SUBJECTIVE EVALUATION OF DELTA CODECS IN QUALITY MUSIC AND SOUND BROADCAST DISTRIBUTION

PHASE II

FINAL REPORT

MARCH 31, 1981

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DSS CONTRACT #OST 80-00018

Acknowledgement

The authors gratefully acknowledge the facilities provided by CJUS-FM. The precision obtained in the results would not have been possible without the high quality sound studio and high fidelity equipment which were available. The authors thank the following individuals whose contributions were most valuable to this project. Al Pippin of CJUS-FM, Don Wohlberg of SED Systems, Ed Wojczynski of Electrical Engineering Graduate School and all of the participants in both the initial and final subjective evaluation.

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1. Introduction

Various digital encoding/decoding techniques for transmission of high quality program material have been under consideration for such applications as direct to home satellite transmission as well as terrestial recording and broadcasting. Digital transmission techniques include pulse code modulation (PCM) or adaptive delta modulation (ADM), also referred to as delta coding. A major advantage of digital transmission is that intermodulation in the transmission medium will not degrade the encoded signal. Although PCM is superior for exceptionally high quality reproduction, delta coding has the advantage for moderate quality transmission because it requires a lower bit rate than PCM.

Criteria normally used in specifying the performance of analog transmission or reproduction systems include frequency response, signal to idle background noise ratio (SNR_{Idle}) and harmonic distortion. These parameters do not inherently ascribe program quality or listener acceptance levels, instead they are simply measureable system parameters which are used to infer quality levels based on judgement and past experience. Unfortunately, these implied quality assessments are not directly transferable to the performance parameters of adaptive, frequency dependent systems. Measurable parameters for digital systems include max. sinusoid to Idle noise ratio (SNR_{Idle}), average signal to dynamic average noise ratio (SNR_{Dyn}), gain/frequency response and harmonic distortion. Variations of these parameters with signal amplitude and frequency do not permit objective comparisons between digital and standard analog transmission systems. It is therefore necessary to establish subjective quality assessments for digitally modulated systems related to the operating or performance parameters of these systems. Furthermore, it would be highly desirable to establish a quality equivalence between digital and analog transmission systems based on subjective quality assessments, with each system specified in terms of its own operating and performance parameters.

The objective of the activities conducted under the terms of DSS Contract No. OST 80-00018 as are reported herein are an attempt to persue the above broadly stated goals. In particular, the purpose of the work was to subjectively evaluate adaptive delta modulation (ADM) as a coding technique for the digital transmission of high quality music. Subjective tests and evaluations were conducted in order to:

(a) establish a quality equivalence of ADM quantizing bit rate with the signal to noise ratio of analog systems
(b) recommend a "satisfactory" ADM bit rate for quality reproduction.

This report describes the tests conducted and documents the results obtained. Recommendations and conclusions are offered based on those results. This project is a sequel to activities previously conducted under DSS Contract No. OSU 79-00288.

2. Testing Methods

There appears to be no generally accepted methodology to subjectively evaluate the quality of music reproduction. In the absence of such a standard, the IEEE Recommended Practice for Speech Quality Measurements [reference 1] was consulted. This work identifies three types of preference measurements as possible alternatives, namely the isopreference method, the relative preference method and category-judgement method. Consistent with the limitations discussed by the authors of that work, a modified isopreference test was used in the development of a final test procedure and a modified category-judgement test was used in the final test procedure. Both are outlined briefly below. These modified tests are not unlike those conducted by D. Klench and E. Rogers [reference 9].

Because the quality of normal analog reproduction is generally known as a function of signal to noise ratio, an early decision was taken to use this experientially based knowledge as part of the basis to establish the quality of delta coding. Therefore, tests were devised to assess the quality of delta coding at various bit rates in comparison with analog systems having various signal to noise ratios. This was accomplished in two ways. One is using A/B comparison or preference tests between various delta coded bit rates and different values of SNR. The second is the use of subjective category rating test of both delta coded signals and normal analog reproduction at various quality levels for each. Both of these tests are described in detail in section 4. During the development phase, limited use was made of a modified isopreference method in order to establish the range of SNR for a given bit rate in setting up the A/B comparison test identified above. In this test, a limited number of subjects listened to a fixed bit rate delta coded channel and blind-adjusted the noise added to an analog channel to obtain a perceived equivalent quality for the two channels. This was repeated for various bit rates. The results of this method were acceptable, but a major limitation of the method was the considerable time required by each listener to establish an equivalent additive noise level for each bit rate. Although the method was deemed to be too time consuming for large numbers of listeners, the results of few subjects were used to establish the approximate value and range of SNR to be used at each bit rate in the final A/B comparison test. The results of this modified isopreference test are given in section 3.6.

Several approaches are used to establish an acceptable or satisfactory delta coding bit rate for quality reproduction. One is a deduced satisfactory level based on the results of the preceding delta coding/SNR equivalence test. A second is an A/B comparison test of various bit rate reproductions compared with the original source material, the concept being that the reproduction is satisfactory when a majority of people cannot identify the original. The third method requires subjective ratings of various bit rate reproductions to approach ratings of the original source. All methods are presented in detail in section 4 of this report.

Subjective evaluation of high quality transmission requires skilled listeners who are able to identify minor imperfections. Skilled listeners were solicited through poster advertisements in high fidelity shops and newspaper advertisements under the "Hi-Fi" column. A copy of the type of advertisement used is included in Appendix C. Additional listeners were obtained by contacting ratio station personnel, university music students and high fidelity sales or repair people. It was anticipated that the most skilled listeners could be identified by means of their background (ie: their owning and listening to high fidelity music systems, and other musical involvement), and their hearing acuity. With respect to the latter, subjects for the final tests took a standard audiometer-based hearing test, with the range of the audiometer extended to 20 KHZ. Selection of subjects into skilled and unskilled categories is discussed in section 6 of this report, and some use of this screening is made in presenting results.

3. Selection of Test Equipment and Procedures

3.1 Delta Coding Circuits

Preliminary calculations of the required coding rate for adequate music transmission yielded values in excess of 200 KBPS. During the study period, the fastest available delta codec was the Motorola MC3417/18 CVSD chip which was rated up to 200 KBPS. The newly developed EVSD digital codec was available but existing prototypes would not operate at the required bit rate. An analog EVSD coding scheme [reference 10] was constructed but failed to maintain consistent gain due to component mismatching. As a result, the CVSD codec was used despite it's higher idle noise and slower adaption. It has been shown in reference 10 that CVSD performance approaches that of EVSD when the signal level is high.

A two channel encoder/decoder circuit was built to allow stereo signal coding. Operation up to 400 KBPS was achieved by using maximum supply voltage and by carefully selecting the encoder circuits. Most circuits were satisfactory as decoders.

3.2 Speakers vs Headphones

Although good quality stereo headphones permitted distraction free evaluation, initial tests with 6 subjects revealed higher sensitivity to noise and distortion when the music was reproduced by loudspeakers. This result was also found by Petri-Larmi [reference 1] in his evaluation of Transient Intermodulation Distortion. Consequently, loudspeakers and a high quality sound studio were used in the final testing.

3.3 Source Material

Initial testing revealed that good quality, new records together with good quality turntable and cartridge were required. In some regular quality new records the groove hiss between selections exceeded the delta codec idle noise. This hiss was much larger in records which had been played many times.

Initial preliminary tests were done "live" and it was quite difficult to "run the show" at a reasonable pace. A high level of concentration was required and some errors in recording bit rate or musical selection were made. To avoid these problems and to eliminate progressive wear on the records, it was decided to tape record the entire test sequence once it had been established.

3.4 Tape Recordings

Several tape recorders were evaluated and a good quality consumer cassette deck was selected for the project. The Toshiba PC-X20 recorder when operated with normal, chromium and metal cassette tapes and had a frequency range of 20 Hz to 18 KHz. The advertised specification of 72 dB SNR with Dolby and metal tape was somewhat misleading; the tape hiss was more audible than the idle noise of the codec. Adequate recorder performance was achieved by using a studio quality B-77 Revox open reel tape deck running at 7 1/2 inches per second. A DBX model 157 compander unit was used with the tape recorder to obtain an effective peak signal to idle noise SNR exceeding 80 dB.

3.5 Measurement of Signal to Noise Ratio

In this study, three different measurements of Signal to Noise Ratio (SNR) are used. They are defined as follows:

SNR_{Idle} - Maximum signal to idle noise ratio. The average power of the largest possible unclipped 1 KHz sinewave is measured with an RMS responding meter. The average power of the idle noise is measured with the same meter when the sinewave source is disconnected and replaced with a termination resistor.

SNR_{Vu} - Program signal level to idle noise ratio. As above except the program signal is measured with a Vu meter. The Vu level is greater than the average program signal level (5-10dB) but less than the level of a sinewave with peak amplitude equal to the program signal peak.

To avoid occasional peak clipping, audio equipment is operated with the program Vu level 10 to 20 dB lower than the maximum sinewave level.

SNR_{Dyn} - Average signal to dynamic noise ratio. This is a "loaded" measurement where the system noise is measured with the test signal present. This measurement is useful in adaptive or companded systems where the noise level increases as the signal level increases. The loaded system noise is normally measured by using a notch filter to remove the received sinusoidal test signal. Both the received test signal and the dynamic noise are measured with RMS responding meters.

3.6 Subjective Equivalent Noise

Preliminary subjective evaluation of additive white gaussian noise and delta coding yielded an approximate equivalence relationship (see Appendix B). The average of 5 assessments yielded the following values:

ADM Bit Rate	Approximate Equivalent SNR_{Vu}
100 KB	42 ± 2 dB
200 KB	51 ± 2 dB
400 KB	60* dB

*No evaluations were actually made at 400 dB due to high room noise and the difficulty in using headphones. Instead, the following equation for delta coding was used to predict a 9 dB increase in SNR as the bit rate is doubled.

$$SNR_{Dyn} = K_1 \left(\frac{f_s}{f_m}\right)^2 \cdot \left(\frac{f_s}{f_{BW}}\right)$$

where f_s = bit rate

f_{BW} = output filter bandwidth

f_m = sinewave modulation frequency

4. Final Subjective Evaluations

4.1 Equipment Used

As a result of the initial testing, loudspeakers and a quiet room were required for the subjective listening tests. A partially completed sound studio was available during the month of August at the campus radio station CJUS-FM. The room approximated ideal dimensions with non-parallel walls. [reference 13] The floor and walls were covered with acoustically absorbent material which resulted in a low ambient noise level. Measurement with a B & K Type 2203 sound level meter indicated a background noise level of 25 dBA.

Two JBL 4311B studio monitor loudspeakers were placed in corners furthest from the listeners. Tape deck outputs were connected to the speakers through a YAMAHA P2050 power amplifier. Specifications for the power amplifier are available in Appendix A. The listening level was set between 85 and 90 dBA. This proved satisfactory for the first few listeners

4.2 Test Scheduling and Procedure

Subjective tests were held during the first three weeks in August. Two or three sessions were arranged in each day. One or two listeners participated in each session. To avoid possible overlap, at least two hours were allowed between the start of each test. Listeners were seated in the center of the room approximately 6 feet away from the loudspeakers. The nameplates of the speakers were covered to avoid possible bias on the part of the listeners. For similar reasons, all other equipment and the equipment operator were located behind the listeners. The two listeners were partially screened from each other to avoid the opinion of one influencing the other.

The listening test consisted of the following parts:

a)	Orientation	5 min.
b)	A/B comparison test	30 min.
c)	subjective rating test	30 min.
d)	Hearing evaluation	15 min.
e)	Discussion of results	15 min.

Subjects were given an opportunity to ask questions about the project during the orientation, during the short break between the tests and during the preparation of the summary sheet. A plot of hearing response was completed for each participant. Each subject received a $5 honorarium for his/her participation.

A copy of the blank score sheet is included in Appendix D1. Copies of summary score sheets for all participants are included in Appendix F. These summary sheets indicate the responses to all tests and the results of the audiometer test.

4.3 Choice of Music

The best audio source available to the experimenters was audiophile quality disk recordings. These recordings and standard quality recordings were purchased specifically for the test. Records were selected for high quality and low background noise. On the basis of initial testing, most records were deliberately chosen to be difficult for the delta codec to reproduce. Where convenient, music was chosen which would be familiar to the subjects. A table of musical selections is given below:

Artist/Author	Record Title	Song Title	Type of Music
1. Mahler	Mehta conducts Mahler	Symphony #4, G major first movement	CLASSICAL Symphony Orchestra
2. Eagles	Hotel California	Hotel California	POPULAR Guitar & Vocal
3. Billy Cobham	B.C.	A little travelin' music	JAZZ Horns & Drums
4. Liona Boyd	The English Chamber Orchestra	Jesu Joy of Man's Desiring (Bach)	CLASSICAL Guitar
5. Pink Floyd	Dark Side of the Moon	TIME	ROCK Percussion
6. Emmerson, Lake and Palmer	E.L.P.	The Three Fates	ROCK Organ

Mahler - This audiophile record was an imported pressing of a performance by the Israel Symphony Orchestra. Digital recording (PCM) was used for the master tape to give high signal to noise ratio (90 dB) and low distortion. The record, however, was produced in the usual manner. This record had much higher background hiss when compared with the Pink Floyd audiophile record.

Eagles - This is a well recorded popular album. The selection chosen had low dynamic range making it difficult to detect background or idle noise.

Cobham - The song selected has large components at high frequency. It includes trumpets, symbols, drums, violin, bass violin and piano. The level was consistently high with fast steady beat. A "Full energy spectrum" recording.

Pink Floyd - This is a half speed mastered audiophile recording. The test portion had high dynamic range and extremely low background noise making the quantizing noise easy to detect. The test passage had isolated notes of both low and high frequency.

Boyd - Columbia "Masterworks" recording. Single treble guitar notes (300 - 500 Hz fundamental), low frequency notes (100 - 200 Hz fundamental), violin and bass violin. Consistent amplitude.

Emerson - This used recording had high surface noise due to wear. The test passage was organ music which proved to be difficult to reproduce with the delta codec.

4.4 Description of A/B Tests

In this evaluation, two processing methods were compared during the course of a musical selection. The first 10 seconds of music was processed by method A the music was then faded out for 1-2 seconds and the following 10 seconds was processed by method B. This was followed by a 1-2 second fade out, 10 seconds more of process A, another fade then 10 seconds of process B. The format was thus:

fade A fade B fade A fade B fade

The operator stopped the recorder for 10-15 seconds after each comparison to allow the listener to mark his preferred choice and to announce the next test number. A total of 34 comparisons were evaluated.

Three different process comparisons were mixed randomly and the presentation order of A and B was randomized throughout the test. Certain musical selections were used more frequently because of a property such as large dynamic range (Pink Floyd 4). When several tests were done at a particular bit rate, a variety of selections were used. A description of the three types of A/B comparisons is presented in the following sections. Appendix E1 lists the order and contents for the A/B tests as recorded on tape.

4.4.1 ADM vs Additive Random Noise

Comparisons of ADM at 3 bit rates were made with various levels of added white gaussian noise. Based on initial testing described in Section 3.5, a few selected levels above and below the expected value of added noise were used in the comparison with delta coding. The comparison levels are indicated in the following table.

ADM	SNR_{Vu}
100 KB	39, 42, 42, 45
200 KB	48, 51, 51, 54
400 KB	57, 60, 60, 63

4.4.2 ADM versus Original

It was expected that the ADM coded music would become indistinguishable from the original music as the bit rate was increased. Initial testing suggested that this bit rate would lie between 200 KBPS and 400 KBPS therefore the majority of comparisons were made in this range. At 100 KBPS coding, the original was obvious. This was used as the first test to orient the listeners to the format of the tests. The following table illustrates the number of tests performed at the various bit rates.

ADM rate	Number of tests vs original
100	1
150	1
200	4
250	4
300	4
350	2
400	2

4.4.3 Comparison of Equal Quality

Mixed with all other tests there were 4 A/B comparisons where the same processing was used in both cases. This data was intended to check the validity of our techniques and to identify indiscriminant listeners. One test was recorded (both parts) at 200 KBPS, a second at 400 KBPS, a third using codec amplifiers only and a fourth with the original record player output.

4.5 Description of the Subjective Rating Test

This test consists of 28 segments of music each of 50 seconds duration. The segments were separated by a 10 second pause which allowed the listeners time to score their rating and for announcement of the test number. The random sequence of processing included delta coding at various bit rates, added noise at various levels and unprocessed original recordings. Through the courtesy of CJUS-FM we were able to include three segments on the tape from "off air" commercial FM broadcast. The SX780 receiver had clear view of the transmitting antenna at 300 meters distance. The 100% modulation (1 KHz) to background noise ratio for the radio station was 50 dB. A new transmitter with 62 dB SNR_{Idle} is slated for service in May 1981.

