# HALF SPEED RECORDING WITH FERRITE HEADS AND HIGH ENERGY TAPE

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**Summary** This paper describes the results obtained with several new techniques which are being used to extend the frequency bandwidth limits and the signal to noise ratios of instrumentation magnetic tape record/ reproduce systems. During the past decade, wideband magnetic tape information recording densities have advanced in several stages to the currently used 60 to 80 micro inch wavelengths. The new techniques described in this paper now make it practical to record and reproduce wavelengths in the order of 30 to 40 micro inches. This results in a frequency bandwidth of 1.0 MHz at a tape speed of 30 inches per second. In comparison with present wideband systems this means an improvement of 2X in bandwidth, or a reduction of tape speed by one half is now possible while maintaining approximately 20 dB broadband signal to noise ratio with a track width of .025 inches. This width provides 28 tracks per inch of tape width.

This improved performance has been obtained by combining recent improvements in “High Energy” tape, narrow gap ferrite record heads and ferrite reproduce heads. Using a systems approach, electronic signal processing circuits have been developed which coordinate these improvements in tape and heads, resulting in optimized “high performance” record/ reproduce systems.

**Introduction** The performance of wideband analog instrumentation record/ reproduce systems has seen several stages of improvement over the past years. Improvements in recording tapes, record/reproduce heads, and electronics developments have each made possible advances in bandwidth and signal to noise ratio. This paper describes results obtained by combining performance features which have recently become available in ferrite heads and “High Energy” tape. New electronics techniques are used in a systems approach to coordinate and optimize the over-all performance. The result is an extension of 2X in bandwidth, or a reduction of tape speed by one half, while maintaining approximately 20 dB signal to noise ratio with a track width of .025 inches.

**Improvements in Magnetic Tape** With the goal in mind of doubling the recorded information density on magnetic tape, new and improved techniques were needed to make practical the advancement from the currently used 60 to 80 micro-inch wavelengths to wavelengths in the order of 30 to 40 micro-inches. If the geometrical relationships between the head/tape interface and recorded wavelength are to be maintained, it appears that the dimensions of the key magnetic elements should be scaled down in proportion to the reduced recorded wavelengths. These magnetic elements include record and reproduce head gaps, head to tape spacing (due to surface roughness), magnetic tape coating thickness, etc. Azimuth tolerance is maintained by reducing the track width from .050 inch to .025 inch.

The first way in which it is possible to obtain increased recorded information density is with the use of new high performance tape. Data for this paper was taken with 3M Company type 971 “High Energy” tape.

Figure #1 is a comparison between the reproduced signal levels from 3M888 tape and 3M971 “High Energy” tape. These two frequency response curves were taken from the reproduce preamplifier output of an unmodified, wideband, record/reproduce system at a tape speed of 30 ips. Figure #1 shows that, without any modifications, improved signal levels at all frequencies are obtained with “High Energy” tape as compared with 3M888 tape. There is very little difference in reproduced noise levels between these two tapes. The improvement in signal levels is the most pronounced at high frequencies (short wavelengths). At the upper band edge frequency of 500 KHz, an improvement of approximately 8 dB is obtained with an unmodified Record/Reproduce system. This frequency corresponds to a recorded wavelength of approximately 60 micro-inches.

**Improvements in Record Heads** Figure #2 shows the improvements obtainable in short wavelength recorded signal level by the use of a narrow record head gap. An extensive series of studies was made of the effect of record gap dimensions upon recorded signal levels as a function of frequency and wavelength. These studies showed that a wide record gap will record higher signal levels at long wavelengths at the expense of somewhat less recorded level at short wavelength. If most of the noise is at the low frequency end of the pass band, a wide record gap will produce the best wideband signal to noise ratio.

On the other hand, if the major limitation on signal to noise ratio is at high frequencies (short wavelengths), a narrow gap record head will impress greater high frequency (short wavelength) levels on the tape at the expense of somewhat less low frequency level.

In figure 2, typical curves are shown of the unequalized reproduce preamplifier output from recordings made with 200 micro-inch and with 40 micro-inch gap metal record heads. All other system parameters are held constant for these two curves. Record head currents and pre-emphasis are adjusted, in each case, in accordance with IRIG 106-69 procedures. It is seen from these curves that the 200 micro-inch gap records approximately one dB more signal level on the tape at long wavelengths. The 40 micro-inch gap records approximately three to four dB more signal level on the tape at short wavelengths. Intermediate record gaps, between these two extremes, have intermediate frequency distributions of recorded signal level.

In extending the recorded frequency bandwidth, from 500 KHz to 1000 KHz, at a tape speed of 30 inches per second, a limitation on signal to noise ratio is the signal amplitude which can be recorded and reproduced at short wavelengths. In order to optimize the short wavelength response, ferrite record and reproduce heads with extremely narrow gaps have been developed.

One problem which arises in using very narrow record gaps is that more high frequency bias power is required than is needed for wider record head gaps. In the above example, approximately twice as much bias current is required for the 40 micro-inch gap as is required for the 200 micro-inch gap. This is about four times as much bias power for the narrow record gap as for the wide record gap.

**Ferrite Heads** When it is considered that the new "High Energy" tapes require more bias power than does 3M888 tape, the use of narrow gap metal record heads with "High Energy" tapes may present a limitation in available bias power and in heating of the record head structure. This problem is avoided when ferrite record heads are used. One of the advantages of ferrite record heads is that ferrite magnetic circuit losses are considerably less than are the magnetic circuit losses of metal heads at bias frequencies. Therefore, much less bias power is required to bias ferrite record heads, even with "High Energy" tape, than is required to bias metal record heads.

Ferrite heads not only have the advantages of much lower magnetic circuit losses, but have better wear characteristics than do metal heads. Low losses mean that less record power is needed and more reproduce signal level is obtainable, either with conventional instrumentation tape or with "High Energy" tape.

At the present time, Mincom is manufacturing "High Performance" ferrite heads for our wide-band instrumentation record/reproduce system. With a bandwidth of 2.0 MHz at 120 inches per second, the shortest recorded wavelength for these systems is approximately 60 micro-inches. The optimum record head gap for these wavelengths has been found to be approximately 80 micro-inches. In this investigation, the goal is to achieve a record/ reproduce bandwidth of 1.0 MHz at a tape speed of 30 inches per second. This requires a recorded wavelenth of approximately 30 micro-inches on the magnetic tape. Experimental record heads for this study were made with 80 micro-inch gaps and also with 40 micro-inch gaps. Tests results to date indicate that slightly better short wavelength performance may be obtained in this application with a 40 micro-inch record head gap.

**Improvements in Reproduce Heads** In Wideband Instrumentation Record/ Reproduce systems with minimum wavelengths of approximately 60 microinches, the optimum reproduce head gap has been found to be in the order of 27 micro-inches. If the dimensions of the recorded wavelengths are reduced, the head/tape interface dimensions should be reduced in proportion. When tolerances and effective gap width effects were considered, it was decided to build the ferrite reproduce heads, for the 30 micro-inch wavelengths of this project, with a nominal gap width of 11 micro-inches.

