CROSSPLAY COMPATIBILITY OF WIDE-BAND TAPE RECORDER/REPRODUCERS[1]

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Summary. This paper describes the procedure and results of a series of tests on a cross section of tape recorders to determine the effects of record bias and record signal level on the quality of data recorded in the Pre-D (predetection) mode. FM (frequency modulation) and PCM (pulse code modulation) formats were used in the study. The tests were performed on tape recorders at five test sites to determine the effects of crossplay under typical operating conditions. The results are summarized and possible methods of improving crossplay data quality are suggested.

Introduction. Missile test ranges and other facilities involved in magnetic tape recording, reproducing, or dubbing have experienced difficulty in maintaining uniform levels of data quality. Crossplay, defined as recording on one machine and reproducing on another, has been identified as a major contributor to data degradation.

Basic requirements of the task assignments were as follows: (a) Determine the effects of variations in record bias on wide-band tape recorder/ reproducer performance over the range of +3 dB (overbias) through -1 dB (underbias); (b) Determine the effects of variations in record input level over the range of 1% through 3% third harmonic distortion in the recorder; (c) Determine the effects of crossplay on data quality between different types of tape recorder/reproducers at different locations.

In the original concept of the investigation, it was proposed that alignment and adjustments of tape recorder/reproducer in the field be performed according to the normal procedures employed by the user groups. Test signals at selected bias and input levels were recorded to provide quantitive measurements of tape recorder/reproducer performance. The tapes were reproduced and dubbed (re-recorded on other machines.) The test measurements were then compared to the data obtained from the first playback of the master test tapes. Also included were tape signatures for a quick check of reproducer frequency response and azimuth alignment prior to taking measurement data.

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[1] Study performed by the Data Systems Division of the Laboratory Department, Naval Missile Center under a Naval Air Systems Command task assignment in support of the TG (Telemetry Group) of the RCC (Range Commanders Council).

Preparation of Master Tapes. The sources of the test signals used in the recorder/reproducer tests were a set of three 14-inch reels of prerecorded magnetic tape. The tapes were recorded under carefully controlled conditions of record bias, third harmonic distortion in the recorder, and RF signal strength in the signal generating equipment. Two of the master tapes contained notch noise test signals, and were recorded in the Laboratory on an Ampex 1900. The third test tape contained NRZ-L signals, and was recorded on an Ampex FR-1400.

Notch Noise Recording System. Notch noise loading techniques were selected as the best method for measuring the quality of FM data. Measurements of NPR (noise power ratio) and NPRF (noise power ratio floor), at selected notch frequencies throughout the data band, provided the information required to define and compare FM data quality at the output of the tape systems under test. NPRI (noise power ratio intermodulation) may be derived from the NPR and NPRF data.[2]

The NPR test comprised a set of measurements in which wide-band noise having a highly attenuated 3-kHz notch in the spectrum was applied to the input of the system under test. A 1-kHz portion of the attenuated band was examined at the system output to determine the amount of noise introduced by intermodulation plus background floor noise.

The tests reported here were limited to the recording and reproducing of Pre-D signals at a center frequency of 450 kHz and a tape speed of 60 inches per second. Bandpass filters, included in the noise generator, limited the white-noise to a bandwidth of 12 to 204 kHz. Switchable notch filters were provided in the test set for three notch frequencies: 14-kHz, 105-kHz and 185-kHz. The NPR and NPRF measurements at these frequencies provided a sampling of system performance at both ends and the approximate center of the Pre-D data band.

In addition to the notch noise test set,[3] other equipment was required to generate the notch noise test signals as shown in Figure 1. The transmission link characteristics were: (a) RF frequency, S-band, 2250 MHz, (b) RF deviation, 87 kHz rms, (c) Receiver RF input, -35 dBm, and (d) Receiver IF bandwidth, 1 MHz.

Measurements of test system performance, excluding the recorder/reproducer, are indicated in the report as “back-to-back” reference data.

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[2] W. R. Hedeman and M. H. Nichols, “Pre-Detection Recording of Frequency Recording of Frequency Division Telemetry Signals Multiplexed on an FM Carrier”.

[3] Marconi Test Set Model TF-2091-2

Inspection of the back-to-back data in Figure 2 shows that even though the standard test system represented the best overall performance of available ground station hardware, these components introduced relatively large amounts of intermodulation noise at the 105-kHz and 185-kHz notch frequencies. When the recorder/reproducer was included in the system the most significant difference was degradation of NPRF due to the noise generated in the reproducer electronics. Although a test system with better NPR characteristics would be desirable, it was concluded that little, if any, improvement could be realized in the playback data quality because of the high noise level imposed by the recorder/reproducer.

Notch noise tape A contained a series of nine test data conditions, one for each of three record bias settings at each of the three notch frequencies with the recorder input level set for 1% third harmonic distortion. Variations in the bias settings were +3 dB and +1 dB (overbias) and -1 dB (underbias). The notch frequencies were 14, 105 and 185 kHz.

Notch noise tape B contained a similar series of nine test data conditions, one for each of three third harmonic distortion settings in the recorder at each of three notch frequencies, with the recording bias fixed at +1 dB. The third harmonic distortion levels were 1%, 2% and 3%; and the notch frequencies were the same as those listed for tape A.

PCK Recording System. The equipment configuration chosen for recording the PCM test tape is shown in Figure 3.

The Pre-D center frequency of 450 kHz and tape speed of 60 inches per second were used to maintain correlation with the notch noise test tapes. Test signals were recorded at two bit rates, 100 and 400 kilobits per second. The selected bit pattern was the 2047-PN (pseudo-noise) bit sequence available in commercial test equipment. The transmission link characteristics were: (a) Premodulation filter 0.8 x bit rate, (b) RF frequency, S-band, 2250 MHz, (c) RF peak deviation, 0.35 x bit rate, and (d) Receiver IF bandwidth, 100 and 500 kHz, respectively.

The PCM test signals of 100 KBR (kilobits per second) were recorded on the first half of the tape, followed by an identical sequence of test signals recorded at a 400 KBR. The variables in the test signals were: (a) RF input power (-dBm) to the RF receiver, (b) record bias settings in the tape recorder, and (c) third harmonic distortion levels in the recorder.

The test data were recorded on tracks three and five of the master tape. A series of 15 test conditions were recorded at each PCM bit rate, one for each of five selected RF levels, at each of three recording bias settings and with the third harmonic distortion in the recorder fixed at 1%. In addition, nine test conditions were provided for third harmonic distortion data, one for each of three third harmonic distortion levels (1%, 2% and 3%), at each of three record bias settings and at a given input RF power level. The RF input power level and corresponding BEP (bit error probability) obtained from the first PCM master tape playback are shown in Figures 4(a) and (b), for the 100 and 400 KBR, respectively.