Appendix E2 lists the order and content of the subjective rating tests as recorded on tape.

4.6 Description of the Hearing Test

A Maico MA19 audiometer (calibrated to ANSI 1976 Std.) was borrowed from the Sask. Hearing Aid Plan office. This instrument is calibrated to measure hearing loss (from normal sensitivity) in the range 125 - 8,000 Hz. The range of the instrument was extended to 20 KHz by using an external test oscillator set with equal amplitude to the internal 8,000 Hz signal. A digital frequency meter was connected to the test oscillator.

During the test, the subject was faced away from the test equipment and was asked to raise a finger when he could hear the tone. The operator was able to vary the tone amplitude in steps of 2 1/2 dB and to turn the tone on and off with a pushbutton. An amplitude threshold was found at the various frequencies between 125 and 8,000 Hz. A sample scoresheet is included in Appendix D1. At frequencies above 8 KHz, the amplitude was changed in 10 dB steps and the frequency was continuously varied to determine the hearing range. This method proved very repeatable and more rapid than adjusting the amplitude of a fixed frequency. No attempt was made to calibrate the higher frequency amplitudes to "normal" hearing. For the group of listeners in this study, an average and a best hearing response have been tabulated for this uncalibrated region, (see Appendix F).

5. Test Results

5.1 Data Entry for Computer Analysis

To assist in the analysis of the subjectively determined data, a statistical analysis program was used. The Statistical Package for the Social Sciences is a well documented [reference 11] program which was available on both the DEC 2060 and the IBM 370 computers at the University of Saskatchewan. To allow computer analysis, test results were numerically coded 1, 2 and 3 for preferences A, Equal or B. Category ratings Bad, Poor, Fair, Good and Excellent were coded 1, 3, 5, 7 and 9. The matrix of data was stored in the following format.

```
             ┌Age
             │ Background        34 A/B                  28 subjective
             │   │ Sex          comparison                  ratings
             ⌒   │ │      ⌒‾‾‾‾‾‾‾‾‾‾‾^‾‾‾‾‾‾‾‾‾⌒    ⌒‾‾‾‾‾‾‾‾‾‾‾‾‾‾‾‾‾‾^‾‾‾‾⌒
Subject 1    AA  B S      1 2 3 1 2 3 1 2 3 1 2 3 ...   1 2 3 4 5 6 7 8 9 1 2 3 4 ...
   :          :                     :                              :
Subject nn   AA  B S      1 2 3 1 2 3 1 2 3 1 2 3 ...   1 2 3 4 5 6 7 8 9 1 2 3 4 ...
```

This format allowed calculation of mean, standard deviation, etc. for each question based on the 33 responses, but did not readily permit the evaluation of an individual subject's data using SPSS. This was necessary in order to classify the listeners as skilled or unskilled, so the data was re-entered as a transposed matrix with the columns and rows interchanged. This allowed for cross correlation of hearing ability, musical background, deviation from mean values, and deviation from expected trend. Appendix D2 provides the raw data input for both of the formats.

```
            question A          age          X ---------------------- Y
                     A          age          X ---------------------- Y
                     B       background      X ---------------------- Y
                     S          sex          X ---------------------- Y

                   ⎧ 1   100 KB - Original   1                        3
     34            ⎪ 2          :            2                        2
    A/B            ⎨ :          :            3 ---------------------- 1
 comparison        ⎪ :          :            1                        3
                   ⎩ 34         :            2                        2

                   ⎧ 1                       1                        9
                   ⎪ 2                       2                        8
     28            ⎨ 3                       3 ---------------------- 7
  ratings          ⎪ :                       9                        1
                   ⎪ :                       8                        2
                   ⎩ 28                      3                        3
```

5.2 Analysis of Subjective Category Ratings

Numerical rating data on a scale 1-9 was available for the 50 second music segments. A mean subjective rating was obtained for all 33 listeners for each of the 28 musical segments. A graph was prepared showing the relationship between ADM bit rate and subjective rating as illustrated on page 15. Additive noise SNR vs subjective rating is also shown on the same graph. The noise and delta coding scales were alligned using the equivalence determined from initial testing. Data points for additive noise (including zero added noise) are indicated by a circle. Data points for delta modulation are indicated by a triangle. Data points for commercial FM transmission are indicated by a square. These FM points have only category rating their vertical position is not determined.

In each data point of the graph, a number has been written to indicate the musical selection. It may be observed that selection 2 (Eagles) is more robust both to added noise and to delta coding. For section 3 (Cobham) there was more tolerance of noise than of delta coding. Selection 6 (Emerson) was rated poorly in all cases. Overall, the graph shows general correlation between ADM coding rate and added noise SNR as a function of subjective rating.

The data points follow an expected relationship between increasing noise and subjective evaluation. The ideal curve should approach both rating limits as illustrated below.

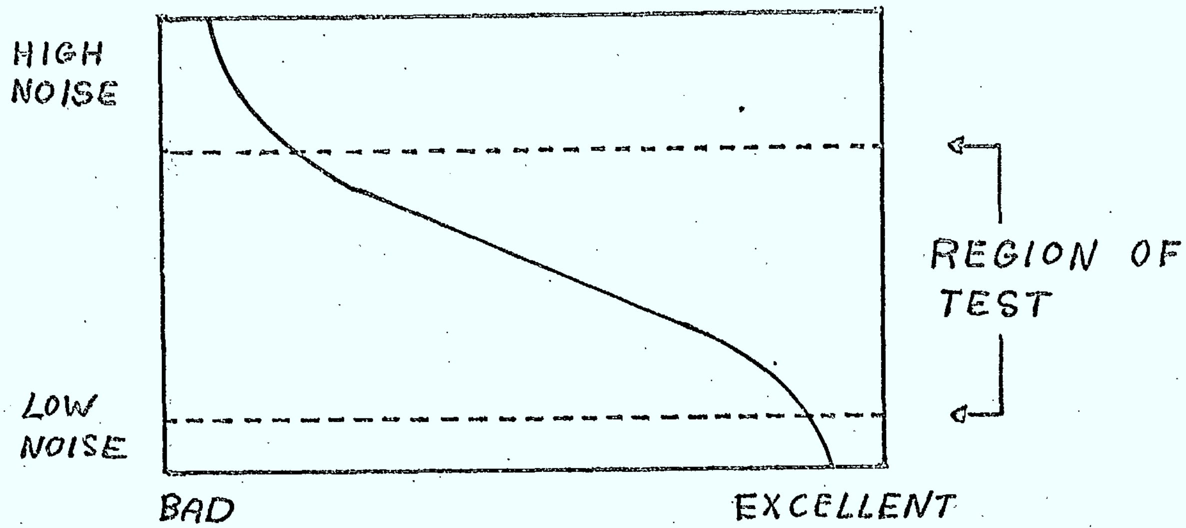


Figure 2. Expected relationship between rating and added noise.

In the test region, a reasonably linear relationship was found. This property was later exploited in the screening of listeners into skilled and unskilled groups.

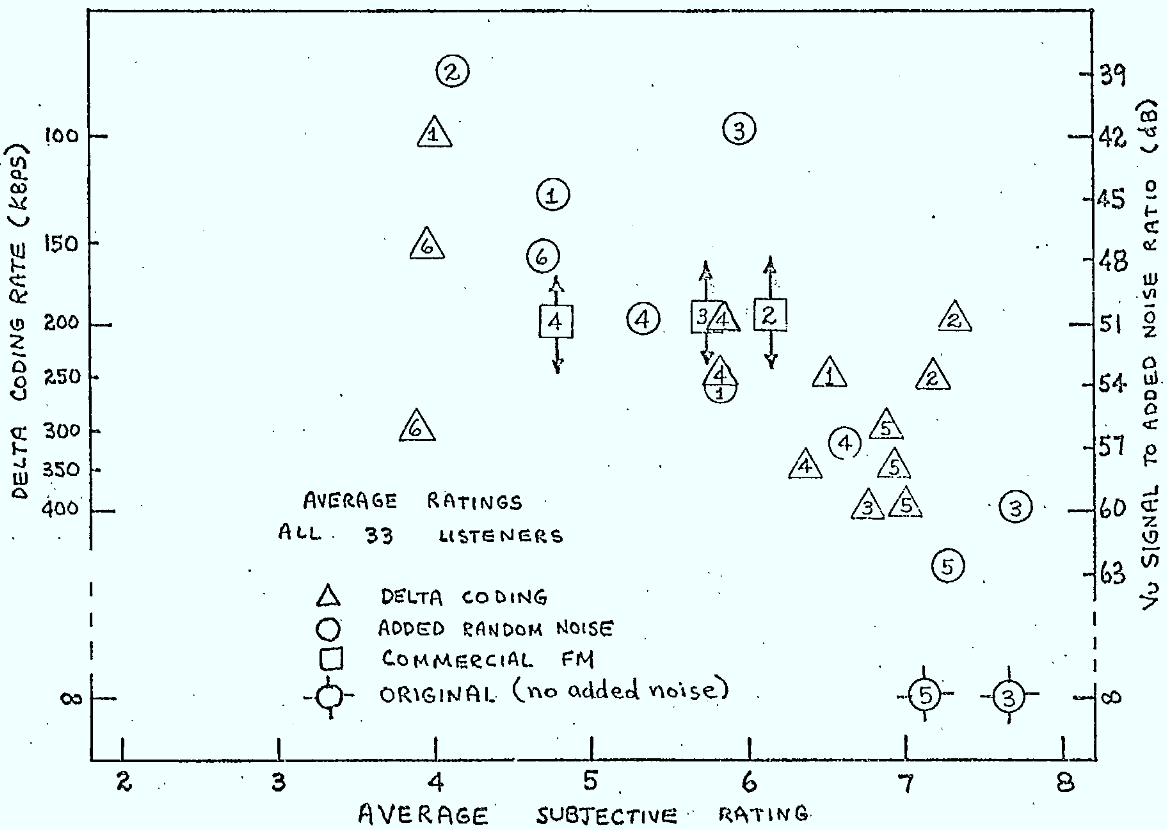

DELTA CODING RATE (KBPS)
100
150
200
250
300
350
400
∞
VU SIGNAL TO ADDED NOISE RATIO (dB)
39
42
45
48
51
54
57
60
63
∞
AVERAGE RATINGS
ALL 33 LISTENERS
DELTA CODING
ADDED RANDOM NOISE
COMMERCIAL FM
ORIGINAL (no added noise)
2
3
4
5
6
7
8
AVERAGE SUBJECTIVE RATING

Figure 3

An alternate method can be used to present the above data so as to produce an SNR/ADM equivalence, rather than presupposing that equivalence and checking it. The data points on the ADM bit rate versus subjective evaluation graph are used to generate the slope and intercept of the best-fit straight line using regression analysis. Similarly, the data points for the SNR versus subjective evaluation graph are used to generate its best-fit straight line slope and intercept. The scales of one of the two straight lines can then be adjusted so that the slopes are equal and moved laterally so that the straight lines coincide. Equivalent values of SNR and ADM bit rate can then be obtained.

The applicability of this method is based on the assumption that the curve is indeed a straight line. In the lower and median subjective evaluation ranges this appears to be valid, while at the higher evaluation levels (7 and 8), the clustering of points (for both graphs) appears to indicate that the curve is asymptotically approaching its vertical limiting value. (See discussion and graph on page 14.) Notice that selections 5 and 3 in the lower right hand corner of the graph on page 15 are original recordings with no added noise or coding. A second assumption which is essential if the two lines are to be coincident is that the "mix" of the selections used for the two processing methods is approximately equal (in terms of ease or difficulty in processing).

Using this approach the best-fit straight line was obtained for delta modulation and for added noise, for both the skilled listeners and the entire population. (Refer to the discussion in section 6 concerning selection of a skilled listener group.) Enforcing straight line coincidence resulted in the following equivalence values.

	EQUIVALENT SNR (in dB)	
KBPS	Skilled listeners	Whole population
100	38	38
200	51	50
400	64	62

These values compare with 42, 51 and 60 dB values obtained from the iso-preference test described in section 3.6.

The correlation coefficient for the best-fit straight lines for each of the above are as follows:

	Skilled listeners	Whole population
delta coding	0.6558	0.5783
SNR	0.8980	0.8704

5.3 Analysis of A/B Comparison Test

5.3.1 Data Tables

The following tables present the response data, grouped first by Artist and second by ADM bit rate. The total of preferences for ADM are listed nearest the bit rate in the left column. Preferences for original or added noise are totaled and listed in the right column next to the comparative process. For the computer analysis, responses in favor of delta coding were valued 1, an equivalent response was weighted 2 and a preference for the comparative process was weighted 3. The mean, median and standard deviation were calculated by the SPSS program. Responses which are tabulated in the reverse order from the test sequence are marked with an asterisk (*).

In contrast to the reasonably clear correlation shown in the previous section, the data from this test did not lead to conclusive results. It should be noted that the test segments were short (10 seconds) and sequential (not identical). On the other hand, the results indicate a consistency of response among the listeners and a comparison of two equal processes produced results which further substantiate that fact.

It appears that a most significant factor or variable that affects the listeners choice is the type of music (ie. the selection) and possibly the particular portion on the test segment. For example, results clearly depended on ADM bit rate for music by Pink Floyd and the Eagles. Responses bear little relation to bit rate for music by Mahler, Cobham and Boyd. Delta coding was not acceptable at any bit rate for music by Emerson. This latter observation is consistent with the subjective rating of music by Emerson.

A/B Test Data - all listeners

Piece		>	=	<		Mean	Median	σ
Mahler 1	*DM 200	5	13	15	Original	2.30	2.39	.73
	*DM 200	7	17	9	Original	2.06	2.06	.70
	DM 250	2	9	22	Original	2.61	2.75	.61
	DM 300	3	8	22	Original	2.57	2.75	.66
	DM 400	8	10	15	DM 400	2.21	2.35	.82
	DM 200	14	9	10	Noise 48	1.88	1.78	.86
	*DM 100	11	11	11	Noise 42	2.00	2.00	.83

Piece		>	=	<		Mean	Median	σ
Eagles 2	*DM 200	1	13	19	Original	2.54	2.63	.56
	DM 250	1	23	9	Original	2.24	2.17	.50
	Buffer	9	15	9	Original	2.00	2.00	.75
	DM 100	14	11	8	Noise 42	1.82	1.73	.81

Piece		>	=	<		Mean	Median	σ
Cobham 3	*DM 200	12	13	8	Original	1.88	1.85	.78
	*DM 250	3	13	17	Original	2.42	2.53	.66
	*DM 300	14	10	9	Original	1.85	1.75	.83
	DM 400	-	11	22	Original	2.67	2.75	.48
	*DM 400	4	13	16	Noise 60	2.36	2.46	.70
	*DM 100	6	10	17	Noise 39	2.33	2.53	.78

Piece		>	=	<		Mean	Median	σ
P. Floyd 4	*DM 100	-	1	32	Original	2.97	2.98	.17
	DM 250	8	15	10	Original	2.06	2.07	.75
	DM 350	10	10	13	Original	2.09	2.15	.84
	*DM 400	9	14	10	Original	2.03	2.04	.77
	Original	10	16	7	Original	1.91	1.91	.72
	DM 400	9	17	7	Noise 60	1.94	1.94	.70
	*DM 200	7	11	15	Noise 54	2.24	2.36	.79
	*DM 100	3	7	23	Noise 45	2.61	2.78	.66

A/B Test Data - all listeners

		>	=	<		Mean	Median	σ
Boyd 5	DM 300	3	5	25	Original	2.67	2.84	.65
	DM 350	10	4	19	Original	2.27	2.63	.91
	DM 200	9	12	12	DM 200	2.09	2.13	.81
	DM 200	22	7	4	Noise 51	1.46	1.25	.71
	*DM 400	19	9	5	Noise 57	1.58	1.37	.75

		>	=	<		Mean	Median	σ
Emmerson 6	DM 150	2	6	25	Original	2.70	2.84	.59
	*DM 300	7	6	20	Original	2.40	2.68	.83
	*DM 400	1	7	25	Noise 63	2.73	2.84	.52
	*DM 200	5	2	26	Noise 51	2.64	2.86	.74

Table 1 A/B comparative Preference Scores ordered by artist.