Delay distortion is reduced with these ferrite heads, both in the recording and in the reproducing processes. Less record pre-emphasis is required, thus less phase shift is produced by the record head driver circuits. Less high frequency “roll-off” occurs in the reproduced signal at the pre-amplifier output, therefore less delay distortion is generated by the reproduce equalizer.

The fact that ferrite is an extremely hard, long wearing material means that there should be very little change in Record/Reproduce head properties with time. Gap length and depth can be optimized at the time of manufacture without the allowances for dimensional changes (and magnetic properties) occuring in metal heads with wear. Record and reproduce head innerface, for example, can be more nearly optimized if the allowances needed for wear are reduced by the use of ferrite.

The reproduce head output level at all frequencies is increased by raising the impedance of the reproduce head winding. maximum head impedance in the critical high frequency region is obtained when the head winding is resonant at the upper band edge frequency with head wiring and preamplifier input capacitance. Maximum reproduce head impedance and output level is obtained at lower frequencies with the maximum possible number of turns in the reproduce head winding. Preamplifier input capacitance has been reduced for optimum performance with these high impedance reproduce heads.

Figure 3 shows a comparison between the performance of a 2000 ohm ferrite reproduce head and of a 5000 ohm ferrite reproduce head. It is seen on these curves that both heads have approximately the same frequency response. The 5000 ohm head has approximately 3 dB more output level than does the 2000 ohm head. The mid-band tape noise is approximately 2 dB higher with the 5000 ohm head than with the 2000 ohm head. Noise at the upper and lower portions of the passband is approximately the same with either reproduce head impedance.

**Head/Tape System Considerations** We have described above, the performance improvements which are possible in the three areas of “High Energy” tape, narrow gap ferrite record heads, and “High Impedance/Narrow Gap” reproduce heads. The next step in the application of these three improvements is to combine them into a Record/

Reproduce System in such a way as to gain the maximum performance in an optimized system.

In Figure 4 are plotted three curves of slot signal-to-noise ratio, showing improvements obtained in Mincom ’s “High Performance” record/ reproduce system. The lower curve is the signal-to-noise ratio of an unmodified 2.0 MHz record/reproduce system using metal heads and 3M888 tape at 120 ips. The second curve shows the slot signal-to-noise ratio of this system when ferrite record and reproduce heads are used in place of the metal heads. Approximately 11 dB improvement is a result of the use of a narrower record gap (80 micro-inches) and a high impedance, high Q, ferrite reproduce head. When 3M971 “High Energy” tape is used with these ferrite heads, an additional improvement in signal-to-noise ratio at 2.0 MHz results as shown in the upper curve.

**System Linearity** Figure 5 (A) shows a typical transfer characteristic with metal heads and 3M888 tape. By the use of narrow gap ferrite heads and “High Energy” tape, in curve 5 (B), we have extended the available dynamic range by more than six dB.

Referring to Figure 6, there are four curves of the Record/Reproduce System “transfer characteristic” at four different frequencies. In these curves are plotted the dBm output of the reproduce pre-amplifier as a function of the dBm. input to the record amplifier. The record amplifier gain is adjusted so that zero dBm input level produces 1.0% third harmonic distortion in the reproduced output.

It is seen that several dB of linearity is available above normal recording level. The limiting case is the curve for 1000 KHz which has a linear range of approximately 8 dB above normal recording level. This means that approximately 8 dB of dynamic range is available for record pre-emphasis and for recording at distortion levels above 1%, if desired. These curves, taken with narrow gap ferrite heads and “High Energy” tape show much more dynamic range than was obtained with the unmodified system of Figure 5 (A).

Figure 7 shows the effect of recording at levels above a zero reference level of 1.0% third harmonic distortion (THD), with ferrite heads and “High Energy” tape. It is seen here that increasing the reference recording level from 1.0% THD to 2.0% THD would raise the recording level by approximately 3.5 dB. Recording at 3.0% THD reference level would raise the recording level by approximately 4.5 dB. If the recordings were made of pulses, the gradual change of slope of the transfer characteristic would allow thse higher record levels. If the record input signals are of sine waves, the THD may be minimized by signal processing prior to recording.

In Figure 8 is shown curves of the relationship between record input level and third harmonic distortion, both with and without the signal processing circuit. These curves show that the use of this processing circuit makes possible an increase of three to four dB in record level when zero reference level is defined in terms of one percent THD.

Now that we have shown the effects of the signal processing circuit in reducing harmonic distortion, there remains the question of the effects of this circuit on intermodulation distortion products . Figure 9 shows the distribution of intermodulation distortion producst with and without the linearizing circuit in use. Even though there is some increase in IM products, these products are all more than 35 dB below the reference level. Therefore the IM distortion products are all well below the wide band noise level.

**Performance of Modified System** Figure 10 shows the amplitude vs. frequency response at 30 ips of a complete half speed record/reproduce system with narrow gap ferrite heads and 3M “High Energy” tape. A reproduce equalizer, modified for use with these ferrite heads, was used to equalize the pre-amplifier output signal in accordance with IRIG 106-69.

Figure 11 shows the equalized amplitude/frequency response of this modified record/reproduce system at 1 7/8 ips. At this tape speed, it was found adviseable to use a toroidal core step-up transformer between the reproduce head winding and the pre-amplifier input terminals. This transformer was designed and optimized to provide the proper transducer source impedance range for best preamplifier noise figure. When this is done, the wide band, equalized signal-to-noise ratio is approximately 20 dB at 1 7/8 ips tape speed and at 30 ips tape speed. This is obtained with a track width of .025 inch, providing 28 tracks per inch of tape width.

**Conclusions** This investigation has shown that recent improvements in magnetic tape and heads have made possible much improved efficiency in the recording and reproduction of short wavelength signals. It has also been found that when these improvements are combined in an optimized record/ reproduce system, an extension of dynamic range results. The transfer characteristic curve between the normal 1% THD recording level and tape saturation is more nearly linear. Several more dB of additional signalto-noise ratio are also available by recording at the 2% or 3% THD levels. A reduction in third harmonic distortion at these higher record levels may be obtained, if desired, by modifying the waveshape of the record head signal current to compensate for the non-linearity of the magnetic tape transfer characteristic.

The net result of combining these improvements is that the use of recorded wavelengths down to 30 micro-inches is now possible with a broadband signal-to-noise ratio of more than 20 dB. The track width of .025 inch provides 28 tracks per inch of tape width.