Tape Signatures. Each of the test tapes contained recordings of wideband noise and/or sweep oscillator. These signals were of equivalent bandwidth and were for observing or adjusting the playback frequency response and head azimuth alignment of tape reproducers under test. In addition, a sine-wave signal of appropriate frequency was recorded on two separate tracks of each headstack for a playback lissajous pattern display of azimuth alignment.

Test Procedures. An example of the test procedures followed througout the course of the tape recorder/reproducer investigation is given as follows: The three master test tapes, along with the notch noise and PCM data readout equipment, were carried to the test site. The first step was an evaluation of a tape reproducer at the site for playing back the master tape signals. Tape machine adjustments or repairs were usually required to obtain playback data quality comparable to the original set of data values obtained in the laboratory playback of the master tapes, at the time they were recorded. Assuming that a suitable tape reproducer became available at the site, the next step was to record copies of the master tapes on a second machine. A complete set of data measurements were taken at the output of the reproducer, which in turn, was the input signal to the dub recorder. Later the dub recording was reproduced on the master playback machine and another set of data was taken. The effects of recording and reproducing could then be measured in terms of the difference between input and output data measurements. On occasion, the dubbed tape was also reproduced on other machines at the site to obtain additional samples of crossplay data. The final step was a playback of the dub on tape repoducers in the laboratory, which included the same machine on which the original masters were recorded.

Quantity of Test Data. A brief summary of the data measurements taken, types of tape machines involved, and quantity of data obtained at the various test sites is presented as follows: Notch noise playback tests, 52; PCM playback tests, 30; Dubs of master tapes recorded during the tests, 23; Independent data measurements taken, 2,376; Tape machines involved, 13; Types of tape machines, 8; Test sites, 5.

Presentation of the Test Data. The original data were tabulated on prepared forms at the test sites while the tests were in progress. At the conclusion of the testing phase all data were transferred to plots for a preliminary analysis. These plots are not included in the report because of space limitations; however, a summary of all data taken throughout the study is presented in Tables 1, 2 and 3. The tables contain data values for the back-to-back system, the first playback of the master test tapes, the sample mean[4], the sample standard deviation[5], and the sample range[6] of all test data points. In the notch noise tables 1 and 2, the mean was calculated in the following manner: The measured dB values were converted to power in watts and averaged; the result is shown in dB. The sample mean is the average of all data points for a given test condition. The sample standard deviation indicates the spread of the data measurements about the mean. The sample range shows the maximum excursion of the sample measurements for a given test condition.

Analysis of Record Bias Test Data. Figure 5(a) is a summary of the notch noise record bias data obtained from Table 1. The reference and mean columns of data are plotted for the three bias levels, with the third harmonic distortion fixed at 1%. The trends, due to changes in record bias are indicated by the slope of the connecting lines between plotted points, and the magnitude is measured by the vertical difference between points of the traces on the NPR/NPRF (dB) scale.

The vertical displacement between corresponding "REF" and "Mean" traces indicates the difference between the first master playback and the mean of the test playbacks. This displacement has no direct relationship to the effects of record bias variations but will be considered later in a discussion of the overall data quality.

Higher data quality is indicated by increasing values of NPR/NPRF (dB). Solid and dashed lines indicate NPR and NPRF data, respectively.

The NPRF appeared to improve at all notch frequencies as the bias was increased. The slope of the connecting lines was minimum between +1 dB and +3 dB bias settings in five of six NPRF traces. The -1 dB bias was clearly the worst case in all of the NPR and NPRF plots. Over the range of +1 dB to +3 dB bias, the maximum variation in NPR/NPRF was 1 dB, which was within the limits of measurement. accuracy.

The plotted PCM data in Figure 5(b) may be analyzed in the same manner as that described in the foregoing plots of notch noise record bias data. The PCM plots show variations of record bias with respect to equivalent RF input power. Equivalent RF input power is that RF signal level required to overcome BEP losses in test data, when compared back to the reference. The equivalent RF input power was derived from an expanded calibration curve of the first playback data similar to that of the curves in Figure 4.

4. $$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

5. $$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}}$$

6. $$sr = x_{max} - x_{min}$$

Trends in the 100 KBR data of Figure 5(b) are similar in direction for both the first master-tape playback and the mean of the test data. A record bias of +1 dB appeared to be best at the 100 KBR; however, the effects of bias variations were negligible in terms of the difference in equivalent RF input power.

The effects of variations in record bias were greater in the 400 KBR plots of Figure 5(b). The +3 dB bias level appeared to be least desirable at the higher bit rate.

On the basis of the test results, data quality losses caused by variations in record bias over the range of +1 dB to +3 dB were within ±0.1 dB and ±0.5 dB in equivalent RF input power at the 100 and 400 kilobit rates respectively.

Analysis of Third Harmonic Distortion Data. The third harmonic distortion (or record input level) data are presented in Figure 6, and the same methods of analysis used in the foregoing record bias plots are applicable to the third harmonic distortion plots. The record bias was fixed at +1 dB in all of the third harmonic distortion tests.

It is noted that the NPRF in Figure 6(a) improved as the third harmonic distortion percentage was increased. The greatest improvement was 3 dB at the 185 kHz notch. Essentially, the increase in record input level required to obtain 3% third harmonic distortion was reflected as a floor noise improvement at the 185 kHz notch. Variations in NPR over the range of 1% to 3% third harmonic distortion were well within 1 dB, and are considered negligible. In the PCM data of Figure 6(b) the greatest difference in equivalent RF input power was 0.1 dB at the 400 KBR. The effects of variations in third harmonic distortion over the range of 1% to 3% were considered to be negligible in both the notch noise and the PCM test data.

Analysis of Overall Data Quality. In the foregoing analysis of record bias and record input level, the losses of data quality were shown to be small and relatively insignificant; however, the variations and losses in data quality from test-to-test were far greater. Some indication of this is shown by the vertical offset between the first master tape playback and the corresponding mean of the test playbacks in Figures5 and 6. A better indication of the magnitude of variations from test-to-test is shown in the Sample Standard Deviation and the Sample Range columns of Tables 1, 2 and 3. For example, in Table 1 the NPR data from 36 playback tests at the 105 kHz notch frequency, and at +1 dB record bias varied by an average of ±3.0 dB about the mean value in 68% of the samples, assuming a normal distribution. The largest excursion in this data was 12 dB as shown in the Sample Range column. This example is presented as typical of the large variations in NPR and NPRF from test to test. Test-to-test variations were least in the 100 KBR PCM data. It was evident that serious losses in data quality occurred in the notch noise and 400 KBR PCM tests which were unrelated to record bias and/or third harmonic distortion levels in the recorder.

