Report SAM-TR-75-50

THE TONE-COUNT AUDIOMETRIC COMPUTER

December 1975

Progress Report for Period January 1973 - December 1974

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

NOTICES

This progress report was submitted by personnel of the Internal Medicine and Otolaryngology Branches, Clinical Sciences Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7996-02-AA.

This technical report has been reviewed and is approved for publication.

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This paper describes a means of implementing a modified Hughson-Westlake procedure in automated audiometry using a small audiometric computer and a tone-counting technique. The detailed description of the audiometric computer includes its operation manual, programmed flow chart, and circuit schematics.

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THE TONE-COUNT AUDIOMETRIC COMPUTER

INTRODUCTION

The need for an automatic audiometer has been evident since Bekesy's description of such a device 25 years ago (11). This need has become more apparent because of recent increases in the number of military and civilian audiograms performed, particularly by technicians in military induction centers and in hearing conservation programs. The major advantage sought through automatic audiometry is the forced standardization of testing procedures. Bekesy-type audiometry, which has been a popular approach to automation, has attracted criticism, particularly where some examinees may desire to give false responses (3-5, 10). We have undertaken to devise a new and improved automatic technique.

APPROACH

A major goal in our effort was to devise an automatic technique as much like manual audiometry as possible, since the manual technique remains the standard against which other approaches are compared. The Hughson-Westlake procedure for manual audiometry and slightly modified versions have been the most generally accepted in clinical audiometry (2, 8, 9). We selected the Carhart-Jerger modification as a basic pattern for automation.

Two types of error can occur during audiometric examination: Type 1 -- an examinee hears the pure-tone stimulus, but does not register an affirmative response; Type 2 -- the examinee does not hear the stimulus, but registers an affirmative response. Little can be done to eliminate Type 1 errors made by an uncooperative examinee, but Type 2 errors can be reduced by adopting the tone-count stimulus-response method (1, 6, 7). This method presents a number of tone pulses at a given frequency and hearing level, and the examinee reports the number of tones heard.

The response procedure uses a small light and four pushbutton switches. The small light flashes to warn the examinee that an aural stimulus will occur. One through four tones, varied randomly, are presented in the stimulus. The examinee has 1.5 seconds after the last tone to respond by depressing the appropriately numbered button on his response panel. If he has not responded at the end of this time, an incorrect response is assigned and the test procedure continues. This technique reduces the probability of a Type 2 error; also, it increases the confidence in any correct answer, because the chance of a correct guess following a subthreshold stimulus is only one out of four, or 25%.

Our testing procedure, with the tone-count response, uses a simplified programmer, or state generator, to do the incremental tasks and logical decision branching. At each pure-tone frequency, the first stimulus, one to four tones, is presented at a 30-dB hearing level. If the examinee gives an incorrect response, the hearing level of each successive stimulus is increased in 15-dB steps until the examinee responds correctly. After each correct response, the hearing level is decreased 10 dB for the next stimulus. After the first correct response has been recorded, each incorrect response is followed by a 5-dB hearing level increase for the next stimulus. This sequence, 10-dB decrease after each correct response and 5-dB increase after each incorrect response, is continued until threshold for that frequency is established.

Threshold is established when two consecutive incorrect-to-correct responses (5-dB ascents) occur and the second correct response is equal to or 5 dB greater than the first; when they differ, threshold is set at the first (lower) response. This deviation from the "two out of three correct responses at the same level following ascent" was judged as minor because of the increased validity of correct responses, and was made to avoid excessive test times expected with the more restrictive approach.

The first frequency tested is 500 Hz in the right ear. This is followed by 1000, 2000, 3000, 4000, and 6000 Hz, in that order. The same frequency order is then used for the left ear.

The flow chart (Fig. 1) shows a systematic technique to implement the procedure just described. One of the beneficial properties of the algorithm shown in Figure 1 is that the examinee can make multiple mistakes without deriving an erroneous hearing threshold level. An examinee can make three sequential Type 1 or 2 errors with no risk of a false determination. In addition, single invalid responses separated by four valid responses will not yield false determinations. This ability to disregard a few random invalid responses during the testing procedure increases confidence in test results.

We believe that this new procedure will be more valid than existing techniques. An examinee not hearing the aural stimulus may be reluctant to guess when faced with four choices. Of course, if an examinee responds randomly to all subthreshold stimuli, he may achieve a false determination. A simplified model predicts that a biased examinee making random responses to all subthreshold stimuli may achieve false subthreshold determinations for approximately one-third of the frequency and ear combinations tested. This is better than with present automated techniques where biased examinees can more easily obtain false threshold determinations for <u>all</u> frequency and ear combinations.

EXPERIMENTAL DEVICE

A small, dedicated digital computer and audiometer designed to implement the flow chart (Fig. 1) and use the tone-count stimulus previously described are shown in Figures 2 and 3. Functional description of controls and indicators is given in Appendix A. The Tone-Count

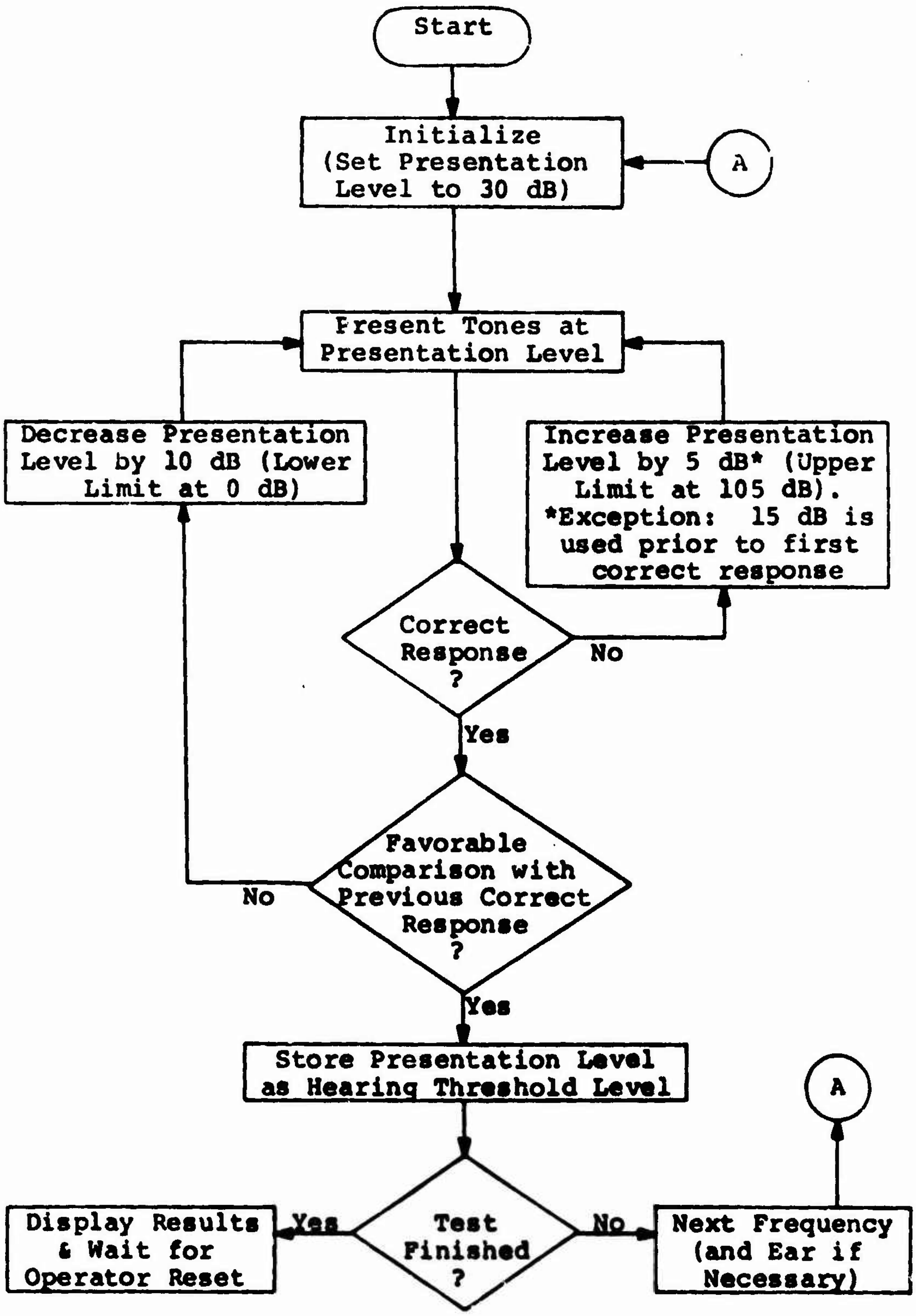


Figure 1. Generalized flow chart.

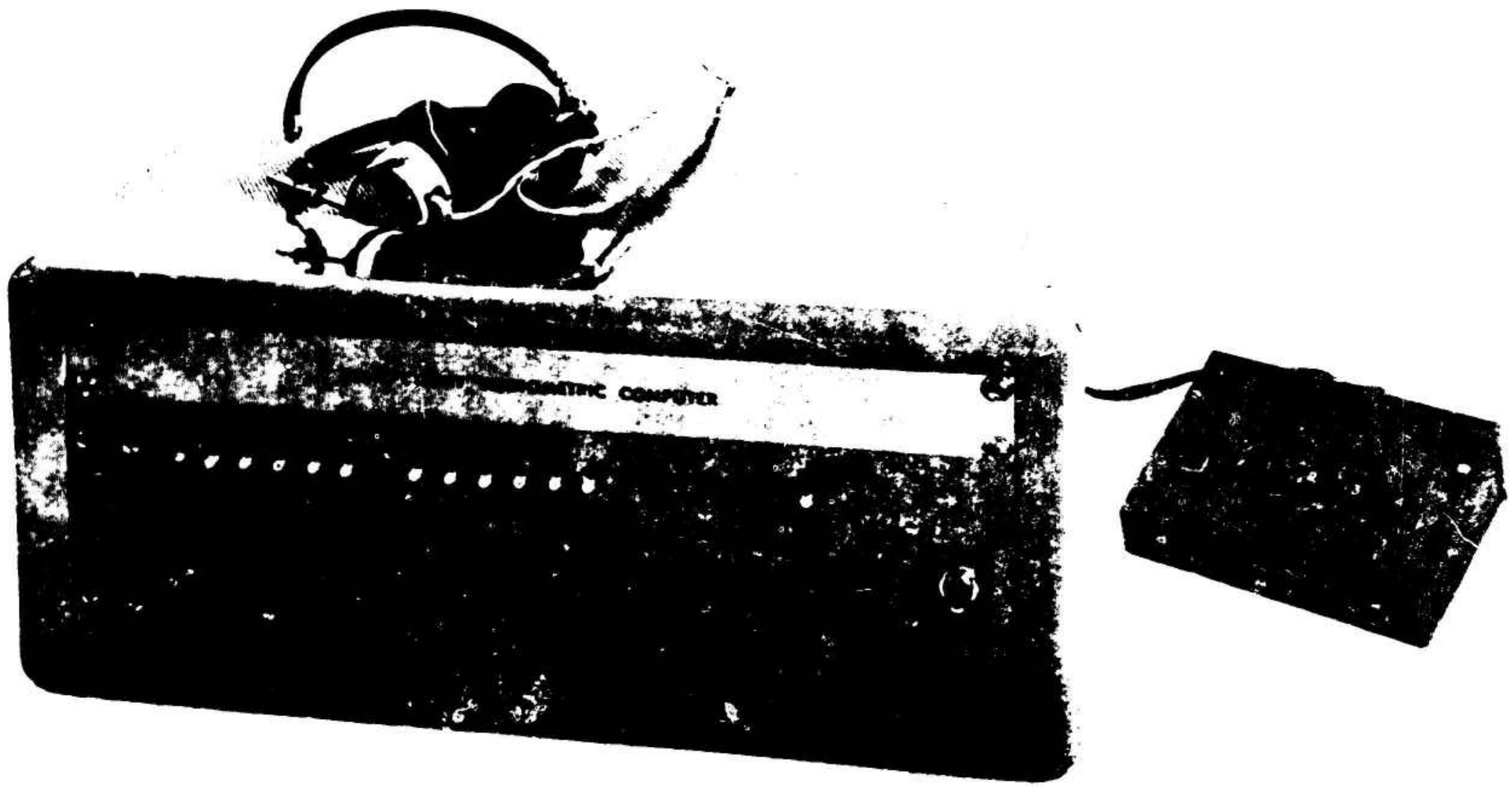


Figure 2. Audiometer and computer.

