DOUBLE DENSITY ANALOG MAGNETIC RECORDING

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ABSTRACT

This paper discusses measured performance of double density recording. Tests were conducted using different recorders, playback machines, and magnetic tapes. The main topics discussed are slot signal-to-noise ratio (SNR) and high density digital bit error rate (BER).

INTRODUCTION

These tests were conducted primarily to measure the slot SNR and high density digital BER performance of double density (aka half speed) recording. Double density recording basically means the recording of signals at twice the frequency of Inter-Range Instrumentation Group (IRIG) wideband II at the same tape speed. At a tape speed of 30 inches per second, double density recording has an upper frequency of 1 MHz (30 microinch wavelength) versus 500 kHz (60 microinch wavelength) for IRIG wideband II. This means that the recording time on a reel of tape is twice as long with double density as with IRIG wideband II. The double density head configurations used in this test were IRIG in-line heads with 25 mil track widths. The majority of the recording was done on two airborne recorders (different models). One tape was recorded on a laboratory recorder. The majority of the playbacks were done using two laboratory recorders (different models). This was done to more closely simulate the recording scenario of a particular project. The recording speeds were 7.5 and 30 inches per second.

The tapes used in this test were Ampex 721 and Minnesota Mining and Manufacturing 5198. Several reels (from more than one lot) from each manufacturer were used. One reel of Ampex 799 tape was also used. This tape yielded SNRs that were 6-10 dB lower than the other tapes at a wavelength of 30 microinches. The high density digital data at packing densities of 40 kilobits per inch (kbi) suffered from a lack of bandwidth with 799 tape. This was apparent because most of the bit errors were due to single bits which were low in amplitude.

The test setups are shown in figure 1. All of the test equipment was under computer control with the exception of the multicoupler, PCM bit synchronizer, and analog oscilloscope. During the high density digital recording tests, a 2047-bit pseudo random signal was recorded on tracks 2 through 13 of the recorder. The codes recorded were non-return-to-zero level (NRZ-L) and Miller (DM-M). The packing densities were varied from 20 kbi to 60 kbi. The playback technique was:

1. Align azimuth for best output of the track under test

2. Adjust equalizers for "good" eye pattern

3. Measure errors per ten million bits and record results on computer disk. The digital oscilloscope was set up to record playback output when errors occurred.

A series of sine waves was recorded during the slot SNR and frequency response tests. The frequencies recorded were: 1 kHz, 10 kHz; and 0.1, 0.25, 0.5, 0.75, 1.0, and 1.25 times the upper bandedge frequency of the recorder. A time interval with no input signal was also recorded between each frequency to allow measurement of the noise power at each frequency. The normal record level for these tests was the level that produced approximately 3.5 percent third harmonic distortion. Sine wave signals were also recorded at levels 2 dB greater and 3 and 6 dB smaller than this level. The playback test was synchronized to the data recorded on tape by recognizing the start of a recorded signal with frequency equal to one-half of the upper bandedge. This signal was also used to correct for tape speed variations between machines by varying the measurement frequencies of the wave analyzer. The second and third harmonics of the signal recorded at 0.1 times the upper bandedge were also measured. In addition, the unfiltered wideband SNR was measured. An IRIG B time code signal was also recorded on baseband to check the low frequency capability of double density recording. All recordings were made on virgin tapes that were degaussed before use. The reproduce equalizers were the normal IRIG wideband Group II equalizers except that the 60 inch per second equalizer was used for 30 inch per second double density playback. The equalizers were only adjusted if the eye pattern looked "poor".

