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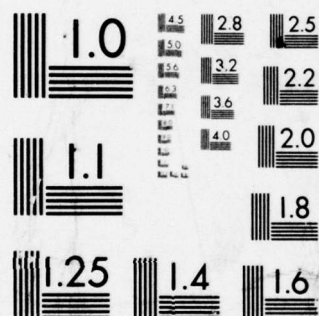
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# EXPERIMENTS WITH COCHLEAR-TRANSFORMED SPEECH--

## A FIFTH YEAR STUDY

by

Victor W. Bolie

A Condensed Report for the Activities of

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# EXPERIMENTS WITH COCHLEAR-TRANSFORMED SPEECH-- A FIFTH YEAR STUDY

## Background

The preliminary findings reported herein are based on the results of earlier studies in machine learning [1], feature vector extraction [2], and cochlear modelling [3, 4]. It was quickly found in the earlier studies that a real-time hardware system was essential.

A block diagram of the hardware system is shown in Figure 1. The design of the artificial cochlea is a mix of digital modules for data transfer and short term memory, and of various analog components to handle the necessary information processing at high speed. A preliminary version of the system was assembled and tested six months ago, and used to obtain the results reported here. Minor hardware problems (mainly crosstalk between digital and analog signals in the ground busses) necessitated a hardware rebuild which is now nearly complete.

A key feature of the various hybrid components of the system shown in Figure 1 is their "socket-board construction" and the consequent ease with which they can be modified to take advantage of a new finding quickly. For example, it was discovered during recent tests that the separability of an "OO" sound from an "NN" sound could be greatly improved by making a substantial change in the "middle ear" component. Key feature of the digital portions of the system are compactness, flexibility, ample memory, and facility for handling English-text (separate fragments and/or connected strings).

## Experimental Results

Experiments with the preliminary version of the above described system were done with the phonemes listed in Table 1. Twelve samples of each sound were captured in the data acquisition and stored on the tape to give a total file of  $12 \times 21 = 252$  cochlear-transformed sounds for training and challenge tests. In loading these phonemes the unvoiced sounds (4 out of 21) were held steady, and for the voiced sounds (17 out of 21), the pitch was varied in a sing-song manner. The 12 samples of each sound were used to develop 21 reference vectors and 21 tolerance vectors, which were stored as a condensate of the training.

All 252 phoneme samples were then submitted in sequence as challenges to the recognition algorithm, and the resulting 252 response vectors were stored for later study of errors and threats. Figure 2 shows the average response vector (a horizontal row in the chart) for any given sound challenge. Fortunately, the largest number in each row falls on the diagonal of this 21 x 21 matrix. The greatest consistent threat appears to be that of the "OU" against the "LL" sound, and the safest sounds appear to be the unvoiced ones (SS, FF, KH, SH).

The 252 response vectors were analyzed further with respect to recognition dangers. For this purpose a measure of hazard was constructed, using the formula,

$$H(E,I) = \frac{B(E,E) + B(E,I)}{A(E,E) - A(E,I)}, \text{ for all } I \neq E,$$

in which  $A(E,I)$  is the element in Row E and Column I of the response-vector matrix shown in Figure 2, and in which  $B(E,I)$  is the average deviation of the 12 contributions to that element. Each row of the resulting "hazard matrix" was then searched to find the greatest hazard value. The various phonemes were then ranked in ascending order of this value. The results are listed in Table 2, together with the actual recognition errors found from a trivial search for the largest element in each of the 252 response vectors. As expected, the most errors occur where the computed hazard values are greatest, i.e., in the bottom region of Table 2. For more detail, the nature of perception errors are listed in Table 3, where it is seen that practically all of the perception errors are recoverable in the "second-choice" responses.

A pleasant surprise was a finding of high consistency in the first moment of the cochlear response to a given phoneme, irrespective of pitch. This is illustrated in Table 4 in which the maximum value, minimum value, average, and standard deviation of the first moment for each phoneme is listed. Thus, even though the FF sound has a nearly pure noise appearance on the oscilloscope, it has a very well defined cochlear first moment value ( $75.6 \pm 2.1$ ).

The information shown in Figure 2 and Tables 1-3 is still somewhat plastic, and subject to refinements made through further experiments and tests. Nevertheless, it is apparent from the data that



error-free and pitch-independent automatic recognition of many of the key English phonemes is electronically realizable. Further, an accurate identification of any phoneme traversed in continuous speech provides a hard "time-lock" for resetting any probabilistic algorithm used to resolve interim ambiguities.