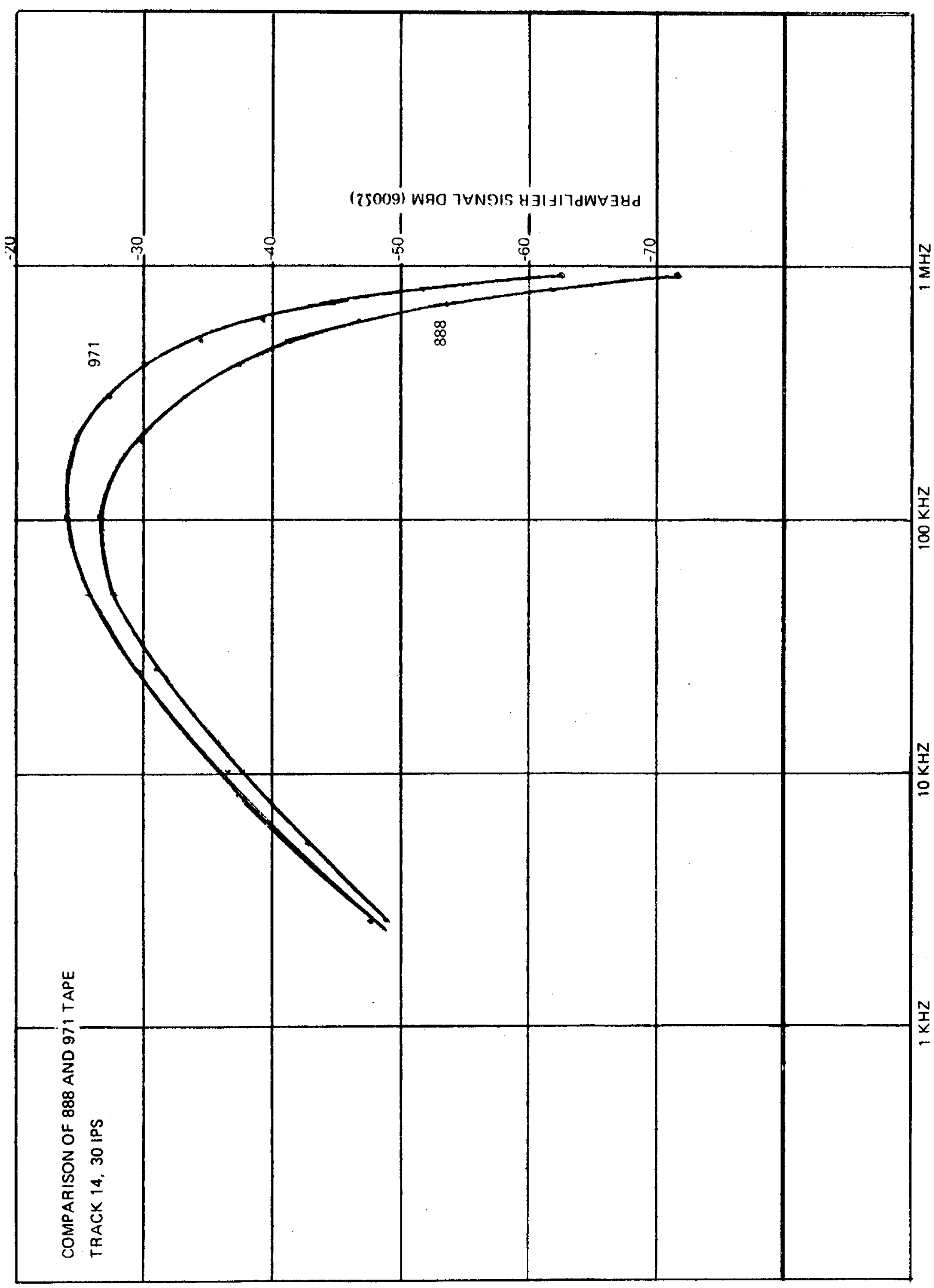


**Figure 1**

A comparison of reproduced signal levels from 3M888 tape and 3M971 tape at 30 inches/second on an urmodified record/ reproduce system.

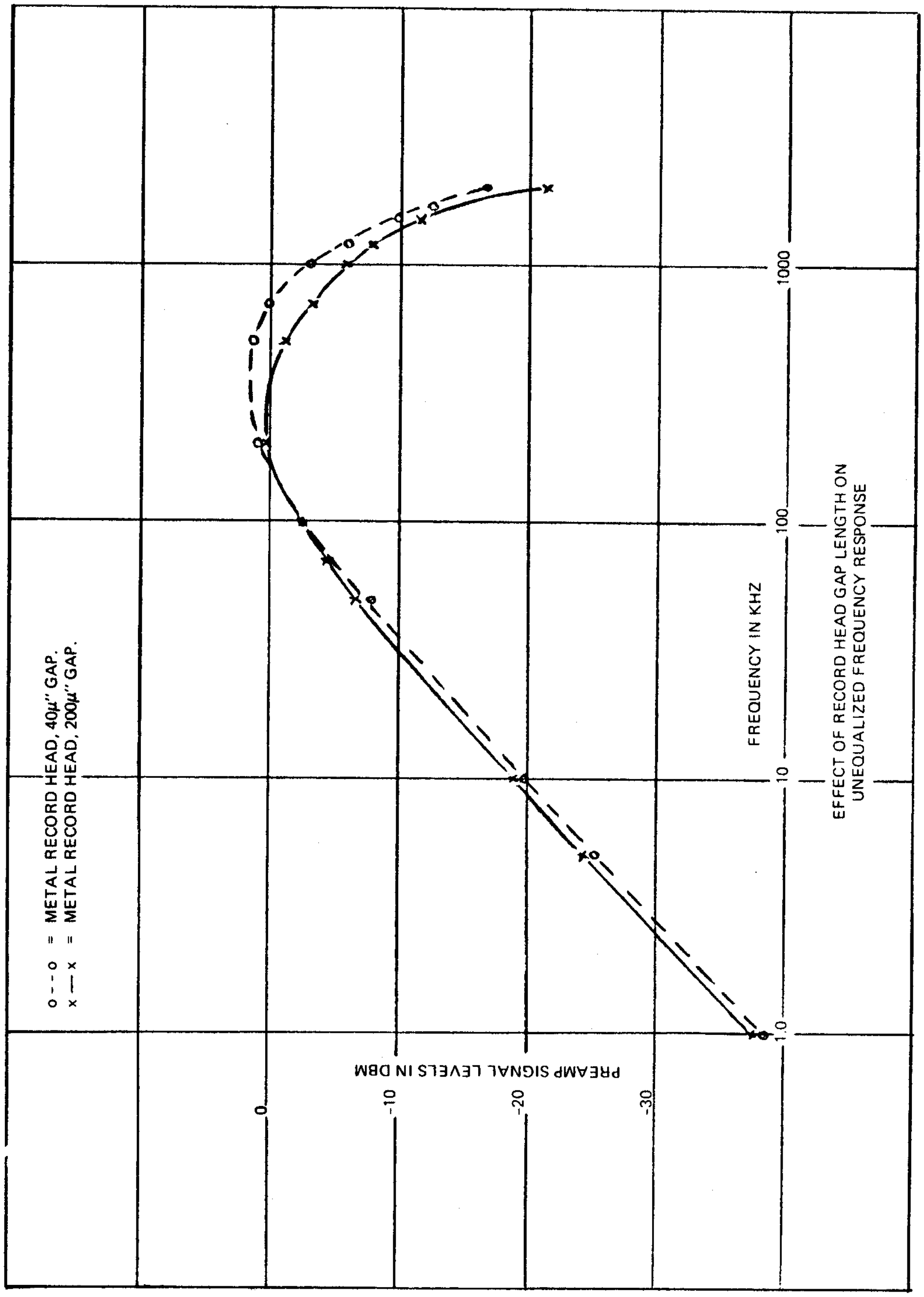


**Figure 2**

A comparison of the effects of long and short record head gap lengths on unequalized reproduce frequency response.