Conclusions. Data quality losses caused by variations of third harmonic distortion in the recorder from 1% to 3% were negligible except for a slight improvement in NPRF (background noise level) as the third harmonic distortion percentage was increased. However, this improvement was not reflected in the notch noise NPR or PCM test data.

Average losses in notch noise data quality throughout the tests were significantly greater than could be attributed to variations in record bias or record input level; whereas, losses in PCM data quality were less under the same operating conditions.

The data values presented in the report regarding overall data quality are believed to be over-optimistic with respect to the actual performance of tape machines in the field because trial runs of the master test tapes were made before each set of data was taken. Maintenance work on the recording and reproducing equipment usually had to be performed before the tests were resumed and the final data were tabulated. In accordance with the original concept of the study, the reproducer equalization was usually not “tuned” to the master test tape signals but rather to the characteristics of the record section of the same machine. Therefore, some of the crossplay data contained herein were taken with frequency response variations which were outside of the IRIG standard limits of ±3 dB. This condition was clearly evident by monitoring the test tape signature patterns during the tests; therefore, it may be assumed that improved data quality would have resulted in some instances, if the reproducer equalization had been adjusted for the best response of the master tape signatures.

The identification of data losses with variations in record head gap or other record parameters was beyond the scope of this investigation. Such effects may have been responsible for some degradation in crossplay frequency response observed from machine to machine.

It was observed that losses in master test tape data quality throughout the course of the investigation were negligible and that the results and conclusions of the study were not significantly compromised by deterioration of the master test tape signals.

In every instance where tests were scheduled in the field, maintenance problems arose in the recording or reproducing equipment which either prevented the taking of data, or the test had to be postponed until maintenance work was accomplished. Furthermore, most of the tape machines which were found unsuitable for recording or reproducing the master test tape signals were being used routinely in data processing operations or in the dubbing of flight-test tapes, with no apparent check of data quality.

Problems encountered in the field during the tests, in approximately the order of the frequency of occurrence, are listed as follows: (1) Playback head azimuth misalignment, (2) Playback equalization misadjustment, (3) Inter-rack cabling, loss of high frequency response between playback and dubbing machines, (4) Improper or unknown trunk line loads, (5) Tape transport malfunctions, (6) Critical, unstable, or insufficient range of alignment adjustments, (7) Exchange of heads without checking equalization (8) Station electrical grounding problems, (9) Excessive periods of elapsed time between maintenance, (10) Worn record/reproduce heads, (11) Intermittent contacts in monitor phone jacks on tape machines, (12) Defective test equipment used in maintenance.

Problems with equipment in the field were always discovered during trial runs of the master test tapes. Alignment and maintenance deficiencies were first indicated by the playback of prerecorded signature signals on the master tapes and later confirmed by actual data values obtained in the trial runs. A question was raised as to why serious deficiencies in recorder/reproducer crossplay performance were apparently not recognized by the user groups and yet were obvious within a few minutes of a trial run of the master test tape. The answer is believed to be twofold: (a) the master test tapes contained tape signature signals by which the playback frequency response of the original recording was visible; (b) personnel using the master tapes and conducting the tests were concerned specifically with the quality of the output data.

Rather than a lack of zeal in the performance of maintenance, perhaps the problem lies with the lack of “tools”. Specifically, a standardized tape signature on all prime data tapes and the training of personnel involved in recording, reproducing, and dubbing operations in the need, value and use of tape signatures. A typical display of azimuth misalignment is shown in Figure 7. As a minimum, tape signatures on prime data recordings would alert station personnel to the need for repair, adjustment, or maintenance during all phases of tape use including original recording, playback and dubbing operations.

The potential user of tape signatures may be unnecessarily discouraged by difficult and time-consuming signature recording procedures. The difficulty of assembling test equipment, changing patch connections, measuring frequencies, and voltages should be eliminated from the procedure. The types of standardized signatures should be limited to one to simplify and minimize the equipment and training requirements.

Automation should also be considered in the implementation of tape signature recording and playback schemes. The inputs to all tracks of an existing recorder could, for example, be switched to record the signature signals by the addition of a “black box” located at the input terminals of the recorder. By means of a push button, the operator could start the automatic tape transport control and return to the normal recording inputs. A single sweep generator could serve all recorders at a given location, if appropriate isolation driver amplifiers are provided at the signal generator and at each recorder location. The operating procedure should provide for a single fixed signature pattern generator with no adjustments required to accommodate all types of wide-band recorders and all tape speeds from 7.5 to 120 IPS. A sweep frequency signature is shown at several tape speeds in Figure 8.

The playback of the tape signatures may be automated in existing equipment by means of a track output selector switch permanently wired to a dedicated display scope adjacent to the tape machine.

The possibility of obtaining new recording and reproducing equipment with built-in signature generating and display devices should also be explored, if a standard tape signature format is defined and published in RCC Standards.

Based on experiences with tape signatures throughout the recorder/ reproducer study and a later experimental investigation, it was concluded that a single signature recording of either a sweep frequency oscillator signal or, as an option, a multifrequency oscillator signal would provide the necessary playback information for both reproduce head azimuth and frequency response equalization measurements or adjustments. Appropriate frequency markers or fixed frequency segments in the multifrequency oscillator may be chosen to permit use of the signature at tape speeds of 7.5, 15, 30, 60 and 120 IPS without adjustments of the signature generator controls. A scheme for automating the functions of recording and reproducing tape signatures in existing equipment is suggested in Figure 9.

Acknowledgement. The authors wish to thank Mr. T. B. Jackson, Head of the Data Systems Division, for his contribution to this work.