#### The Re-Packaged System

The final hardware system, nearly complete now (August 1976), corrects the shortcomings encountered during the acquisition of the above reported experimental data, and provides the means for obtaining the more comprehensive data needed for advanced studies (e.g., plosive transients, masking noise, text synthesis). This final system includes a re-packaging of the hybrid electronic modules into a smaller and neater (7 x 17 x 20") chassis box, mounted on top of the HP-9830A, and includes four power supplies instead of three to avoid any further problems with ground currents and digital-analog crosstalk. The DIP circuit boards (5 master boards) are made larger (12 3/8 x 14 3/8) so as to substantially reduce the number of vulnerable slide-interconnects. Also, numerous front-panel controls are eliminated by use of programmable sub-circuits. The key elements of the final system are listed in Tables 5 and 6.

#### Advanced Studies

Beginning in October 1976, all of the anticipated hardware refinements will have been completed, and the entire research effort will thereafter be devoted to the automatic recognition of continuous speech, i.e., words, phrases, and sentences. Word decomposition will be like that shown in Table 7, with provisions for the plosives (at least BB, GG, PP, and TT). Speaker-to-speaker differences will be studied by using one trainer and several challengers, and by generating a reference and tolerance vector set from a composite of male and female voices.

In processing the continuous stream of voiced phonemes, a high-level "lock-on" program will be used to drastically reduce the ongoing decision options whenever an uncompromised phoneme (i.e., one in the upper zone of Table 2) is recognized. This is precisely where the meticulous hardware work of the past several years will pay off, since

the number of decision options would grow catastrophically toward a "combinatorial explosion" unless a significant fraction of the voiced (variably pitched) and unvoiced phonemes are in the low-hazard category.

For word strings, i.e., phrases, the gaps between words (as opposed to gaps between syllables) will be identified as they occur in real time, by means of an experimentally verified "silence monitor." Transitions into and out of the uncompromised phonemes will present no difficulty. A dictionary-dependent subroutine will be used, together with danger-weighted decision options, to cope with transitions into and out of the heavily compromised phonemes--taking advantage of any adjacent leading or trailing silence gap. Flexibility in dictation speed, inflection, and pitch will be retained to the fullest extent possible.

As the experimental results accumulate, the elementary aspects of context [8], orthography [9], and vocabulary scope [10, 11, 12] will be studied as potential aids to the ASR process. For example, it is believed that an uncompromised phoneme may well retain a significant portion of its decision-option-reduction value even if it occurred several words earlier in the voiced sentence. Also, certain rules of word structure (e.g., the rarity of B either before or after G, or the almost-zero occurrence of words ending in V, U, Q, or I) are clearly useful in resolving decision options which otherwise might be indeterminate. Even without the context and orthography aids, it is easy to modify the real time ASR print-out to include all the homonyms (e.g., bear and bare) and isophonemics (e.g., three and free) found in the stored vocabulary.