HIGH DENSITY DIGITAL RECORDING TEST RESULTS

The bit error rate for 40 kbi NRZ-L reproduced at 30 inches per second varied from 10^{-6} to 10^{-9} on tracks 5 through 10 for the tapes tested . The error rate and loss of synchronization rate were higher for tracks near the edge of the tape. The error rate does not include intervals where synchronization was lost. The probability of loss of synchronization varied from tape to tape and from recorder to recorder. The worst tape had a loss of synchronization approximately every 5 X 10^8 bits when reproduced on the recorder with the fewest losses of synchronization. No other tape exhibited a loss of synchronization on tracks 5 through 10 with this recorder at 40 kbi (approximately 4.7 X 10^9 bits were tested with other tapes). The worst recorders had a loss of synchronization approximately every 5 X 10^8 bits with the "good" tapes. The rate with tape type A was a loss of synchronization approximately every 1 X 10^9 bits and with tape type B synchronization was lost approximately every 2.8 X 10^8 bits. One of the type B tapes had a 10 - 15 dB dropout of 400 - 500 microsecond duration every 1.457 seconds at 30 inches per second. One of these dropouts is shown in figure 2. This occurred throughout the entire tape on tracks 7 and 8 with the same time between dropouts. Therefore, these dropouts must have been produced during the tape manufacturing process. This tape was not included in the loss of synchronization rate calculated for tape type B. The loss of synchronization rates for 60 kbi NRZ-L reproduced at 30 inches per second were similar to those for 40 kbi NRZ-L while the bit error rates were approximately ten times larger for 60 kbi than 40 kbi. Plots of bit error rate versus time are shown in figures 3 through 9 for several tape and recorder combinations. Problems were encountered when the NRZ-L data was reproduced at 7.5 inches per second. The majority of bit errors under these conditions were due to baseline wander effects (pattern sensitivity). The bit error rate varied from approximately 10^{-4} to 5 X 10^8. The variation appeared to be mostly caused by phase and amplitude equalization effects. Some equalizers could not be adjusted to give good data at 7.5 inches per second with NRZ-L data. Similar problems were also encountered at 60 kbi at 30 inches per second on one recorder. It should be emphasized that the equalizers were not designed for double density recording and in one case the reproducer and electronics are more than 10 years old. Therefore, the use of NRZ type codes at playback bit rates below 400-500 kb/s or at packing densities above 50 kbi with normal recorders and double density heads should be approached with caution. Proper phase equalization is especially important. The digital recording discussed in this section used a higher than normal record level (approximately 3.5 percent third harmonic distortion with same level sine wave). Tests will be conducted to determine the effect of record level on BER and on SNR margin. It should also be emphasized that these test results are based on a small sample of tapes and recorders.

SLOT SNR TEST RESULTS

The results of the slot SNR tests are shown in Table 1. This data shows that tape type A yielded SNRs that were 2-4 dB better than tape type B at both upper bandedge (UBE) and one-tenth UBE. Typical slot SNRs for an IRIG wideband group II recorder/reproducer with a tape speed of 60 inches per second and 50 mil track widths are 71 dB at 0.1 UBE and 59 dB at UBE. Therefore, the use of IRIG in-line double density recording degraded the slot SNR by 13 to 28 dB at UBE and 8 to 14 dB at 0.1 UBE. Reducing the tape speed and track widths by a factor of 2 will degrade the SNR by 6 to 12 dB (3 to 6 dB for each parameter). The amount of reduction depends on whether most of the noise is generated in the tape or the heads and preamplifiers. Typical slot SNR data is plotted in figures 10 through 14.

Several other parameters were also measured on a limited basis during the slot SNR tests. The crosstalk between tracks was the worst at UBE and was approximately -28 dB at 30 inches per second. When the azimuth was peaked on one track, all other tracks measured were within 2 dB of their best azimuth adjustment at UBE. The reproducer output was frequently not the same in forward and reverse directions. The variations were as large as 5 dB (usually less than 3 dB) and were independent of frequency. The reverse direction usually yielded the highest signal output. This may be due to imperfect head transducer alignment and slight tape tracking differences between forward and reverse directions of play. This also accounts for some of the difference between double density and normal density slot SNRs. The baseband IRIG B time code signal could be properly decoded at playback speeds of one-half the record speed. Slowing the tape down by a factor of 4 created problems for the time code reader. All of these parameters will vary with different heads and recorders.

CONCLUSIONS

The major conclusions are:

Fourteen track IRIG in-line double density recording yielded significantly lower slot SNRs (8 to 14 dB lower at 0.1 UBE, with greater degradation at shorter wavelengths) than fourteen track IRIG wideband II recording. This is mainly due to narrower tracks and slower tape speeds. The difference would be less for 28 track systems.

2. Serial high density digital recording at linear packing densities of 40 to 50 kbi (NRZ codes) with double density heads and tapes yields acceptable BERs. The SNR margin is less than with packing densities of 20 to 25 kbi and IRIG wideband II heads and tapes.

3. The rate of synchronization lose appears to depend on the type of reproduce machine.

4. Type A tapes provided higher SNRs, fewer dropouts and more consistent performance than type B tapes.

5. A potential problem area exists in the playback of NRZ signals at low tape speeds especially when old reproduce electronics are used. This problem needs further investigation.