A/B Test Data - all listeners

		>	=	<			Mean	Median	σ
	*	6	10	17	Noise 39	Cobham 3	2.33	2.53	.78
		14	11	8	Noise 42	Eagles 2	1.82	1.73	.81
DM 100	*	11	11	11	Noise 42	Mahler 1	2.00	2.00	.83
	*	3	7	23	Noise 45	P. Floyd 4	2.41	2.78	.66
	*	0	1	32	Original	P. Floyd 4	2.97	2.98	.17

	>	=	<			Mean	Median	σ
DM 150	2	6	25	Original	Emerson 6	2.70	2.84	.59

		>	=	<			Mean	Median	σ
		14	9	10	Noise 48	Mahler 1	1.88	1.78	.86
		9	12	12	DM 200	Boyd 5	2.09	2.13	.81
		22	7	4	Noise 51	Boyd 5	1.46	1.25	.71
	*	5	2	26	Noise 51	Emerson 6	2.64	2.86	.74
DM 200	*	7	11	15	Noise 54	P. Floyd 4	2.24	2.36	.79
	*	5	13	15	Original	Mahler 1	2.30	2.38	.73
	*	7	17	9	Original	Mahler 1	2.06	2.06	.70
	*	1	13	19	Original	Eagles 2	2.55	2.63	.56
	*	12	13	8	Original	Cobham 3	1.88	1.85	.78

		>	=	<			Mean	Median	σ
		2	9	22	Original	Mahler 1	2.61	2.75	.61
		1	23	9	Original	Eagles 2	2.24	2.17	.50
DM 250	*	3	13	17	Original	Cobham 3	2.42	2.53	.66
		8	15	10	Original	P. Floyd 4	2.06	2.07	.75

A/B Test Data - all listeners

Coding rate		>	=	<	A	B	Mean	Median	σ
DM 300		3	8	22	Original	Mahler 1	2.58	2.75	.66
	*	14	10	9	Original	Cobham 3	1.85	1.75	.83
		3	5	25	Original	Boyd 5	2.67	2.84	.65
	*	7	6	20	Original	Emerson 6	2.39	2.68	.83
DM 350		10	10	13	Original	P. Floyd 4	2.09	2.15	.84
		10	4	19	Original	Boyd 5	2.27	2.63	.91
DM 400	*	19	9	5	Noise 57	Boyd 5	1.58	1.37	.75
		8	10	15	DM 400	Mahler 1	2.21	2.35	.82
	*	4	13	16	Noise 60	Cobham 3	2.36	2.46	.70
		9	17	7	Noise 60	P. Floyd 4	1.94	1.94	.70
	*	1	7	25	Noise 63	Emerson 6	2.73	2.86	.52
		0	11	22	Original	Cobham 3	2.67	2.75	.48
	*	9	14	10	Original	P. Floyd	2.03	2.04	.77
ORIGINAL	*	9	15	9	Buffers	Eagles 2	2.00	2.00	.75
		10	16	7	Original	P. Floyd 4	1.91	1.91	.72

Table 2 A/B comparative Preference Scores ordered by coding rate.

5.3.2 Relationship Between ADM and Added Noise

Comparison with equivalent noise levels are illustrated in the bar graph below. Initial subjective evaluations described in section 3.6 (and Appendix B) indicate that equivalent values for 100 KB and 200 KB are 42 ± 2 dB and 51 ± 2 dB SNR. While these values were used in selecting comparisons for the tests and (indirectly) in setting up the graph below, the bar graphs do not disagree in general with those initial evaluations.

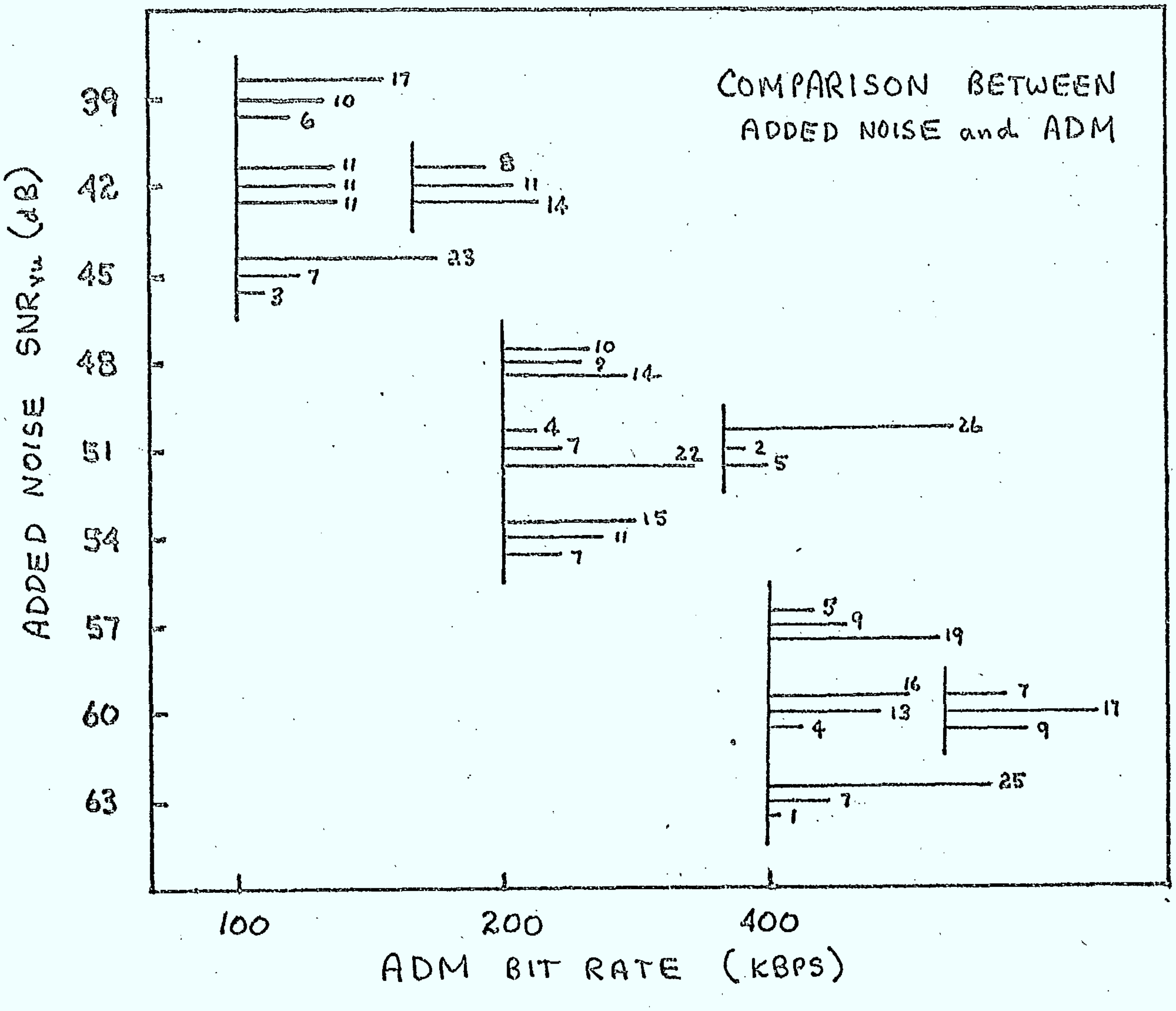


Figure 4. Comparison between added noise and ADM.

5.3.3 Comparison Results - ADM vs Original

In the comparison of delta coding with original source music, the difference diminished as the bit rate was increased. Although preference votes were given to both coded and original versions, the original was most frequently preferred even at the highest bit rate. An "equal to or better than original recording" tabulation is shown in the following figure. No clear improvement is achieved as the bit rate is increased above 200 KBPS; the apparent variation of responses is probably related to the music selection as previously discussed. Notice that the higher KBPS coding rates do not approach original/original comparisons plotted on the extreme right of the graph.

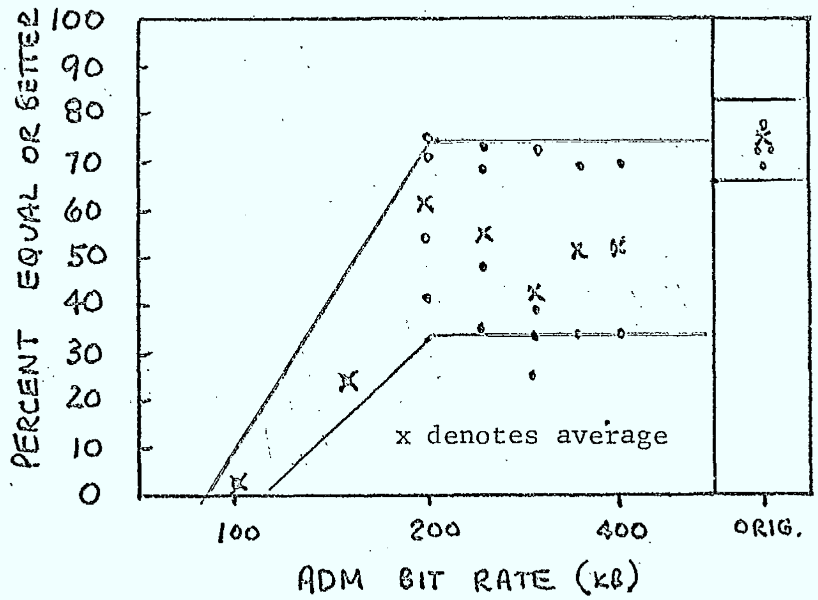


Figure 5. A/B Comparison ADM against original.

Adaptive delta modulation quality was rated consistently lower than original recordings as the bit rate was increased. This property may be explained by considering the two degredations which occur in delta coding. "Granular" quantizing noise appears dominant at rates below 200 KBPS and reduces with increasing bit rate. Slope clipping and adaption time constant are independent of bit rate in this CVSD codec and most probably represent the major degredation at high bit rates. The adaption time constant was 3 mS to maximum for increasing amplitude and 3 dB/mS for decreasing amplitude. Making these adaption rates more rapid unforuntately results in higher idle (background) noise. The optimum compromise would depend on the musical selection used in the testing; some recordings are sensitive to distortion, others to background noise. It should be noted that EVSD coding does not degrade in idle noise as the adapting rate is increased. A digital EVSD codec [Reference 14] will adapt up to 40 dB/mS at 300 KBPS. Rapid adaption will reduce, but not eliminate, slope clipping distortion.

6. Results from Skilled Listeners

Several attempts were made to separate the subject group into skilled and unskilled listeners. Hearing ability, musical background information and test data were analyzed for possible correlations. It was planned to use the A/B comparisons of equal processing in this analysis, however no significant correlation was found with hearing ability or musical background.

A second possible factor for subject screening was the deviation of each subjects data from the average of all subject data. This evaluation included a correction for the subjects mean and range of rating. This factor also showed little correlation with hearing ability and musical background.

A dollar value for each subject's home stereo system was not directly requested. Discussions with listeners indicated that this may have been a good classifier (20/20 hindsight). It was observed that the 6 female participants had less sensitive hearing (an unexpected result) and provided less consistent data. Correlation calculations were not attempted because of the low number of participants. No correlation with age was attempted because few listeners were over 30 or under 20.

The method which was finally used to categorize the subjects, correlated their judgement ratings to a linear trend for increasing degredation (see section 5.2). The SPSS software was used to calculate a best-fit line to the data and the Pearson correlation coefficient. Significance factors (probability of no straight line correlation) were calculated using a two tailed T test. Out of 33 listeners, 19 skilled listeners were selected as having significance factor exceeding an arbitrary level of .02. The following graphs and data tables are similar to those presented in section 5 except that they represent the 19 skilled listeners.

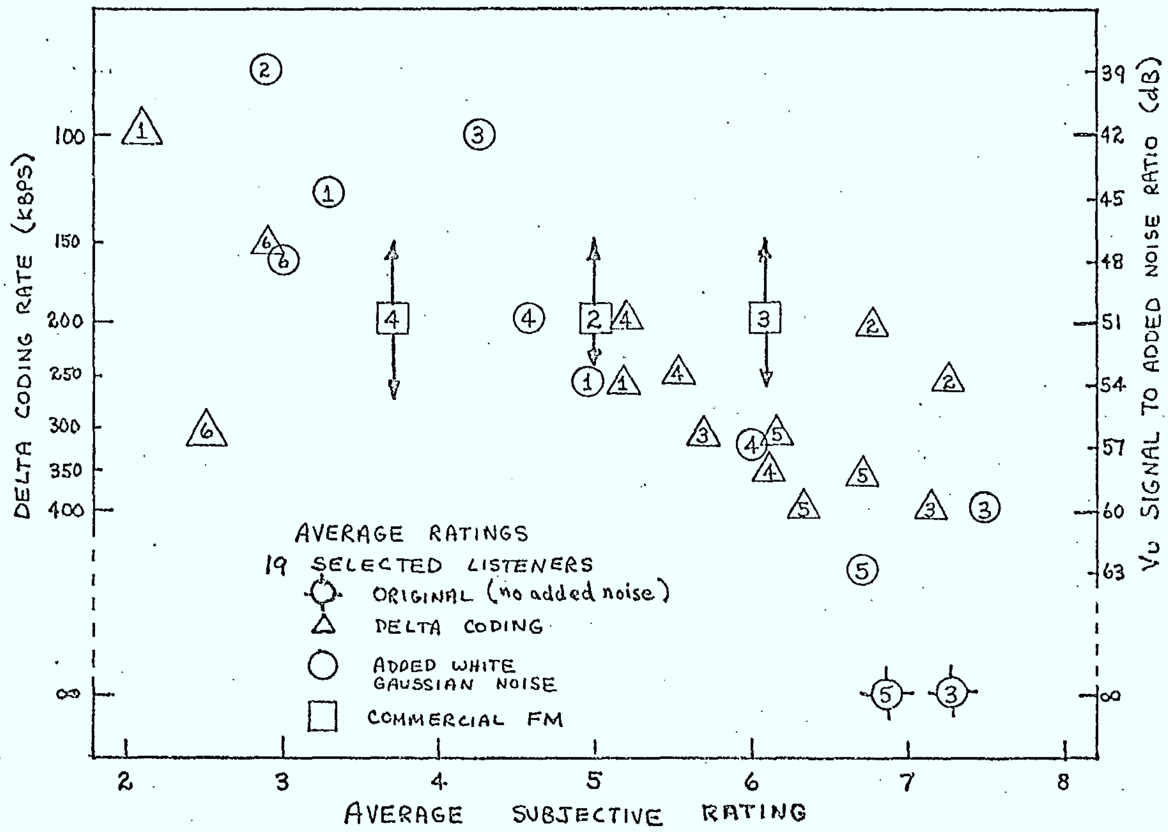
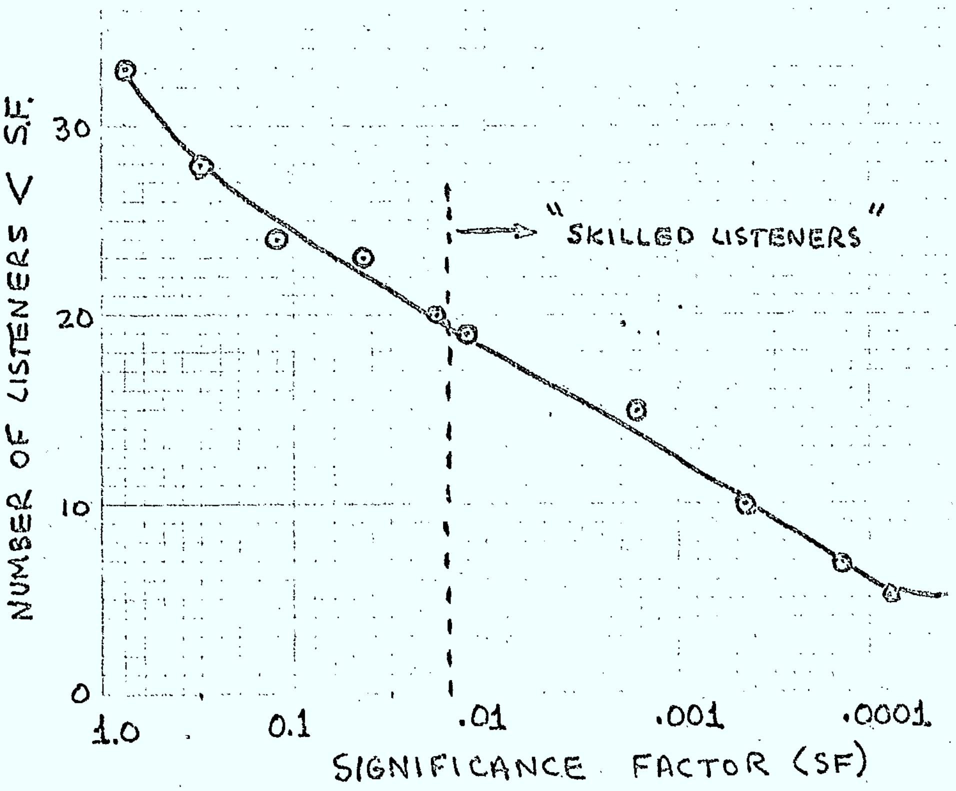

