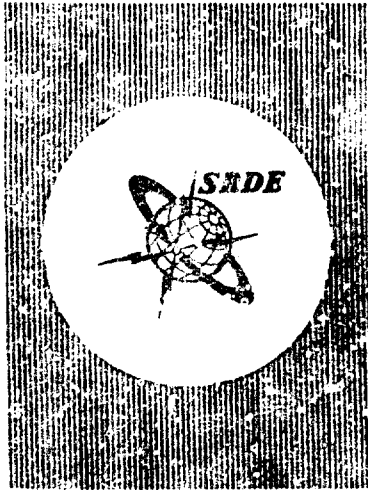


AD 696931

69014



UNLIMITED

SIGNALS RESEARCH & DEVELOPMENT  
ESTABLISHMENT

THE RATING OF  
 DELTA SIGMA MODULATING SYSTEMS,  
 WITH CONSTANT ERRORS,  
 BURST ERRORS AND TANDEM LINKS  
 IN A FREE CONVERSATION TEST  
 USING THE REFERENCE SPEECH LINK

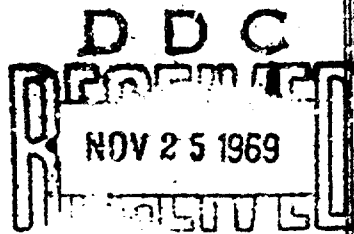
by

L. S. Butler

and

Lesley Kiddle

MINISTRY OF TECHNOLOGY  
CHRISTCHURCH, HANTS.



SIGNALS RESEARCH AND DEVELOPMENT ESTABLISHMENT  
MINISTRY OF TECHNOLOGY

REPORT NO. 69014

U. D. C. No. 534.781+621.376.5

THE RATING OF DELTA SIGMA MODULATING SYSTEMS, WITH CONSTANT  
ERRORS, BURST ERRORS AND TANDEM LINKS, IN A FREE  
CONVERSATION TEST USING THE REFERENCE SPEECH LINK

by

L. S. Butler  
and Lesley Kiddle

SUMMARY

This report describes a free conversation opinion test, designed on a statistical basis, to assess the performance of Delta Sigma equipments, connected both singly and in tandem. Tests were made at digit rates of 19.2 kb/s and 12 kb/s. The single links were tested with errors introduced into the digit stream, the errors being either randomly distributed at a constant density of 10% or in bursts.

In all cases the Delta Sigma equipments were rated higher on the sensitivity/noise scale than the Army Standard.

FEBRUARY 1969

## C O N T E N T S

<u>Section</u>		<u>Page</u>
1	INTRODUCTION .....	1
2	EQUIPMENT SET-UP .....	2
3	EXPERIMENTAL PROCEDURE .....	3
4	RESULTS AND ANALYSIS .....	5
5	CONCLUSIONS .....	8
	REFERENCES .....	9
APPENDIX A	COMPARISON OF RHYME TEST WITH FREE CONVERSATION TEST .....	10

## ILLUSTRATIONS

- Figure 1 Input/output characteristics of delta sigma equipment
- Figure 2 The Army Standard System
- Figure 3 Schematic diagram of delta sigma link
- Figure 4 Age distribution of subjects
- Figure 5 Circuit conditions
- Figure 6 Latin square
- Figure 7 Conversation material, a typical pair of photographs
- Figure 8 Opinion Form 8A
- Figure 9 Table of Results of Free Conversation Test
- Figure 10 R. S. L. Characteristic and rating of "unknown" circuits in Free Conversation Test.
- Figure 11 Example of Rhyme Test Word Cards
- Figure 12 Table of Word Results
- Figure 13 R. S. L. Characteristic and rating of "unknown" circuits in Rhyming Word Test.

## 1. INTRODUCTION

1.1 The tests described in this report were carried out by Acoustics Group with the object of assessing

- (a) the performance of various combinations of Delta Sigma links in tandem
- (b) the performance of single Delta Sigma links with random and burst errors introduced into the digit stream.

The circuits under test were compared with the Army Standard circuit using the Reference Speech Link (RSL)<sup>1</sup>.

As part of an attempt to relate assessments made using the free conversation test with assessments made by other subjective methods, the test circuits were also compared using a modified rhyme test<sup>2</sup>. Details of this test are given in Appendix A.

1.2 The digital equipments were made at S.R.D.E. and are models of the GEC Mk. 3 Companded Delta Sigma Modulation System<sup>3</sup>.

1.3 The systems tested were as follows:-

- (a) Four wire speech circuit provided by the GEC. 3 Delta Sigma system working at a digit rate of 19.2 kb/s.
- (b) Four wire speech circuit provided by the GEC. 3 Delta Sigma system working at a digit rate of 12 kb/s.
- (c) Four wire speech circuit provided by the GEC. 3 Delta Sigma system working at a digit rate of 19.2 kb/s with bursts of 50% errors, 1536 digits long, introduced randomly at an average rate of one every 3.4 seconds into the digit stream.
- (d) Four wire speech circuit provided by the GEC. 3 Delta Sigma system working at a digit rate of 19.2 kb/s with bursts of 50% errors, 1536 digits long, introduced randomly at an average rate of one every 0.4 seconds into the digit stream.
- (e) Four wire speech circuit provided by three GEC. 3 Delta Sigma links connected in tandem through analogue interfaces, the digit rates being 19.2, 19.2 and 19.2 kb/s respectively.
- (f) Four wire speech circuit provided by three GEC. 3 Delta Sigma links connected in tandem through analogue interfaces, the digit rates being 12, 19.2 and 12 kb/s respectively.

- (g) Four wire speech circuit provided by two GEC. 3 Delta Sigma links connected in tandem through analogue interfaces, the digit rates being 12 and 19.2 kb/s.
  - (h) Four wire speech circuit provided by 12 kb/s GEC. 3 Delta Sigma system with randomly distributed digital errors introduced into the digit stream at a constant density of 10%.
- 1.4 The circuits under test, together with the Army Standard, were rated with the Reference Speech Link in a free conversation test<sup>4</sup>.