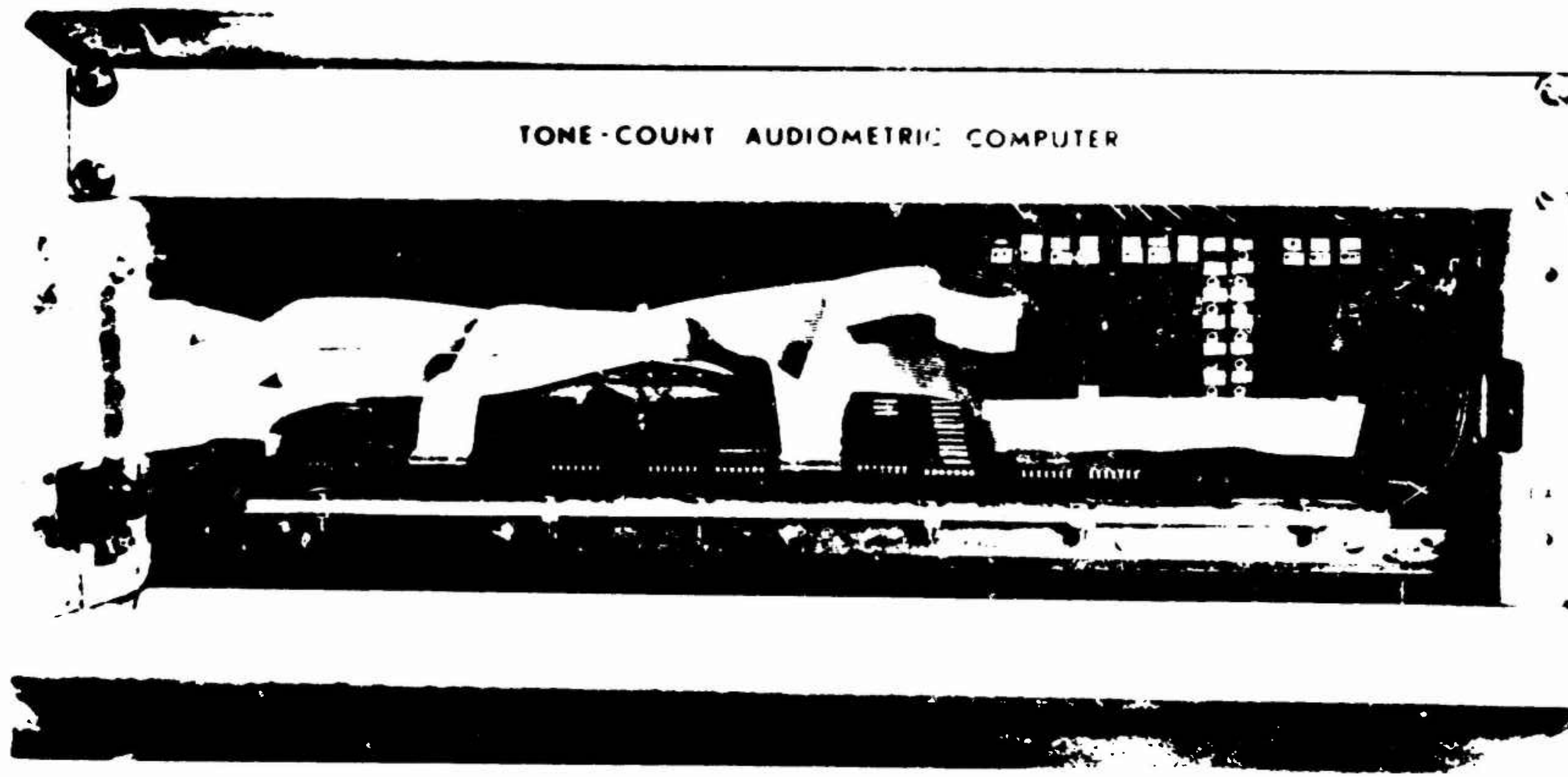


Figure 3. Internal view of TCAC.

Audiometric Computer (TCAC) was designed and constructed for clinical evaluations. The TCAC automatically determines the examinee's hearing threshold levels and retains these values until either manual interrogation and transcription occurs, or automatic transfer occurs to a printer or computer. Normal operation of the TCAC is described in Appendix B. After the scores have been recorded and the TCAC reset, the next examinee starts his test by depressing the START button on his response panel.

The TCAC uses 5 DPDT (double pole, double throw) relays to select or bypass 5 constant impedance attenuator sections of 5, 10, 20, 30, and 40 dB to attain tone-intensity presentations over the range of 0-105 dB. Change in intensity from one aural stimulus to the next is under program control. This relay switching of the attenuator sections yields excellent linearity throughout the 105-dB range. The TCAC also uses a high-frequency oscillator as a pseudorandom number generator to select the number of tones presented in each aural stimulus. The state generator which implements the flow chart of Figure 1 is a shift register capable of parallel entry. Only 42 states are needed for this flow chart. The signal-flow block diagrams for the TCAC are shown in Figures 4 and 5. Appendixes C, D, and E discuss procedures for system calibration, interfacing, and trouble shooting, respectively. In

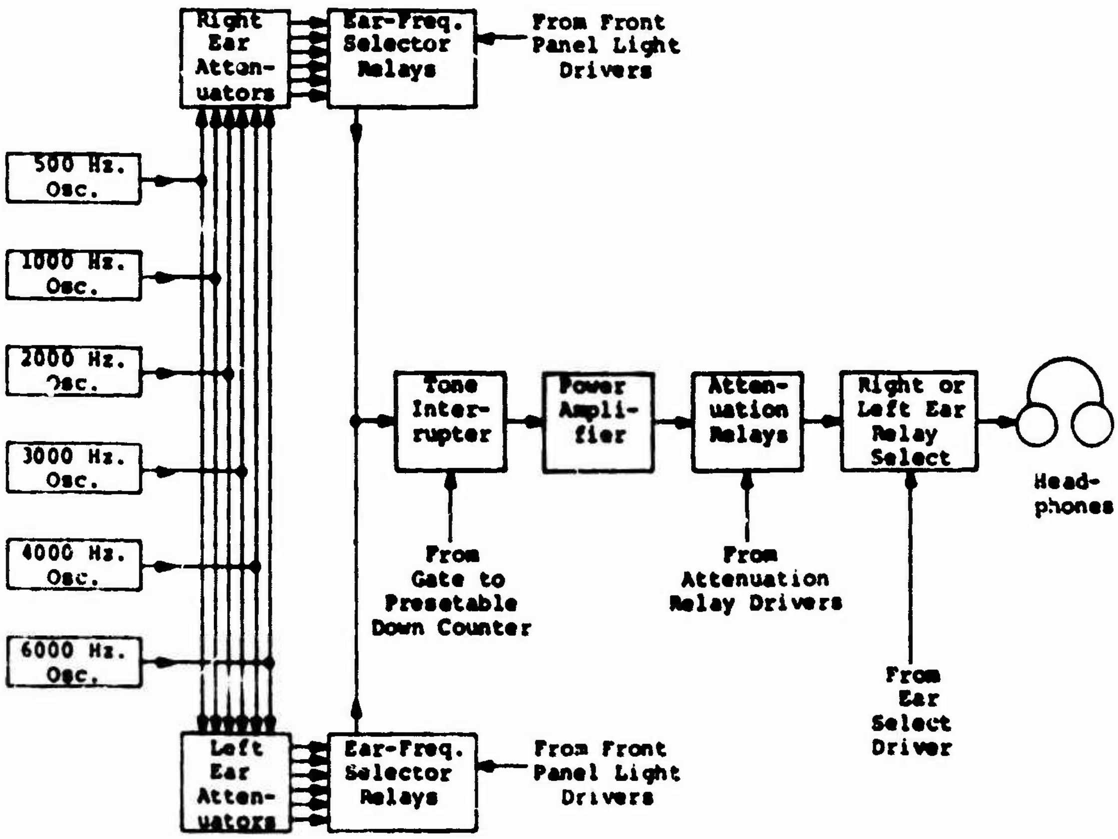


Figure 4. Audiometer subunit.

Appendix F, the individual operations and their order of performance are shown in the detailed flow chart. The numbering of each state in the flow chart is consistent with the numbering of off-page connectors on the state generator schematic. The internal binary code for hearing levels must be multiplied by 5 to obtain the base ten equivalent; e.g., the internal binary code for 25 dB is 0101. Appendix G shows the function of the 26-pin connector, and Appendix H contains circuit schematics.

PRELIMINARY RESULTS

Selected test sequences recorded during operation are graphed in Figure 6. The data were obtained by converting the digital contents of the register controlling the attenuator sections to an analog voltage and recording it on a strip-chart recorder. Sample A is a common pattern: correct responses occur at 30- and 20-dB hearing levels, followed by incorrect responses at 10 and 15 dB and then a correct response at 20 dB, with the last three results repeated. Sample B is also a common pattern where consecutive ascending correct responses are at slightly different levels. Sample C is a typical pattern when the examinee's threshold is greater than 30 dB.