ACKNOWLEDGMENT

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	TAPE TYPE A		TAPE TYPE B	
7.5 inches per second:	0.1 UBE	UBE	0.1 UBE	UBE
Minimum slot SNR	52.2	36.8	50.9	31.7
Maximum slot SNR	59.1	38.5	54.7	37.2
Average slot SNR	55.9	37.6	51.6	34.1
30 inches per second:				
Minimum slot SNR	59.3	33.1	56.9	31.1
Maximum slot SNR	63.0	46.2	61.1	41.1
Average slot SNR	61.0	41.1	58.7	36.9

Table 1. Double Density Slot SNR test results for two types of tape (3.1 kHz slot bandwidth and approximately 3.5 percent third harmonic distortion)

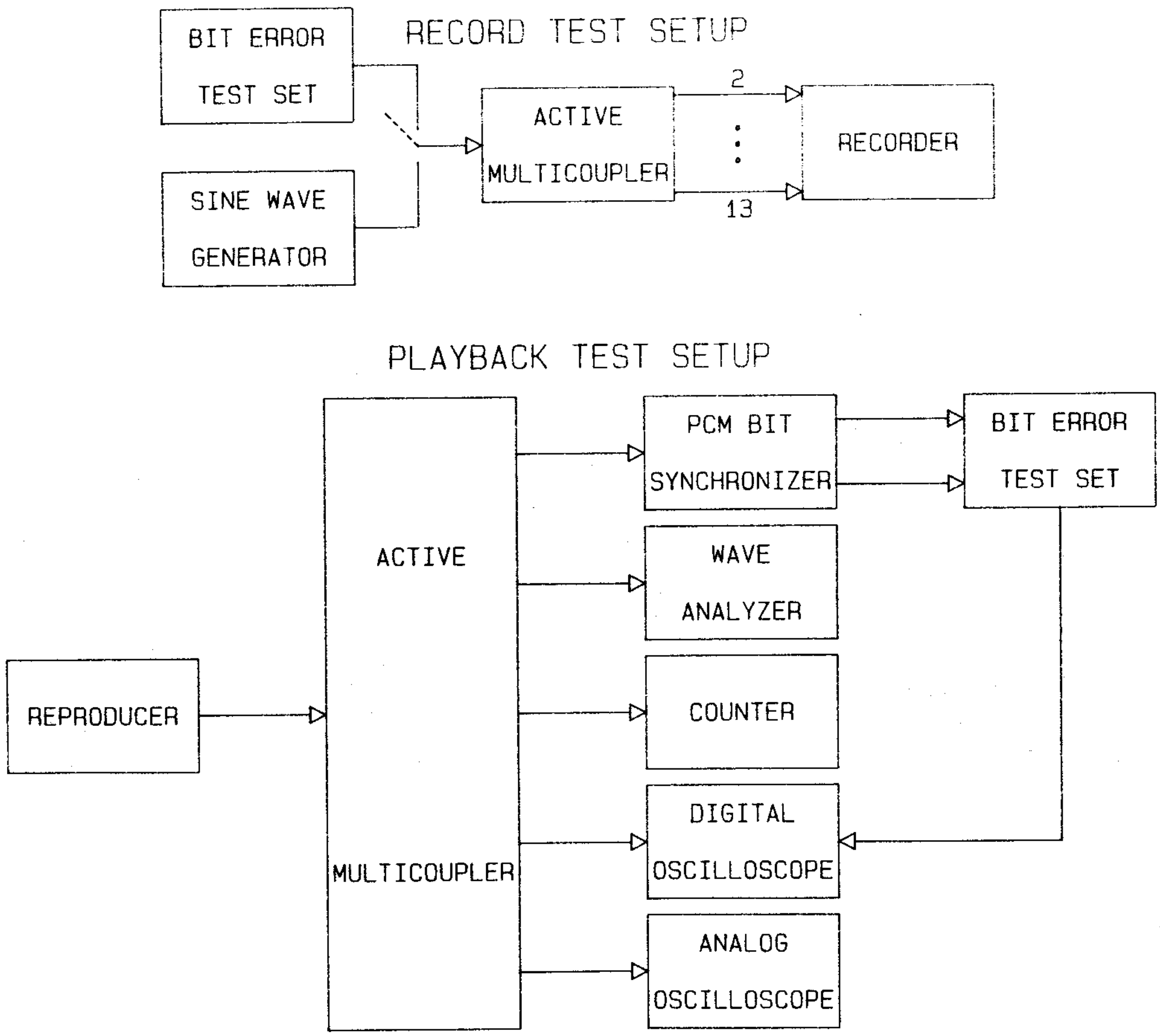

FIGURE 1. TEST SETUPS.