DELTA CODING RATE (KBPS)
VU SIGNAL TO ADDED NOISE RATIO (dB)
AVERAGE RATINGS
19 SELECTED LISTENERS
ORIGINAL (no added noise)
DELTA CODING
ADDED WHITE GAUSSIAN NOISE
COMMERCIAL FM
AVERAGE SUBJECTIVE RATING

Figure 6


NUMBER OF LISTENERS < S.F.
"SKILLED LISTENERS"
SIGNIFICANCE FACTOR (SF)

A/B Data - Skilled Listeners

Mahler 1

	>	=	<		Mean	Median	σ
* DM 200	2	8	9	Original	2.37	2.44	.68
* DM 200	3	8	8	Original	2.26	2.31	.23
DM 250	1	5	13	Original	2.63	2.77	.60
DM 300	2	5	12	Original	2.53	2.71	.70
DM 400	3	9	7	DM 400	2.21	2.22	.71
DM 200	10	4	5	Noise 48	1.74	1.45	.87
* DM 100	7	7	5	Noise 42	1.89	1.86	.81

Eagles 2

	>	=	<		Mean	Median	σ
* DM 200	0	8	11	Original	2.58	2.64	.51
DM 250	0	14	5	Original	2.26	2.18	.45
Buffer	4	12	3	Original	1.95	1.96	.62
DM 100	10	6	3	Noise 42	1.63	1.45	.76

Cobham 3

	>	=	<		Mean	Median	σ
* DM 200	7	7	5	Original	1.90	1.86	.81
* DM 250	2	9	8	Original	2.32	2.33	.67
* DM 300	7	7	5	Original	1.90	1.86	.81
DM 400	0	7	12	Original	2.63	2.71	.50
* DM 400	3	9	7	Noise 60	2.21	2.22	.71
* DM 100	3	7	9	Noise 39	2.32	2.43	.75

P. Floyd 4

	>	=	<		Mean	Median	σ
* DM 100	0	1	18	Original	2.95	2.97	.23
DM 250	3	10	6	Original	2.16	2.15	.69
DM 350	5	6	8	Original	2.16	2.25	.83
* DM 400	5	10	4	Original	1.95	1.95	.71
Original	5	9	5	Original	2.00	2.00	.75
DM 400	6	10	3	Noise 60	1.84	1.85	.69
* DM 200	4	7	8	Noise 54	2.21	2.29	.79
* DM 100	1	2	16	Noise 45	2.79	2.91	.54

A/B Data - Skilled Listeners

Listener		>	=	<		Mean	Median	σ
Boyd 5	DM 300	1	3	15	Original	2.74	2.87	.56
	DM 350	6	4	9	Original	2.16	2.38	.90
	DM 200	4	8	7	DM 200	2.16	2.19	.77
	DM 200	13	4	2	Noise 51	1.42	1.23	.69
	* DM 400	13	6	0	Noise 57	1.32	1.23	.48
Emmerson 6	DM 150	0	3	16	Original	2.84	2.91	.38
	* DM 300	4	3	12	Original	2.42	2.71	.84
	* DM 400	0	3	16	Noise 63	2.84	2.91	.38
	* DM 200	2	1	16	Noise 51	2.74	2.91	.65

Table 3

A/B Data - Skilled Listeners

		>	=	<			Mean	Median	σ
DM 100	*	3	7	9	Noise 39	Cobham 3	2.32	2.43	.75
		10	6	3	Noise 42	Eagles 2	1.63	1.45	.76
	*	7	7	5	Noise 42	Mahler 1	1.89	1.86	.81
	*	1	2	16	Noise 45	P. Floyd 4	2.79	2.91	.54
	*	0	1	18	Original	P. Floyd 4	2.95	2.97	.23

		>	=	<			Mean	Median	σ
DM 150		0	3	16	Original	Emmerson 6	2.84	2.91	.38

		>	=	<			Mean	Median	σ
DM 200		10	4	5	Noise 48	Mahler 1	1.74	1.45	.87
		4	8	7	DM 200	Boyd 5	2.16	2.19	.77
		13	4	2	Noise 51	Boyd 5	1.42	1.23	.69
	*	2	1	16	Noise 51	Emmerson 6	2.74	2.91	.65
	*	4	7	8	Noise 54	P. Floyd 4	2.21	2.29	.79
	*	2	8	9	Original	Mahler 1	2.37	2.44	.68
	*	3	8	8	Original	Mahler 1	2.26	2.31	.73
	*	0	8	11	Original	Eagles 2	2.58	2.64	.51
	*	7	7	5	Original	Cobham 3	1.90	1.86	.81

		>	=	<			Mean	Median	σ
DM 250		1	5	13	Original	Mahler 1	2.63	2.77	.60
		0	14	5	Original	Eagles 2	2.26	2.18	.45
	*	2	9	8	Original	Cobham 3	2.32	2.33	.67
		3	10	6	Original	P. Floyd 4	2.16	2.15	.69

		>	=	<			Mean	Median	σ
DM 300		2	5	12	Original	Mahler 1	2.53	2.71	.70
	*	7	7	5	Original	Cobham 3	1.90	1.86	.81
		1	3	15	Original	Boyd 5	2.74	2.87	.56
	*	4	3	12	Original	Emmerson 6	2.42	2.71	.84

A/B Data - Skilled Listeners

		>	=	<			Mean	Median	σ
DM 350		5	6	8	Original	P. Floyd 4	2.16	2.25	.83
		6	4	9	Original	Boyd 5	2.16	2.38	.90
		>	=	<			Mean	Median	σ
DM 400	*	13	6	0	Noise 57	Boyd 5	1.32	1.23	.48
		3	9	7	DM 400	Mahler 1	2.21	2.22	.71
	*	3	9	7	Noise 60	Cobham 3	2.21	2.22	.71
		6	10	3	Noise 60	P. Floyd 4	1.84	1.85	.69
	*	0	3	16	Noise 63	Emmerson 6	2.84	2.91	.38
		0	7	12	Original	Cobham 3	2.63	2.71	.50
	*	5	10	4	Original	P. Floyd 4	1.95	1.95	.71
		>	=	<			Mean	Median	σ
ORIGINAL		3	12	4	Buffers	Eagles 2	2.05	2.04	.62
		5	9	5	Original	P. Floyd 4	2.00	2.00	.75

Table 4

7. Conclusion

The results of the tests described above indicate that delta coding has good potential for quality sound distribution. At coding rates above 300 KBPS, delta coding reproduction receives "very good" subjective evaluations. These subjective ratings are comparable to those for analog reproduction with signal to noise ratios of 55 to 60 dB and approach ratings for the original source recordings. Subjective ratings indicate a performance exceeding that of commercial FM.

The effect of delta coding has been subjectively equated to added noise. Three methods of equating the fluctuating noise and distortion to a fixed noise have yielded similar results. The quality of adaptive delta coding at 100 KBPS, 200 KBPS and 400 KBPS exceeds the quality of 38 dB, 50 dB and 60 dB SNR_{VU} respectively.

Test data has shown that the perceived quality depends on the type of music which is encoded. One selection with organ music received a low quality rating regardless of bit rate. It is assumed that slow adaption rate and slope clipping caused significant distortion in this music. In the CVSD codec these properties are independent of bit rate. This single identifiable problem may be substantially reduced with EVSD adaption. It is recommended that similar organ music be used in a comparative study as soon as high speed EVSD circuits become available.

In summary, adaptive delta modulation can provide quality music transmission at a coding rate of 300 KBPS.

8. References

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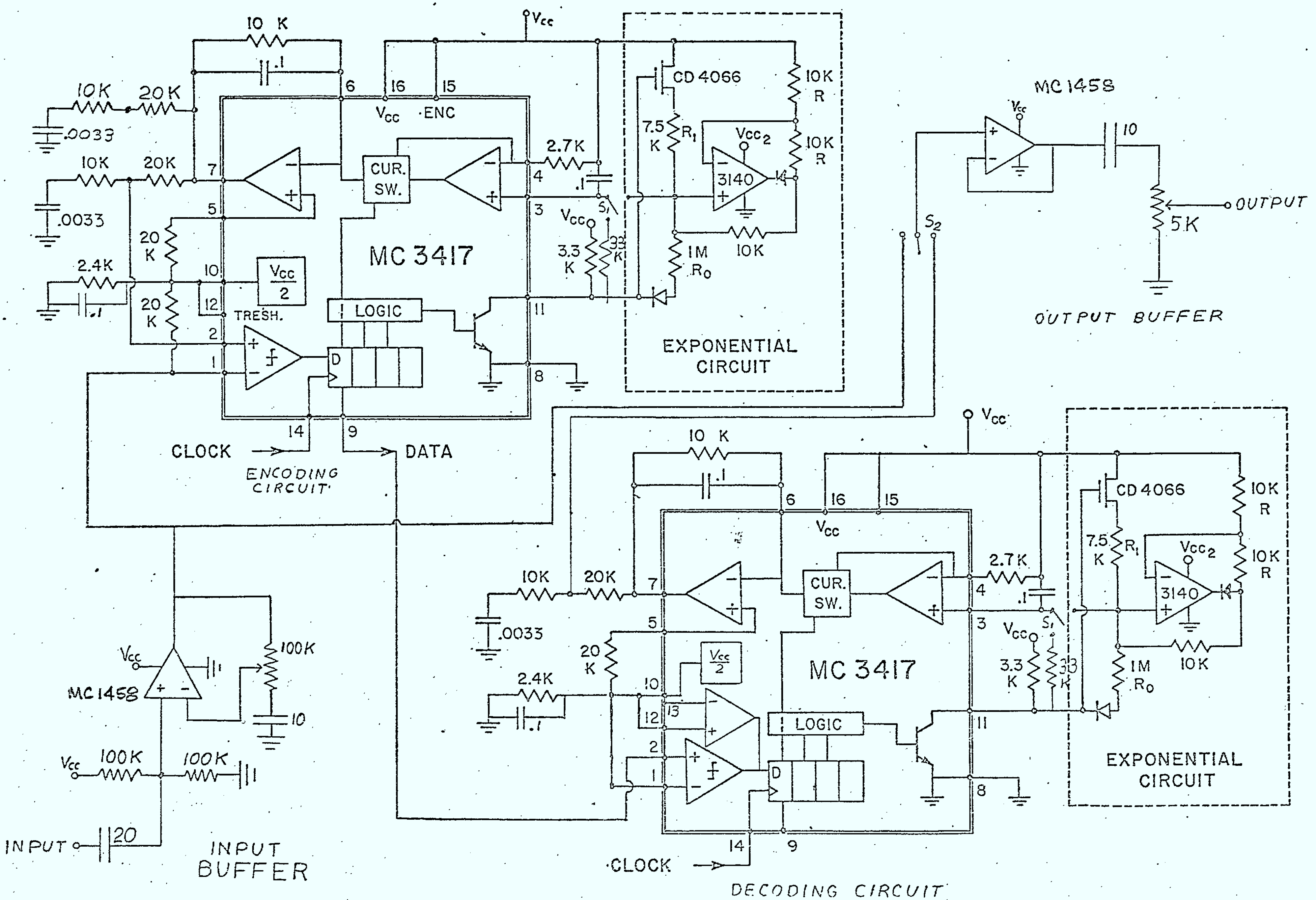
14. D.E. Dodds, A.M. Sendyk, and D.B. Wohlberg, "Error Tolerant Adaptive Algorithms for Delta Coding", IEEE Transactions on Communications, Vol. 28, No. 3. (27)

15. CCIR - International Telecommunication Union, "Recommendations and Reports for Broadcasting Service (Sound)", XIVth Plenary Assembly Koyoto, 1978.