## 2. EQUIPMENT SET-UP

- 2.1 All the systems under test were located in the laboratory, and the handsets were extended into separate test rooms to isolate them from the equipment noise.
- 2.2 The input level to the digital system was adjusted just to avoid peak clipping with a speech input at mean normal talking level. The optimum level was defined for each digit rate as the speech signal having a peak amplitude equal to the peak amplitude of a sinusoidal signal of a 1000 Hz, at the level at which the input/output characteristic just begins to deviate from linear with increasing input level. However, the optimum levels for the two digit rates were not greatly different, and the figure appropriate to the 12 kb/sec digit rate was used for all circuit conditions. Since the Delta Sigma links used were designed as zero-loss circuits, this avoided the need for level matching between links in the tandem connections. Input/output graphs for a sinusoidal signal of 1000 Hz are shown in Figure 1.
- 2.3 The listening levels used for the digital circuits measured in terms of the signal voltage applied to the telephone receivers, were as determined for a previous experiment by a preferred listening level test<sup>5</sup>.
- 2.4 In tests on tandem links, each individual duplex link was fed from a separate power supply and digit rate generator to reduce the possibility of analogue speech breakthrough or crosstalk. Tests made with optimum signal level applied to the input of one tandem channel only showed that the signal level measured at the receive end of the same channel either with any digital signal path broken or with the clock signal removed from any one demodulator was not larger than -50 dB relative to the normal receive signal. The signal at the receive end of the other channel (near-end crosstalk) with all connections intact was -56 dB relative to the normal receive level, though any crosstalk here would merely add to the sidetone signal during actual tests.

- 2.5 The randomly distributed digital errors were introduced into the digit streams using an S. R. D. E. designed generator of random errors of controllable density<sup>6</sup>.
- 2.6 The burst errors were introduced by using gating circuits to replace 1536-digit groups of traffic digits by random digits at the same bit rate, the interruptions occurring randomly but at controllable average rates. Tests using this form of interruption were originally included in connection with a possible need to introduce synchronising patterns into the traffic stream. However, the results may have relevance to interruptions arising in other ways, e. g. intermittent losses of received signal. Since any digit in the random burst has a 50% probability of having the same state as the digit in the traffic stream which it replaces, the random stream represents the traffic stream with 50% errors. (100% errors would merely invert the traffic stream and the output waveform).
- 2.7 The handsets used with all systems were chosen at random from a number of instruments which had been tested to specification prior to the experiment. These handsets were fitted with earphone element, magnetic, Y1/5965-99-940-2368. The microphone for the RSL and Delta Sigma systems was the microphone element, magnetic Y1/5965-99-901-1184 and for the Army Standard system microphone capsule (carbon) No. 10, YA-7982 was used.
- 2.8 The microphone used with the digital systems has a rising frequency response resulting in an output speech voltage spectrum which is substantially flat. This type of input suits the flat overload characteristic of the GEC. 3 Delta Sigma system.
- 2.9 The sensitivity/noise settings of the RSL<sup>4</sup> used for the RSL circuit tests were 45, 33, 21 and 9 dB. These were thought to have a wide enough range to cover the "unknown" circuits.
- 2.10 The Army Standard circuit, which consisted of two telephone sets 'J' connected by 24 miles of cable, electric, D10, had an attenuation of 36 dB at 1000 Hz. An artificial cable designed in sections of 4, 8 and 12 miles was used in the laboratory.
- 2.11 Details of the test circuits are given in Figures 2 and 3.

### 3. EXPERIMENTAL PROCEDURE

- 3.1 The selection of 13 pairs of subjects for the tests was facilitated by the use of an Elliott 920A computer. The computer was programmed to select from the S. R. D. E. civilian staff list a group of 26 members (22 males and 4 females) who had not

participated in a recent test and whose age distribution was similar to that of the officer population of the British Army (Figure 4). The final list was arranged as 11 pairs of male subjects and 2 pairs of female subjects.

- 3.2 Each pair appeared for four separate sessions of approximately 30 minutes duration over a period of two weeks, three circuit conditions being presented at each of three sessions and four circuit conditions at the fourth. The subjects were given no information about the circuit conditions during the experiment.
- 3.3 The final selection of 13 circuits (Figure 5) consisted of four settings of the RSL, the Army Standard and the eight systems under test.
- 3.4 The order in which the 13 circuits were presented to a given pair of subjects was determined from a randomised 13 x 13 latin square (Figure 6), which was obtained from statistical tables. This reduced systematic errors to a minimum.
- 3.5 The subjects were housed in separate rooms, designated F and G, having contact with the operator via a monitoring system in the main laboratory. Extraneous noise was largely excluded from the rooms. Ambient noise, typical of that experienced in city offices<sup>7</sup>, was artificially set up and controlled. The two rooms, although acoustically different in normal use, were modified with suitable materials to produce similar ambient noise characteristics at the positions occupied by the subjects. The effects of any remaining differences were reduced by ensuring that the subjects alternated between the rooms during the course of experiment.
- 3.6 The subjects were allowed to converse in as free and natural a manner as the circuit condition permitted. To stimulate conversation, the subjects were provided with photographs of local scenes (Figure 7). For each test, a pair of photographs was used showing the same scene from the same view point but with a short time lapse between them, so that similarities and differences could be discussed.
- 3.7 After talking for about 10 minutes the participants were asked to express, separately, their opinion of the circuit, in terms of the effort required to conduct the conversation. A 5 point scale, form 8A (Figure 8) was used.

The opinions were subsequently given numerical values of A=4, B=3, C=2, D=1 and E=0, and the results were then passed to Computer Applications Group for analysis using the Elliott 920A Computer.

#### 4. RESULTS AND ANALYSIS

- 4.1 The table (Figure 9) shows the numerical scores obtained by the subjects for each circuit condition. Mean opinion scores and statistical analyses are given in tables 1 and 2.
- 4.2 The characteristic for the RSL (Figure 10) was obtained by plotting the mean opinion scores against the sensitivity/noise ratios. The mean opinion scores for the remaining circuit conditions are shown as intercepts on the RSL characteristic. In this manner the rating for the Army Standard and the 'unknown' circuits were obtained in terms of sensitivity/noise settings on the RSL. These are listed in Table 1.