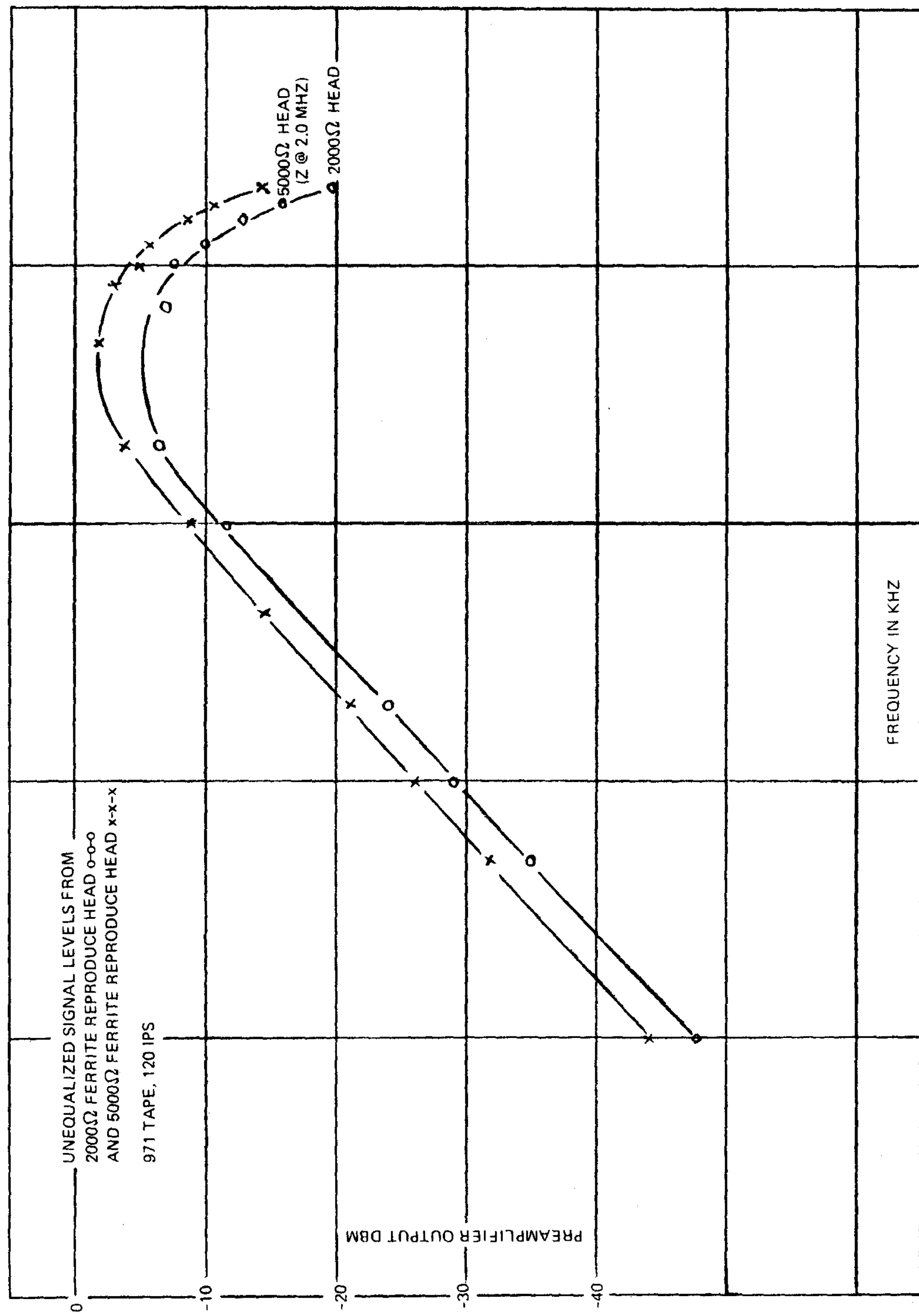


**Figure 3**

A caparison of output signal levels from a 2000 ohm ferrite reproduce head and a 5000 ohm ferrite reproduce head.

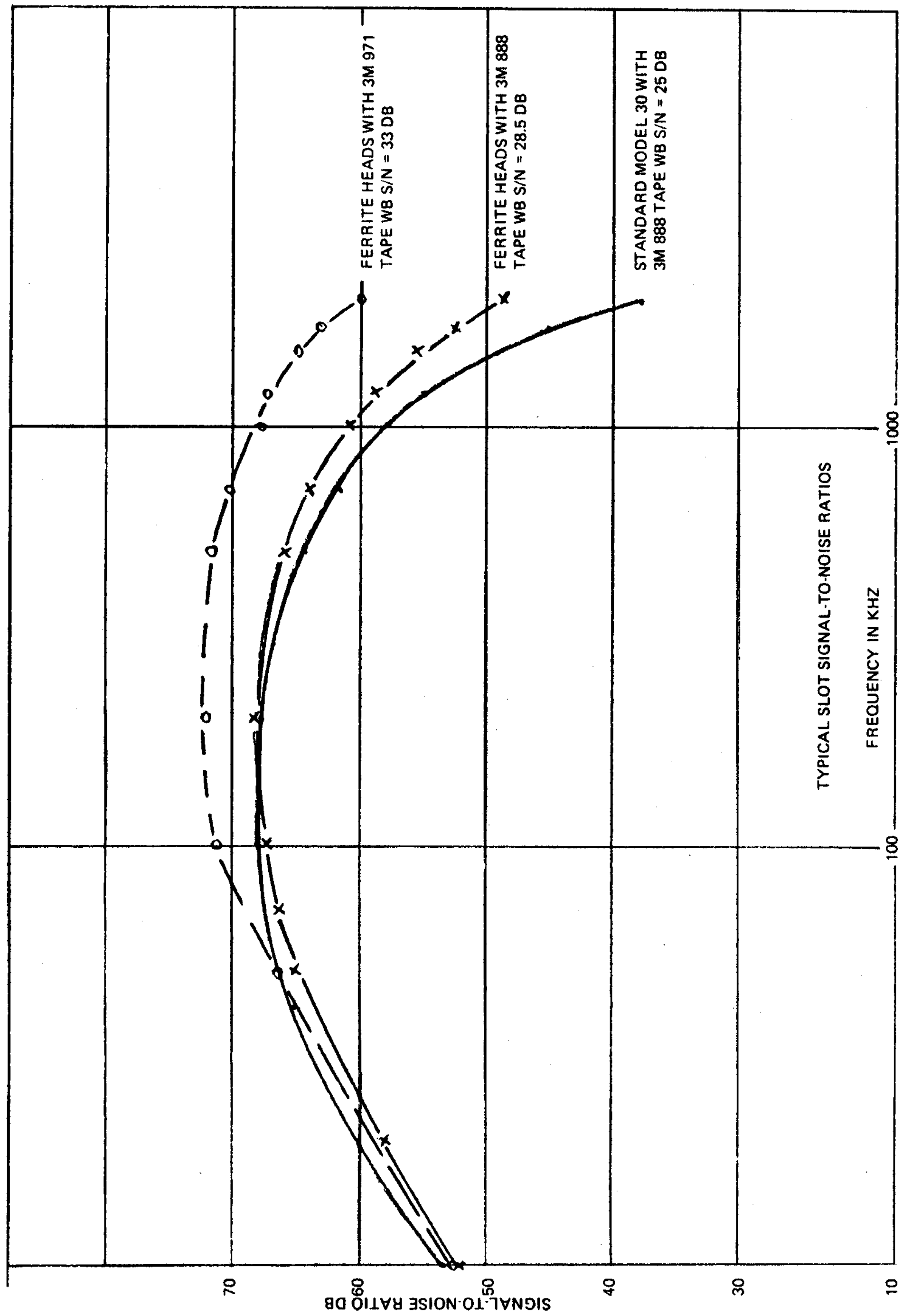


**Figure 4**

Typical curves of narrow band signal-to-noise ratio, showing improvements obtained by the use of ferrite heads and high energy tape.