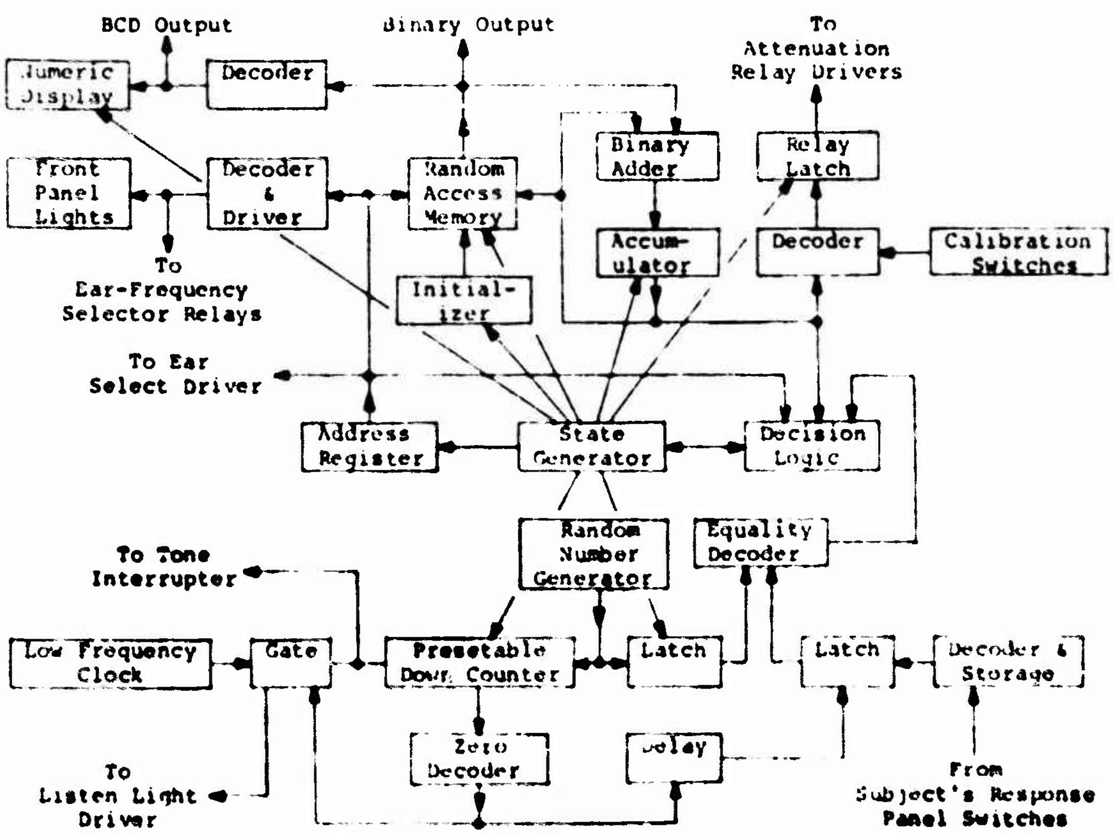
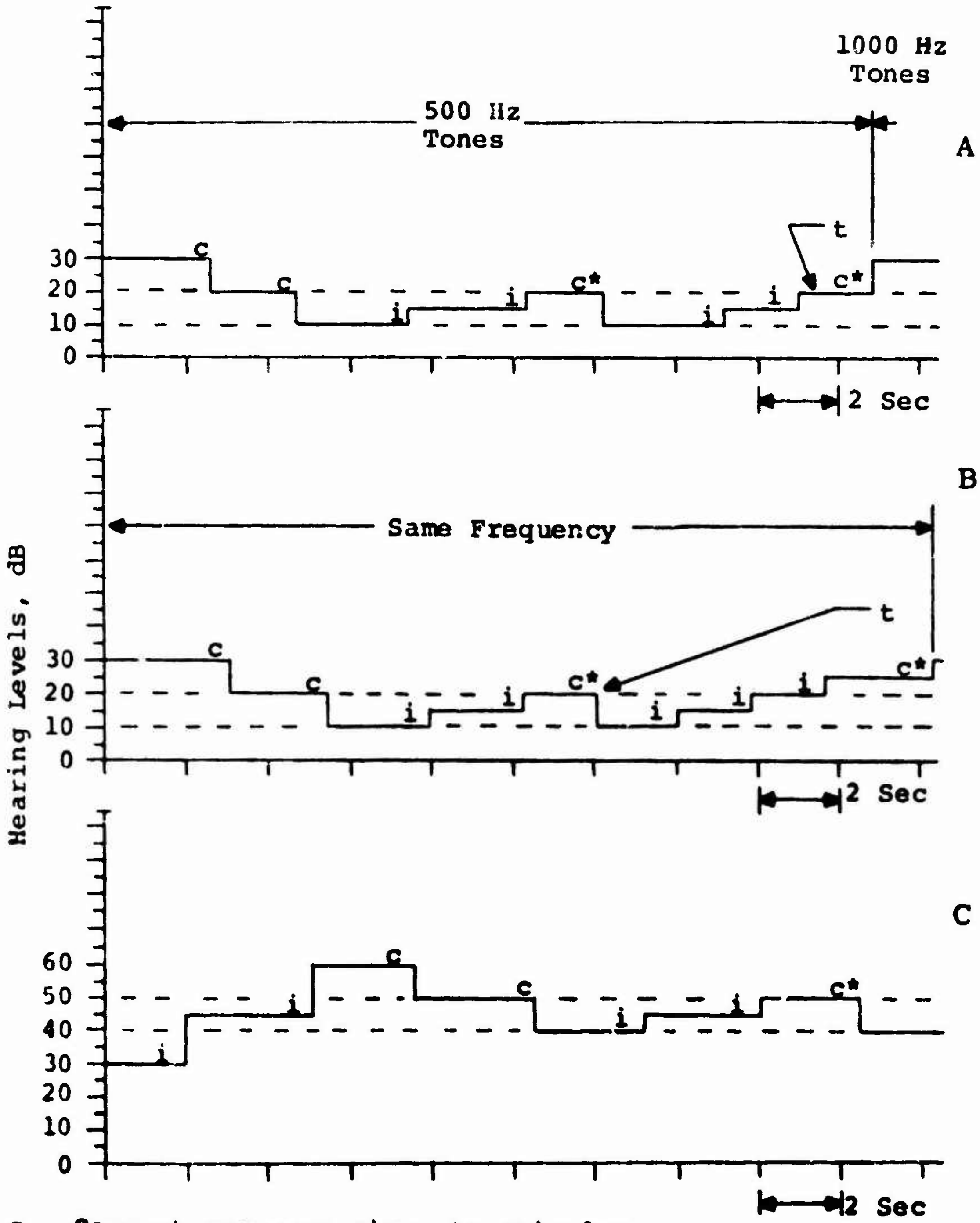


Figure 5. Computer subunit.



c -Correct response given to stimulus.
c* -Key correct responses used to assign threshold level.
i -Incorrect response.
t -Identifies hearing level picked as threshold.

Figure 6. Selected test sequences.

Total test time, all frequencies and both ears, ranged from 2.75 to 5.25 minutes for 7 moderately experienced examinees. The fastest test time possible is 2.5 minutes and would require all correct responses. Test times for inexperienced examinees have not yet been determined.

The preliminary testing with moderately experienced personnel was encouraging in that thresholds with the TCAC compared favorably with thresholds from manual audiometry. Also, repeat testing on a single day gave no suggestion of poor reliability. Both test-retest reliability and comparison with manual audiometry will require extensive further testing.

ACKNOWLEDGMENT

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APPENDIXES

APPENDIX A: FUNCTIONAL DESCRIPTION OF CONTROLS AND INDICATORS

SUBJECT'S RESPONSE PANEL

LISTEN Indicator -- Signals subject that aural-stimulus presentation is pending.

READY Indicator -- Signals subject that TCAC is ready to accept his START command.

START Switch -- Momentary depression of START switch during READY status causes programmed test to start.

1, 2, 3, 4, Switches -- Subject uses response switches to indicate number of tones heard in aural stimulus.

COMPUTER FRONT PANEL

CAL-NORMAL Switch -- Determines mode of operation: NORMAL for administration of test; CAL for calibration procedure in conjunction with 5, 10, 20, 40, and 80 DB switches.

EXAMINE Switch -- After completion of test, each momentary depression of switch allows sequential viewing of the computed hearing levels.

ON-OFF Switch -- 115 VAC power switch.

RESET Switch -- Momentary depression returns state generator to first state (Ready Status--prepared to start test in right ear at 500 Hz).

5, 10, 20, 40, 80 DB Switches -- In calibration mode, the sum of DB switches placed in up-position corresponds to the hearing level desired for presentation in earphones. In normal mode, all switches should be placed in down-position.

DB HEARING LEVEL Indicator -- Number displayed is the hearing-threshold level determined in the preceding test for ear and frequency denoted by the lighted indicator.

EAR-AND-FREQUENCY Indicators -- There 12 lights indicate the frequency and earphone (right or left) used either for tone presentation (normal or calibration mode) or to identify the displayed hearing-threshold level determined during preceding test.

TONE Indicator -- Indicator lights up as tone occurs in earphone.

APPENDIX A (Continued)

Computer Internal Controls

Control	PC Board	Function
0.5, 1	X01	Vertical potentiometers set output amplitudes for either the 0.5- or 1-kHz oscillators.
2, 3	X02	Vertical potentiometers set output amplitudes for either the 2- or 3-kHz oscillators.
4, 6	X03	Vertical potentiometers set output amplitudes for either the 4- or 6-kHz oscillators.
0.5, 1, 2, 3, 4, 6	X05	Horizontal potentiometers adjust outputs of indicated oscillators for calibration of left earphone.
0.5, 1, 2, 3, 4, 6	X06	Horizontal potentiometers adjust outputs of indicated oscillators for calibration of right earphone.
RISE TIME	X09	Adjusts rapidity of tone onset (typically 20 msec).
DAC ZERO	X11	Adjusts offset of digital-to-analog converter output corresponding to dB setting of tone attenuator.
DECISION TIME	X11	Adjusts period of time after last tone during which subject can make a correct response (typically 1.5 sec).
SLOW CLOCK	X13	Adjusts repetition frequency and duration of tones.

NORMAL--SINGLE STEP (mounted on right, internal side of chassis) -- Switch in NORMAL position provides high-frequency clocking input to state generator. In SINGLE STEP position, switch provides single clock pulses with every momentary depression of STEP switch.

STEP (mounted on right, internal side of chassis) -- Momentary depression of switch provides single clock pulse to state generator when computer is in SINGLE STEP mode.

APPENDIX B: NORMAL OPERATION

After turning on the TCAC, depress the RESET switch and allow a 30-minute settling time. Set calibration switch to NORMAL and set all dB switches (5, 10, 20, 40, and 80 dB) in the down-position. Place earphones on the subject with red earphone on the right ear. Instruct the subject to observe the LISTEN indicator and to listen carefully when it flashes, to count the number of tones he hears after the light flashes, and then to press the button (1, 2, 3, or 4) corresponding to the number counted.

The test is begun by the subject's momentarily depressing the START switch. Tests, for both ears at each frequency, follow the flow chart in Appendix F, with level of presentation depending on state and evaluation of subject's response. The ear and frequency being tested is denoted by the appropriate lighted indicator light. At the conclusion of the test, the computed hearing threshold levels appear in the lighted numerical display in sequential order after each momentary depression of the EXAMINE switch. The displayed hearing level was obtained under the conditions indicated by the ear-and-frequency light. The results may be examined as many times as necessary to insure correct transcription by the operator. After transcription, momentary depression of the RESET switch prepares the TCAC for the next hearing test.

APPENDIX C: CALIBRATION

After turning on the TCAC, depress the RESET switch and allow at least 30 minutes for settling. Set the calibration switch to CALIBRATE. Set desired dB hearing level by placing the appropriate dB switches in the up-position (the hearing level is the sum of the switches placed in the up-position). The ear and frequency selected is denoted by the lighted indicator. The desired ear-and-frequency combination is selected by sequentially depressing the EXAMINE switch. The actual sound pressure level (SPL) for the chosen combination is altered by adjusting the appropriately labeled potentiometer mounted on board X05 or X06. The potentiometers are accessed by opening the front panel and adjusted by using a small jeweler's screwdriver. If the SPL cannot be increased to the desired setting because the end of travel on the potentiometer has been reached, it is necessary to increase the output of the appropriate oscillator located on board X01, X02, or X03. This output is most easily increased by using an extender card. With the specific potentiometer on board X05 or X06 adjusted to maximum, adjust the appropriately labeled oscillator's potentiometer until the SPL is approximately 10 dB greater than required. After this adjustment increasing the oscillator's output, both potentiometers, on boards X05 and X06, corresponding to the same oscillator frequency will have to be readjusted to achieve the desired SPL.