TABLE 1

Circuit Condition	Mean Opinion Score	Standard Deviation (Opinion)	Rating on RSL Scale dB	dB Relative To Army Standard	dB Relative to OEC.3 12kb/s 10% Constant Errors	95% Confidence Limits	
						± Opinion Score	± dB Equivalent on RSL Scale
RSL 45 dB	3.57	0.757	45	+34.5	+33.2	0.306	
RSL 33 dB	3.46	0.647	33	+22.5	+21.2	0.261	
RSL 21 dB	2.85	0.925	21	+10.5	+ 9.2	0.374	
RSL 9 dB	1.23	0.951	9	- 1.5	- 2.8	0.384	
Army Standard	1.46	0.948	10.5	0	- 1.3	0.383	1.8
Delta Sigma 12kb/s 10% Constant Errors (K)	1.69	0.837	11.8	+ 1.3	0	0.338	2.4
Delta Sigma 19.2 kb/s 0 Errors (D)	3.27	0.533	27.2	+16.7	+16.4	0.215	4
Delta Sigma 12 kb/s 0 Errors (H)	2.54	0.706	18	+ 7.5	+ 6.2	0.285	2
Delta Sigma 19.2 kb/s Burst Errors 1 in 3.4 secs (C)	2.76	0.908	19.7	+ 9.2	+ 7.9	0.367	3
Delta Sigma 19.2 kb/s Burst Errors 1 in 0.4 secs. (I)	1.54	0.706	11.2	+ 0.7	- 0.6	0.285	1.7
Delta Sigma Tandem Link 19.2+19.2+ 19.2 kb/s(B)	2.65	0.846	18.8	+ 8.3	+ 7.0	0.342	3
Delta Sigma Tandem Link 12 + 19.2+ 12 kb/s (G)	2.12	0.653	14.5	+ 4.0	+ 2.7	0.264	2.5
Delta Sigma Tandem Link 19.2+12 kb/s (L)	2.50	0.707	17.5	+ 7.0	+ 5.7	0.286	2

TABLE 2

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio F	Significance relative to 0.05 significance level
Circuits (13)	188.5	12	15.7	30.72	Very highly significant
Subjects (26)	40.8	25	1.96	3.83	Significant
Residual	153.2	300	.511		
Total	390.5	337	1.162		

## 5. CONCLUSIONS

5.1 In the Free Conversation Test, the digital systems were rated in the following order:-

- (1) D 19.2 kb/s 0 errors
- (2) C 19.2 kb/s burst errors, 1 in 3.4 secs.
- (3) B 19.2 + 19.2 + 19.2 kb/s tandem link.
- (4) H 12 kb/s 0 errors
- (5) L 12 + 19.2 kb/s tandem link
- (6) G 12 + 19.2 + 12 kb/s tandem link
- (7) K 12 kb/s 10% constant errors
- (8) I 19.2 kb/s burst errors, 1 in 0.4 secs.

The first six circuits were rated better than "moderate effort required to carry out a conversation". Circuits K and I came out higher than "considerable effort required". All the digital circuits were rated higher than the Army Standard. Among the digital circuits tested, I and K were the only ones to be given a rating of "extreme effort required, prolonged conversation impossible", and in each case this rating was given only once. Four "extreme effort" ratings were recorded for the Army Standard.

5.2 It will be noted that the ratings of circuits C, B, H and L have overlapping confidence limits, i. e. the order of their ratings relative to each other has no statistical significance. Similarly the ordering of circuits K, I and the Army Standard is not significant.

5.3 The rating of the Army Standard was markedly lower than in the previous experiment<sup>5</sup>. It has been observed that the absolute rating of a circuit repeated from experiment to experiment is to some extent dependent on the distribution relative to it of the subjective standards of difficulty of the remaining circuits, i. e. the circuit is rated higher if all other circuits are considered more difficult and lower if all other circuits are considered easier. In the present experiment, all the digital circuits were rated higher than the Army Standard, whereas in the previous experiment more than half the test circuits were rated below the Army Standard. However, each experiment is considered to give a reliable ordering of the circuit assessments within the limits of the statistical significance.

## REFERENCES

1. BUCK, G. A. "Rating of the Post Office transmission standard and other transmission systems with the Reference Speech Link". POED Research Report No. 20561.
2. H. Q., E. S. D., L. G. Hanscom Field, Bedford, Mass.  
ESD, TDR 63-403 "Psycho-acoustic speech tests: A modified rhyme test" June 1963.
3. WILKINSON, R. M. "A Companded Delta Sigma Modulation System" SRDE Report No. 68012.
4. BUCK, G. A. "The Working Reference Telephone Circuit for Speech Link Assessment Studies". POED Research Report No. 20220.
5. BUTLER, L. S. "The rating of Variable Slope Delta and Delta Sigma Modulating Systems in a Free Conversation Test using the Reference Speech Link".. S.R.D.E. Report No. 68024.
6. FULFORD, J. F. "A 2 Channel Random Error Generator" SRDE Memorandum No. T6/67.
7. HOTH, D. F. "Room Noise Spectra at Subscribers Telephone Locations". JASA Vol. 12, No. 4. April 1941.