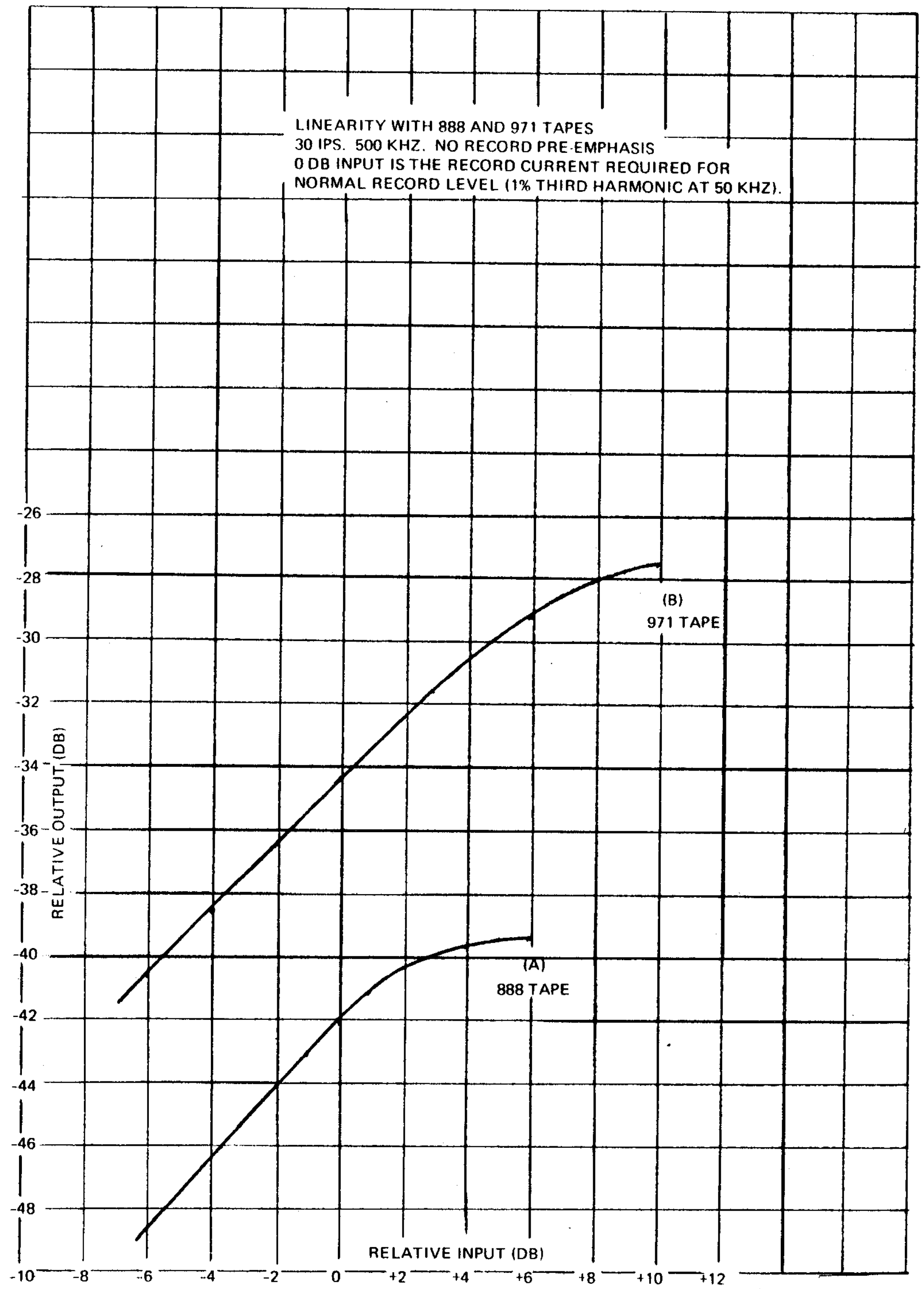


**Figure 5**

Typical curves of Output/Input linearity at 60 micro-inch wavelength, comparing 3M888 tape with 3M971 tape.