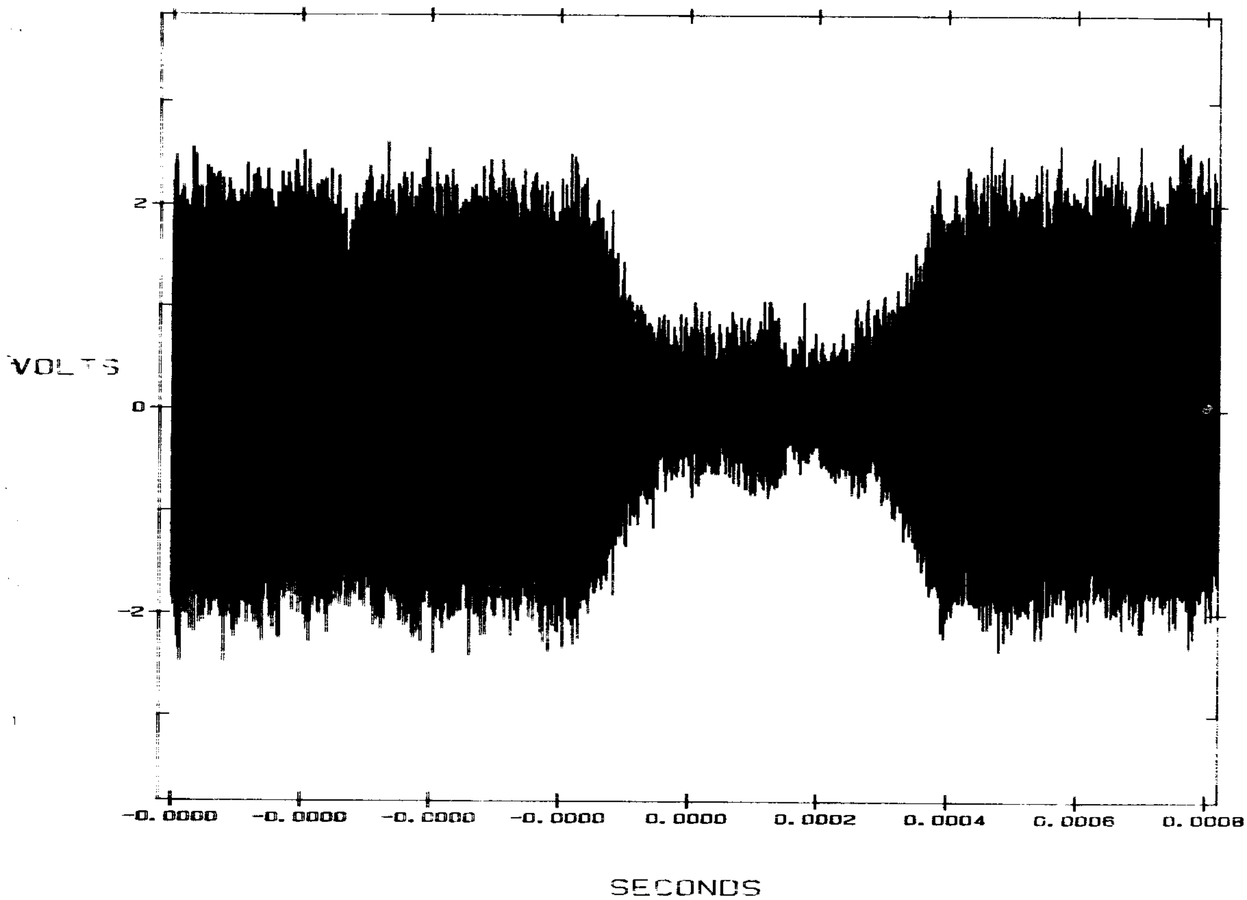

FIGURE 2. PERIODIC DROPOUT TAPE B1.