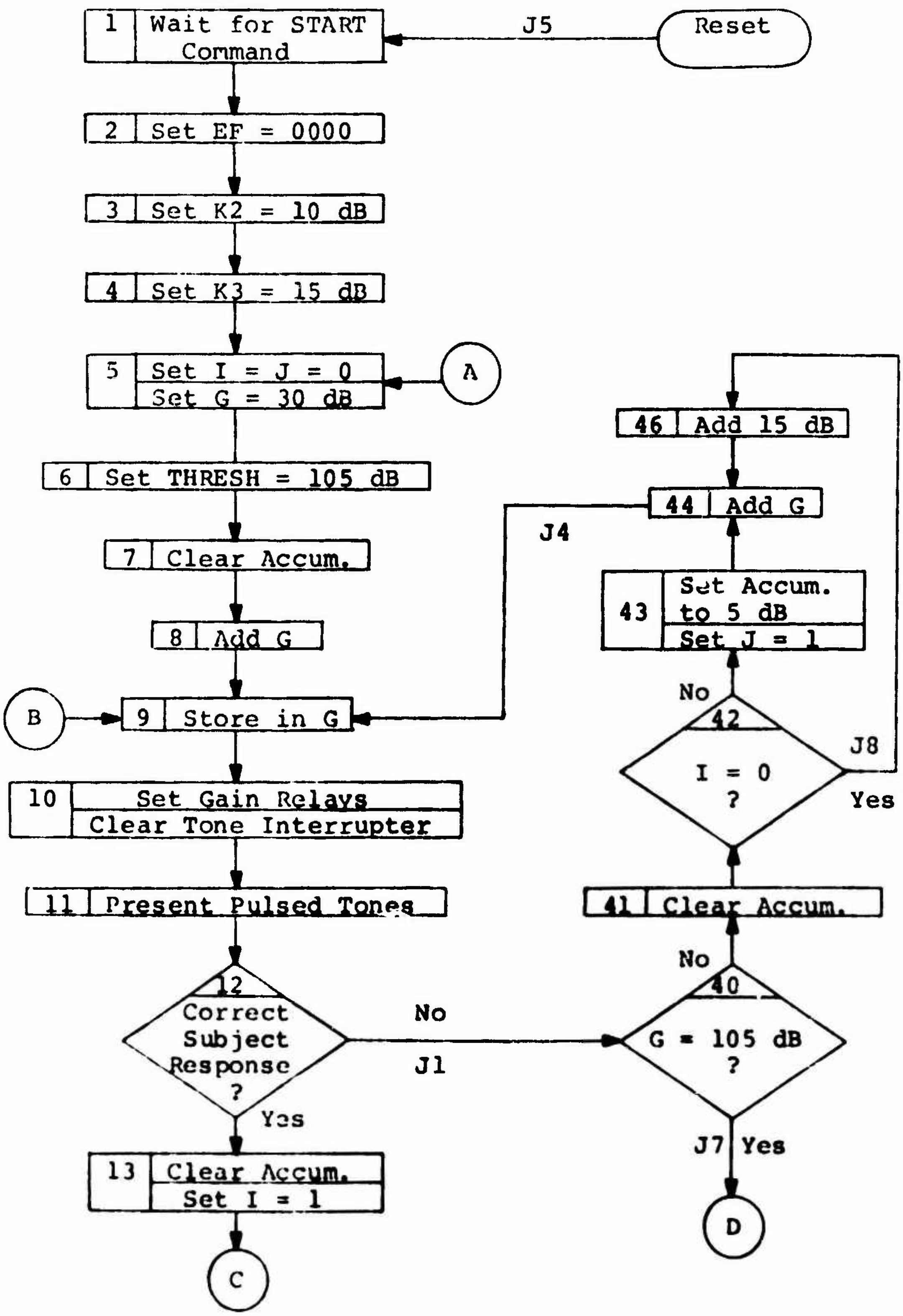
APPENDIX D: INTERFACING

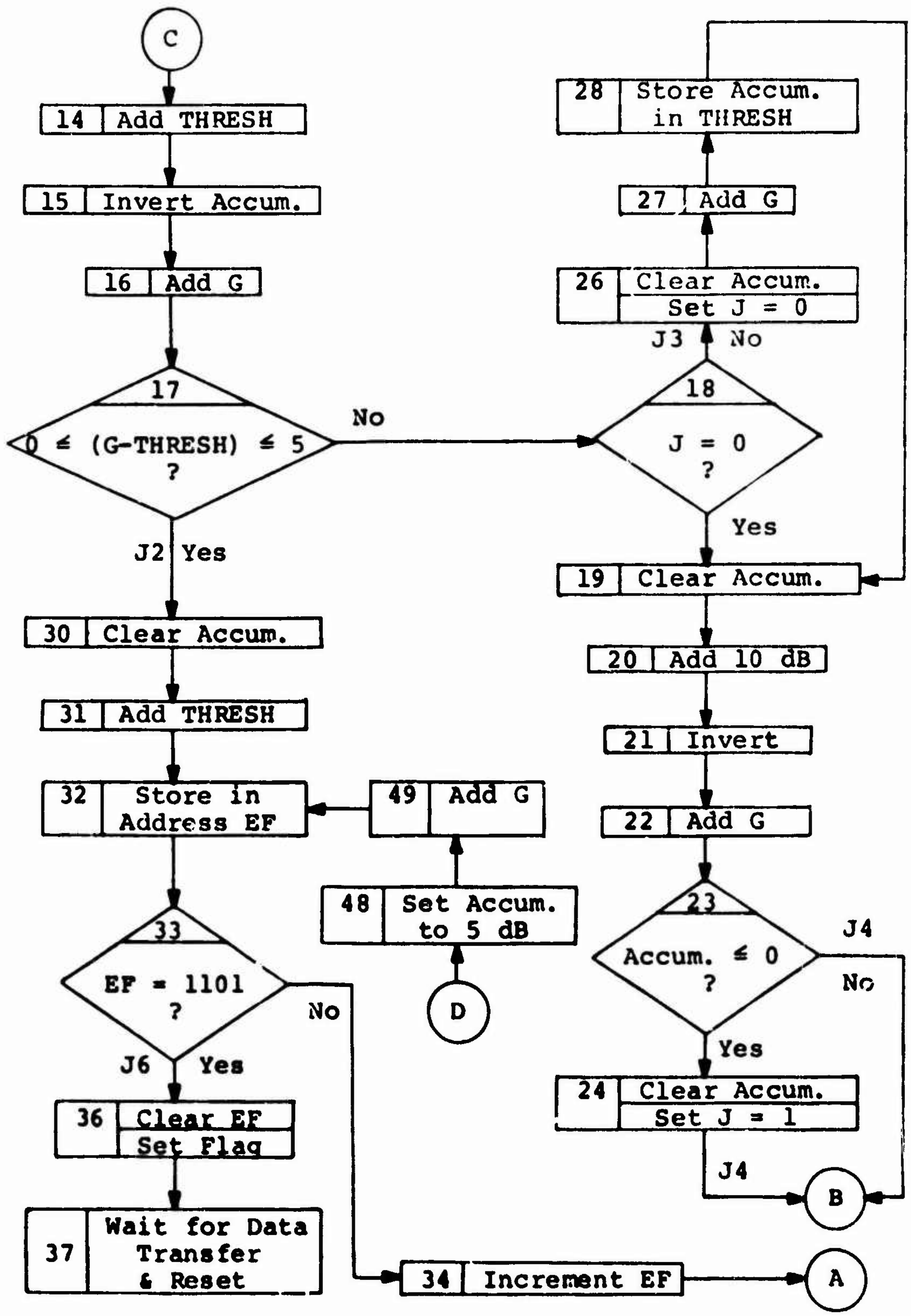
The TCAC may be interfaced with other automated data handling devices. The 26-pin connector at the rear of the chassis contains all necessary output and input lines. Appendixes G and H give a detailed explanation of each of the signals. For example, an automatic, 3-digit, BDC printer could be interfaced by building a small digital controller. The printer should be inactive until the FLAG H signal goes high (about 3.8 VDC). At this time the controller should generate 12 sequential print commands for input to the printer and the TCAC on the TEF L line. This causes printing of the 12 hearing threshold levels in the same order as tested. After the results are printed, the controller should generate a reset pulse for input to the RESET L line. Now the TCAC is ready to administer the next test.

APPENDIX E: TROUBLE SHOOTING

If trouble in the logic program is suspected, the program may be single stepped by setting the normal/single-step switch on the right side of the interior chassis to SINGLE STEP. The state generator may then be incremented only by momentarily depressing the nearby STEP switch.

APPENDIX F: DETAILED FLOW CHART




C
14 Add THRESH
15 Invert Accum.
16 Add G
17
0 ≤ (G-THRESH) ≤ 5
?
No
J2 Yes
30 Clear Accum.
31 Add THRESH
32 Store in Address EF
33
EF = 1101
?
No
J6 Yes
36 Clear EF
Set Flag
37 Wait for Data Transfer & Reset
34 Increment EF
A
49 Add G
48 Set Accum. to 5 dB
D
28 Store Accum. in THRESH
27 Add G
26 Clear Accum.
Set J = 0
J3 No
18
J = 0
?
Yes
19 Clear Accum.
20 Add 10 dB
21 Invert
22 Add G
23
Accum. ≤ 0
?
J4
No
Yes
24 Clear Accum.
Set J = 1
J4
B

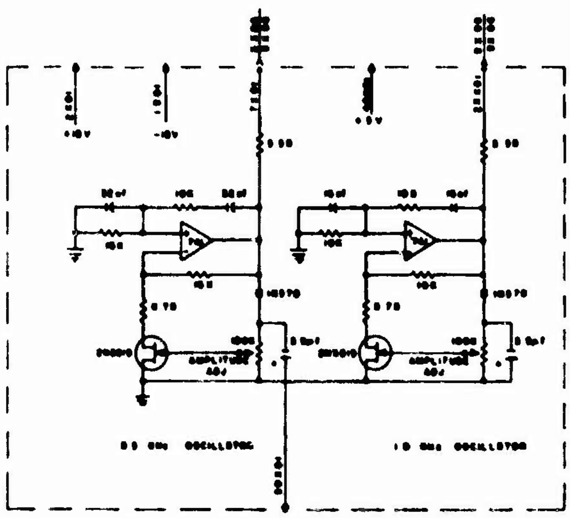
APPENDIX G: 26-PIN CONNECTOR

PINS			
A	24		Binary output ((dB hearing level)/5)
B	23		
C	22		
D	21		
E	20		
F	23	MSD	BCD output (dB hearing level)
G	22		
H	21		
J	20		
K	23		
L	22		
M	21		
N	20		
P	23	LSD	
R	22		
S	21		
T	20		
U	FLAG H	Output goes high when test is finished and data are ready to be transferred.	
V	RESET L	Input which should be forced low to reset TCAC.	
W	TEF L	Trigger input to serially access test results stored in memory.	
X	DAC	Analog voltage output corresponding to set attenuation level.	
Y	+5 V	Power supply output.	

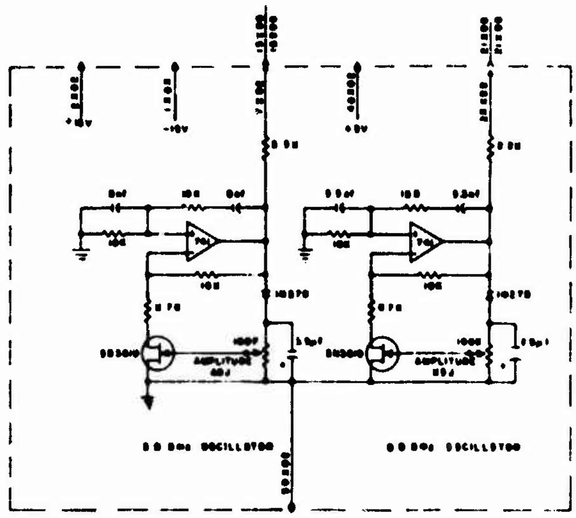
(All signals are supplied to or from 5-V TTL circuits.)

