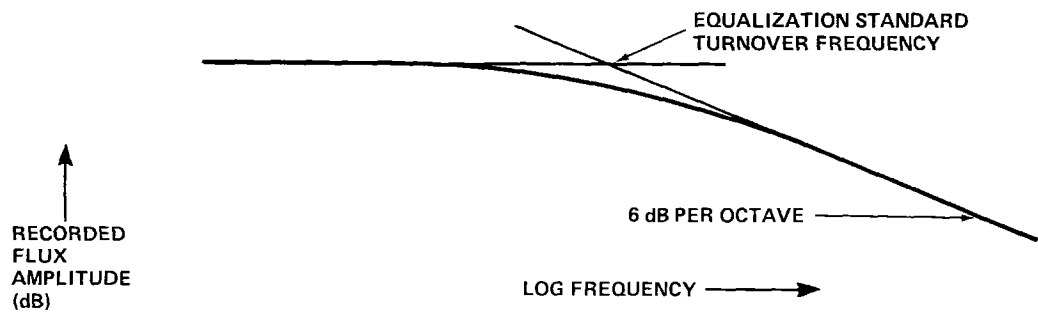
Figure 1



"SIMPLE HEAD FIELD MODEL"

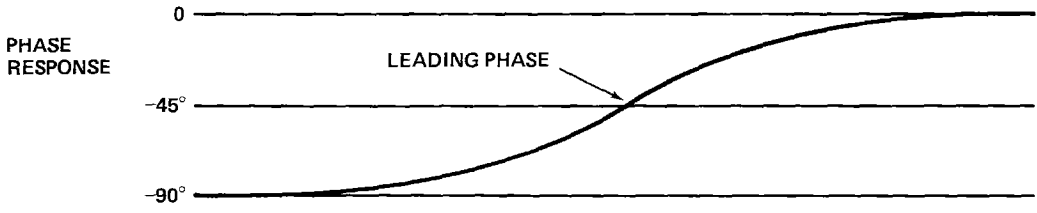
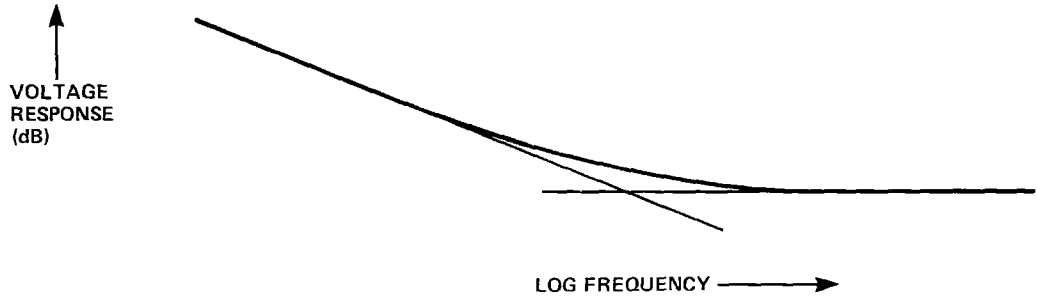
Figure 2





THE "PERFECT" TAPE

Figure 3



IDEAL REPRODUCER

Figure 4

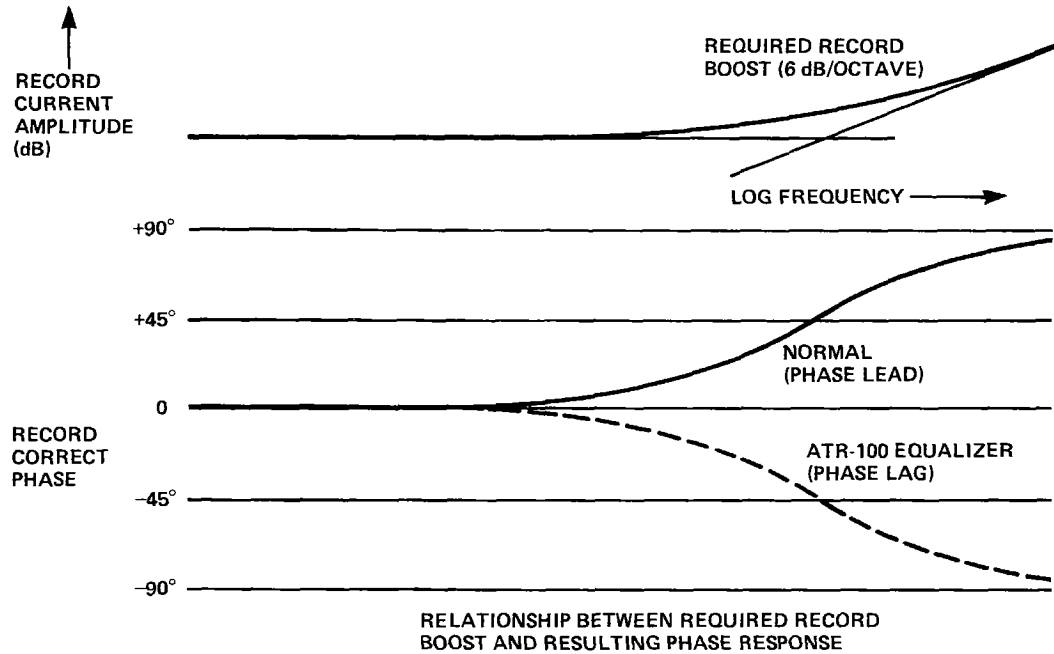
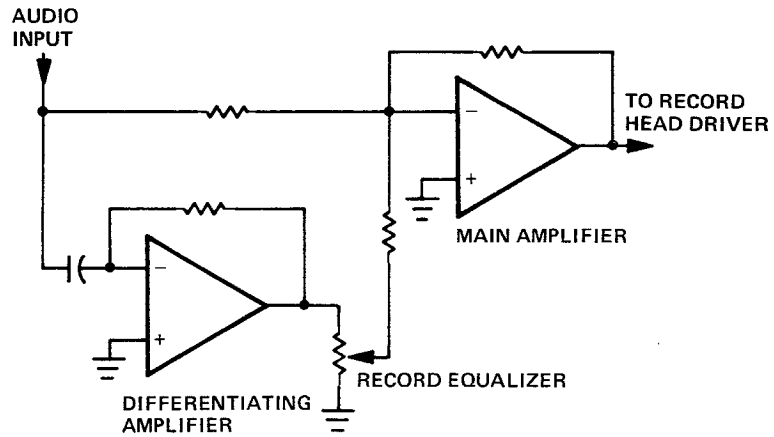


Figure 5



SIMPLIFIED BLOCK DIAGRAM
 ATR-100 RECORD EQUALIZER

Figure 6