Table 1. Notch Noise Composite Bias Test Data (1% Third Harmonic Distortion)

Notch Frequency (kHz)	Record Bias (dB)	Back-to-Back System (B-B)		Reference First Playback (REF)		36 Test Playbacks					
						Mean		Sample Standard Deviation		Sample Range	
		NPR(dB)	NPRF(dB)	NPR(dB)	NPRF(dB)	NPR(dB)	NPRF(dB)	NPR(dB)	NPRF(dB)	NPR(dB)	NPRF(dB)
14	+3	48	51	45	48	42.32	46.39	3.28	2.38	12	11
	+1	48	51	45	47	42.88	45.50	3.52	2.50	11	8
	-1	48	51	44	45	41.24	44.21	3.10	1.97	10	9
105	+3	34	50	30	38	29.16	36.76	2.85	2.03	12	10
	+1	34	50	31	37	29.04	35.86	3.00	3.16	12	9
	-1	34	50	29	33	26.64	32.43	2.68	3.22	11	8
185	+3	26	47	23	32	22.71	30.58	2.40	2.11	17	8
	+1	26	47	24	31	22.80	30.10	2.40	2.46	11	11
	-1	26	47	22	27	22.09	25.98	2.19	2.70	8	12

Table 2. Notch Noise Composite Third Harmonic Test Data (+1dB Record Bias)

Notch Frequency (kHz)	Third Harmonic Distortion (%)	Back-to-Back System (B-B)		Reference First Playback (REF)		16 Test Playbacks					
						Mean		Sample Standard Deviation		Sample Range	
		NPR(dB)	NPRF(dB)	NPR(dB)	NPRF(dB)	NPR(dB)	NPRF(dB)	NPR(dB)	NPRF(dB)	NPR(dB)	NPRF(dB)
14	1	45	47	44	46	41.18	44.17	2.40	1.23	8	4
	2	45	47	44	46	41.08	44.31	2.30	1.27	7	4
	3	45	47	44	46	41.05	44.36	2.32	1.24	7	4
105	1	33	51	32	40	28.43	37.70	2.87	3.34	10	11
	2	33	51	31	42	28.76	39.14	3.11	3.41	11	13
	3	33	51	31	42	28.83	39.77	2.90	3.61	11	12
185	1	25	48	24	34	22.14	31.30	2.48	3.49	10	12
	2	25	48	24	36	22.60	33.59	2.49	3.52	10	14
	3	25	48	24	37	22.30	34.51	2.45	3.81	10	15

Table 3. Pulse Code Modulation Composite Test Data.

Bit Rate (KBR)	Record Bias (dB)	Third Harmonic Distortion (%)	Reference RF Power Level (-dBm)	Back-to-Back System (B-B)	Reference First Playback (REF)		30 Test Playbacks			
				BEP	BEP	RF*Level (-dBm)	Mean BEP	Standard Deviation (BEP)	Sample Range (BEP)	RF*Level (-dBm)
100	+3	1	107	9.63×10^{-3}	9.58×10^{-3}	107.01	9.87×10^{-3}	1.8×10^{-4}	6×10^{-4}	107.02
		2		9.63×10^{-3}	9.83×10^{-3}	107.05	1.05×10^{-2}	4.6×10^{-4}	1×10^{-3}	107.10
		3		9.63×10^{-3}	9.38×10^{-3}	106.95	1.01×10^{-2}	3.2×10^{-4}	8×10^{-4}	107.05
	+1	1	107	9.63×10^{-3}	8.82×10^{-3}	106.90	9.42×10^{-3}	4.1×10^{-4}	1.2×10^{-3}	106.96
		2		9.63×10^{-3}	9.38×10^{-3}	106.97	9.51×10^{-3}	3.0×10^{-4}	1.1×10^{-3}	106.98
		3		9.63×10^{-3}	8.89×10^{-3}	106.90	9.39×10^{-3}	2.9×10^{-4}	1.2×10^{-3}	106.96
	-1	1	107	9.63×10^{-3}	1.00×10^{-2}	107.07	1.03×10^{-2}	6.0×10^{-4}	1.3×10^{-3}	107.08
		2		9.63×10^{-3}	1.06×10^{-2}	107.12	1.10×10^{-2}	2.5×10^{-4}	1.3×10^{-4}	107.18
		3		9.63×10^{-3}	1.08×10^{-2}	107.15	1.11×10^{-2}	6.8×10^{-4}	2.5×10^{-4}	107.19
400	+3	1	99	1.69×10^{-3}	2.5×10^{-3}	99.38	4.5×10^{-3}	3.45×10^{-3}	1.8×10^{-2}	99.98
		2		1.69×10^{-3}	3.25×10^{-3}	99.65	7.9×10^{-3}	7.61×10^{-3}	2.8×10^{-2}	100.63
		3		1.69×10^{-3}	2.75×10^{-3}	99.47	6.15×10^{-3}	5.46×10^{-3}	2.8×10^{-2}	100.31
	+1	1	99	1.69×10^{-3}	1.94×10^{-3}	99.15	2.65×10^{-3}	1.36×10^{-3}	3.7×10^{-3}	99.44
		2		1.69×10^{-3}	2.16×10^{-3}	99.25	2.9×10^{-3}	8.6×10^{-4}	4.0×10^{-3}	99.53
		3		1.69×10^{-3}	2.04×10^{-3}	99.19	2.87×10^{-3}	1.22×10^{-3}	6.6×10^{-3}	99.52
	-1	1	99	1.69×10^{-3}	2.14×10^{-3}	99.25	2.58×10^{-3}	7.6×10^{-4}	4.4×10^{-3}	99.41
		2		1.69×10^{-3}	2.13×10^{-3}	99.25	2.83×10^{-3}	1.01×10^{-3}	5.7×10^{-3}	99.51
		3		1.69×10^{-3}	2.06×10^{-3}	99.2	2.79×10^{-3}	1.03×10^{-3}	6.0×10^{-3}	99.49

*Referred to back-to-back system, BEP versus RF (-dBm)

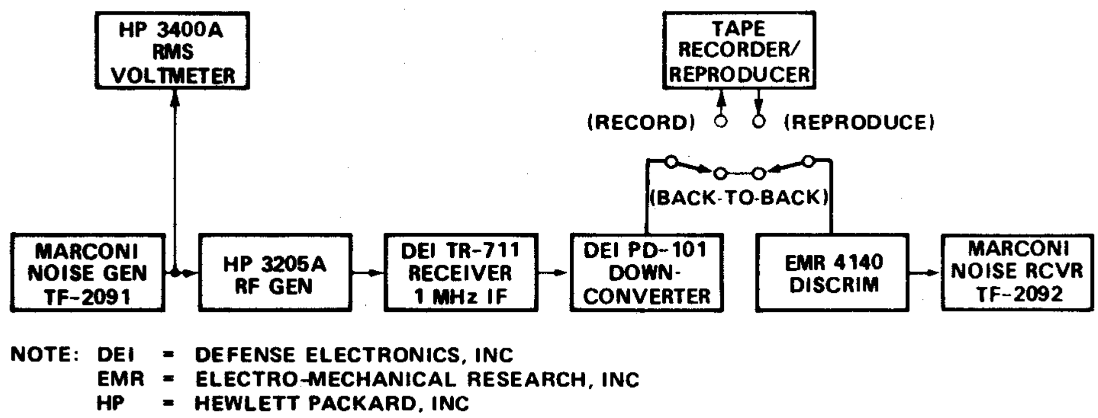


Figure 1. Notch Noise Recording System.