APPENDIX H: CIRCUIT SCHEMATICS

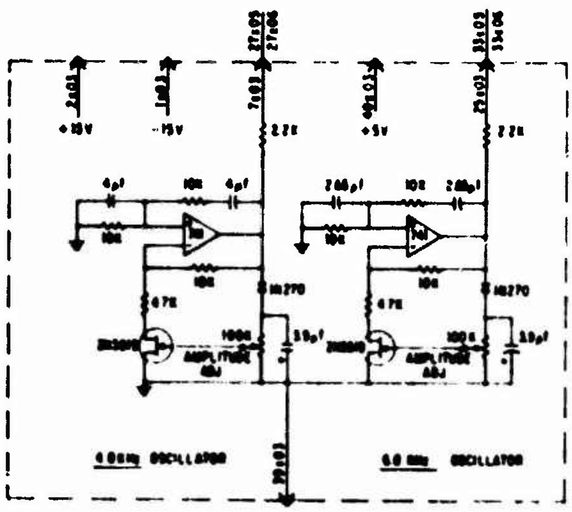
CIRCUIT BOARD 1



CIRCUIT BOARD 2



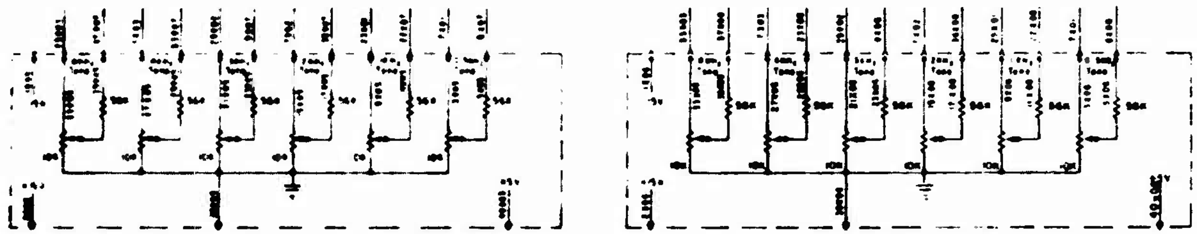
CIRCUIT BOARD 3



APPENDIX H (Continued)

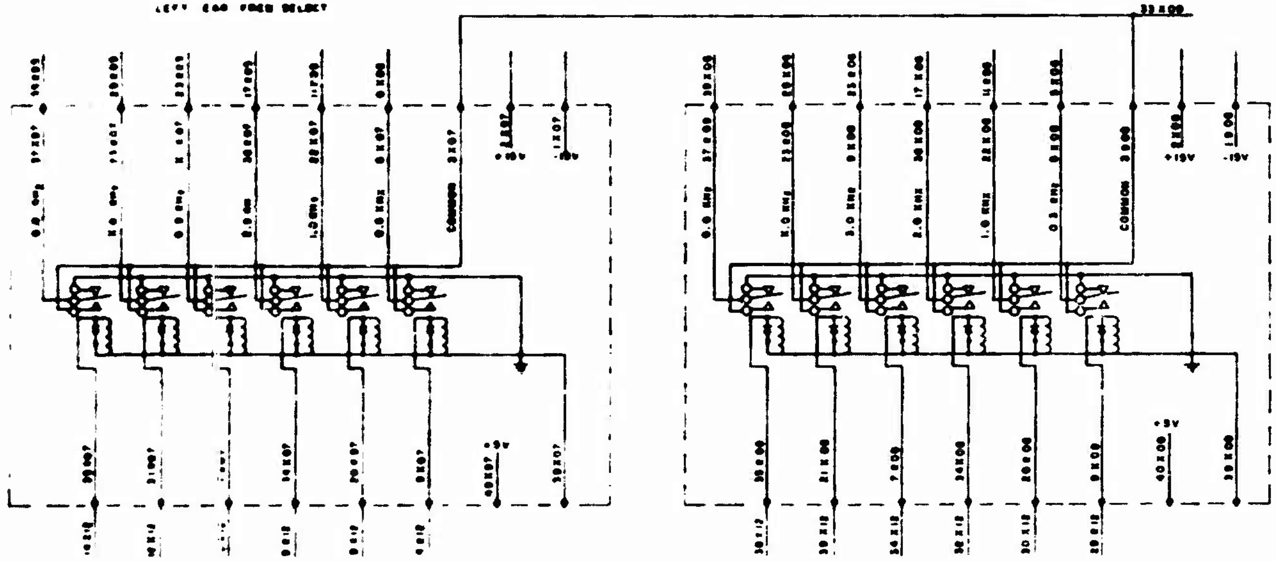
CIRCUIT BOARD 5
LEFT EAR ATTENUATOR

CIRCUIT BOARD 6
RIGHT EAR ATTENUATOR



CIRCUIT BOARD 7
LEFT EAR FREQ SELECT

CIRCUIT BOARD 8
RIGHT EAR FREQ SELECT



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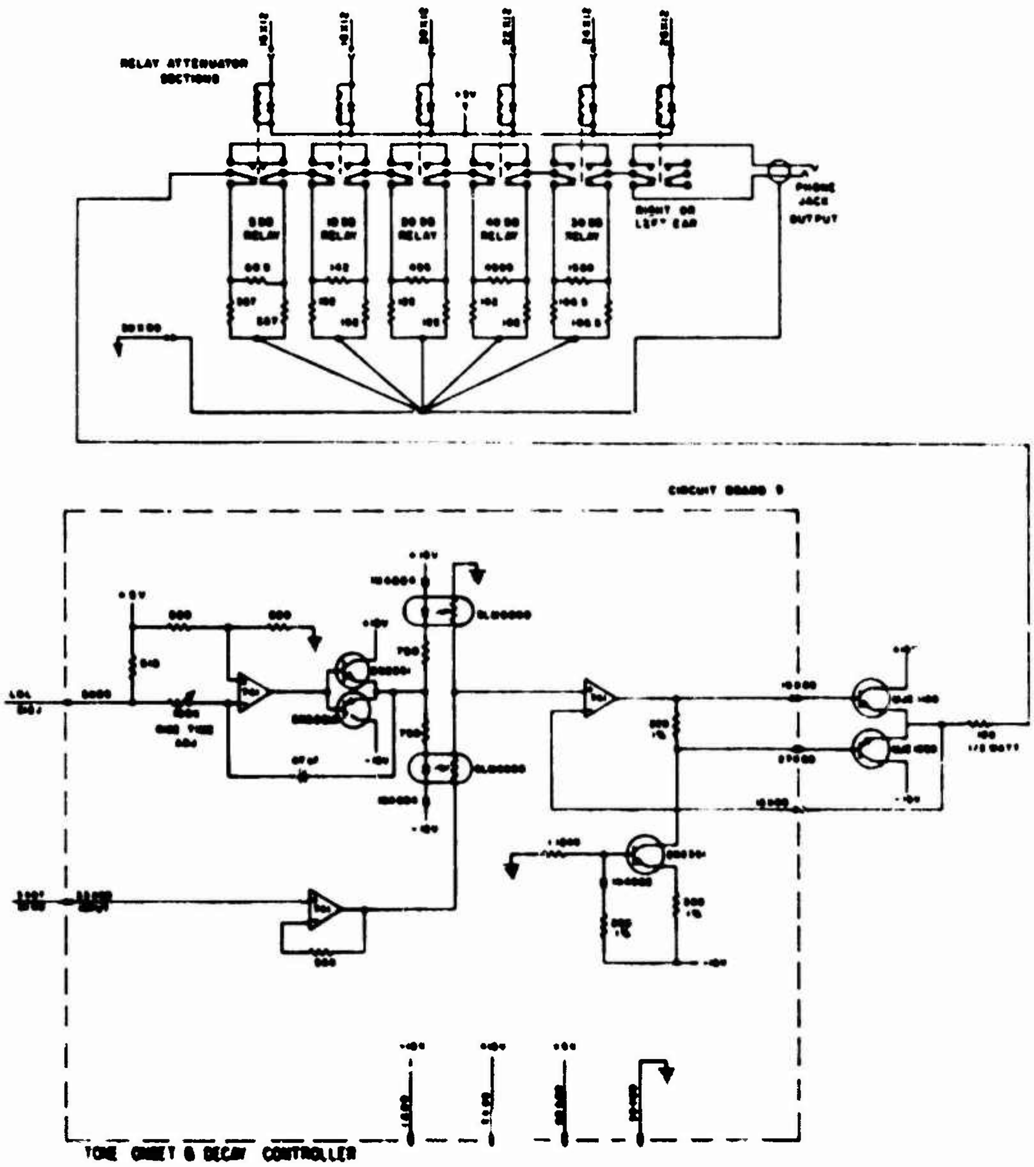

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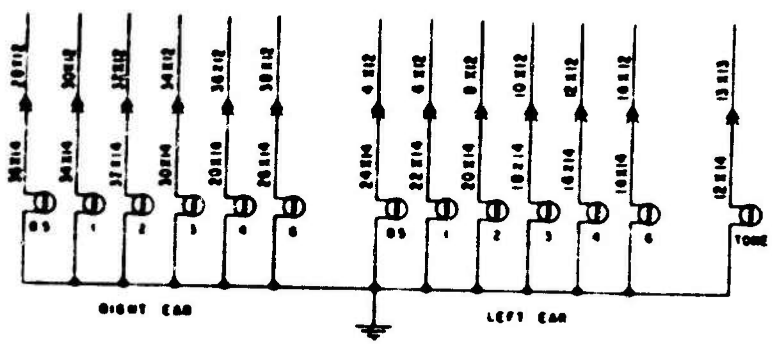
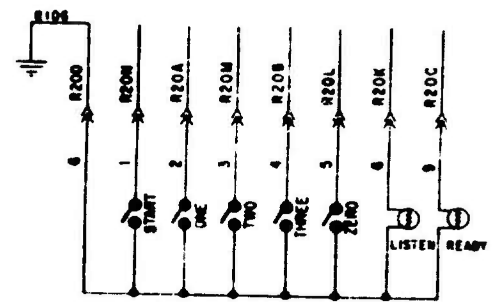
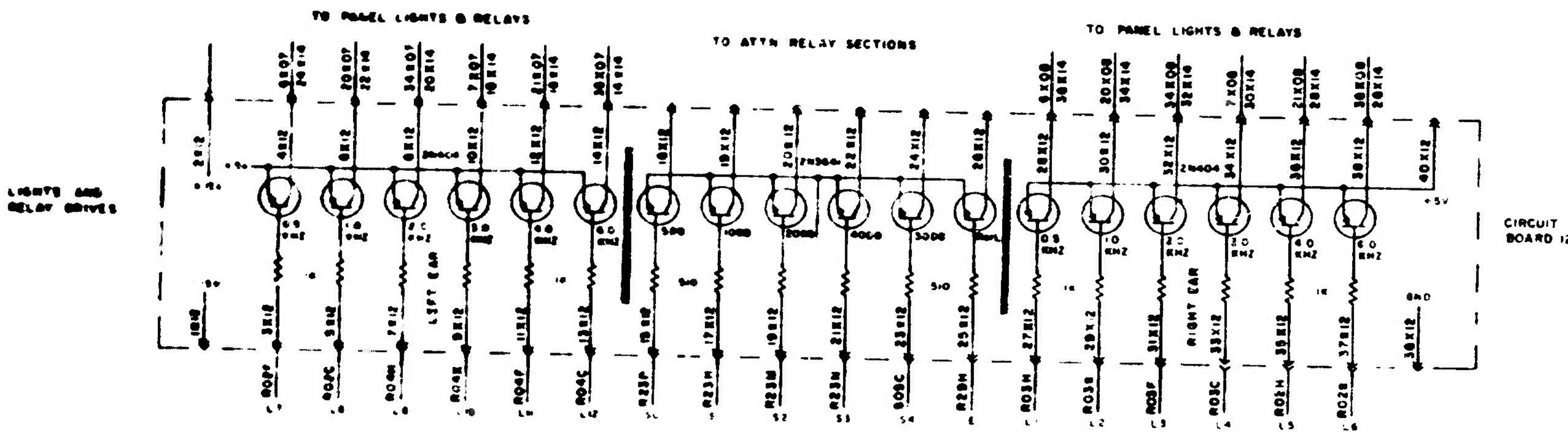