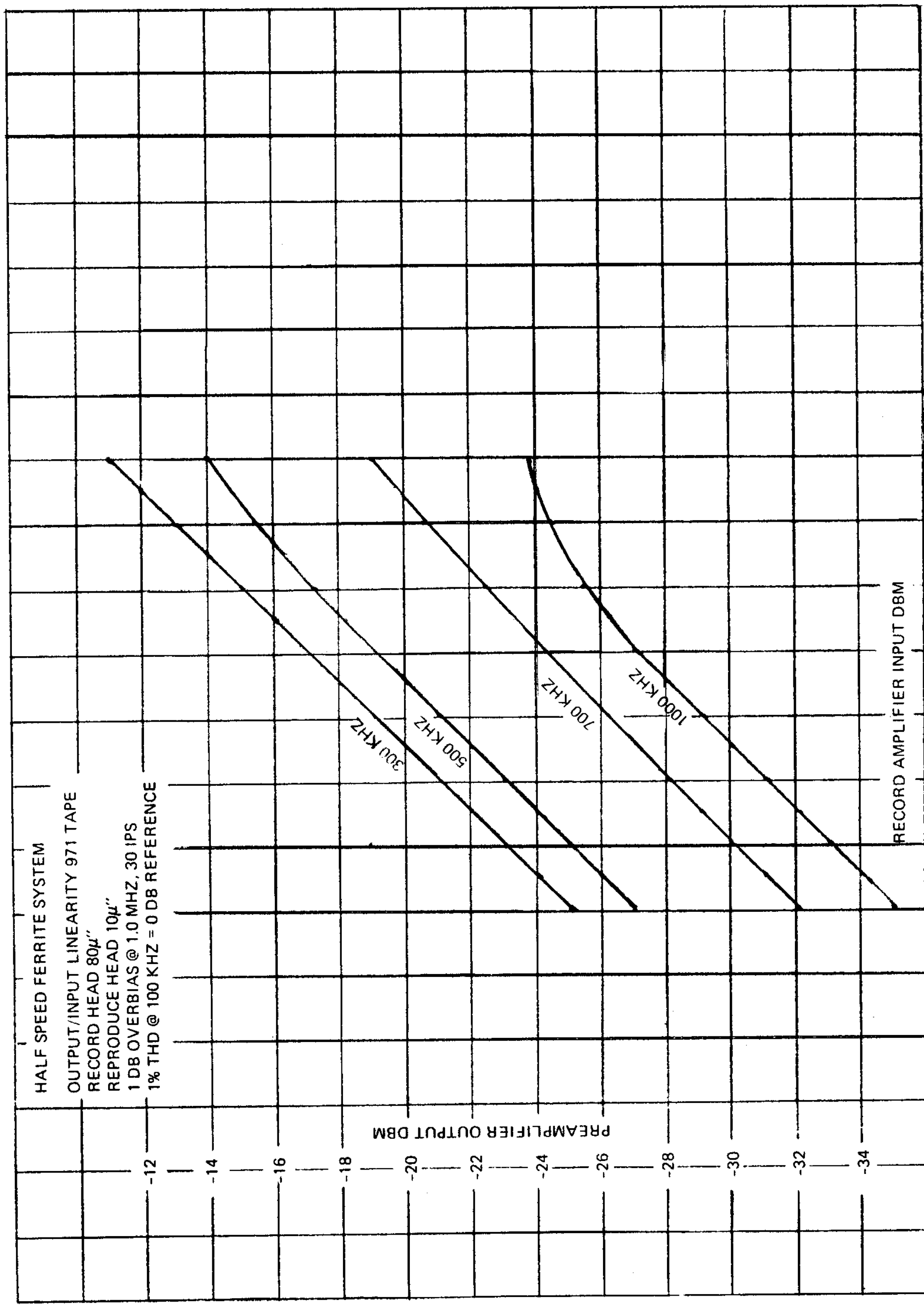


**Figure 6**

Typical Output/Input linearity curves of 3M971 tape with short gap ferrite heads.

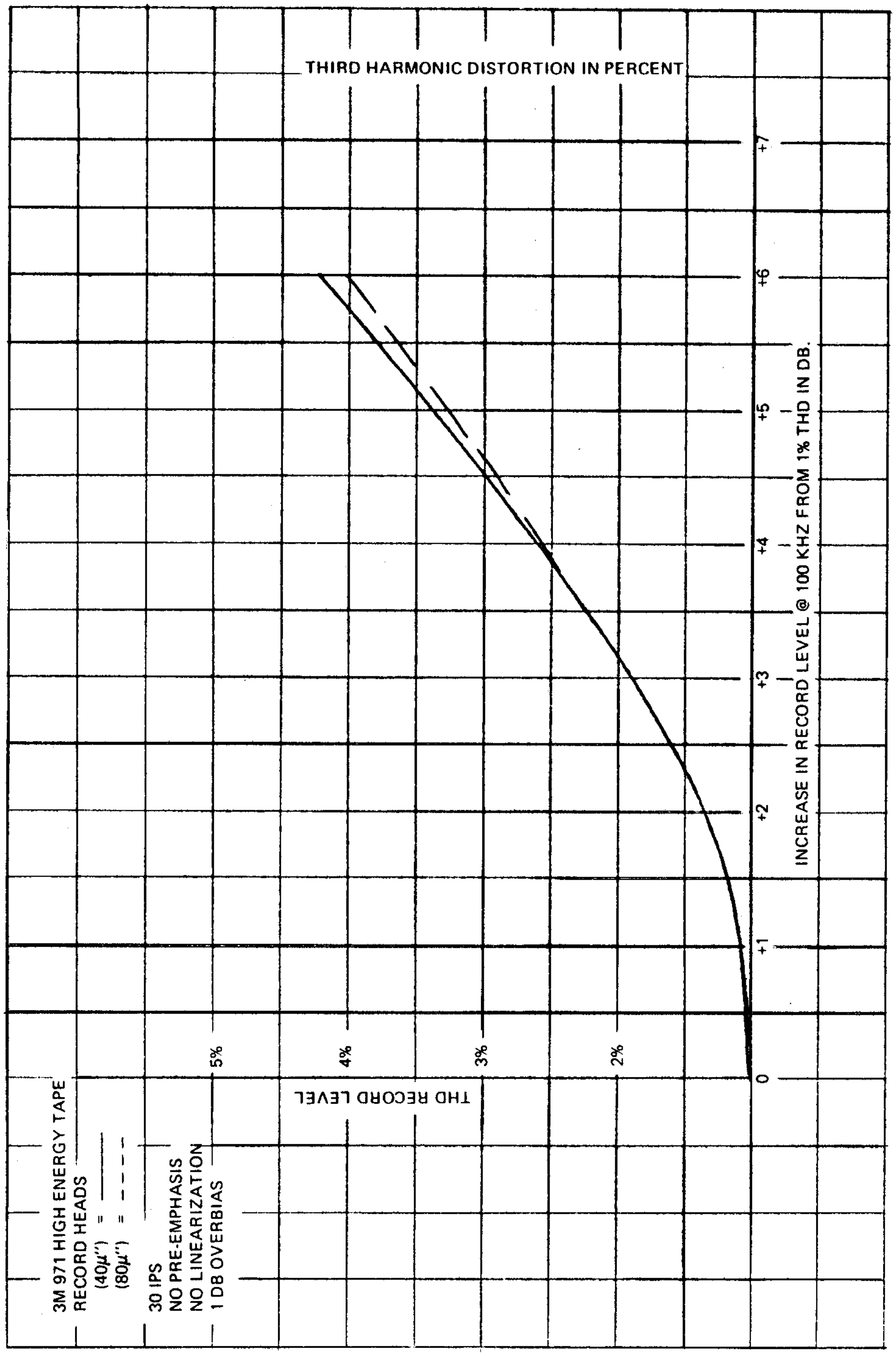


**Figure 7**

Typical curves of third harmonic distortion level in percent as a function of record level with short gap ferrite heads and "High Energy" tape.