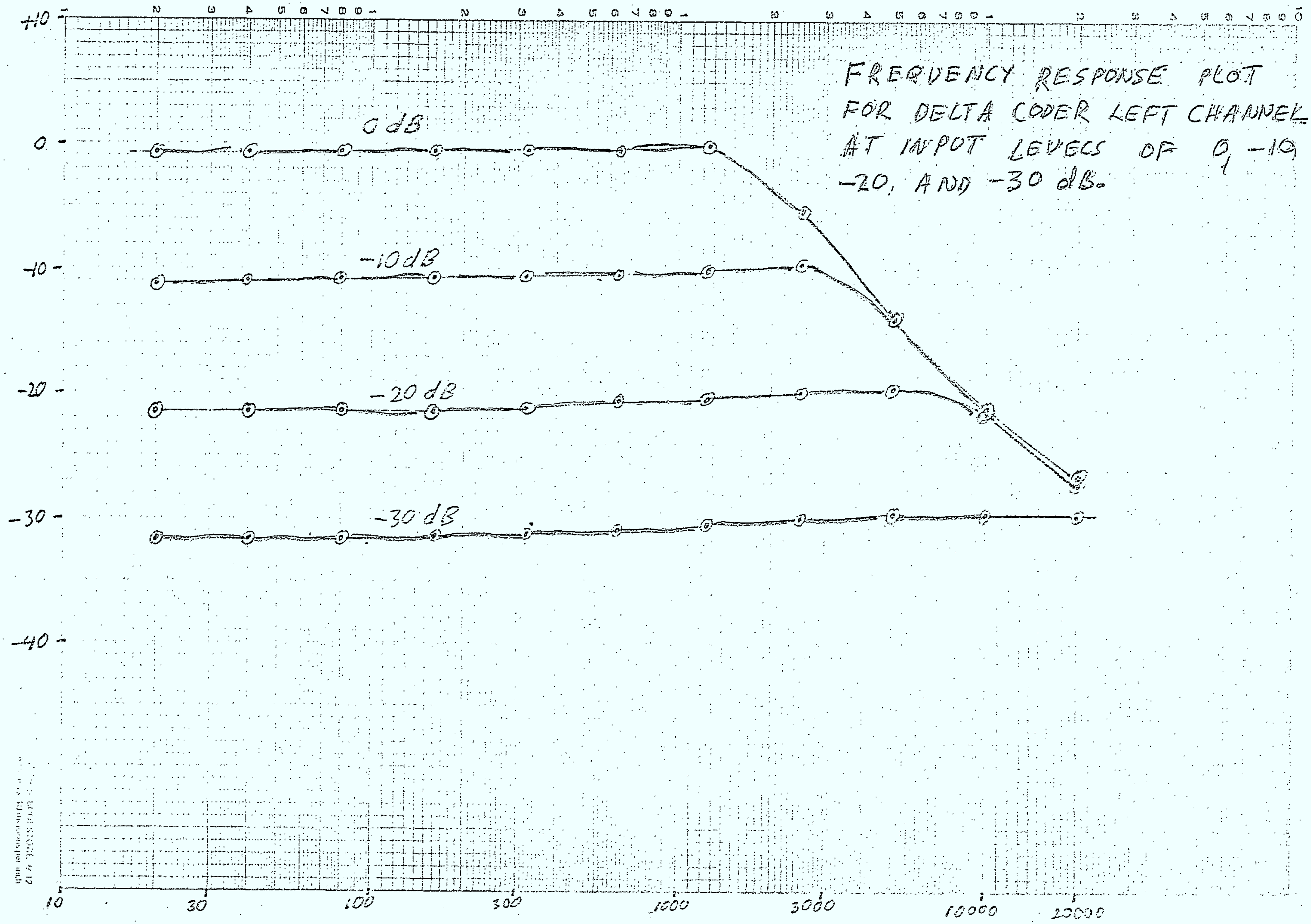
Appendix A

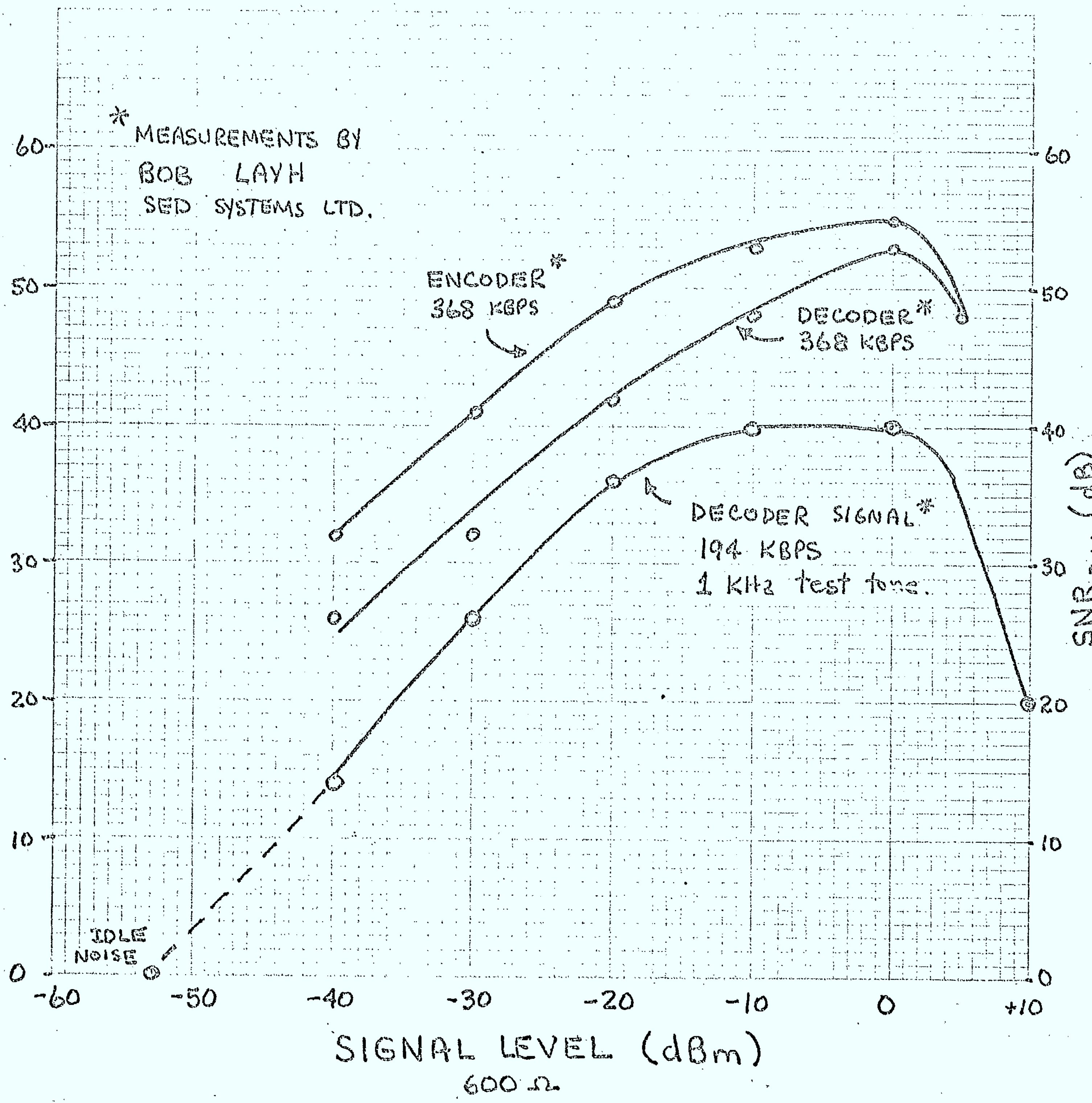
Equipment Specifications

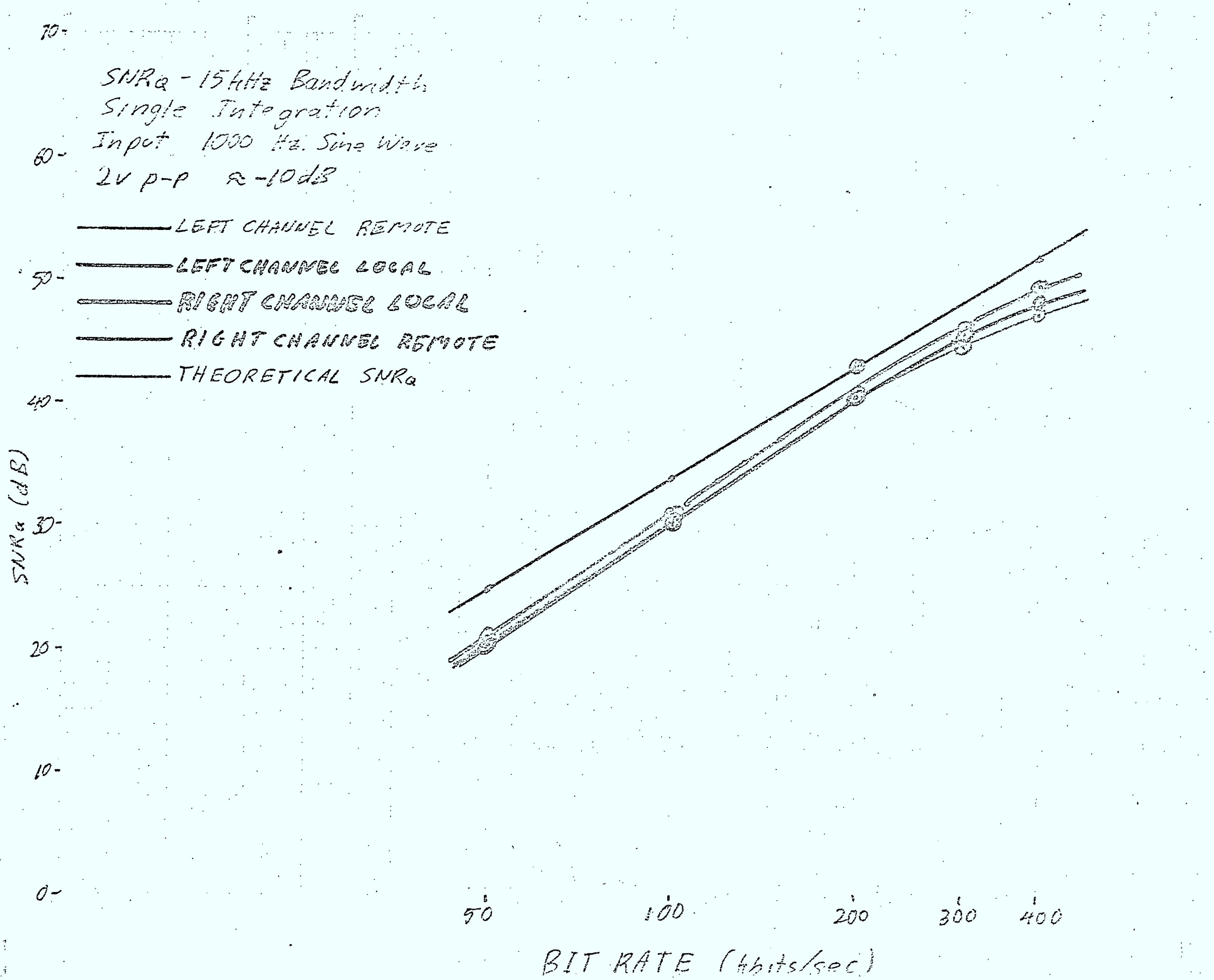
1. Delta coder and decoder circuit diagram.
2. Measured SNR vs modulating frequency for delta codec.
3. Measured SNR vs input signal level.
4. Measured output level vs frequency.
5. MC 3417/18 specifications.
6. Noise measurement set specifications - HP 3555B.
7. Audiophile record information.
8. Cartridge and turntable specifications.
9. Receiver specifications.
10. Cassette tape deck specifications.
11. Power amplifier specification.



MC 3417
CUR. SW.
LOGIC
TRESH.
CD 4066
3140
EXPONENTIAL CIRCUIT
CLOCK
DATA
ENCODING CIRCUIT
MC 1458
OUTPUT BUFFER
OUTPUT
INPUT
INPUT BUFFER
DECODING CIRCUIT
Vcc
ENC
10 K
10K
20K
2.7K
2.4K
3.3 K
33 K
7.5 K
1M
10K R
5K
100K
.0033
.1
10
20
S1
S2
R1
R0
Vcc2


FREQUENCY RESPONSE PLOT FOR DELTA CODER LEFT CHANNEL AT INPUT LEVELS OF 0, -10, -20, AND -30 dB.
0 dB
-10 dB
-20 dB
-30 dB
+10
0
-10
-20
-30
-40
10
30
100
300
1000
3000
10000
20000


* MEASUREMENTS BY
BOB LAYH
SED SYSTEMS LTD.
ENCODER*
368 KBPS
DECODER*
368 KBPS
DECODER SIGNAL*
194 KBPS
1 KHz test tone.
IDLE
NOISE
60
50
40
30
20
10
0
-60
-50
-40
-30
-20
-10
0
+10
SNR DYN (dB)
SIGNAL LEVEL (dBm)
600 Ω


SNRq - 15kHz Bandwidth
Single Integration
Input 1000 Hz. Sine Wave
2V p-p ≈ -10dB
LEFT CHANNEL REMOTE
LEFT CHANNEL LOCAL
RIGHT CHANNEL LOCAL
RIGHT CHANNEL REMOTE
THEORETICAL SNRq
70
60
50
40
30
20
10
0
SNRq (dB)
50
100
200
300
400
BIT RATE (kbits/sec)

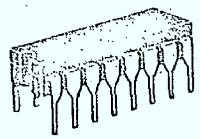
MOTOROLA
SEMICONDUCTORS
P.O. BOX 20912 • PHOENIX, ARIZONA 85036

MC3417, MC3517
MC3418, MC3518

Specifications and Applications Information

CONTINUOUSLY VARIABLE SLOPE DELTA MODULATOR/DEMODULATOR

LASER-TRIMMED INTEGRATED CIRCUIT



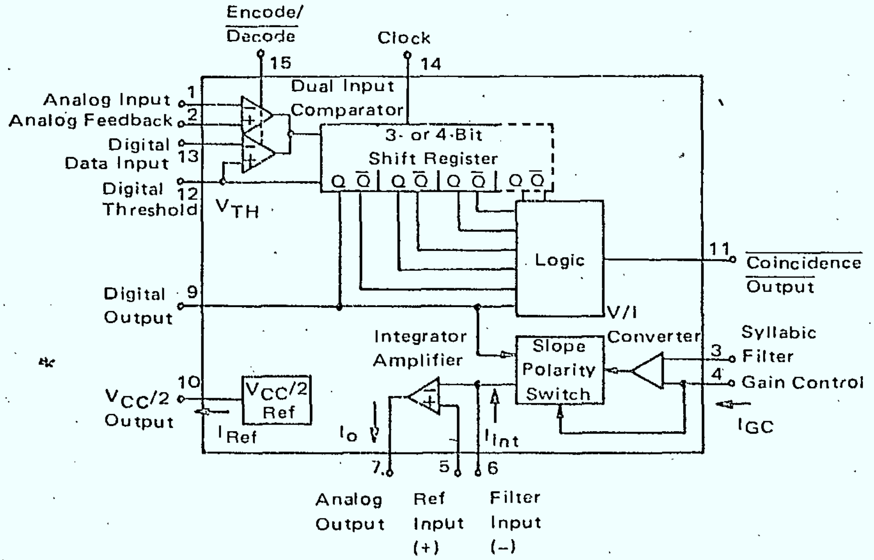
L SUFFIX
CERAMIC PACKAGE
CASE 620

CONTINUOUSLY VARIABLE SLOPE DELTA MODULATOR/DEMODULATOR

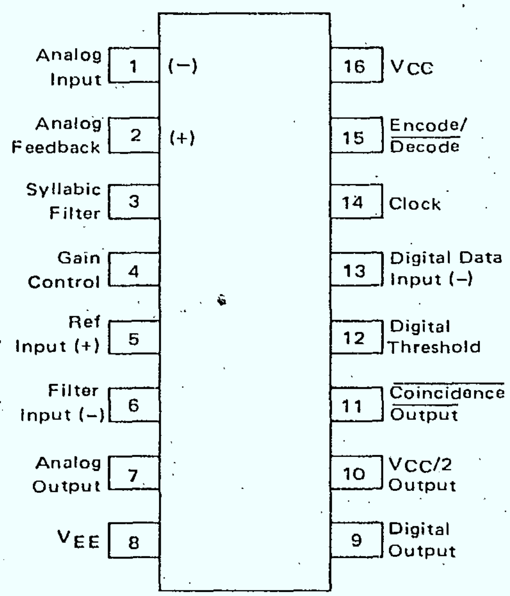
Providing a simplified approach to digital speech encoding/decoding, the MC3517/18 series of CVSDs is designed for military secure communication and commercial telephone applications. A single IC provides both encoding and decoding functions.

- Encode and Decode Functions on the Same Chip with a Digital Input for Selection
- Utilization of Compatible I^2L — Linear Bipolar Technology
- CMOS Compatible Digital Output
- Digital Input Threshold Selectable ($V_{CC}/2$ reference provided on chip)
- MC3417/MC3517 has a 3-Bit Algorithm (General Communications)
- MC3418/MC3518 has a 4-Bit Algorithm (Commercial Telephone)

CVSD BLOCK DIAGRAM



PIN CONNECTIONS



ORDERING INFORMATION

Device	Package	Temperature Range
MC3417L	Ceramic DIP	$0^{o}C$ to $+70^{o}C$
MC3418L	Ceramic DIP	$0^{o}C$ to $+70^{o}C$
MC3517L	Ceramic DIP	$-55^{o}C$ to $+125^{o}C$
MC3518L	Ceramic DIP	$-55^{o}C$ to $+125^{o}C$

MAXIMUM RATINGS

(All voltages referenced to V_{EE}, $T_A = 25^oC$ unless otherwise noted.)

Rating	Symbol	Value	Unit
Power Supply Voltage	V_{CC}	−0.4 to +18	Vdc
Differential Analog Input Voltage	V_{ID}	±5.0	Vdc
Digital Threshold Voltage	V_{TH}	−0.4 to V_{CC}	Vdc
Logic Input Voltage (Clock, Digital Data, Encode/$\overline{Decode}$)	V_{Logic}	−0.4 to +18	Vdc
Coincidence Output Voltage	$V_{O(Con)}$	−0.4 to +18	Vdc
Syllabic Filter Input Voltage	$V_{I(Syl)}$	−0.4 to V_{CC}	Vdc
Gain Control Input Voltage	$V_{I(GC)}$	−0.4 to V_{CC}	Vdc
Reference Input Voltage	$V_{I(Ref)}$	$V_{CC}/2$ − 1.0 to V_{CC}	Vdc
$V_{CC}/2$ Output Current	I_{Ref}	−25	mA

ELECTRICAL CHARACTERISTICS

(V_{CC} = 12 V, V_{EE} = Gnd, $T_A = 0^oC$ to $+70^oC$ for MC3417/18, $T_A = -55^oC$ to $+125^oC$ for MC3517/18 unless otherwise noted.)