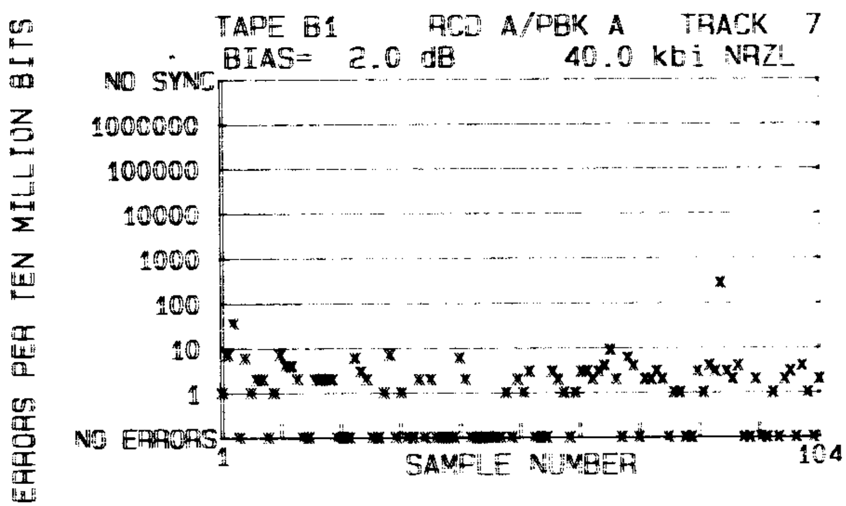

FIGURE 3. BER PROFILE for TAPE B1.

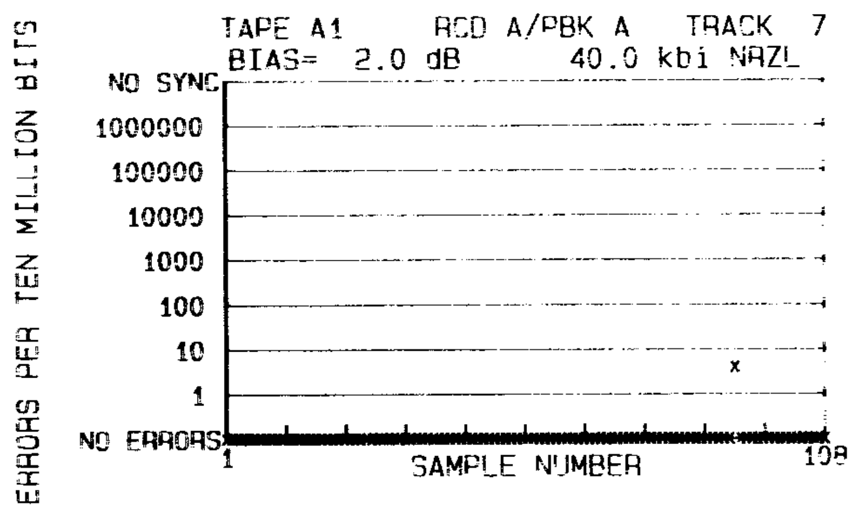

FIGURE 4. BER PROFILE for TAPE A1.

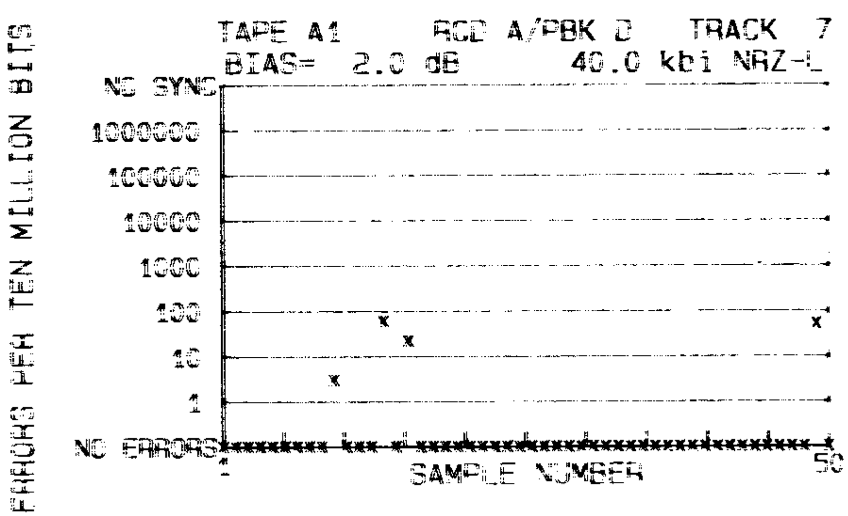

FIGURE 5. BER PROFILE for TAPE A1.