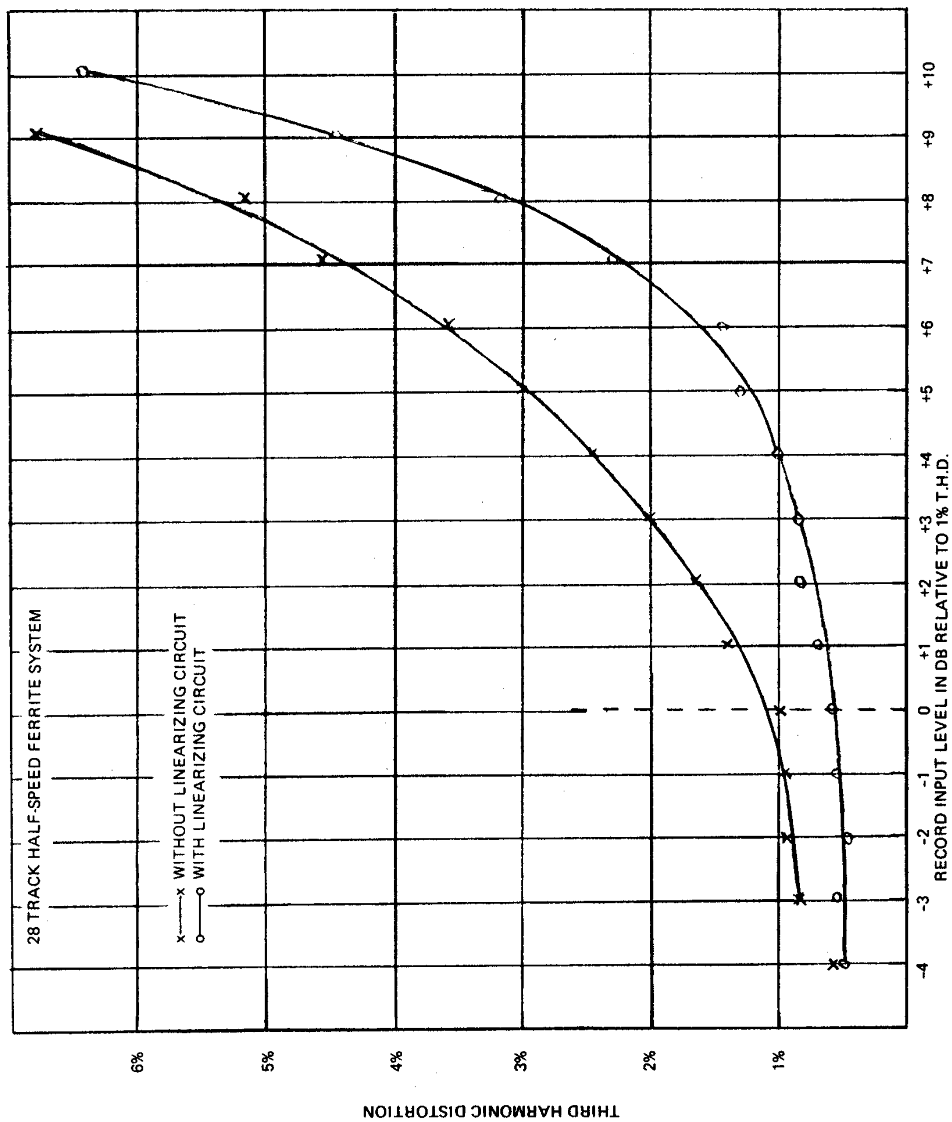


**Figure 8**

Typical curves of third harmonic distortion levels with and without signal processing circuit to reduce recorded distortion.

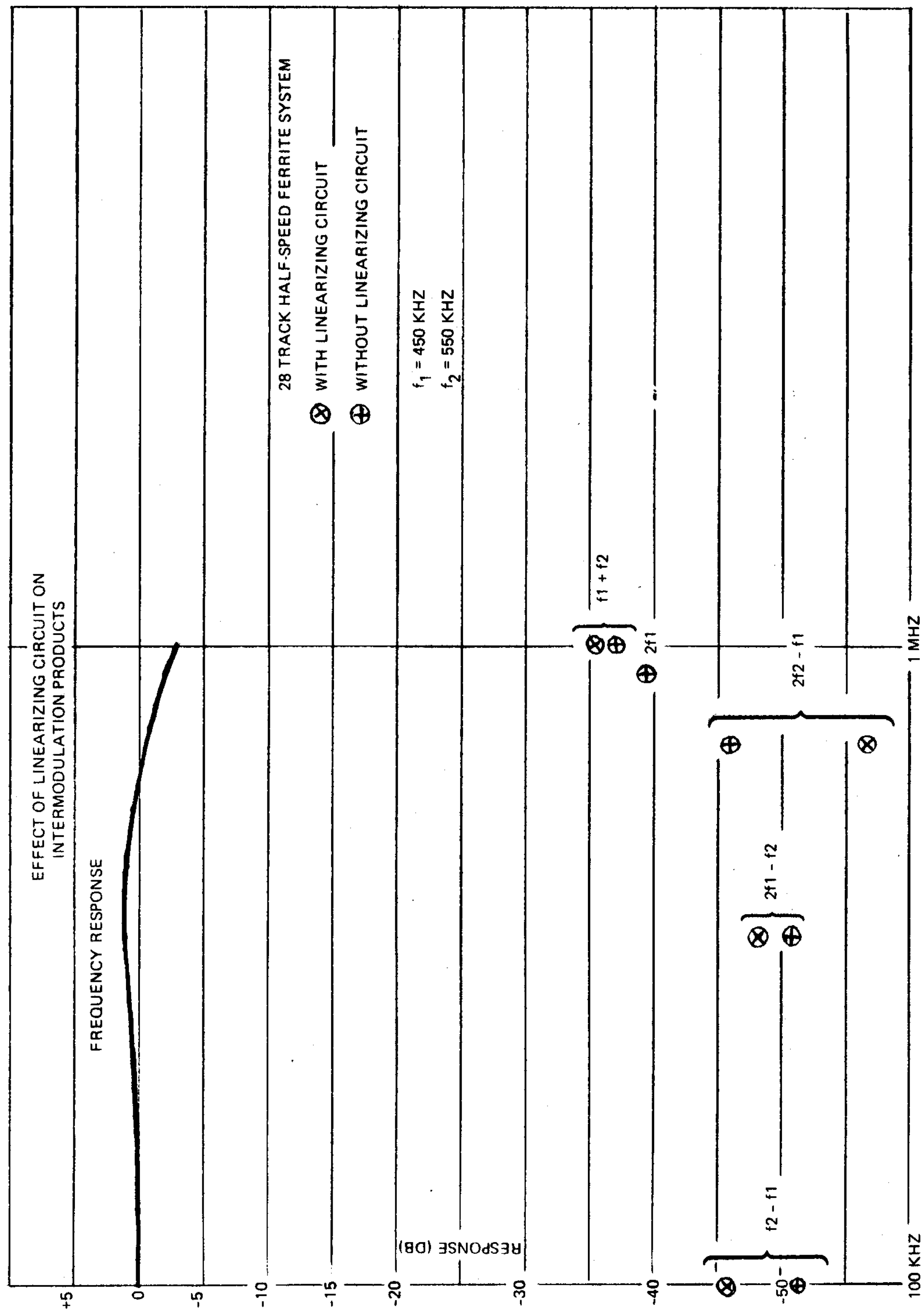


**Figure 9**

Typical measurements of intermodulation products with and without signal processing to reduce harmonic distort on.