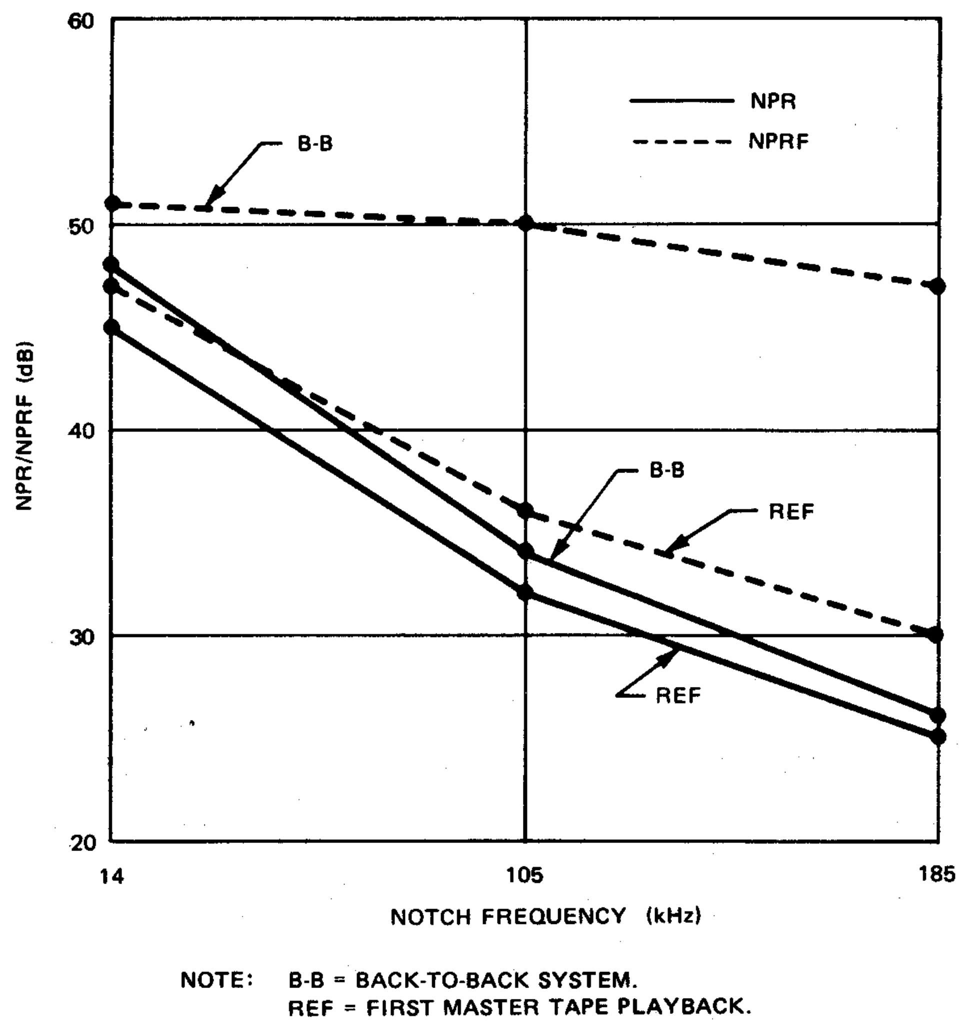


Figure 2. Notch Noise Back-to-Back Versus First Master Tape Playback.

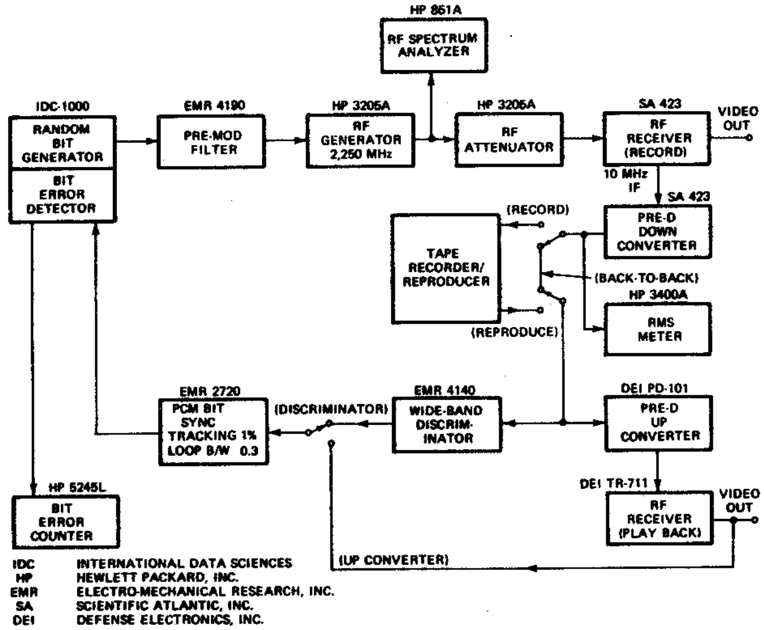
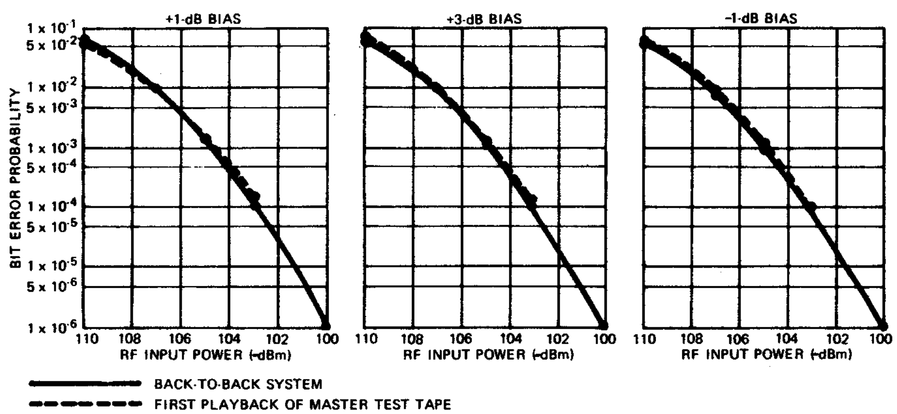
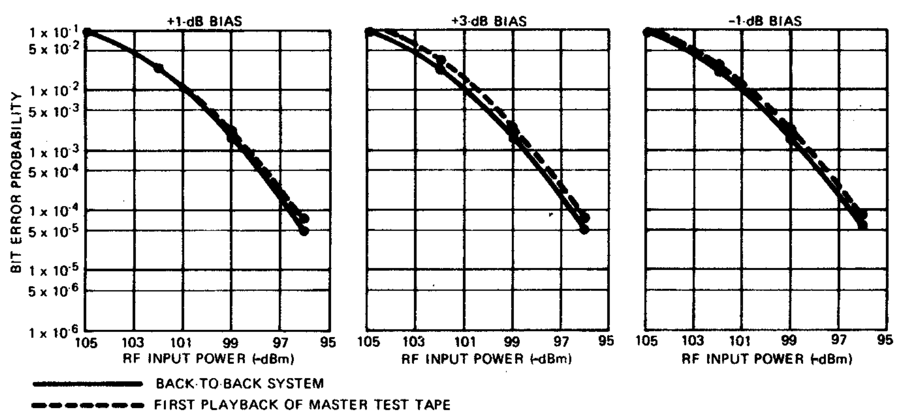


Figure 3. PCM Recording System.