## APPENDIX A

### COMPARISON OF RHYME TEST WITH FREE CONVERSATION TEST

1. As an attempt to relate assessments made using a modified rhyme test<sup>2</sup> to those made in the free conversation test, each subject was asked, at the conclusion of the conversation on each circuit condition, to read out a selection of the words used in the rhyme test. These words were two and three syllable consonant and vowel combinations of the form CV, VC and CVC. The words used were arranged in 104 groups of six, the words in any one group differing from one another by the consonant in a constant end position (i. e. first or last syllable). The selections were chosen so that each subject pair used the whole sequence of groups during the experiment, allowing 4 groups to be used by each subject for each circuit condition. Similarly each circuit condition was tested with every word group during the experiment, so that 104 decisions were made per circuit condition. In any one circuit condition, the speaker read out one word from each of the four groups provided, the words used having been pre-determined by random selection (Figure 11). To control variations in inflection to some extent, each word was embedded in the phrase "will you try. . . now". The words "try" and "now" were chosen for use in the phrase as having final and initial syllables respectively which do not readily form compounds with the initial or final syllables of the test word. The listener selected and noted on his copy of the word list the word which he thought he heard.
2. The numbers of words correctly received were logged, and Figure 12 shows the scores obtained by each subject for each circuit condition. These results were passed to Computer Applications Group for analysis using the Elliot 920A computer, and the results are given in Tables 3 and 4. The mean scores are plotted relative to the RSL scores in Figure 13.
3. The results of the rhyme test as a means of ordering the circuit conditions were disappointing insomuch as the lowest mean subject score was 2.8 words out of 4 received correctly, whereas it had been hoped that the range of circuits would produce results covering the full range of word scores. Reference to Table 3 shows that many of the differences between the main scores for the different circuit conditions are not statistically significant, so that no reliability can be attached to the ordering of the circuits on the basis of the scores, and in fact this ordering is quite different from that obtained from the free conversation test. This result suggests that insufficient words were used in the experiment.
4. The high scores obtained in the rhyme test for circuit conditions rated as difficult by the free conversation test may arise because a degree of attention higher than that which would be considered highly

exhausting for a conversation test can be applied for the short time necessary to carry out the word test. Analysis of the errors shows that about one third of the speech sounds incorrectly heard were confused with sounds within the same phonetic groups, e. g. t with k, m with n, etc. These are confusions which can commonly occur in the presence of noise. The remaining errors, which were distributed over the whole range of speech sounds used, appeared to be attributed randomly to other speech sounds and probably contain a proportion of guesses. The results suggest that the ratings of the circuits largely reflect the varying degrees of quantising and error noise accompanying the signal, as would be expected, rather than any characteristics causing impairments in the received speech which are selective in their effect on the various speech sounds.

TABLE 3

Circuit Condition	Mean Correct Word Score out of 4	Standard Deviation	Rating on RSL Scale dB	95% Confidence Limits
				$\pm$ Correct Score
RSL 45 dB	3.92	0.272		$\pm 0.109$
RSL 33 dB	3.88	0.325		$\pm 0.135$
RSL 21 dB	3.84	0.464		$\pm 0.187$
RSL 9 dB	3.35	0.628		$\pm 0.254$
Army Standard	2.96	1.14	5.5 *	$\pm 0.464$
Delta Sigma 12 kb/s 10% Constant Errors	3.04	0.999	6.0 *	$\pm 0.403$
Delta Sigma 19.2 kb/s 0 Errors	3.46	0.989	11.0	$\pm 0.399$
Delta Sigma 12 kb/s 0 Errors	3.62	0.697	14.0	$\pm 0.281$
Delta Sigma 19.2 kb/s Burst Errors 1 in 3.4 sec.	3.615	0.571	14.0	$\pm 0.231$
Delta Sigma 19.2 kb/s Burst Errors 1 in 0.4 sec.	3.19	0.633	7.5 *	$\pm 0.256$
Delta Sigma Tandem Link 19.2 + 19.2 + 19.2 kb/s	3.12	0.746	6.6 *	$\pm 0.349$
Delta Sigma Tandem Link 12 + 19.2 + 12 kb/s	2.81	0.749	4.0 *	$\pm 0.302$
Delta Sigma Tandem Link 19.2 + 12 kb/s	3.30	0.884	8.9	$\pm 0.357$

\* Extrapolated values

TABLE 4

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio F	Significance relative to 0.05 significance level
Circuits (13)	41.8	12	3.49	6.31	Significant
Subjects (26)	18.85	25	.752	1.36	Not significant
Residual	166	300	.553		
Total	226.65	337	.673		