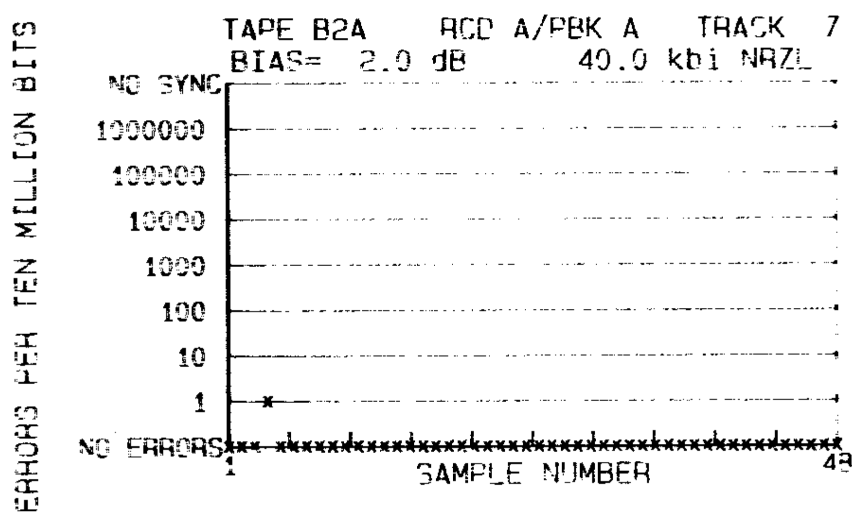

FIGURE 6. BER PROFILE for TAPE B2A.

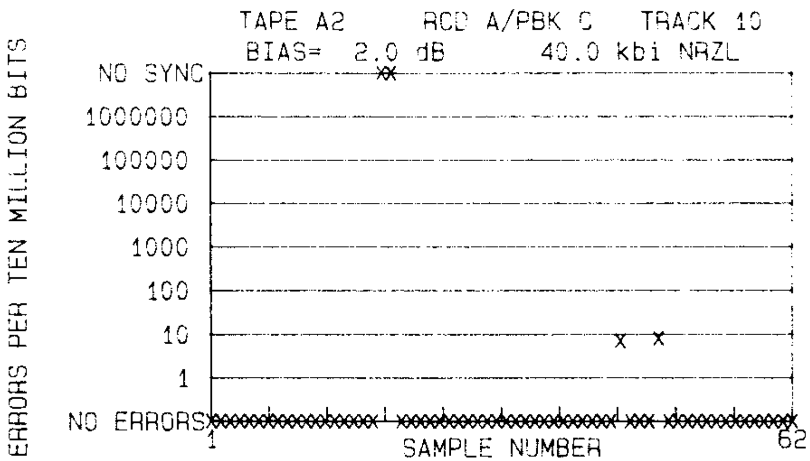

FIGURE 7. BER PROFILE for TAPE A2.

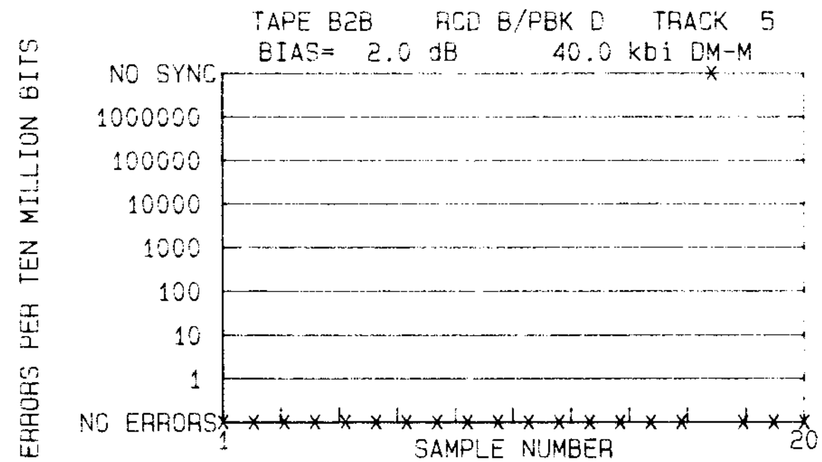

FIGURE 8. BER PROFILE FOR TAPE B2B.