(a) 100 KBR



(b) 400 KBR

Figure 4. PCM Back-to-Back Versus First Master Tape Playback.

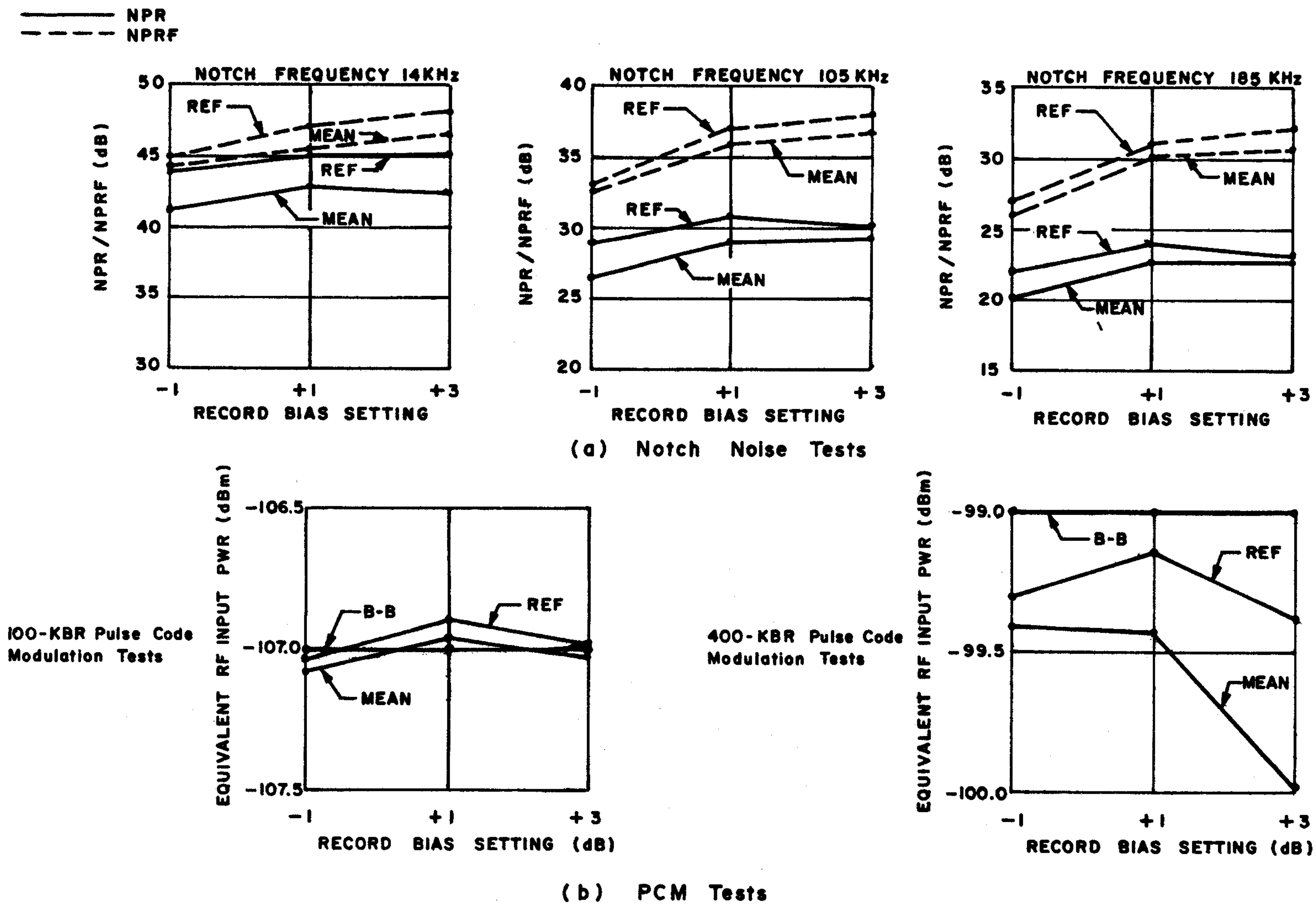
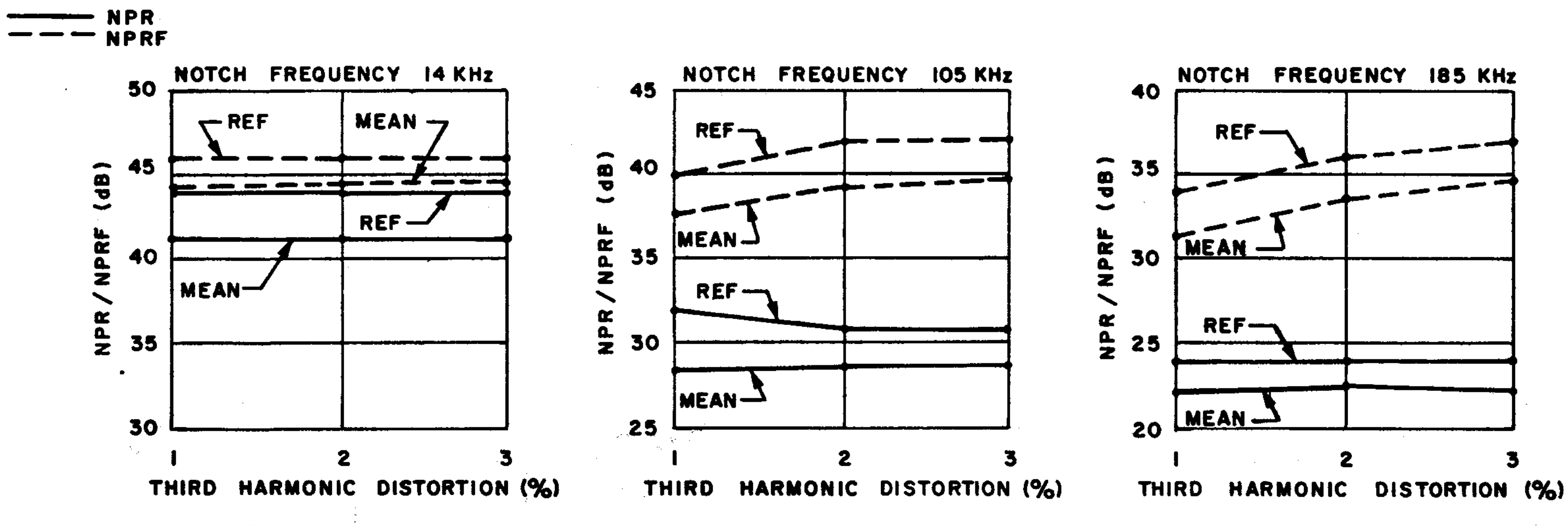
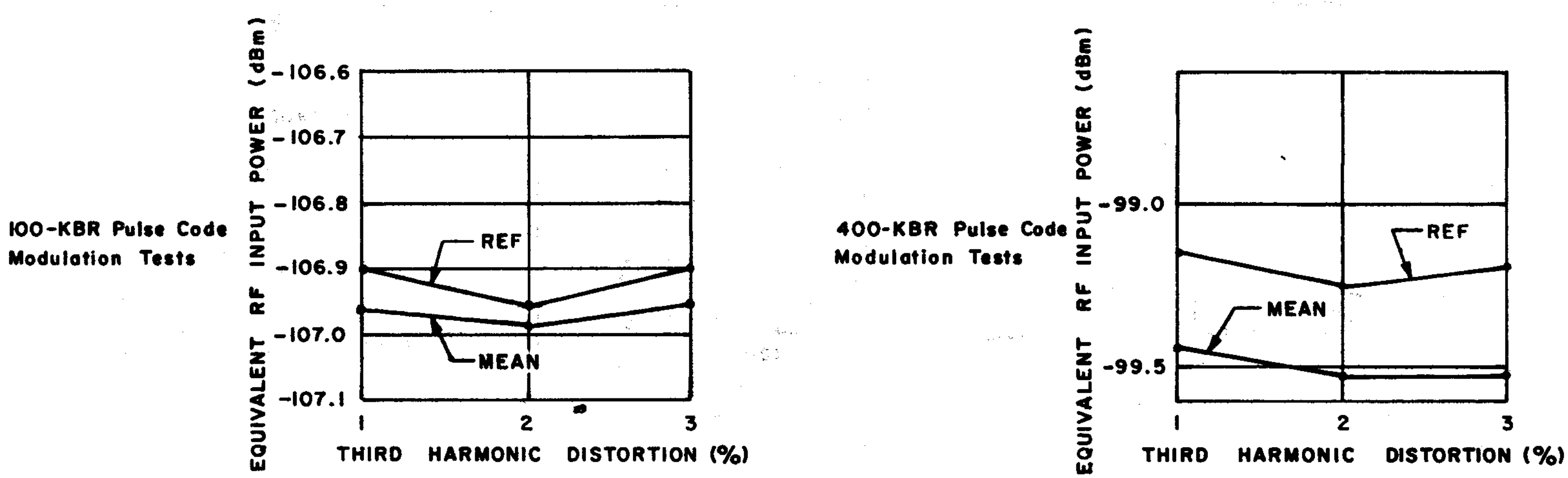