Characteristic	Symbol	MC3417/MC3517			MC3418/MC3518			Unit
		Min	Typ	Max	Min	Typ	Max	
Power Supply Voltage Range (Figure 1)	V_{CCR}	4.75	12	16.5	4.75	12	16.5	Vdc
Power Supply Current (Figure 1) (Idle Channel)	I_{CC}							mA
(V_{CC} = 5.0 V)		–	3.7	5.0	–	3.7	5.0	
(V_{CC} = 15 V)		–	6.0	10	–	6.0	10	
Clock Rate	SR	–	16 k	–	–	32 k	–	Samples/s
Gain Control Current Range (Figure 2)	I_{GCR}	0.001	–	3.0	0.001	–	3.0	mA
Analog Comparator Input Range (Pins 1 and 2) (4.75 V ≤ V_{CC} ≤ 16.5 V)	V_I	1.3	–	V_{CC} − 1.3	1.3	–	V_{CC} − 1.3	Vdc
Analog Output Range (Pin 7) (4.75 V ≤ V_{CC} ≤ 16.5 V, I_O = ± 5.0 mA)	V_O	1.3	–	V_{CC} − 1.3	1.3	–	V_{CC} − 1.3	Vdc
Input Bias Currents (Figure 3) (Comparator in Active Region)	I_{IB}							µA
Analog Input (I1)		–	0.5	1.5	–	0.25	1.0	
Analog Feedback (I2)		–	0.5	1.5	–	0.25	1.0	
Syllabic Filter Input (I3)		–	0.06	0.5	–	0.06	0.3	
Reference Input (I5)		–	−0.06	−0.5	–	−0.06	−0.3	
Input Offset Current (Comparator in Active Region)	I_{IO}							µA
Analog Input/Analog Feedback |I1 − I2| — Figure 3		–	0.15	0.6	–	0.05	0.4	
Integrator Amplifier |I5 − I6| — Figure 4		–	0.02	0.2	–	0.01	0.1	
Input Offset Voltage V/I Converter (Pins 3 and 4) — Figure 5	V_{IO}	–	2.0	6.0	–	2.0	6.0	mV
Transconductance	gm							mA/mV
V/I Converter, 0 to 3.0 mA		0.1	0.3	–	0.1	0.3	–	
Integrator Amplifier, 0 to ± 5.0 mA Load		1.0	10	–	1.0	10	–	
Propagation Delay Times (Note 1)								µs
Clock Trigger to Digital Output (C_L = 25 pF to Gnd)	t_{PLH}	–	1.0	2.5	–	1.0	2.5	
	t_{PHL}	–	0.8	2.5	–	0.8	2.5	
Clock Trigger to Coincidence Output (C_L = 25 pF to Gnd) (R_L = 4 kΩ to V_{CC})	t_{PLH}	–	1.0	3.0	–	1.0	3.0	
	t_{PHL}	–	0.8	2.0	–	0.8	2.0	
Coincidence Output Voltage — Low Logic State ($I_{OL(Con)}$ = 3.0 mA)	$V_{OL(Con)}$	–	0.12	0.25	–	0.12	0.25	Vdc
Coincidence Output Leakage Current — High Logic State (V_{OH} = 15.0 V, $0^oC \le T_A \le 70^oC$)	$I_{OH(Con)}$	–	0.01	0.5	–	0.01	0.5	µA

NOTE 1. All propagation delay times measured 50% to 50% from the negative going (from V_{CC} to +0.4 V) edge of the clock.

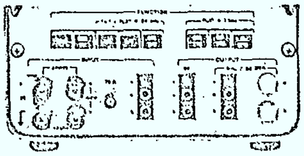
ELECTRICAL CHARACTERISTICS (continued)

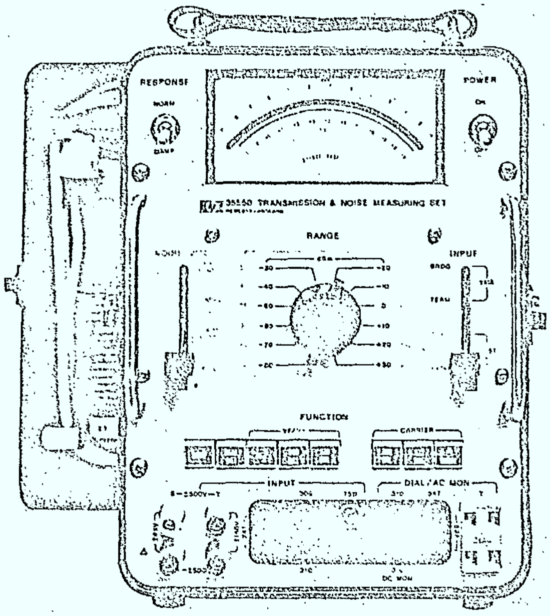
Characteristic	Symbol	MC3417/MC3517 Min	Typ	Max	MC3418/MC3518 Min	Typ	Max	Unit
Applied Digital Threshold Voltage Range (Pin 12)	V_{TH}	+1.2	—	$V_{CC}-2.0$	+1.2	—	$V_{CC}-2.0$	Vdc
Digital Threshold Input Current ($1.2\ V \leqslant V_{th} \leqslant V_{CC}-2.0\ V$)	$I_{I(th)}$							μA
(V_{IL} applied to Pins 13, 14 and 15)		—	—	5.0	—	—	5.0	
(V_{IH} applied to Pins 13, 14 and 15)		—	−10	−50	—	−10	−50	
Maximum Integrator Amplifier Output Current	I_O	±5.0	—	—	±5.0	—	—	mA
$V_{CC}/2$ Generator Maximum Output Current (Source only)	I_{Ref}	+10	—	—	+10	—	—	mA
$V_{CC}/2$ Generator Output Impedance (0 to +10 mA)	z_{Ref}	—	3.0	6.0	—	3.0	6.0	Ω
$V_{CC}/2$ Generator Tolerance ($4.75\ V \leqslant V_{CC} \leqslant 16.5\ V$)	ϵr	—	—	±3.5	—	—	±3.5	%
Logic Input Voltage (Pins 13, 14 and 15)								Vdc
Low Logic State	V_{IL}	Gnd	—	$V_{th}-0.4$	Gnd	—	$V_{th}-0.4$	
High Logic State	V_{IH}	$V_{th}+0.4$	—	18.0	$V_{th}+0.4$	—	18.0	
Dynamic Total Loop Offset Voltage (Note 2) — Figures 3, 4 and 5	ΣV_{offset}							mV
$I_{GC} = 12.0\ \mu A$, $V_{CC} = 12\ V$								
$T_A = 25^oC$		—	—	—	—	± 0.5	± 1.5	
$0^oC \leqslant T_A \leqslant +70^oC$ MC3417/18		—	—	—	—	± 0.75	± 2.3	
$-55^oC \leqslant T_A \leqslant +125^oC$ MC3517/18		—	—	—	—	± 1.5	± 4.0	
$I_{GC} = 33.0\ \mu A$, $V_{CC} = 12\ V$								
$T_A = 25^oC$		—	± 2.5	± 5.0	—	—	—	
$0^oC \leqslant T_A \leqslant +70^oC$ MC3417/18		—	± 3.0	± 7.5	—	—	—	
$-55^oC \leqslant T_A \leqslant +125^oC$ MC3517/18		—	±4.5	±10	—	—	—	
$I_{GC} = 12.0\ \mu A$, $V_{CC} = 5.0\ V$								
$T_A = 25^oC$		—	—	—	—	± 1.0	± 2.0	
$0^oC \leqslant T_A \leqslant +70^oC$ MC3417/18		—	—	—	—	± 1.3	± 2.8	
$-55^oC \leqslant T_A \leqslant +125^oC$ MC3517/18		—	—	—	—	± 2.5	± 5.0	
$I_{GC} = 33.0\ \mu A$, $V_{CC} = 5.0\ V$								
$T_A = 25^oC$		—	± 4.0	± 6.0	—	—	—	
$0^oC \leqslant T_A \leqslant +70^oC$ MC3417/18		—	± 4.5	± 8.0	—	—	—	
$-55^oC \leqslant T_A \leqslant +125^oC$ MC3517/18		—	± 5.5	± 10	—	—	—	
Digital Output Voltage								Vdc
($I_{OL} = 3.6\ mA$)	V_{OL}	—	0.1	0.4	—	0.1	0.4	
($I_{OH} = -0.35\ mA$)	V_{OH}	$V_{CC}-1.0$	$V_{CC}-0.2$	—	$V_{CC}-1.0$	$V_{CC}-0.2$	—	
Syllabic Filter Applied Voltage (Pin 3) (Figure 2)	$V_{I(Syl)}$	+3.2	—	V_{CC}	+3.2	—	V_{CC}	Vdc
Integrating Current (Figure 2)	I_{Intl}							
($I_{GC} = 12.0\ \mu A$)		8.0	10	12	8.0	10	12	μA
($I_{GC} = 1.5\ mA$)		1.45	1.50	1.55	1.45	1.50	1.55	mA
($I_{GC} = 3.0\ mA$)		2.75	3.0	3.25	2.75	3.0	3.25	mA
Dynamic Integrating Current Match ($I_{GC} = 1.5\ mA$) Figure 6	$V_{O(Ave)}$	—	± 100	± 250	—	± 100	± 250	mV
Input Current — High Logic State ($V_{IH} = 18\ V$)	I_{IH}							μA
Digital Data Input		—	—	+5.0	—	—	+5.0	
Clock Input		—	—	+5.0	—	—	+5.0	
Encode/$\overline{Decode}$ Input		—	—	+5.0	—	—	+5.0	
Input Current — Low Logic State ($V_{IL} = 0\ V$)	I_{IL}							μA
Digital Data Input		—	—	−10	—	—	−10	
Clock Input		—	—	−360	—	—	−360	
Encode/$\overline{Decode}$ Input		—	—	−36	—	—	−36	
Clock Input, $V_{IL} = 0.4\ V$		—	—	−72	—	—	−72	

NOTE 2. Dynamic total loop offset (ΣV_{offset}) equals V_{IO} (comparator) (Figure 3) minus V_{IOX} (Figure 5). The input offset voltages of the analog comparator and of the integrator amplifier include the effects of input offset current through the input resistors. The slope polarity switch current mismatch appears as an average voltage across the 10 k integrator resistor. For the MC3417/MC3517, the clock frequency is 16.0 kHz. For the MC3418/MC3518, the clock frequency is 32.0 kHz. Idle channel performance is guaranteed if this dynamic total loop offset is less than one-half of the change in integrator output voltage during one clock cycle (ramp step size). Laser trimming is used to insure good idle channel performance.

Transmission & noise measuring set
Models 3555B & 3556A

- Voice and carrier testing





Description

Hewlett-Packard's 3555B Transmission and Noise Measuring Set is designed especially for telephone plant maintenance. It measures attenuation, distortion, cross-talk coupling and noise. Weighting networks designed to comply with Bell System Technical Reference Publication number 41009, and include C-message, 3 kHz, 15 kHz flat and program.

HP's 3556A performs the same tasks as the 3555B. It also has built-in weighting networks designed to that comply with CCITT requirements, which include telephone (psophometric) 3 kHz flat, and 15 kHz flat, Programme (P53) weighting filters.

Operating instructions printed in the protective cover are available in most languages at no extra charge.

Complementary equipment for the 3555B is HP 236A Telephone Test Oscillator (236A Opt. H10 for the 3556A). When used together, they make a complete transmission test set for accurate, convenient voice and carrier measurements.

Specifications

	3555B (North American Standards)	3556A (CCITT Standards)
VOICE FREQUENCY LEVEL MEASUREMENTS: 20 Hz to 20 kHz		
dB/volt range	−91 dBm to +31 dBm	−78 dBm to +32 dBm/0.1 mV to 30 V F.S.
Level accuracy**	±0.5 dB: ±0.2 dB, 40 Hz to 15 kHz, level >60 dBm	100 Hz to 5 kHz: ±0.2 dB; 20 Hz to 20 kHz: ± 0.5 dB
Input	Terminated or bridged 600Ω or 900Ω balanced. Bridging loss: <0.3 dB at 1 kHz. Balance: >80 dB at 60 Hz >70 dB at 6 kHz, >50 dB to 20 kHz. Return loss: 30 dB min (50 Hz to 20 kHz)	Terminated: 600Ω symmetrical. Non-terminated: 10 kΩ symmetrical. Non-terminated error: <0.4 dB at 800 Hz. Symmetry: >80 dB at 50 Hz, >70 dB at 6 kHz, >50 dB to 20 kHz. Return loss: 30 dB min (50 Hz to 20 kHz)
Holding circuit	700Ω dc resistance, 60 mA max. loop line current at 300 Hz. With holding circuit in, above specs apply from 300 Hz to 4 kHz	
NOISE MEASUREMENTS:		
dB/volt range	−1 dBrn to +121 dBrn	−78 dBm to +32 dBm/0.1 mV to 30 VF. S.
Weighting filters	3 & 15 kHz flat, C-message, and program (Bell system technical reference pub #41009)	3 & 15 kHz flat, Telephone and Programme (P53, CCITT)
Input	Same as for voice frequency measurements	
CARRIER FREQUENCY LEVEL MEASUREMENTS:		
dB/volt range	−61 dBm to +11 dBm	−48 dBm to +12 dBm/3 mV to 3 VF.S.
Level accuracy	600Ω balanced (symmetrical): 1 kHz to 150 kHz ±0.5 dB; 10 kHz to 100 kHz, ±0.2 dB. 135Ω balanced (or 150Ω balanced)†: 1 kHz to 600 kHz, ±0.5 dB; 10 kHz to 300 kHz, ±0.2 dB. 75Ω unbalanced (asymmetrical): 100 Hz to 600 kHz, ±0.2 dB; 30 Hz to 1 MHz, ±0.5 dB; 1 MHz to 3 MHz, ±0.5 dB ±10% of meter reading	
Input	Terminated or bridged 135Ω† or 600Ω balanced (symmetrical) and 75Ω unbalanced (asymmetrical)	
Return loss	600Ω: 26 dB min., 3 kHz to 150 kHz; 135Ω†: 26 dB min. 1 kHz to 600 kHz; 75Ω: 30 dB min. to 3 MHz	
Bal/symmetry	>70 dB to 10 kHz, >60 dB to 100 kHz, >40 dB to 600 kHz	
GENERAL:		
Meter	Linear dB scale	Linear dBm scale
External battery	24 V or 48 V office battery, <15 mA	
Internal battery	Single NEDA 202, 45 V "B" battery Option H03 uses rechargeable batteries and similar to 3556A	4 rechargeable batteries (25 V total) or power line from 90 V to 250 V ac, 48 Hz to 440 Hz, <10 VA. Option 001 uses same battery as 3555B
AC	115 or 230 V (specify for 3555B) (switch for 3556A) 48 Hz to 440 Hz, <10 VA	
Dimensions	299 mm H X 197 mm W X 207 mm D (11¾" X 7¾" X 8⅛")	
Weight	Net, 6.8 kg (15 lb). Shipping. 7.5 kg (17 lb).	
Jacks	Will accept Western Electric 241, 309, 310, 358, 289 and 347 plugs; 1011B hand-set or 52 type headset	Will accept Siemens 9 REL KL1-6A, 4 mm diameter banana plugs or 3-prong Siemens 9 REL STP-6AC connector

**For levels >1 dBm accuracy spec applies only for freq. above 100 Hz.
†150Ω for 3556A.

Ordering Information

HP 236A Telephone Test Oscillator (complementary equipment for 3555B) see page **577**

3555B Transmission and Noise Measuring Set
3556A Psophometer

MFSL 1-017

Produced by PINK FLOYD
Recorded at Abbey Road Studios, London
between June 1972 and January 1973

Engineer Alan Parsons
Assistant Peter Jones
Mixing Supervised by Chris Thomas

Saxophone on 'Us and Them' and 'Money' Dick Parry

Backing Vocals Doris Troy,
Leslie Duncan, Liza Strike, Barry St John
Vocals on 'The Great Gig in the Sky' by Clare Torry

Sleeve Design by Hipgnosis
Sleeve Art by George Hardie N.T.A.
Photography by Hipgnosis
Stickers Art by George Hardie N.T.A.

All lyrics by ROGER WATERS.

All selections published by TRO-Hampshire House Publishing Corp.

SIDE ONE
1 SPEAK TO ME (Mason)
2 BREATHE (Waters, Gilmour, Wright)
3 ON THE RUN (Gilmour, Waters)
4 TIME (Mason, Waters, Wright, Gilmour)
5 THE GREAT GIG IN THE SKY (Wright)

SIDE TWO
1 MONEY (Waters)
2 US AND THEM (Waters, Wright)
3 ANY COLOUR YOU LIKE (Gilmour, Mason, Wright)
4 BRAIN DAMAGE (Waters)
5 ECLIPSE (Waters)

DAVID GILMOUR Vocals, Guitars, VCS3
NICK MASON Percussion, Tape Effects
RICHARD WRIGHT Keyboards, Vocals, VCS3
ROGER WATERS Bass Guitar, Vocals, VCS3, Tape Effects

Half-Speed Mastering by Stan Ricker, JVC
Super High Definition Vinyl (extended life)
Imported Pressing
Static Free Inner Sleeve
Source: the *original* stereo master tape

LONDON DIGITAL RECORDING

L DR

Master tape recorder	London Digital	Conventional Analog
Frequency response	20-20,000 Hz (±0.5 dB)	30-20,000 Hz (±2 dB)
Dynamic range (Signal-to-noise ratio)	90 dB	70 dB
Distortion at maximum volume	unmeasurably small	1.0% (rms)
Wow and flutter	unmeasurably small	0.05%

The original master recording from which these records have been produced was made on a London digital master tape recorder which yields significant quality improvement compared with conventional analog tape records.

By employing advanced digital technology, London engineers have developed a master tape recorder whose reproduction quality is as good as the signal fed into it from the studio mixing console during recording.

The new master recorder was developed specifically to meet the needs of London's recording operations, renowned for their continual quest for higher quality.

These records are derived from a London Digital Recorder and are indistinguishable in quality from so-called "Direct Cut" records, but they benefit artistically from the performing and editing freedom associated with a master tape.