FRONT PANEL LIGHTS



SUBJECT RESPONSE PANEL



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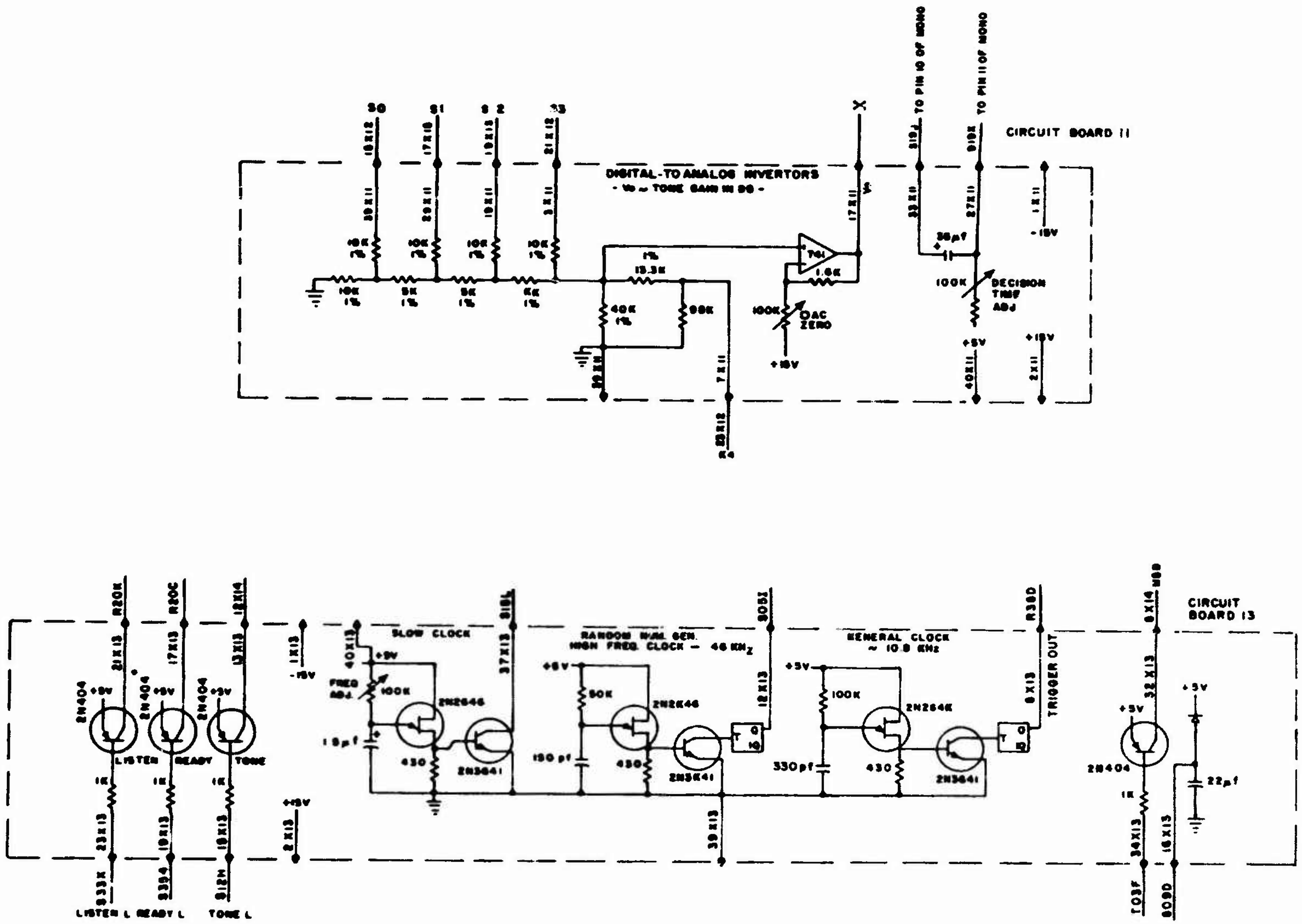

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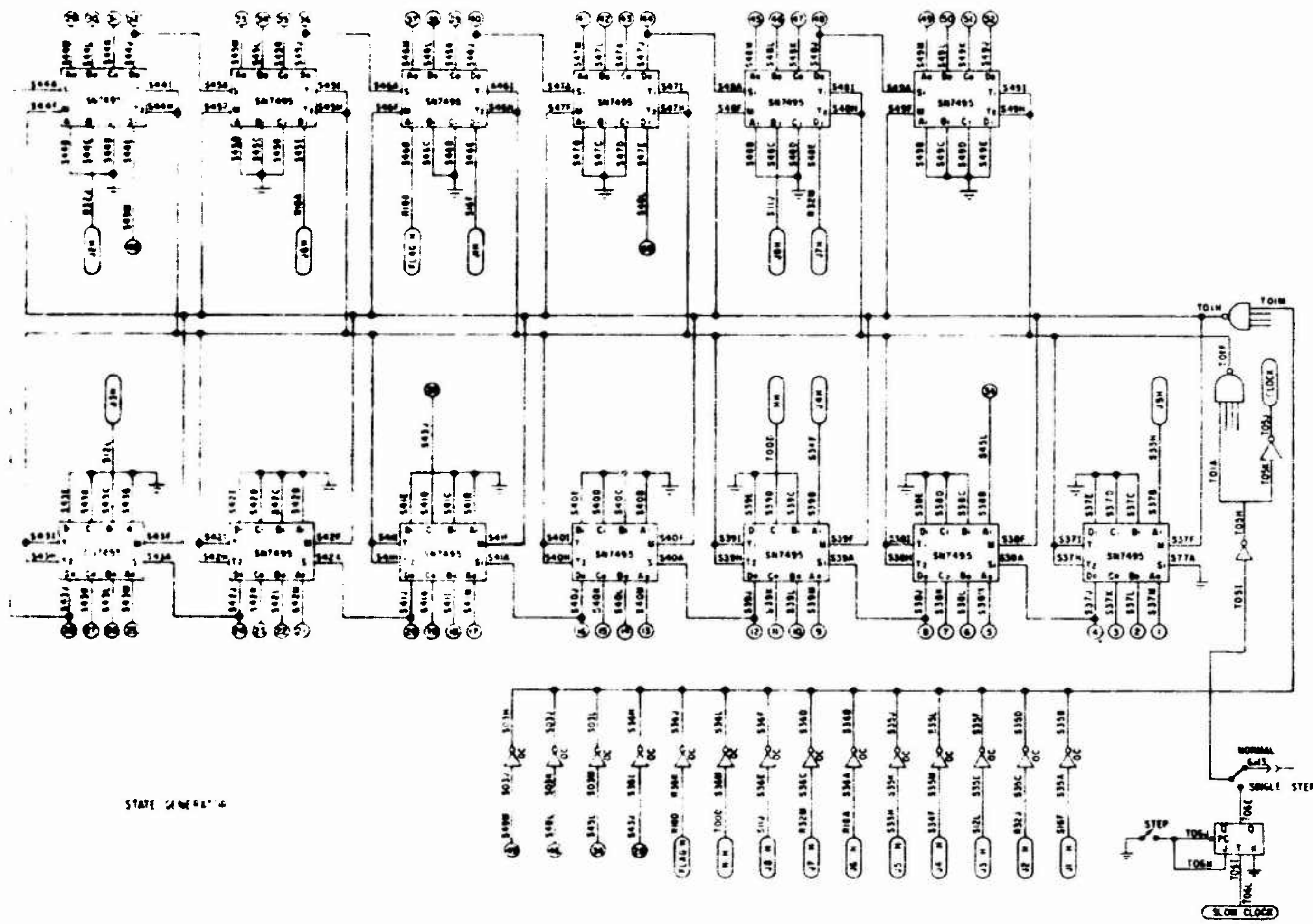

STATE GENERATING

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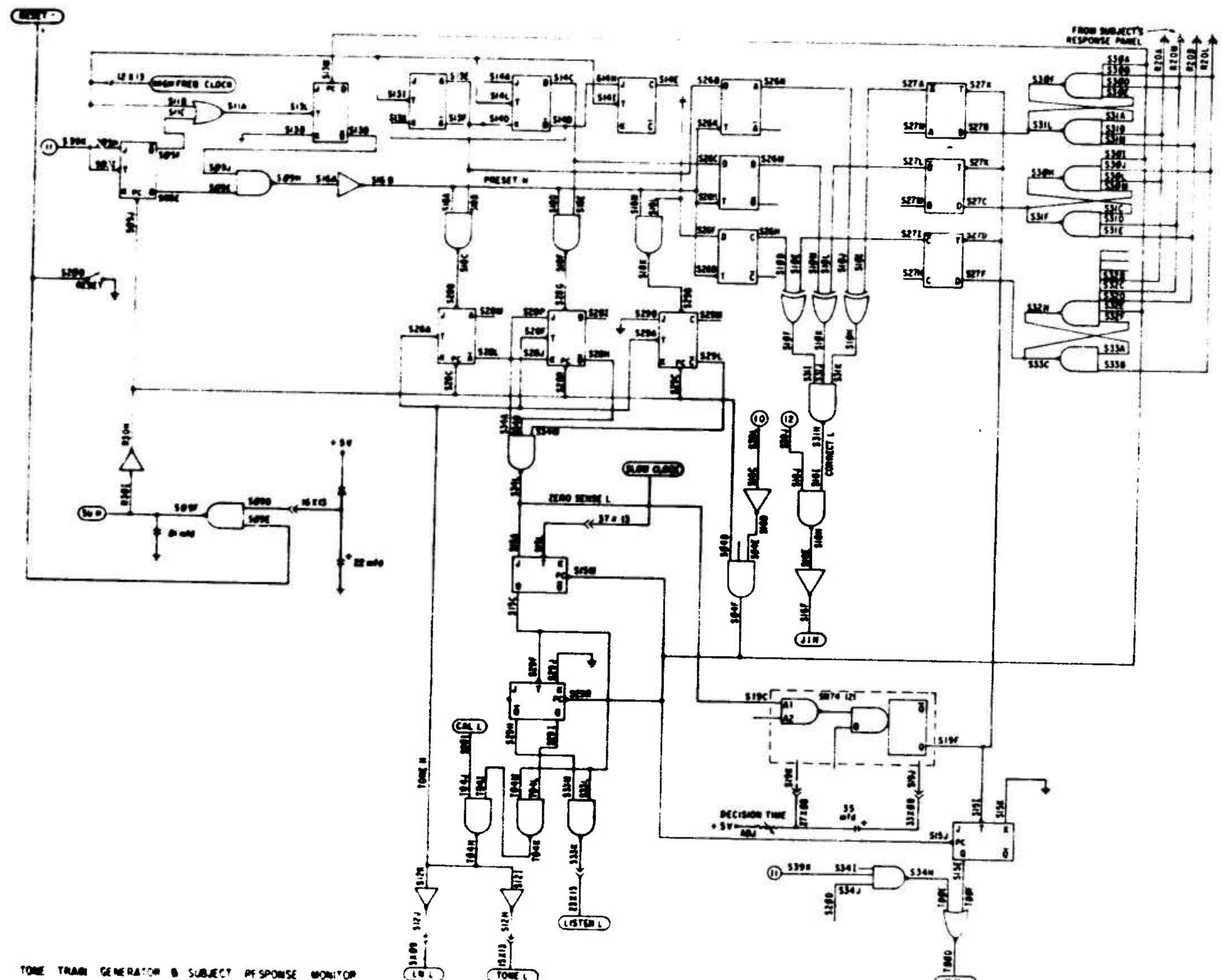