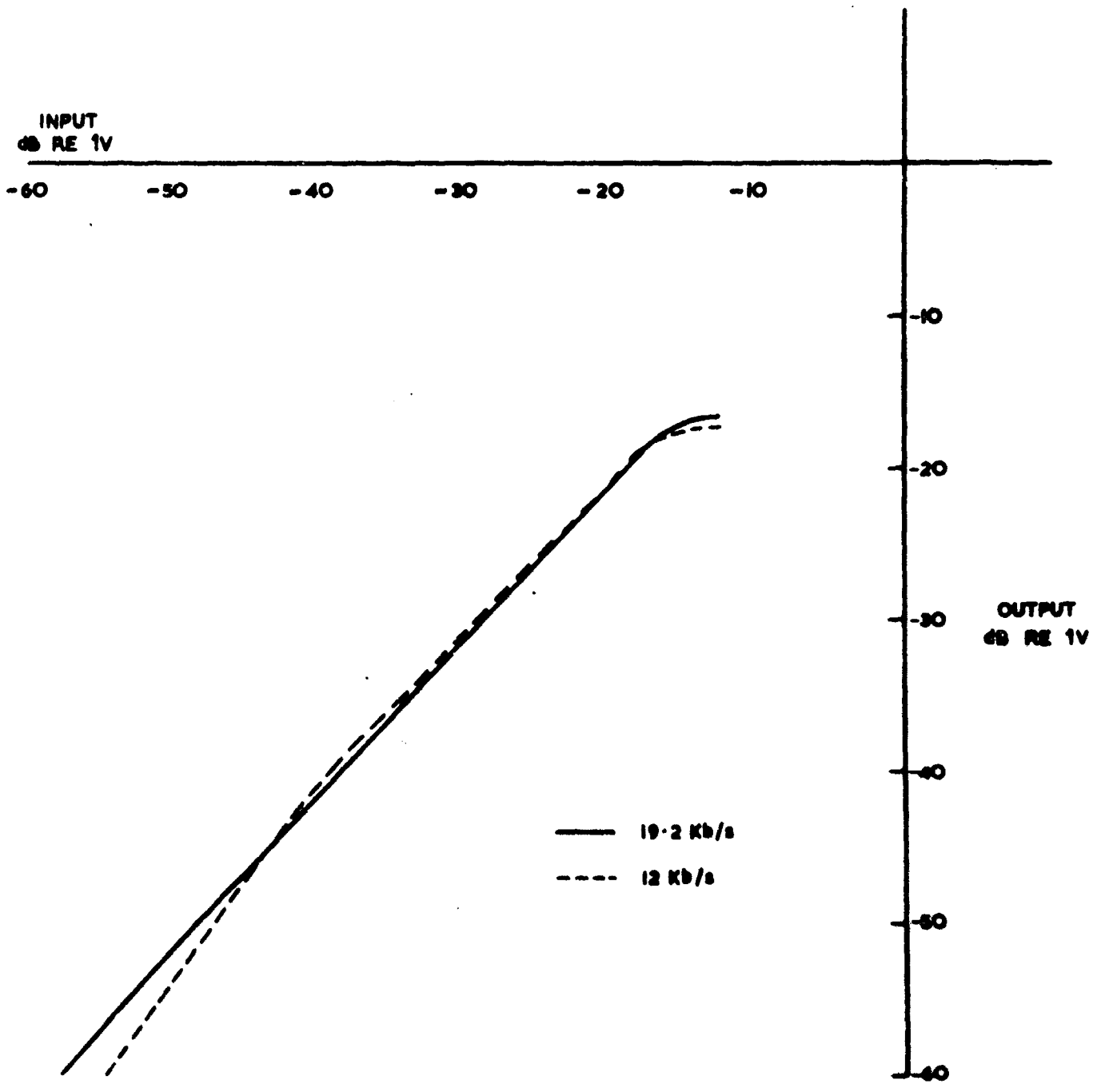
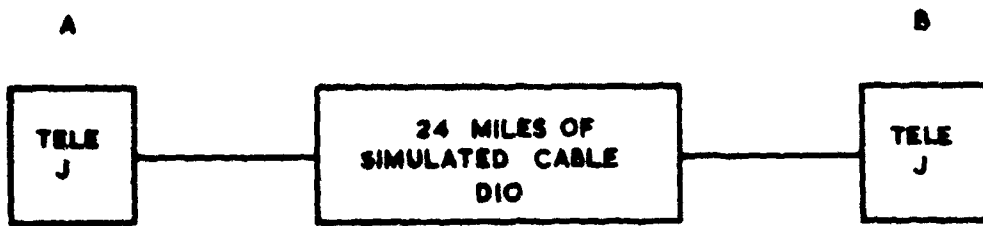