Figure 5. Summary of Record Bias Data (1% Third Harmonic Distortion).

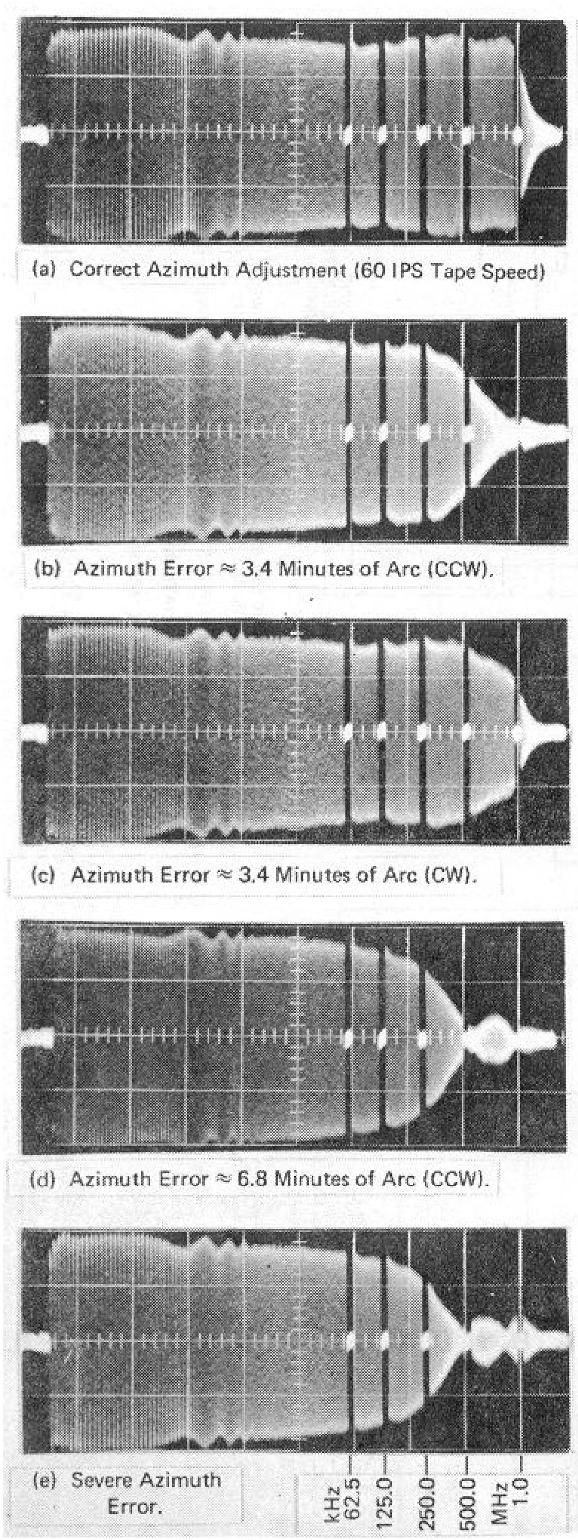


(a) Notch Noise Tests



(b) PCM Tests

Figure 6. Summary of Third Harmonic Distortion Data (+1 dB - Record Bias Level).