The London Digital Recorder virtually eliminates the small but significant distortions which occur with even the best analog recorder. For comparison, the principal performance characteristics are listed.

IMPORTANT NOTE:
THESE ARE NORMAL STEREOPHONIC RECORDS FOR USE WITH CONVENTIONAL RECORD REPRODUCING EQUIPMENT.

THE IMPROVED QUALITY WILL BE MOST CLEARLY APPARENT ON HIGH QUALITY PLAYING EQUIPMENT.

THE RECORDS WILL BENEFIT FROM THE USUAL CAREFUL HANDLING AND PROTECTION FROM DUST AND OTHER CONTAMINATION.

Recorded March, 1979, Mann Auditorium, Tel Aviv
Recording Producer: Ray Minshull
Recording Engineers: James Lock, David Frost
Digital Engineer: Tony Griffiths

Library of Congress Catalog Card Number 79-750301 applies to LDR 10004

A|D|C Audio Dynamics Corporation

XLM MK III and VLM MK III SPECIFICATIONS

CARTRIDGE	XLM MK III	VLM MK III
OUTPUT @ 5.5 cm/S	5.5 mV	5.5 mV
TRACKING FORCE	¾ to 1½ Gm	¾ to 1½ Gm
FREQUENCY RESPONSE	10kHz to 20kHz ±1dB 20kHz to 24kHz ±1½dB	15Hz to 24kHz ±2dB
SEPARATION	28dB	26dB
STYLUS TIP DIAMOND	Elliptical .0002" x .0007"	Elliptical .0003" x .0007"
CARTRIDGE WEIGHT	5.75 Gm	5.75 Gm
LOAD RESISTANCE	47K Ohms	47K Ohms
LOAD CAPACITANCE	275pF	275pF

LIMITED WARRANTY

This cartridge is warranted to be free of manufacturing defects for a one year period from the date of purchase. During that time, should a defect occur, the unit will be repaired or replaced without cost. This warranty covers neither stylus wear, nor damage caused by accident or mishandling.

Specifications Technics 1400

Turntable section

Type .... Direct Drive Automatic Turntable System, Automatic start, Automatic return, Automatic shut-off and MEMO-REPEAT play, Manual play
Drive method .... Direct Drive
Motor .... Back Electromotive Force Frequency Generator servo DC motor employing one chip IC
Turntable platter .... Aluminum die-cast, 33 cm (13")
Turntable speeds .... 33-1/3 and 45 r.p.m.
Pitch controls .... Individual adjustment controls, 10% adjustment range
Wow and flutter .... 0.025% W.R.M.S. (JIS C5521)
±0.035% Weighted zero to peak (DIN 45507)
Rumble .... −50 dB (DIN 45539A)
−73 dB (DIN 45539B)

Tonearm section

Type .... Universal tubular arm, static-balanced type
Effective length .... 230 mm (9-1/16")
Overhang .... 15 mm (19/32")
Friction .... 7 mg (horizontally and vertically)
Effective mass .... 22 g (6.0 g cartridge weight 1.75 g stylus pressure)
Tracking error angle .... Within +3° {at the point of 145 mm (5-45/64") from the centre}
Within +1° {at the point of 55 mm (2-3/16") from the centre}
Offset angle .... 21.5°
Adjustable stylus pressure range .... 0 to 3 g (stylus pressure direct reading type)
Cartridge weight range .... 5 to 11 g
Head shell weight .... 9.5 g

General

Power supply .... AC 120 V, 50 or 60 Hz
Power consumption .... 6 W
Dimensions (H × W × D) .... 12.5 × 45.3 × 36.9 cm
(4-15/16 × 17-12/16 × 14-9/16 inches)
Weight .... 9.0 kg (19.8 lbs.)

Weight and dimensions shown are approximate.
Specifications subject to change without notice.

SX-780 SPECIFICATIONS

AMPLIFIER SECTION

Continuous Power Output of 45 watts* per channel, min. at 8 ohms from 20 hertz to 20,000 hertz with no more than 0.05% total harmonic distortion, or 45 watts* per channel at 4 ohms from 20 hertz to 20,000 hertz with no more than 0.08% total harmonic distortion.

Total Harmonic Distortion: (20Hz to 20,000Hz from AUX)	No more than 0.05% (continuous rated power output) No more than 0.03% (23 watts per channel power output, 8 ohms) No more than 0.03% (1 watt per channel power output, 8 ohms)
Intermodulation Distortion: (50Hz: 7,000Hz=4:1, from AUX)	No more than 0.05% (continuous rated power output) No more than 0.03% (23 watts per channel power output, 8 ohms) No more than 0.03% (1 watt per channel power output, 8 ohms)
Damping Factor:	30 (20Hz to 20,000Hz, 8 ohms)
Input Sensitivity/Impedance:	
PHONO:	2.5mV/50k ohms
AUX:	150mV/50k ohms
TAPE PLAY 1:	150mV/50k ohms
TAPE PLAY 2:	150mV/50k ohms
PHONO Overload Level:	
PHONO:	200mV (1kHz, T.H.D. 0.05%)
Output Level/Impedance	
TAPE REC 1:	150mV
TAPE REC 2:	150mV
SPEAKERS:	A, B, A+B
HEADPHONES:	Low impedance
Frequency Response	
PHONO (RIAA Equalization):	20 to 20,000Hz ±0.2dB
AUX, TAPE PLAY:	5 to 80,000Hz +0dB, −1dB
Tone Control	
BASS:	+8dB, −7dB (100Hz)
TREBLE:	+7dB, −6dB (10kHz)
Filter	
LOW:	15Hz (6dB/oct.)
Loudness Contour: (Volume control set at −40dB position)	+6dB (100Hz), +3dB (10kHz)
Hum and Noise (IHF, short-circuited A network, rated power)	
PHONO:	76dB
AUX, TAPE PLAY:	95dB

FM TUNER SECTION

Usable Sensitivity:	Mono; 10.3dBf (1.8μV)
50dB Quieting Sensitivity:	Mono; 16.2dBf (3.6μV) Stereo; 37.0dBf (39.0μV)
Signal-to-Noise Ratio (at 65dBf):	Mono; 80dB, Stereo; 72dB
Distortion (at 65dBf)	
100Hz:	Mono; 0.07%, Stereo; 0.15%
1kHz:	Mono; 0.07%, Stereo; 0.15%
6kHz:	Mono; 0.12%, Stereo; 0.25%
Frequency Response:	30 to 15,000Hz +0.2dB, −0.8dB
Capture Ratio:	1.0dB
Alternate Channel Selectivity:	75dB
Spurious Response Ratio:	65dB
Image Response Ratio:	65dB
IF Response Ratio:	90dB
AM Suppression Ratio:	50dB
Muting Threshold:	19.2dBf (5μV)
Stereo Separation:	45dB (1kHz), 35dB (30Hz to 15kHz)
Subcarrier Production Ratio:	55dB
SCA Rejection Ratio:	65dB
Antenna Input:	300 ohms balanced 75 ohms unbalanced

AM TUNER SECTION

Sensitivity:	300μV/m (IHF, ferrite antenna) 15μV (IHF, ext. antenna)
Selectivity:	26dB
Signal-to-Noise Ratio:	50dB
Image Response Ratio:	40dB
IF Response Ratio:	40dB
Antenna:	Built-in ferrite loopstick antenna

SEMICONDUCTORS

FETs:	5
ICs:	11
Transistors:	26
Diodes:	22

MISCELLANEOUS

Power Requirements:	120V 60Hz or 110/120/220/240V (switchable) 50-60Hz
Power Consumption:	150W (UL), 280VA (CSA)
Dimensions:	Without package: 18-7/8(W) x 5-1/2(H) x 12-5/8(D) inches 480(W) x 140(H) x 320(D)mm
Weight:	Without package: 24 lb. 11 oz./11.2kg

*Measured pursuant to the Federal Trade Commission's Trade Regulation Rule on Power Output Claims for Amplifiers.
NOTE: Specifications and design subject to possible modification without notice.

PIONEER

PIONEER ELECTRONIC CORPORATION /4-1, Meguro 1-chome, Meguro-ku, Tokyo 153, Japan
U.S. PIONEER ELECTRONICS CORP. /85 Oxford Drive, Moonachie, New Jersey 07074, U.S.A.
PIONEER ELECTRONIC (EUROPE) N.V. /Luithagen-Haven 9, 2030 Antwerp, Belgium
PIONEER MARKETING SERVICES PTY. LTD. / P.O. Box 317, Mordialloc, Victoria 3195, Australia

50,000F-F-12-78 Printed in Japan

Specifications TOSHIBA PC-X20

Power supply:	120 V AC, 60 Hz
Power consumption:	18 W
Track system:	4-track 2-channel (stereo)
Recording and erasing:	AC bias (85 kHz)
	AC erasure
Head:	(Record/playback) AS (All-Sendust) head to enable use of metal tape
	(Erase) 4-gap AF (Ferrite) head to enable use of metal tape.
Motor:	DC servomotor
Tape speed:	4.8 cm/sec.
Fast forward and rewind time:	About 80 seconds (for C-60)
Semiconductors:	ICs 5
	Transistors 21
	Diodes 43
	(including 31 LEDs)
Wow and flutter:	0.05% (WTD RMS)
SN ratio:	<Metal tape> 62 dB (line input, peak, WTD)
	<Chrome position tape> 58 dB (line input, peak, WTD)
	DOLBY NR <IN> mode improves SN ratio by 5 dB at 1 kHz and 10 dB at above 5 kHz.
Frequency characteristics:	0 dB input <Metal tape> . . . . 20 Hz ~ 12.5 kHz
	<Chrome position tape> . . . . 20 Hz ~ 8 kHz
	−20 dB input <Metal tape> . . . . 20 Hz ~ 18 kHz
	<Chrome position tape> . . . . 20 Hz ~ 18 kHz
	<Normal tape> . . . . 20 Hz ~ 17 kHz
Distortion:	<Metal tape> . . . . 0.4% (400 Hz, 0 dB)
Input jacks:	MIC . . . . 0.25 mV (600 ohm ~ 10 kohm)
	LINE . . . . 70 mV (over 50 kohm)
Output jacks:	LINE . . . . 0.5 V (50 kohm)
	Headphone . . . . 1 mV (8 ohm at max. volume)
Dimensions:	(W)420 x (H)116 x (D)278 mm
Weight:	5.1 kg
Accessories:	Connection cords (PIN-PIN) 2
	Head cleaning swab 1

- Specifications and appearance are subject to change without notice for performance improvement.

GENERAL SPECIFICATIONS

Power Outper Per Channel: *(Refer to Figure 3)*
45 watts continuous average sine wave power into 8 ohms with less than 0.05% THD, over a bandwidth of 20Hz to 20kHz, both channels driven.

Frequency Response: *(Refer to Figure 5)*
+0dB, −1dB, 20Hz to 50kHz.

Total Harmonic Distortion: *(Refer to Figures 6 —8)*
Less than 0.01% @ 25 watts, 8 ohms, 1kHz.
Less than 0.02% @ 25 watts, 8 ohms, 20Hz to 20kHz.

Intermodulation Distortion
Less than 0.03% using frequencies of 70Hz and 7kHz, mixed in a ratio of 4:1, single channel power output of 25 watts into 8 ohms.

Input Sensitivity
An input of 0dB* (0.775V), ±0.5dB, produces an output of 45 watts into 8 ohms, INPUT attenuator set for maximum level.

Input Impedance: *(Refer to Figure 10A)*
25kohms, minimum (unbalanced).

Actual Output Impedance: *(Refer to Figure 10B)*
Less than 0.08 ohms from 20Hz to 1kHz; less than 0.18 ohms from 20Hz to 20kHz.

Damping Factor: *(@ 8 ohms) (Refer to Figure 9)*
Greater than 100 at any frequency from 20Hz to 1kHz; greater than 45 at any frequency from 20Hz to 20kHz.

Hum and Noise
At least 110dB signal-to-noise ratio (I.H.F./A.S.A. #Z24.3-1944).

Rise Time
3.8 microseconds, or better (10% — 90% of 1 volt @ 1kHz square wave output).

Slew Rate
15 volts per microsecond, or better (at 30 watts into 8 ohms, 200kHz square-wave input).

Channel Separation: *(Refer to Figure 11)*
At least 82dB at 1kHz, at least 70dB at 20kHz.

Phase Shift: *(Refer to Figure 12)*
20Hz to 20kHz, ±10 degrees.

Offset Voltage
Less than ±30mV DC.

Unit Step Function Response
See scope photo (Figure 20, Page FOUR 4), and discussion (Page FOUR 6).

Thermal Characteristics
Massive black anodized heat sinks are thermally joined with the chassis, thereby utilizing the entire amplifier as a heat sink.

Protection Circuits
A *self-resetting* thermal switch shuts down the AC power if the power transformer winding temperature reaches 130 degrees Centigrade. See Page SIX 13 for power overload circuit discussion.

Turn On/Turn Off Characteristics
There is no turn off transient; the turn on transient is minimal (see Page SIX 13). Warm up time is less than 0.2 seconds.

Power Requirements *(Refer to Figure 13)*
AC, 120 volts nominal, 50-60Hz (105V min., 135V max.); 1.8 amperes maximum at 120VAC; 216 volt-amperes maximum at 120 volts; approximately 25 volt-amperes at idle.**

Efficiency: *(Refer to Figure 13)*
As high as 52%.

Input Connectors
One "female" XLR connector, pin 2 "hot", pin 3 connected to pin 1 (shield); switchable for pin 3 "hot". XLR is unbalanced and in parallel with two tip-sleeve (standard) phone jacks.

Output Connectors
Standard 3/4-inch spacing, "5-way" binding posts. (U.S., Canadian and Australian models)
Conventional binding posts. (other territories' models)

Indicator
"Power ON" indicator LED.

Controls
INPUT ATTENUATORS (one per channel)
22-position, log-linear, detented and dB-calibrated; they attenuate input signal in 2dB steps from 0dB attenuation to −34dB, then steps of −37dB, −42dB, −50dB, infinity.
POWER switch (ON/OFF).
INPUT POLARITY switches.

HIGH PASS FILTER switch; FLAT, 20Hz low cut or 200Hz low cut @ 12dB/octave.
MODE switch (MONO/STEREO).

Fuse
AGC (3AG) type, 3-amp fuse for the AC line input.**

Dimensions
Mounts in a standard 19-inch (48 cm) rack. 3-1/2" high (8.8 cm); maximum depth behind front panel is 11-1/4" (28.5 cm); maximum depth including front handles 12-5/8" (32.0 cm).

Weight
16 Pounds (7.2 kg).

Color
Semi-gloss black.

* *In these specifications, when dB represents a specific voltage, 0dB is referenced to 0.775V. "dBm" denotes a power level, whereas "dB" denotes a voltage level which is referenced to the voltage measured across 600 ohms. 0dBm is referenced to 1mW (0.775V RMS driving a 600-ohm termination). For example, when 12.3V is fed to a high impedance, the level is designated "+24dB". When +24dB (12.3 volts) drives a 600-ohm termination, the level is designated "+24dBm". The level in "dB" is specified, wherever applicable, to avoid confusion when the input is fed by various low and high impedance sources. See the APPENDIX beginning on Page EIGHT 1 for a further discussion of dB.*

** *For U.S. and Canadian models only. For other territories' models, see the rear panel of the P2050.*

Appendix B

Results of Isopreference Test

An isopreference test was conducted during the developmental phase to establish the approximate value and range of SNR which is perceived equivalent to various bit rates. Subjects were asked to blind-adjust the amount of noise added to an analog channel until its quality was considered equal to that of the delta coded channel at a particular bit rate. Partial results were obtained for five subjects and are presented as a function of bit rate. Values shown in the table are the noise level setting in volts rms prior to an attenuator. The mean value of this noise level for each bit rate was used to determine the corresponding signal to noise ratio on the basis of known system parameters. Results at 400 Kbit/sec. were not obtainable in the laboratory environment where the tests were made and since earphones were being used.

Subject	100 KPBS Source Noise (volts)	200 KBPS Source Noise (volts)
A	.142	.038
B	.138	.040
C	.115	.027
D	.120	
E	.105	
Mean	.124	.035
SNR (Vu)	42 dB	51 dB

The noise source was coupled to the audio system through a 100K/3K attenuator (30 dB) and the noise was bandlimited to 20 KHz by a single pole lowpass filter. Noise level was measured at the amplifier output using a HP 3555B noise measuring set with 15 KHz filter bandwidth. Standard methods were used to obtain a Vu measurement of the program signal. The meter was set to normal Vu damping and the bandwidth of measurement was 15 KHz.