FIG 1 INPUT /OUTPUT CHARACTERISTICS OF SEC III DELTASIGMA EQUIPMENT

PRECEDING PAGE BLANK



**FIG 2 THE ARMY STANDARD SYSTEM**

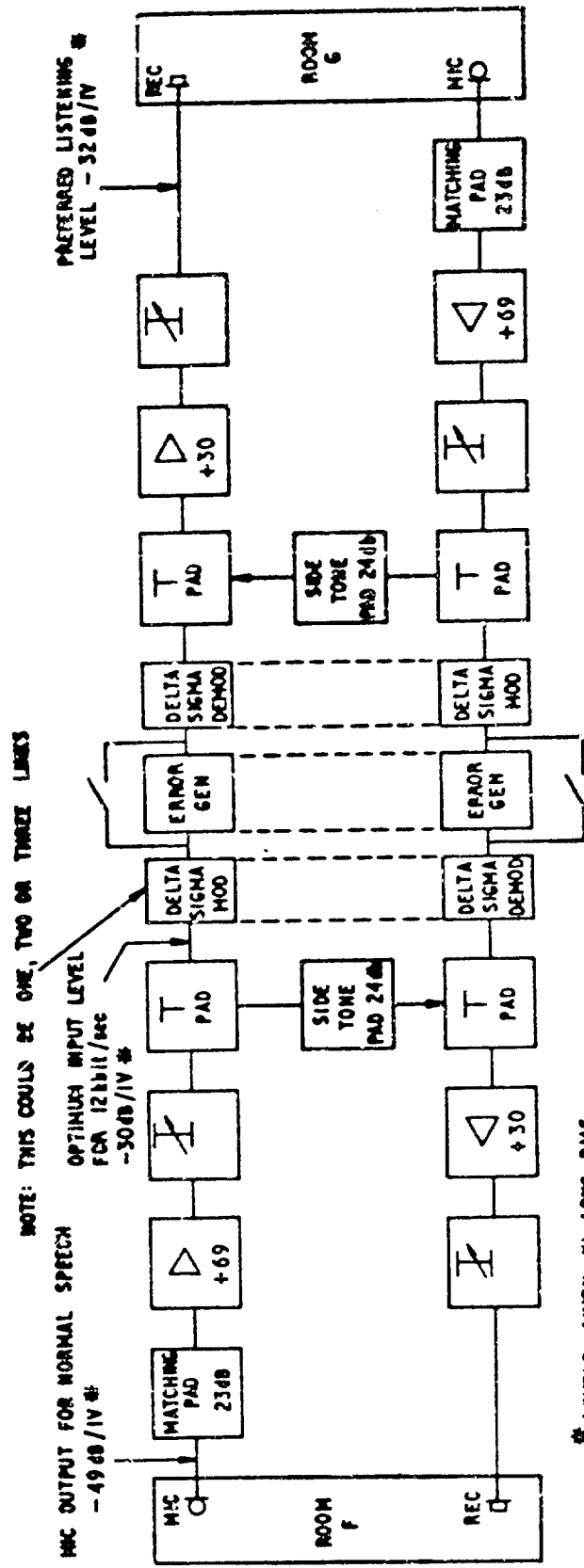


FIG 3 SCHEMATIC DIAGRAM OF DELTASIGMA LINK

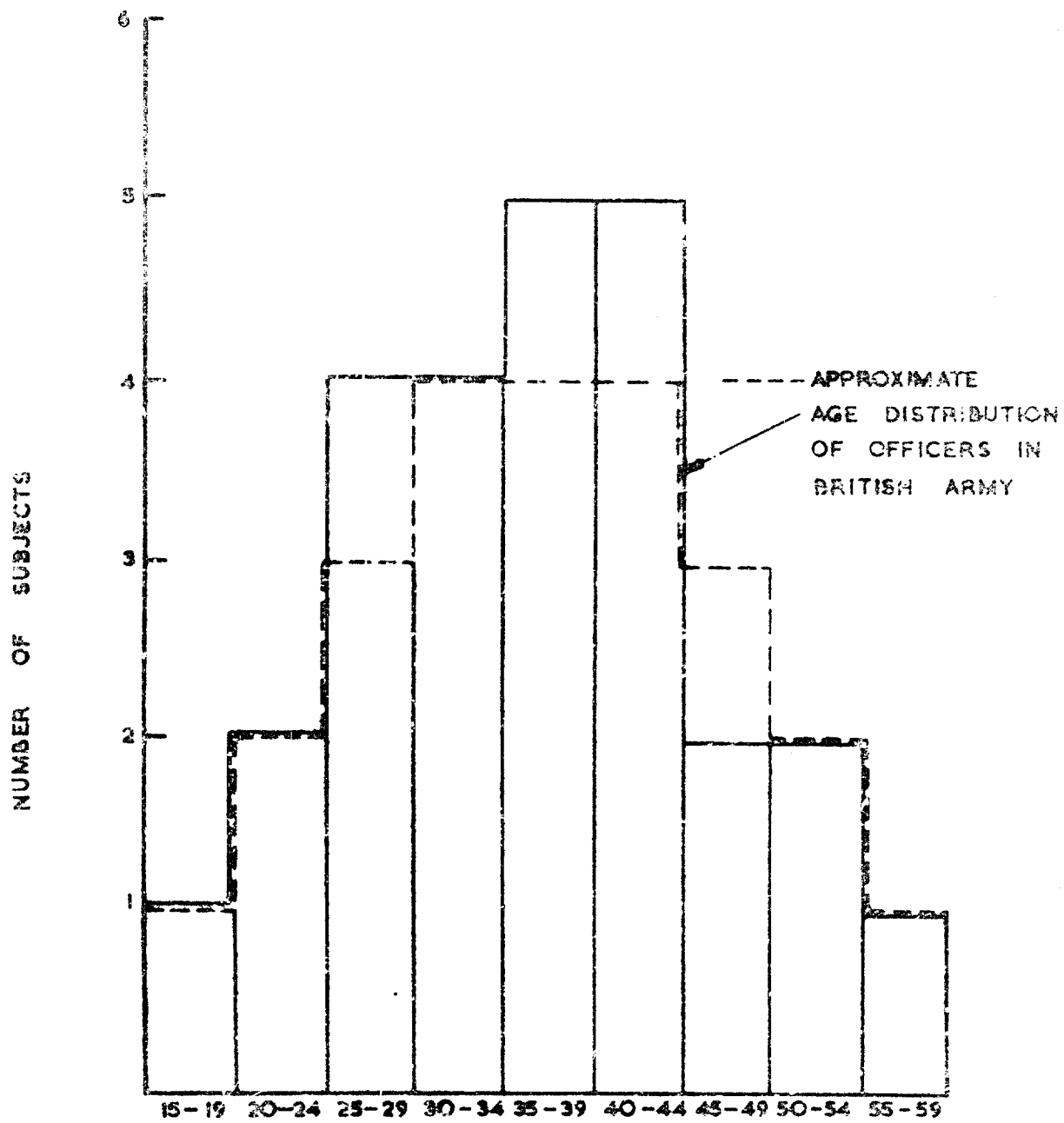


FIG 4 AGE DISTRIBUTION OF SUBJECTS

Circuit	Experiment Ref.	Sensitivity/noise Ratio dB	Attenuation	Injected Noise Level dB/IV	Ambient Noise dB/.0002 dyne/cm <sup>2</sup>	Circuit Shown in Fig.
Reference Speech Link	M	45	10	- 25	50	-
Reference Speech Link	F	33	16	- 19	50	-
Reference Speech Link	E	21	22	- 13	50	-
Reference Speech Link	J	9	28	- 7	50	-
Army Standard	A				60	2
Delta Sigma GEC. 3 12 kb/s 10% Constant Errors.	K				60	3
Delta Sigma GEC. 3 19.2 kb/s Nil Errors.	D				60	3
Delta Sigma GEC. 3 12 kb/s Nil Errors.	H				60	3
Delta Sigma GEC. 3 19.2 kb/s Burst Errors, average 1 in 3.4 secs.	C				60	3
Delta Sigma GEC. 3 19.2 kb/s Burst Errors, average 1 in 0.4 secs.	I				60	3
Delta Sigma GEC. 3 Tandem Link 19 + 19 + 19 k. bits/sec.	B				60	3
Delta Sigma GEC. 3 Tandem Link 12 + 19 + 12 k. bits/sec.	G				60	3
Delta Sigma GEC. 3 Tandem Link 12 + 19 k. bits/sec.	L				60	3

FIG. 5 CIRCUIT CONDITIONS

PAIRS	CIRCUIT CONDITIONS												
	1	M	F	L	E	H	C	B	K	J	I	G	D
2	G	M	E	H	L	K	C	B	D	A	J	F	I
3	B	H	G	M	A	F	D	E	K	L	C	I	J
4	I	J	B	D	E	L	F	C	A	M	K	H	G
5	D	I	J	C	F	G	L	A	E	K	H	B	M
6	E	L	C	A	D	H	J	F	B	G	I	M	K
7	A	B	K	G	C	M	H	I	F	J	D	E	L
8	F	A	H	J	I	D	K	L	C	E	M	G	B
9	L	D	A	I	K	J	G	M	H	B	E	C	F
10	H	K	M	F	J	B	I	D	G	C	A	L	E
11	K	E	D	L	G	A	M	H	I	F	B	J	C
12	J	C	F	K	B	I	E	G	M	H	L	A	D
13	C	G	I	B	M	E	A	J	L	D	F	K	H

FIG. 6 LATIN SQUARE



FIG 7 CONVERSATION MATERIAL. A TYPICAL PAIR OF PHOTOGRAPHS

Opinion Form 8a

Opinion Ratings based on Effort Required to  
Conduct a Conversation

Please express your opinion, when notified by the operator, by ticking the appropriate letter.