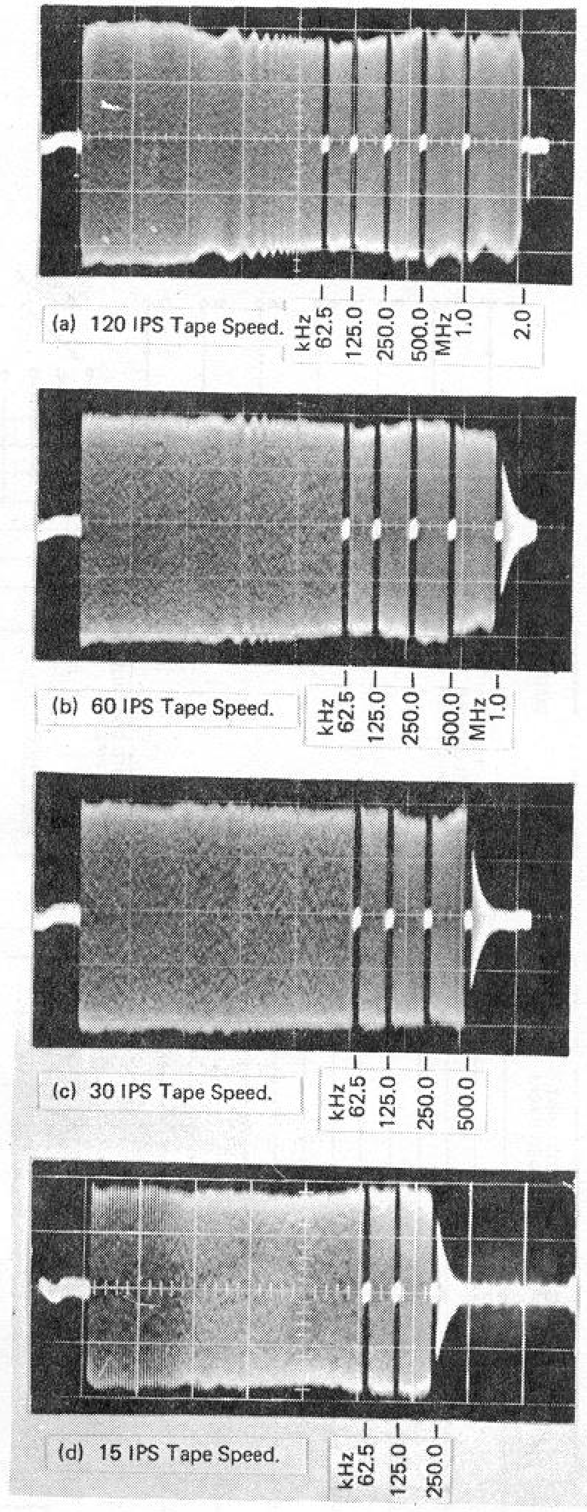


Figure 7. Sweep Frequency Display of Azimuth Misalignment

Figure 8. Appearance of the Proposed Sweep Frequency Signature at Several Tape Speeds.

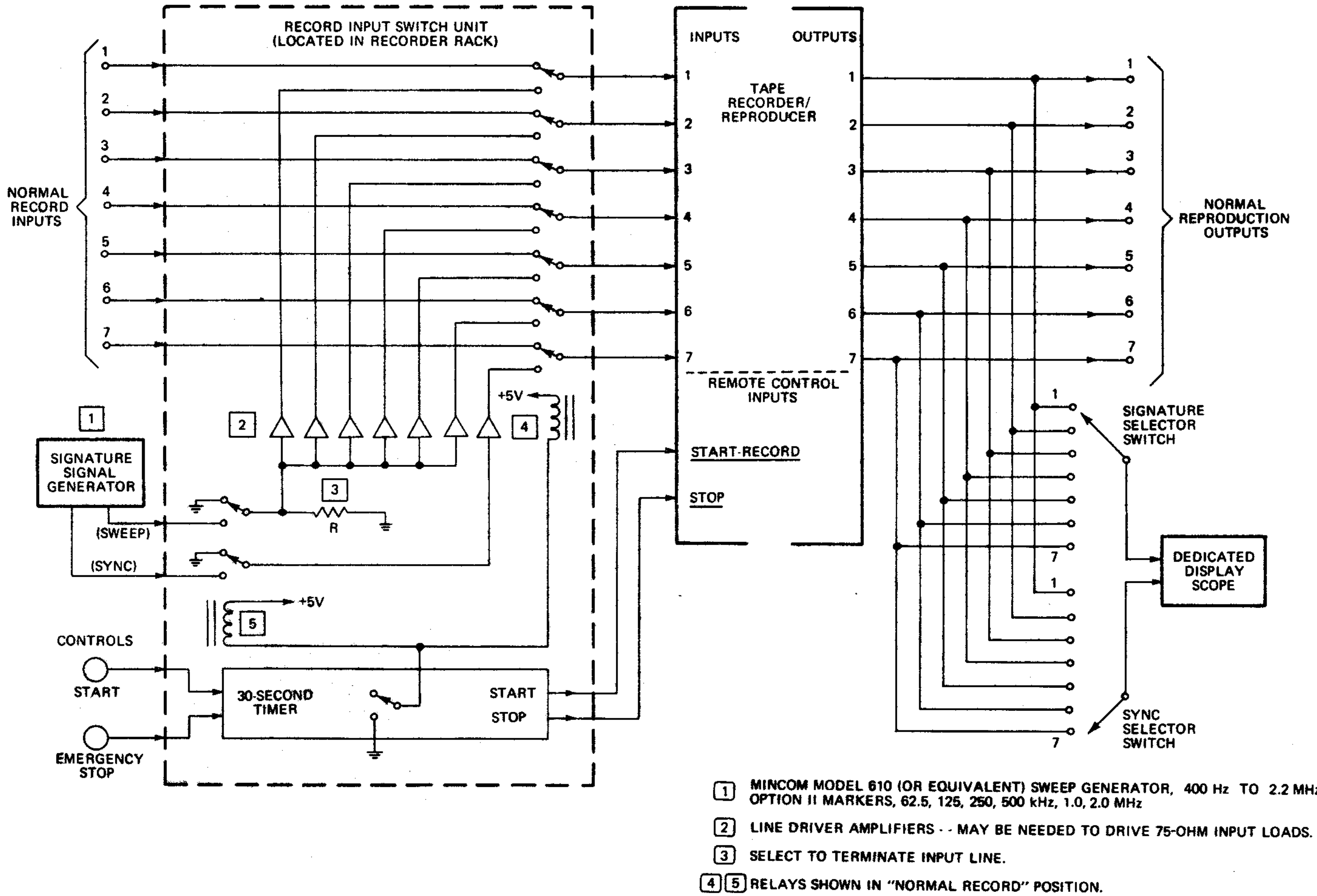


Figure 9. Proposed Arrangement for Recording and Reproducing Tape Signatures.