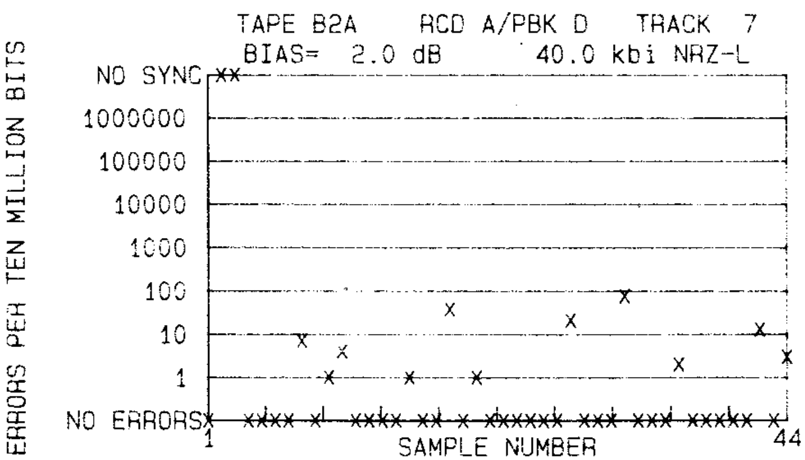

FIGURE 9. BER PROFILE for TAPE B2A.

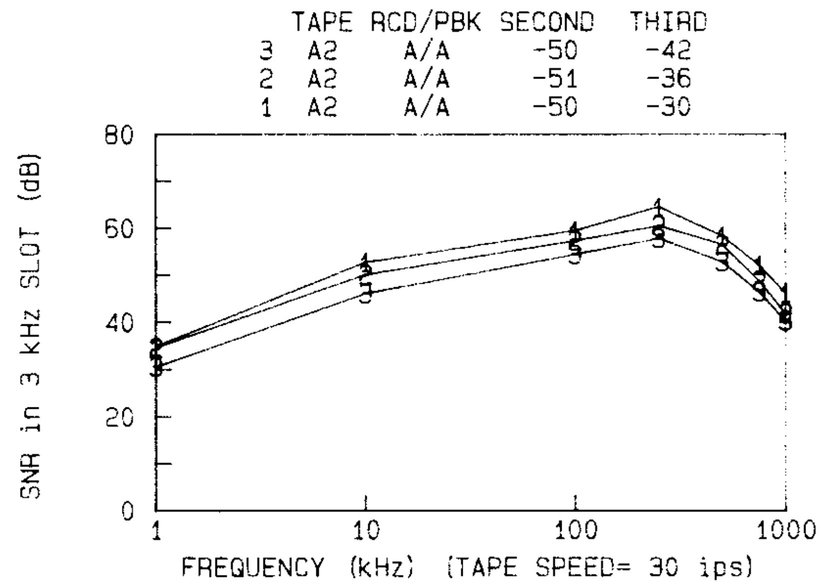

FIGURE 10. SLOT SNR for THREE RECORD LEVELS (3 db STEPS)