N. B. Do not discuss your opinion with your companion

- A. Complete relaxation possible; no effort required .....
- B. Attention necessary, no appreciable effort required .....
- C. Moderate effort required .....
- D. Considerable effort required .....
- E. Extreme effort required; prolonged conversation impossible

---

Name

Test No.

---

Date

---

FIG. 8 OPINION FORM 8a

Circuit Condition	PAIRS												
	1	2	3	4	5	6	7	8	9	10	11	12	13
A	2 2	1 0	2 1	2 1	2 1	2 1	3 4	0 1	1 2	2 0	2 1	2 0	2 1
B	1 2	2 1	3 4	3 3	3 3	3 2	4 3	3 3	2 1	2 2	3 4	3 3	3 3
C	2 1	2 2	4 2	3 3	3 3	2 1	3 4	4 2	3 2	3 3	2 4	4 3	3 4
D	2 1	3 2	3 4	3 3	3 3	3 4	3 3	4 3	4 3	3 3	3 3	4 3	3 4
E	3 3	2 0	3 4	3 2	3 3	3 3	4 2	3 2	3 2	2 3	4 2	3 3	3 4
F	3 4	2 4	3 4	4 3	4 3	3 4	3 4	4 3	3 4	3 4	4 2	4 3	3 4
G	3 4	2 2	2 3	1 2	2 2	3 2	3 2	1 2	2 2	2 2	3 3	3 2	3 2
H	2 2	1 2	4 3	2 2	3 3	3 2	2 3	2 2	3 2	3 4	3 2	3 3	3 2
I	1 0	1 1	2 3	2 2	2 2	1 2	2 1	1 2	2 1	1 1	3 2	1 1	1 2
J	1 0	0 0	0 1	1 2	1 1	1 2	3 1	0 2	1 1	2 1	3 2	0 3	2 1
K	1 1	0 1	1 2	1 1	2 1	2 1	2 3	1 1	2 2	3 1	3 2	2 1	2 2
L	3 1	3 2	3 2	2 2	2 2	2 2	4 3	3 3	2 4	2 3	3 2	2 3	3 2
M	4 4	3 4	3 4	4 2	4 4	4 4	4 4	3 4	3 3	3 4	4 1	4 4	4 4

Note: Score in top left of each square represents subject in room F  
Score in bottom right of each square represents subject in room G.

FIG. 9 TABLE OF RESULTS OF FREE CONVERSATION TEST

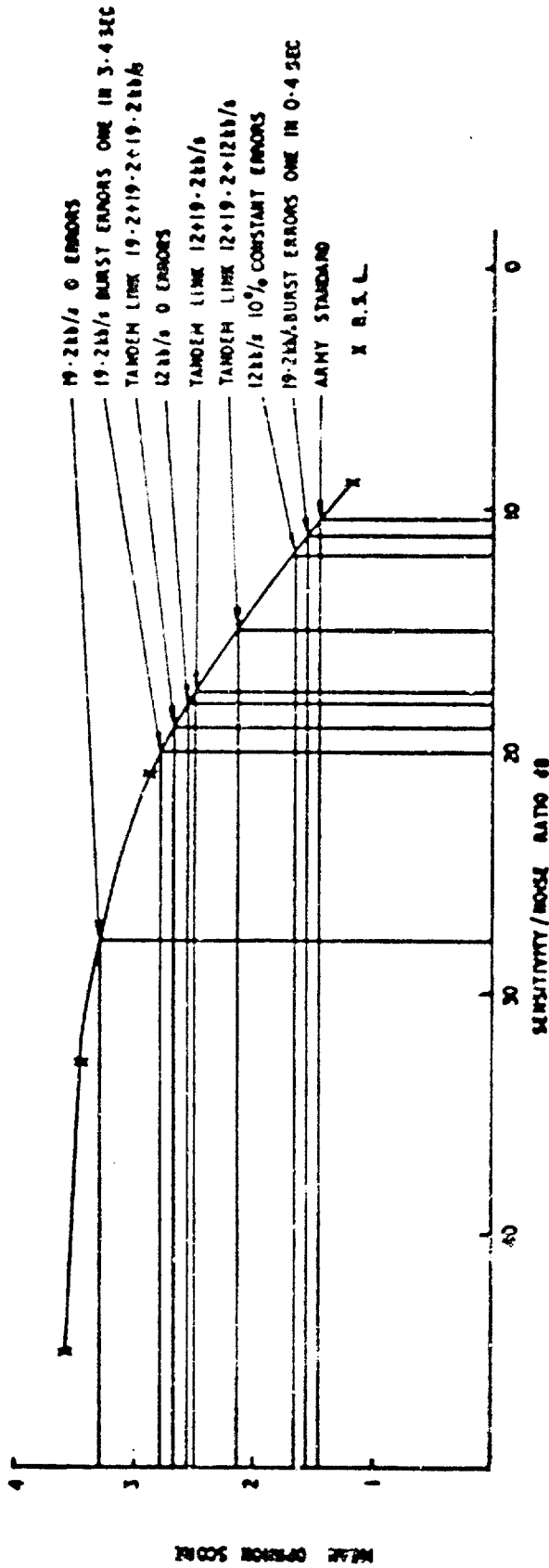


FIG 10 RSL CHARACTERISTIC AND RATING OF DELTA-SIGMA AND ARMY STANDARD CIRCUITS IN A FREE CONVERSATION TEST

SENDER'S CARD

Sheet 1S

101	PERK WORK	SHIRK MURK	<u>LURK</u> TURK
102	ODE <u>LOAD</u>	GOAD CODE	TOAD ROAD
103	LEAK WEEK	<u>TEAK</u> BEAK	MEEK PEAK
104	TART CART	PART <u>DART</u>	MART HART