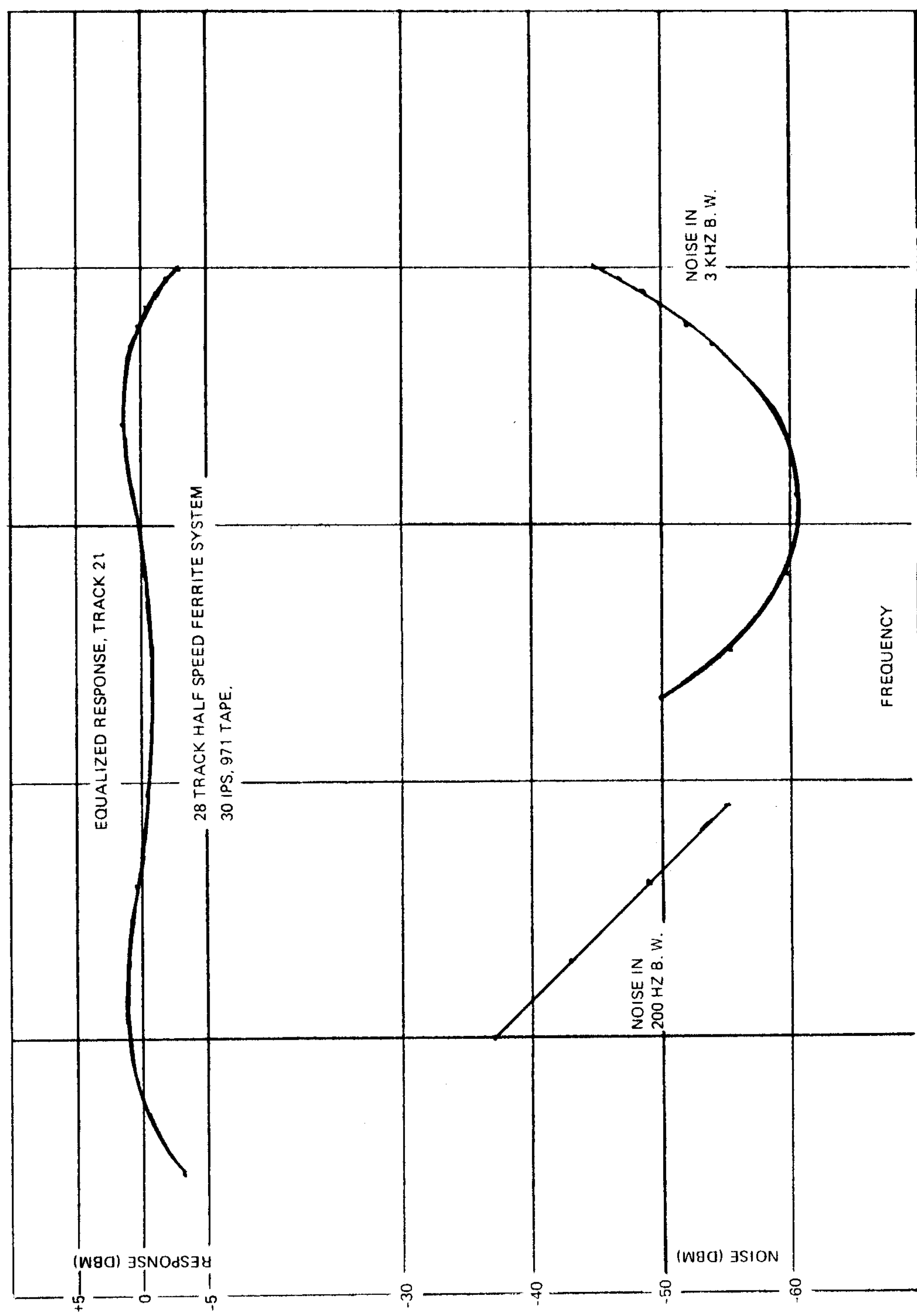


**Figure 10**

Amplitude vs. frequency response of 28 track, half-speed system at 30 inches/second.

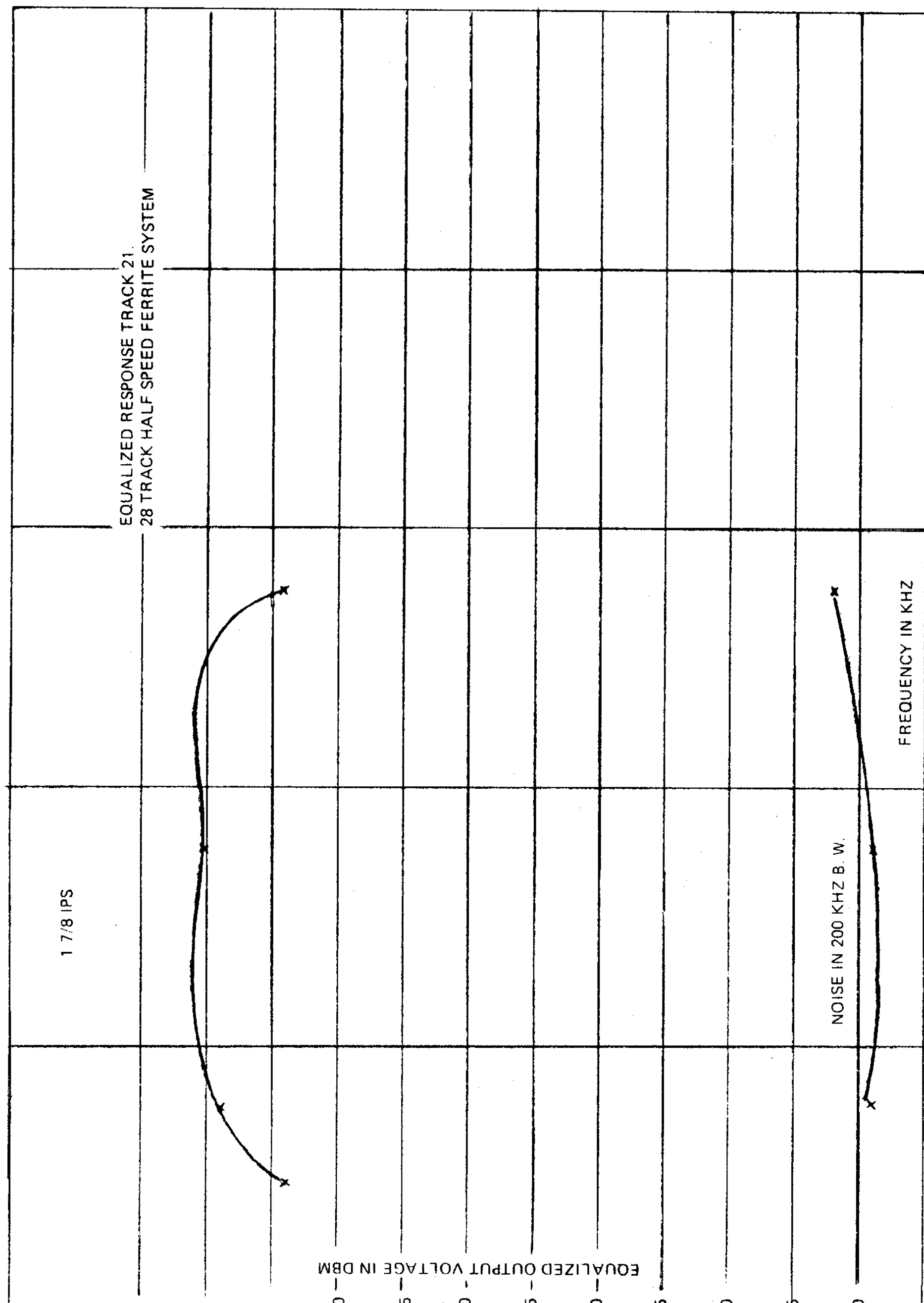


**Figure 11**

Amplitude vs. frequency response of 28 track, half-speed system at 1 7/8 inches/second.