Appendix C

Advertisement Used in Soliciting Participants

Subjective evaluation of high quality transmission requires skilled listeners who are able to identify minor imperfections. Skilled listeners were solicited through poster advertisements in high fidelity shops and newspaper advertisements under the "Sound Equipment" column. Copies of these advertisements are attached. Additional listeners were obtained by contacting radio station personnel, university music students and high fidelity sales or repair people. Although the investigators attempted to enlist a mixed group of listeners, female audiophiles were difficult to find. As a result, only 18% of the 33 participants were female.

ATTENTION AUDIOPHILES

TAKE PART IN A

LISTENING TEST

A novel digital transmission technique is now under study for possible broadcast applications. Listeners are required for one hour subjective evaluations. Digital transmission will be compared to original source material with controlled background noise. The test will include a standard hearing evaluation. Participants will receive a five dollar honorarium.

For further information and to arrange a time, phone 343-2673 (8:30 - 12:00 noon and 1:00 - 4:30) before Wednesday, August 6. Ask for Professor D. Dodds or Professor G. Wacker.

Department of Electrical Engineering, University of Saskatchewan.

. . . . 382-0037.

...ax camera, lenses... ...es. Phone 374-6211 af...

...UM OR LARGE format camera wanted. Also, any other photographic equipment. 242-6125.

SX70 POLAROID LAND camera. Never used. Asking $125. Call 653-2395.

Sound Equipment 123

AUDIOPHILES

Volunteers are needed for evaluation of a novel digital broadcasting technique. Listening tests will be used to determine any loss in music quality which occurs during transmission. Listener will be given a standard hearing test and a $5 Honorarium. For further information, telephone Electrical Engineering, U. of S., at 343-2673 (9-12 and 1-4 p.m.). Ask for Prof. G. Dodds.

CABINET STEREO for sale. $675. Phone 373-1326.

CONSIGNMENT
Stereo Shop

An excellent way to dispose of all your old stereo goodies. Let us do the selling. Big Shooter 821 Broadway Ave. 665-2464.

FOR SALE: 1 Kenwood 7100, 1 Teac A103, 1 SSII, Techinques SL1401, ADC MQ XLM MKIII. Infinity Cupe. After 7, 664-2075.

MODERN STEREO with stand & speakers. $150. 653-1490.

MUST SELL: San-Sui speakers, Akai deck, turntable, amp., 6 pieces. $400. 343-9137.

PIONEER 1000 CASSETTE deck. New, in sealed box. Cost $1000, offers. 759-2381.

STEREO FOR sale. 373-5305.

YAMAHA PA system for sale including EM 150 6 channel amp, mixer, with reverb, equalization, monitor system, etc. Also, HS 1115 speakers, excellent sound for instruments or vocal. Two AKG mikes, D-160 & D-190. Speaker & mike lines included. $2,000 takes all, ask for separate prices. After 7, 664-8986.

Sol...
YELL... $1.00. Ph... south on L... Club, turn ri... and go to sign:

Pets

ADORABLE American Coc... livered anyw... van.

AUSTRALIA... $25 each. 477-... den. Will bri...

BEA'S COU... ing to small, 661-2339.

BLACK MA... $150. 2 Budg... Also small ...

CHAMPION... Puppies for...

CLIP' CLE... and profes...

COCKER S... istered, rea... 2683.

D...
JANLYN... Breeders c...

EXCELLE... trainable ... German S... 8249.

FEMALE ... Other kitt... Delisle.

FERRET ... children, ... 9111, roo...

FLUFFY ... Please c... John A.

FOR ... and reg... tact CK... 7317.

FOR SA... and cag... icking ...

KITTE...

Listener Mailing List

August 1980

1.	Dave Allen	21 - 3719 - 8th St. East	374-7938
2.	David Bailey	1772 East Heights	373-9273
3.	Gerry Bowers	22 - 2512 Louise Street	374-9253
4.	Brian Clavier	920 - 10th Street East	665-7967
5.	Susan Clayton	2620 - 7th Street East	374-6523
6.	Craig Cowper	309 - 865 Confederation Drive	384-2752
7.	Mark Poepker	202 - 27th Street West	653-4370
8.	D.E. Dodds	Dept. of Electrical Engg.	373-2673
9.	Arthur Dyck	1025 - 12th Street East	343-7871
10.	Ron Eisler	222 Winnipeg Avenue North	382-8781
11.	Dorothy Forrest	2921 Cumberland Avenue South	373-2956
12.	Donna Fraser	2502 William Avenue	343-2956
13.	Beatrice Gaudet	455 - 423 Pendygrass Road	384-6724
14.	Ed Gregorich	1402 Wiggins Avenue	343-1075
15.	Joan Gregorich	1402 Wiggins Avenue	343-1075
16.	Bruce Klein	215 Streb Crescent	382-8897
17.	Bob Layh	408 - 423 Pendygrass Road	384-1401
18.	Lloyd Litwin	1543 - 10th Avenue North	664-2327
19.	Jerry Lucky	Box 514, Saskatoon	244-0734
20.	Pat Mahan	1023 - 7th Street East	343-6486
21.	Mike Neudouf	214 Guelph Crescent	373-7231
22.	Kent Newson	111 Michener Crescent	384-2658
23.	Dave Nicholson	1109 - 15th Street East	665-7368
24.	Daphne (Laurel) Osborn	8 - 1216 Morgan Avenue	373-2407
25.	Nick Penry	114 - 109th Street	373-0501
26.	Al Pippin	Box 47, R.R. 3	668-4835
27.	Robin Robinson	1318 McKercher Drive	373-5253
28.	Rod Rollack	2309 Hanover Avenue	343-0708
29.	Richard Thiessen	419 - 109th Street	373-3224
30.	Ron Trischuk	430 Avenue L North	244-1867
31.	Martin Wacker	25 Webb Crescent	374-1747
32.	John Werle	724 Broadway Avenue	652-0002
33.	Ed Wojczynski	2332 Munroe Avenue	343-0994

APPENDIX D1

Listener's Score Sheet

SUBJECTIVE EVALUATION OF DELTA CODECS

The purpose of this test is to evaluate the quality of reproduction using a digital coding technique. Higher quality can be achieved with increased digital coding rate. Unfortunately, this results in more costly transmission. Several coding rates will be assessed in the tests. Digitally coded reproduction is to be evaluated by comparison with high quality sound tracks from six different musical selections and with similar tracks distorted with various additive noise levels. The test consists of two parts and a hearing assessment.

Part 1 - Comparison Test

This part is an AB comparison test. You will be asked to make a series of 34 individual assessments. For each assessment, you will hear a 10 second interval of music using reproduction method A, then using method B. This sequence will immediately be repeated, i.e.: A, B, A, B. You must then assess which is better or if the two are equal in quality. This sequence cannot be repeated and you will have approximately 20 seconds to mark your choice. You will not know which passage, if either, has been digitally coded.

Part 2 - Subjective Evaluation

Using your own musical listening experience as a guide, please judge the quality of each of the musical segments using the scale shown below. Mark your evaluation with a circle on the scale as follows:

Each segment will be one minute long and cannot be repeated; you will then have a few seconds to indicate your evaluation.

Listeners Name ______________________ Address ______________________

Age __________ Telephone No: ______________ ______________________

Male/Female (Cirle one)

Musical Background ____

____

TABLE I

LINE	JUDGEMENT			COMMENT
1	A	B	EQUAL	
2	A	B	EQUAL	
3	A	B	EQUAL	
4	A	B	EQUAL	
5	A	B	EQUAL	
6	A	B	EQUAL	
7	A	B	EQUAL	
8	A	B	EQUAL	
9	A	B	EQUAL	
10	A	B	EQUAL	
11	A	B	EQUAL	
12	A	B	EQUAL	
13	A	B	EQUAL	
14	A	B	EQUAL	
15	A	B	EQUAL	
16	A	B	EQUAL	
17	A	B	EQUAL	
18	A	B	EQUAL	
19	A	B	EQUAL	
20	A	B	EQUAL	
21	A	B	EQUAL	
22	A	B	EQUAL	
23	A	B	EQUAL	
24	A	B	EQUAL	
25	A	B	EQUAL	
26	A	B	EQUAL	
27	A	B	EQUAL	
28	A	B	EQUAL	
29	A	B	EQUAL	
30	A	B	EQUAL	
31	A	B	EQUAL	
32	A	B	EQUAL	
33	A	B	EQUAL	
34	A	B	EQUAL	

TABLE II

BAD POOR FAIR GOOD EXCELLENT

1.

2.

3.

BAD POOR FAIR GOOD EXCELLENT

4.

5.

6.

7.

BAD POOR FAIR GOOD EXCELLENT

8.

9.

10.

11.

BAD POOR FAIR GOOD EXCELLENT

12.

13.

14.

15.

BAD POOR FAIR GOOD EXCELLENT

16.

17.

18.

19.

BAD POOR FAIR GOOD EXCELLENT

20.

21.

22.

23.

BAD POOR FAIR GOOD EXCELLENT

24.

25.

26.

BAD POOR FAIR GOOD EXCELLENT

27.

28.

Hearing Assessment

An audiometer is used to check your hearing ability at various frequencies and intensity levels.

Hearing Loss (db)	Frequency										
	125	250	500	750	1000	1500	2000	3000	4000	6000	8000
0											
5											
10											
15											
20											
25											

Hearing Loss (db)	Frequency										
	125	250	500	750	1000	1500	2000	3000	4000	6000	8000
0											
5											
10											
15											
20											
25											

Appendix D2

Raw Data Entered to SPSS Program

The following computer printouts list the data which was obtained from the listeners. The table on the right indicates subjective rating, the center table indicates A/B preference and the table on the left indicates subject information. The middle table shows a 1 where the first process was preferred, it shows a 2 when they were considered equal and shows a 3 when the second process was preferred. The information table shows 2 digits for listener number, 2 digits for listener age, and 1 digit each for listener sex (0 = female, 1 = male), for musical background (3 = good, 2 = moderate, 1 = little), left ear hearing (3 = good, 2 = fair, 1 = poor) and right ear hearing.

LLAASMLR	TESTS AB1 TO AB34	TESTS SUBJECTIVE 1 TO 28
01221333	1113232213113311311211331332222122	3756531856774728176717582466
02221333	1133233232311211312213333132232123	1959353939671935183918553294
03271322	1211122311111232212211321332133111	4433432445454544454665754435
04251323	1323112211311223112232223212223122	7936544757496537285334853156
05170222	1112232232212312221213321221222323	6968788759993938388888975377
06231311	1221222123312231111213311322321121	1788751738861326154526452182
07351211	1232323231112213312313331212212133	1868385958472515264535343000
08231312	1122312211113133112213211123312121	7868865876686887586878583455
09271321	1213313231213311313213331123211133	1776472758762827387757674000
10211321	1122222231113231132313223232332123	3858382735443736365835561000
11320221	1111332211112123111232311111122121	5677353757675748777667783673
12200233	3213333231233313121331323331332321	5667765766583547478746564454
13243011	1212232221132213121112321331121132	4783535574562486863488864629
14261111	1232323331211333312222331123323311	5868573858884848488777882578
15250322	1313113232112313312131323113233132	4732324958672966788877765667
16281111	1123112112231113322332331313232323	5764554755472545665465664577
17221321	1311112311112223111211211311212123	4835411656463525162537431000
18241222	1133122213113321313213223313233133	5858733777786767376867576000
19261333	1313322313333131122123113122223133	3756454657672726162786561323
20300312	1232312231221122312223331133232122	4785663754862637688676887767
21211232	1113122213113323212211321333213123	2766755767873756188758781616
22211333	1211132213112312122213123322122321	7425564756776576757788865637
23211323	1113112331132211313213333211232123	1857281948653815163424351363
24400311	1231322312222233112233323321222322	8653446865465879374788945356
25201333	1131132212132311112211311312232123	3857342668373736174655361475
26271312	1133212211123112113213321113222123	5727451777672734175577661000
27271321	1111222211111121111213211111212132	7757683887565658664587764568
28271333	1331273233112323112211311312312123	7536534776675788374685773535
29381332	1333133133332332312313323332332233	6755544766576565376676655547
30331212	1333333213113133311233233332232122	2868282826583827274735342285
31181321	1311322213112132312211313211313121	5767674657664655366757765645
32281311	1332223211312333131323232211132321	4523424332343443532445444223
33281223	1132233223121333212212223133322132	2697453776763746456866573567

LL - LISTENER NUMBER
AA - LISTENER'S AGE
S - LISTENER'S SEX
M - LISTENER'S MUSICAL BACKGROUND
L - QUALITY OF LEFT EAR
R - QUALITY OF RIGHT EAR

The data table presented below is a transposition of the previous subjective rating table. This permitted analysis of the subjects using the SPSS software.

```
SSQQQQ ┌───SUBJECT 1 TO SUBJECT 33───┐
       ↓                             ↓
010300315741151344333554331627356652461
020800795977866855666797766397876468675
030597554348646565742644575164524246548
040800694668865866261467645482776548656
050500535557363326432556456433345442563
060675354465846845251522554593457238644
070375133461561224413422424325212332362
081100895757966766468776666697677668556
090600535533554345634566545455677652456
100597696778847565367576736594876558645
110742765478446454465456677673364545556
120500776976765467566777756665775668565
130100415611241342121245212544324453352
141100796573568764368566756497775648566
150400235312161333725435224626334752463
160675855766556676565566665568647747455
170200115211232363726622151622115222273
180900786865667666567676677476775667554
190500635564446567267535277643453354545
200742797365566856357467756656654557667
210200117362354353756645864737577763465
220800786466566565756586657757576455675
230597558874335564766654576748366653664
240700856555466675565646677563665644566
250675235332313123314425161424113242462
260500425111020053535500365542404442544
270500694558030064155700251274705238345
280500646652030023866700365645507465456
```

SS - SELECTION NUMBER
QQQQ - SELECTION QUALITY (ASSIGNED)

Appendix E1

This appendix lists the order and content of the A/B Preference Tests as recorded on tape. The "line" designation corresponds to Table 1 of the listener score sheet.

Line	Selection	DM vs Noise		Equal	DM vs Original	
1	4				0	DM 100
2	1	DM 200	SNR 48			
3	1				0	DM 200
4	4				0	DM 400
5	1	SNR 42	DM 100			
6	5			DM 200		
7	3				DM 400	0
8	5				DM 300	0
9	3				0	DM 250
10	3	SNR 39	DM 100			
11	6				0	DM 300
12	5	DM 200	SNR 51			
13	1			DM 400		
14	4				DM 250	0
15	2	DM 100	SNR 42			
16	1				0	DM 200
17	3	SNR 60	DM 400			
18	6	SNR 51	DM 200			
19	5				DM 350	0
20	6				DM 150	0
21	4	SNR 45	DM 100			
22	4	DM 400	SNR 60			
23	2				DM 250	0
24	3				0	DM 300
25	2				0	DM 200
26	4			ORIG.		
27	4	SNR 54	DM 200			
28	4				DM 350	0
29	5	SNR 57	DM 400			
30	3				0	DM 200
31	1				DM 300	0
32	1	SNR 63	DM 400			
33	1				DM 250	0
34	2			Buff/orig.		

Appendix E2

This appendix lists the order and content of the Subjective Rating Tests as recorded on the tape. The "line" designation corresponds to Table II of the listener score sheet.

Line	Selection	Processing
1	Mahler (1)	SNR 45 dB
2	Cobham (3)	SNR 60 dB
3	P. Floyd (4)	DM 250
4	Cobham (3)	DM 400
5	P. Floyd (4)	SNR 51 dB
6	Cobham (3)	DM 300
7	Emerson (6)	CM 150
8	Cobham (3)	Original
9	Mahler (1)	SNR 54
10	Eagles (2)	DM 250
11	P. Floyd (4)	DM 350
12	Eagles (2)	DM 200
13	Eagles (2)	SNR 39
14	Boyd (5)	Buffer Amps.
15	Emerson (6)	SNR 48
16	Boyd (5)	DM 300
17	Mahler (1)	DM 100
18	Boyd (5)	SNR 63
19	P. Floyd (4)	DM 200
20	Boyd (5)	DM 350
21	Cobham (3)	SNR 42
22	Boyd (5)	DM 400
23	Mahler (1)	DM 250
24	P. Floyd (4)	SNR 57
25	Emerson (6)	DM 300
26	P. Floyd (4)	CJUS-FM
27	Cobham (3)	CJUS-FM
28	Eagles (2)	CJUS-FM