TONE TRAIN GENERATOR & SUBJECT RESPONSE MONITOR

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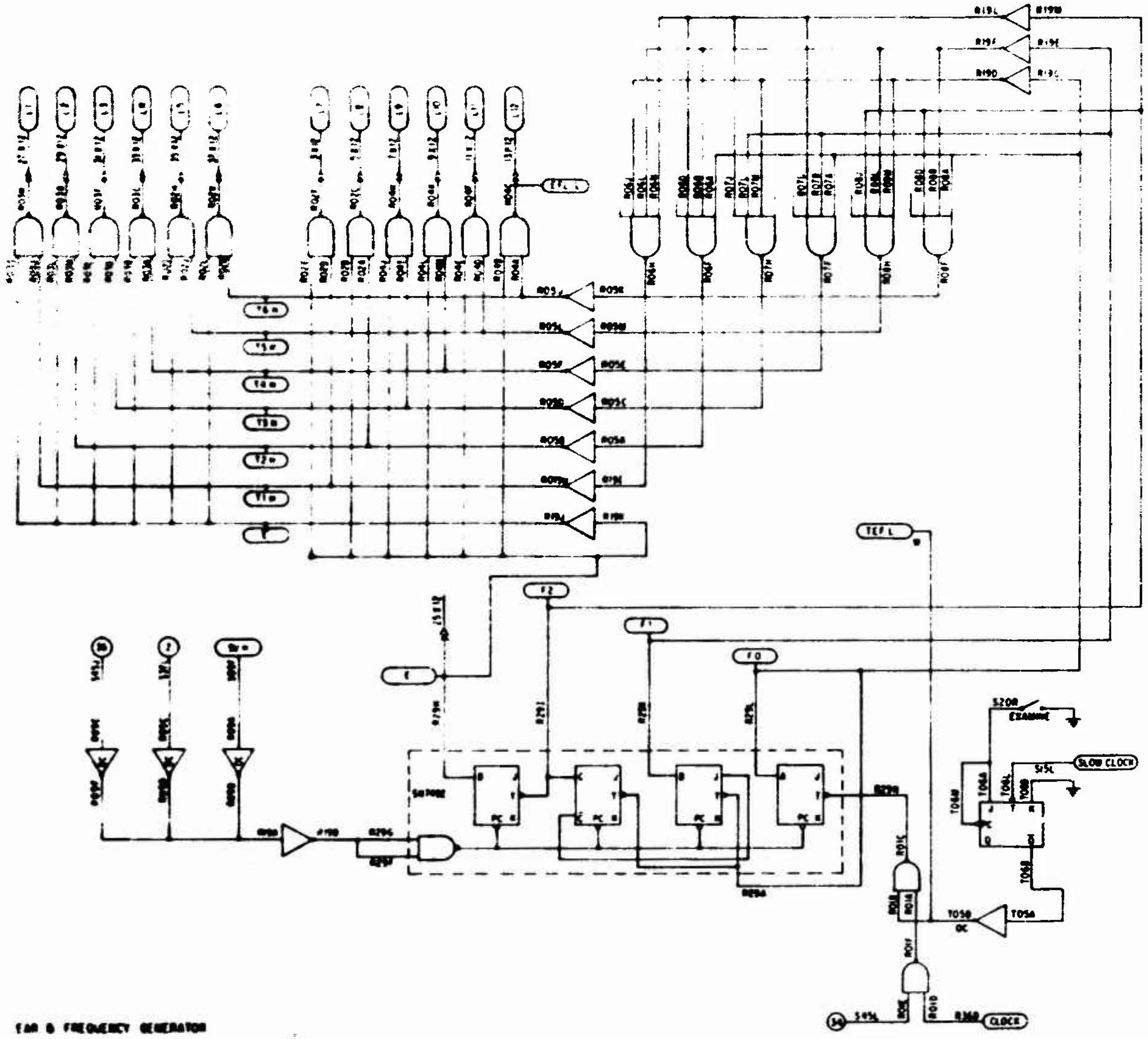

EAR & FREQUENCY GENERATOR

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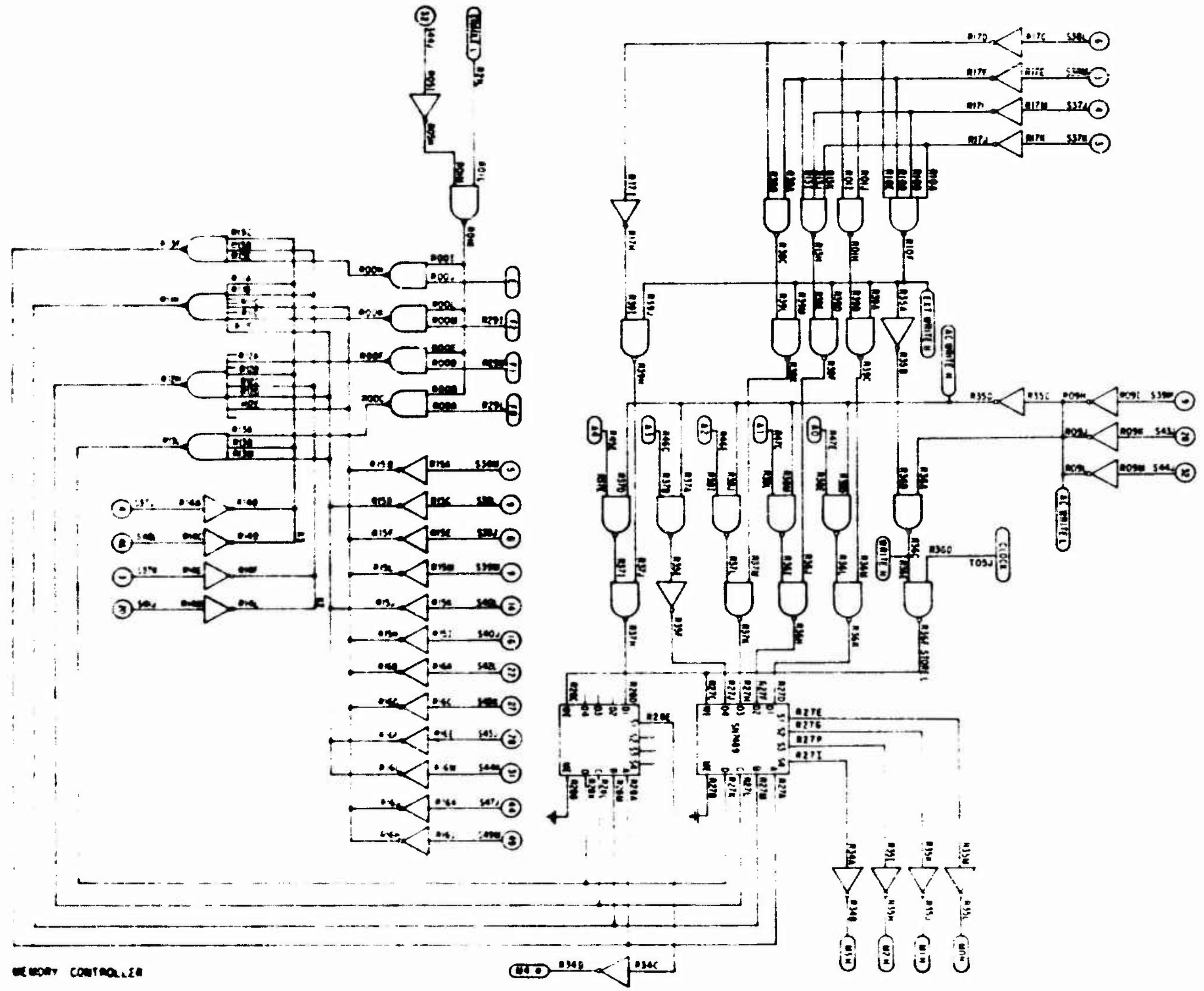

MEMORY CONTROLLER

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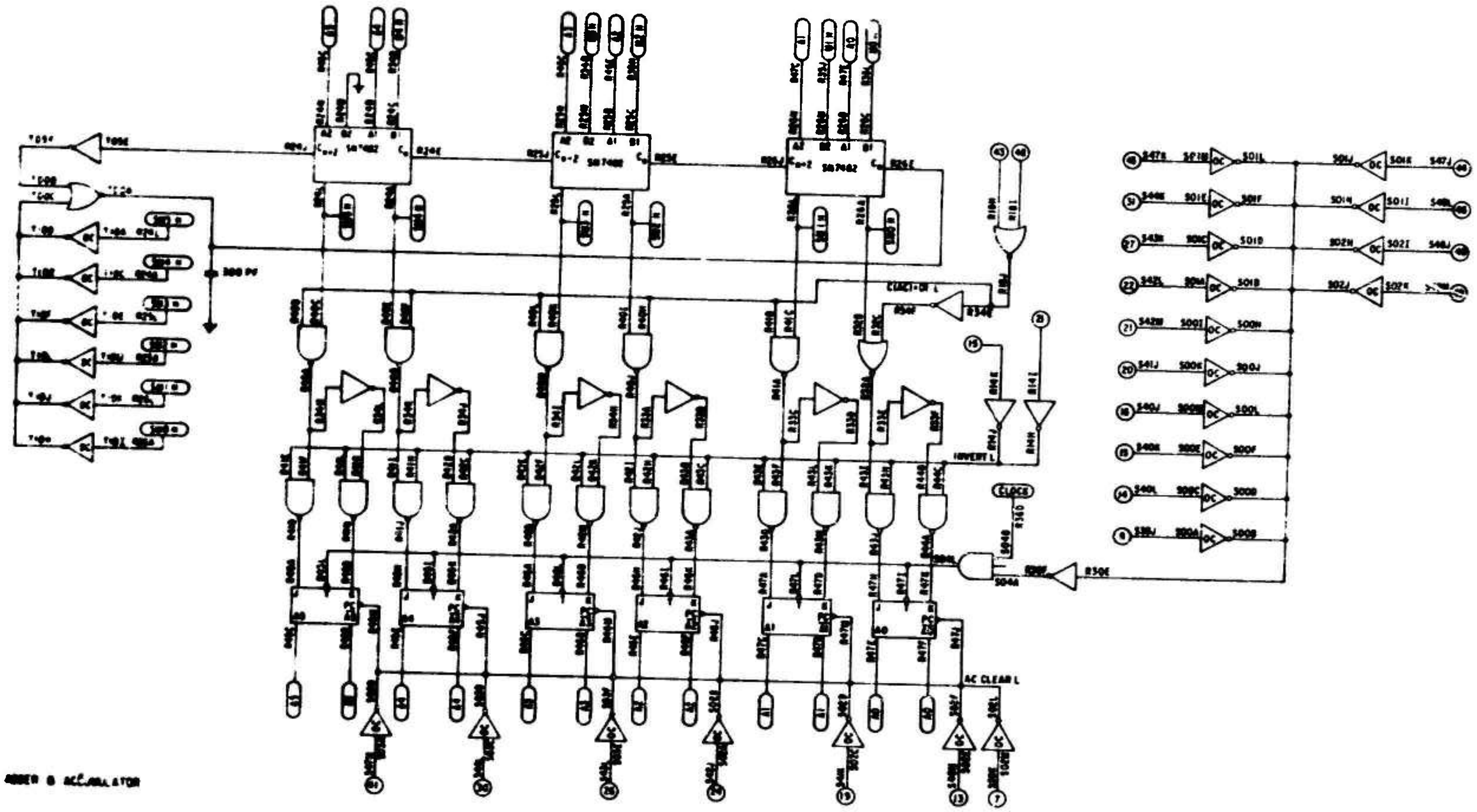