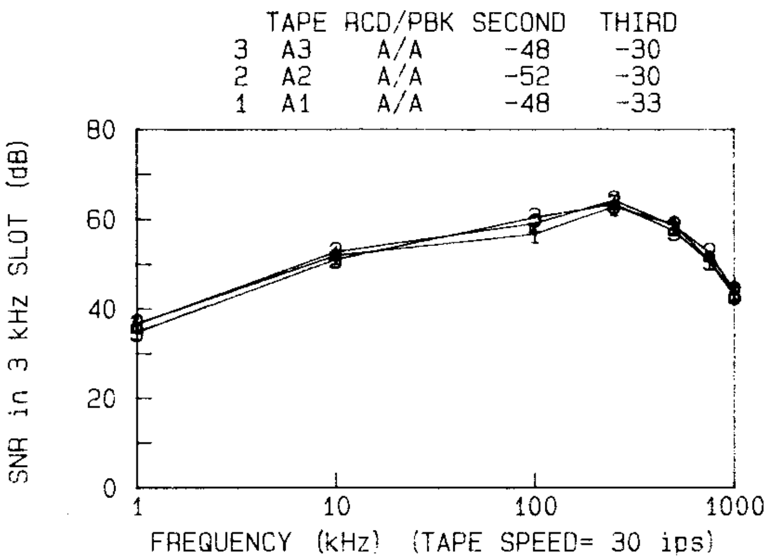

FIGURE 11. SLOT SNR for THREE TYPE A TAPES

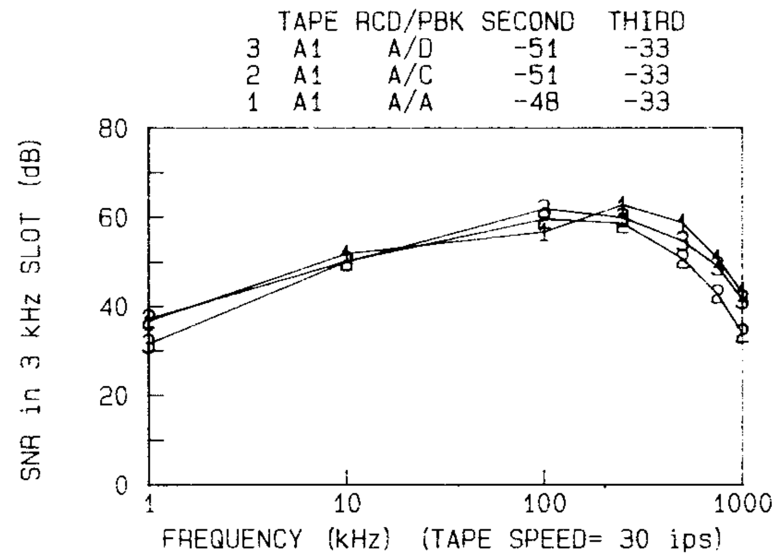

FIGURE 12. SLOT SNRs for THREE PLAYBACK MACHINES

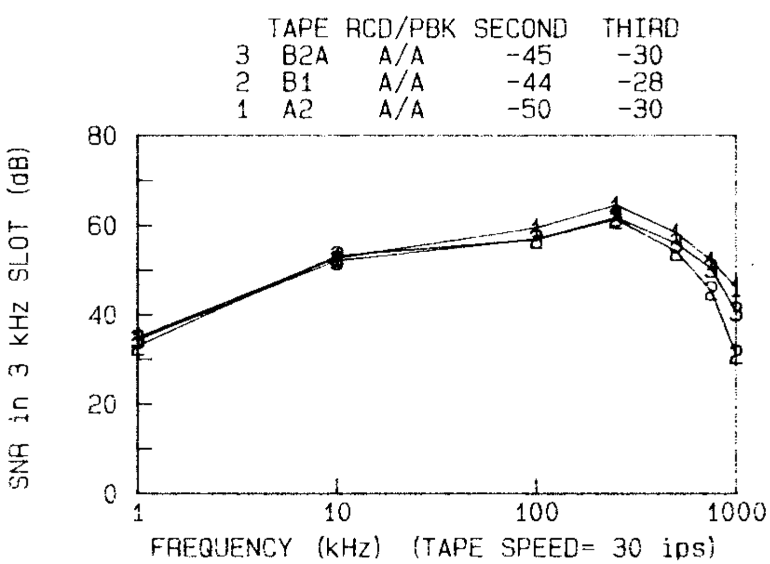

FIGURE 14. SLOT for THREE DIFFERENT TAPES.

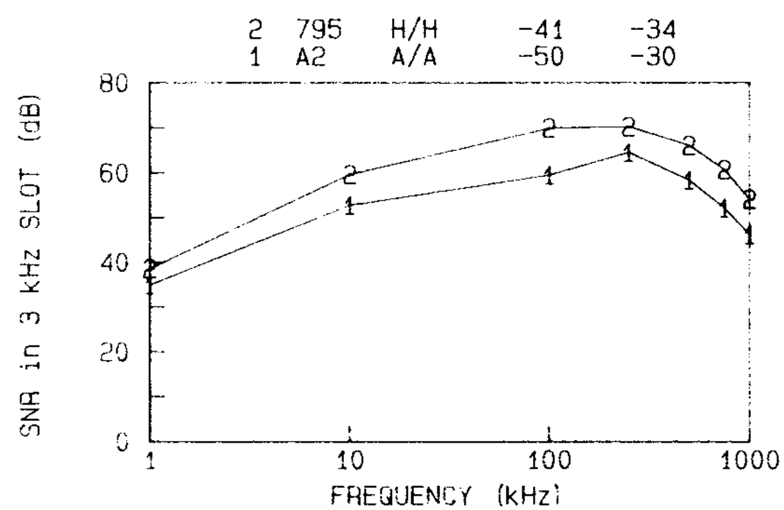

FIGURE 14. SLOT SNRs for SINGLES and DOUBLE DENSITY.