RECEIVER'S CARD

Sheet 1R

101	MURK SHIRK	PERK WOPK	LURK TURK
102	ROAD TOAD	GOAD CODE	LOAD ODE
103	TEAK MEEK	LEAK WEAK	PEAK BEAK
104	HART PART	DART TART	CART MART

FIG. 11 EXAMPLE OF RHYME TEST WORD CARDS

Circuit Condition	PAIRS												
	1	2	3	4	5	6	7	8	9	10	11	12	13
A	4 4	3 3	1 1	3 4	4 4	4 4	3 3	2 3	0 3	4 3	3 4	3 1	4 2
B	4 3	1 4	3 4	4 4	2 2	4 4	2 3	3 3	3 4	4 3	2 2	3 3	4 3
C	3 4	4 4	4 4	4 3	3 2	3 4	4 3	4 4	4 4	4 4	4 3	3 4	3 4
D	4 3	4 4	3 4	4 4	3 1	4 4	4 3	4 3	3 0	4 4	3 4	4 4	4 4
E	4 4	4 4	4 4	2 4	4 4	4 4	4 4	4 4	3 4	4 4	4 4	3 4	4 4
F	4 4	4 3	4 4	4 4	4 4	4 4	4 3	4 4	4 4	4 4	4 4	3 4	4 4
G	2 4	4 3	2 2	3 3	3 4	2 3	3 2	3 2	2 4	3 3	2 2	4 3	3 2
H	3 4	4 3	4 4	3 4	4 4	4 4	1 4	4 4	3 4	4 4	3 4	3 4	4 3
I	4 3	4 3	4 3	3 3	2 2	4 3	3 4	2 3	4 3	3 3	4 4	3 3	3 3
J	4 3	3 4	3 3	4 3	3 3	4 4	4 3	3 4	2 4	4 4	3 3	3 4	2 3
K	3 4	4 4	3 2	3 3	2 2	4 3	2 1	2 4	4 1	4 2	4 3	3 4	4 4
L	3 4	3 4	2 3	2 3	4 4	4 4	4 3	4 2	3 3	3 4	4 4	2 4	4 4
M	3 4	4 4	4 4	4 4	4 4	4 4	3 4	4 4	4 4	4 4	4 4	4 4	4 4

Note: Score in top left of each square represents number of correct words scored out of four in room F.

Score in bottom right of each square represents number of correct words scored out of four in room G.

FIG. 12 TABLE OF WORD RESULTS

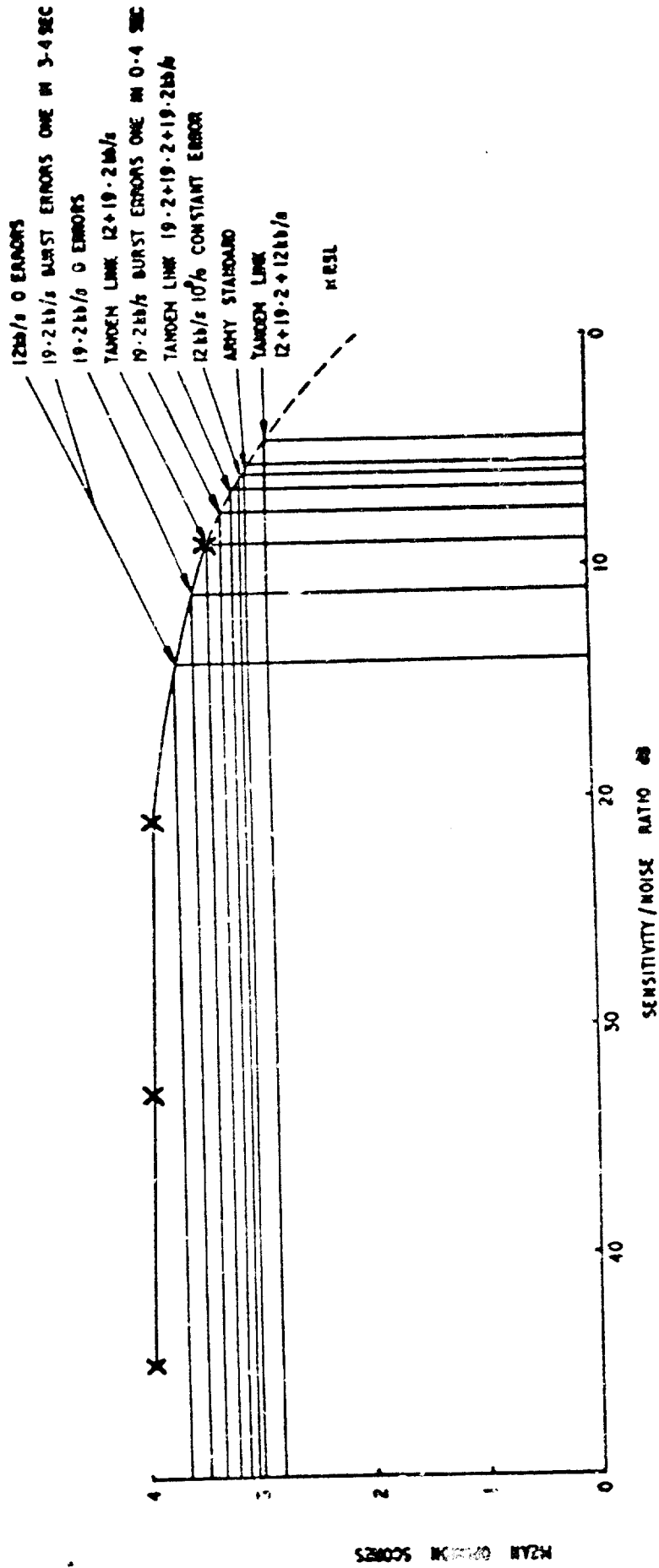


FIG 13 RSL CHARACTERISTIC AND RATING OF DELTA-SIGMA AND ARMY STANDARD CIRCUITS IN RHYMING WORD TEST