ADDER & ACCUMULATOR

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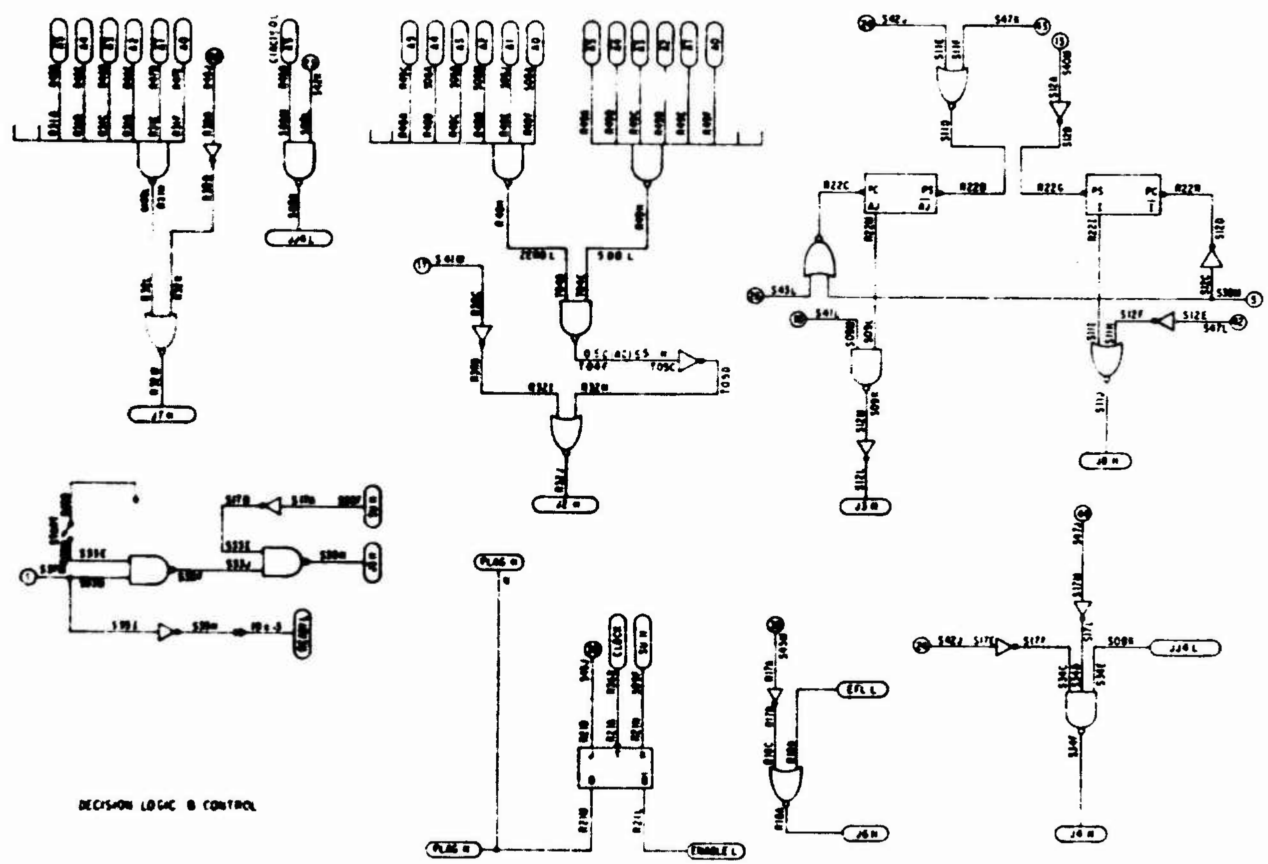
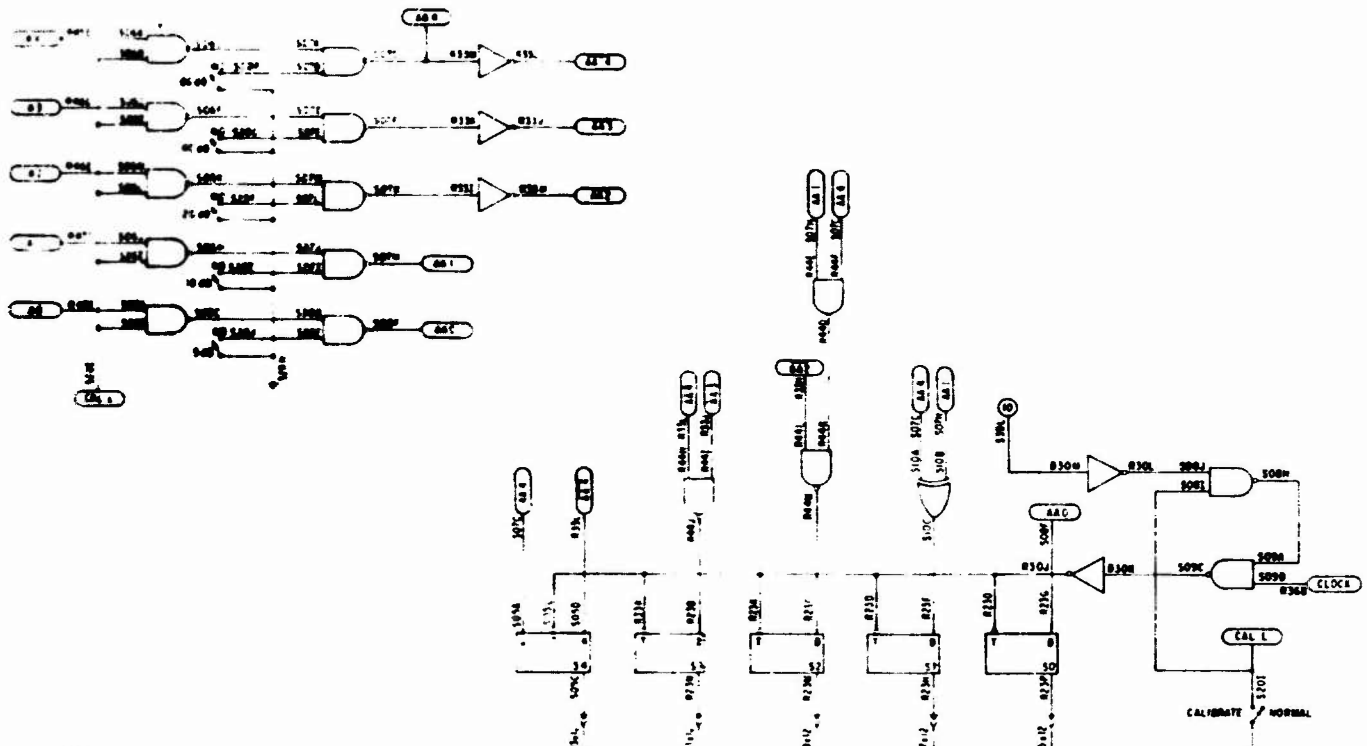


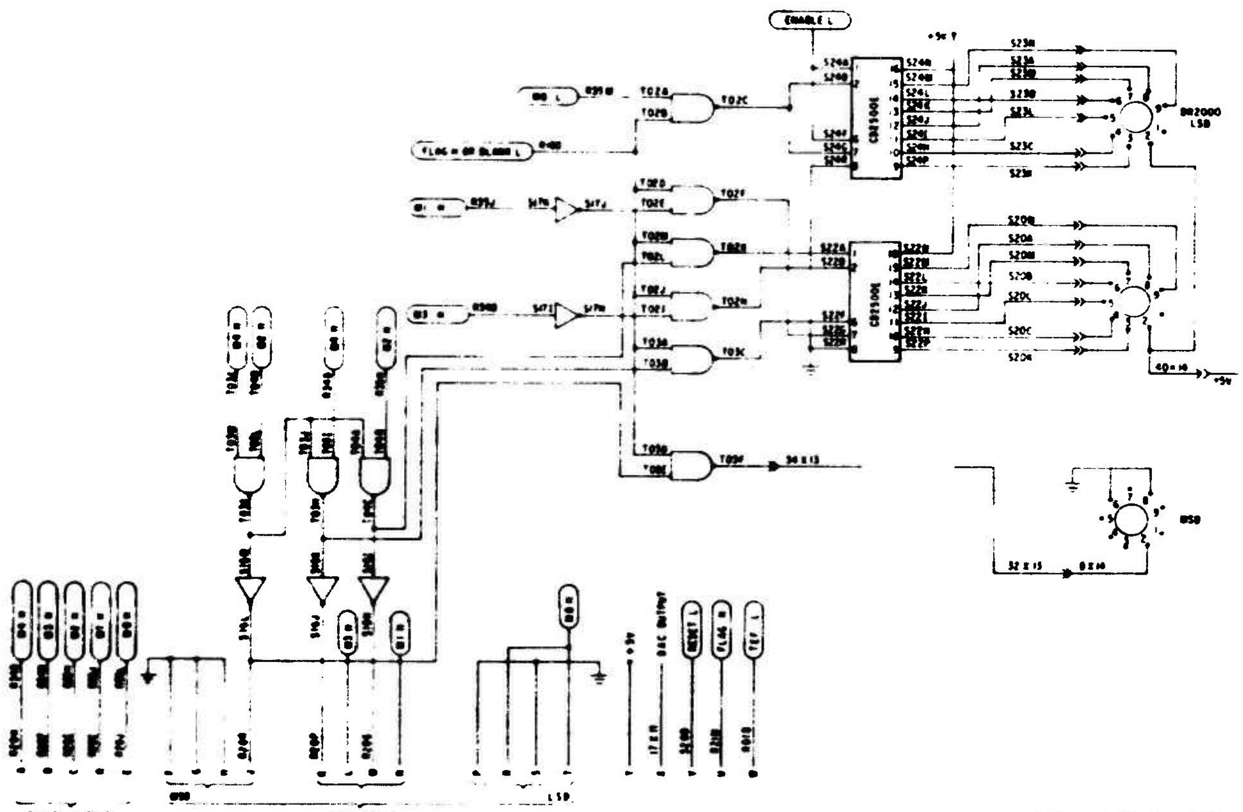
DECISION LOGIC & CONTROL

APPENDIX H (Continued)



RELAY ATTENUATOR DECODER

APPENDIX H (Continued)



DISPLAY & OUTPUT DECODER