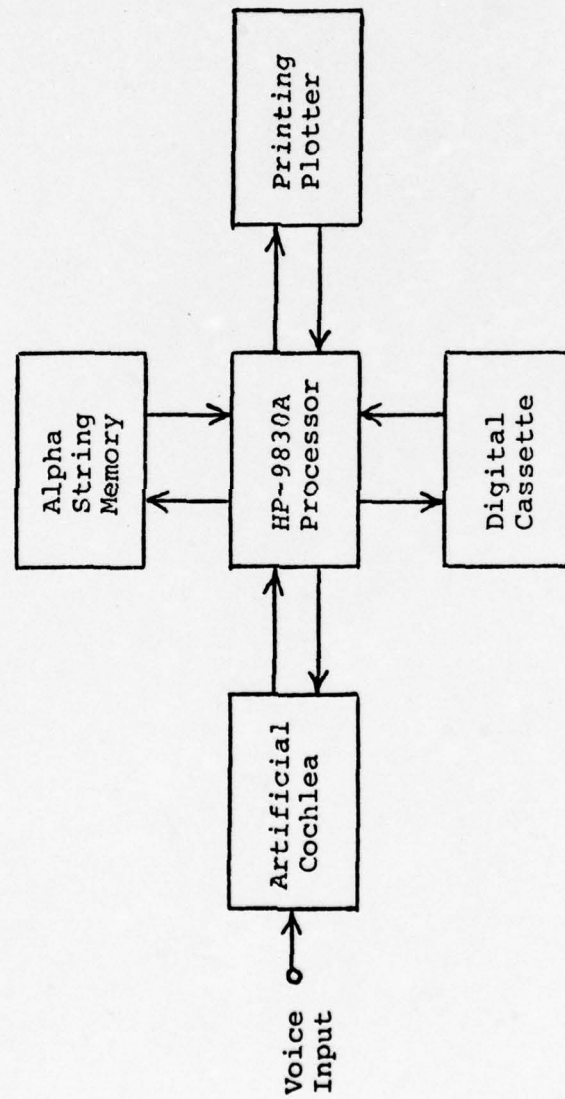


Figure 1. The Bolie/USAF Automatic Speech Recognition System



| OH | EE | EH | SS | AA | ZZ | AY | FF | OU | LL | KH | AH | RR | OO | AW | SH | VV | II | ZH | UH | NN |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 59 | 7  | 7  | 4  | 12 | 9  | 6  | 6  | 14 | 6  | 13 | 12 | 13 | 12 | 10 | 5  | 13 | 12 | 4  | 19 | 14 |
| 4  | 56 | 11 | 3  | 13 | 13 | 18 | 4  | 18 | 9  | 5  | 7  | 11 | 3  | 5  | 3  | 24 | 6  | 4  | 10 | 5  |
| 8  | 17 | 56 | 3  | 30 | 12 | 32 | 6  | 17 | 8  | 9  | 12 | 11 | 5  | 6  | 5  | 17 | 8  | 4  | 16 | 7  |
| 8  | 11 | 5  | 67 | 7  | 22 | 6  | 9  | 11 | 5  | 8  | 7  | 6  | 7  | 5  | 6  | 10 | 13 | 6  | 10 | 8  |
| 7  | 10 | 18 | 2  | 54 | 10 | 17 | 4  | 18 | 7  | 7  | 21 | 13 | 5  | 8  | 3  | 16 | 7  | 4  | 12 | 8  |
| 4  | 11 | 6  | 4  | 8  | 54 | 6  | 3  | 17 | 8  | 4  | 8  | 8  | 4  | 5  | 2  | 18 | 10 | 6  | 9  | 6  |
| 5  | 26 | 25 | 3  | 20 | 12 | 55 | 6  | 18 | 8  | 7  | 9  | 11 | 4  | 5  | 4  | 19 | 7  | 4  | 13 | 6  |
| 10 | 14 | 12 | 7  | 13 | 11 | 16 | 64 | 11 | 5  | 15 | 8  | 7  | 6  | 5  | 21 | 12 | 9  | 4  | 15 | 6  |
| 4  | 12 | 6  | 2  | 12 | 14 | 7  | 3  | 53 | 36 | 4  | 11 | 35 | 5  | 12 | 2  | 28 | 8  | 5  | 8  | 8  |
| 4  | 13 | 6  | 2  | 10 | 14 | 7  | 2  | 53 | 56 | 4  | 9  | 34 | 4  | 10 | 2  | 33 | 7  | 5  | 7  | 8  |
| 16 | 12 | 13 | 5  | 17 | 10 | 13 | 13 | 12 | 6  | 59 | 9  | 9  | 7  | 6  | 14 | 13 | 10 | 4  | 20 | 9  |
| 9  | 6  | 6  | 2  | 15 | 10 | 6  | 3  | 18 | 7  | 5  | 55 | 19 | 9  | 15 | 2  | 14 | 9  | 4  | 11 | 16 |
| 5  | 8  | 6  | 2  | 12 | 12 | 6  | 3  | 39 | 15 | 4  | 12 | 54 | 5  | 12 | 2  | 24 | 8  | 4  | 8  | 10 |
| 18 | 7  | 5  | 3  | 11 | 10 | 6  | 4  | 18 | 8  | 8  | 16 | 18 | 60 | 18 | 3  | 13 | 11 | 5  | 12 | 36 |
| 8  | 7  | 6  | 2  | 14 | 11 | 6  | 3  | 25 | 12 | 5  | 27 | 23 | 12 | 57 | 2  | 15 | 9  | 5  | 9  | 18 |
| 12 | 15 | 16 | 7  | 16 | 10 | 21 | 26 | 12 | 6  | 19 | 8  | 8  | 6  | 5  | 66 | 12 | 9  | 4  | 16 | 7  |
| 3  | 13 | 7  | 2  | 11 | 14 | 8  | 2  | 29 | 16 | 4  | 8  | 20 | 3  | 7  | 2  | 53 | 7  | 4  | 8  | 7  |
| 5  | 7  | 4  | 3  | 7  | 14 | 5  | 3  | 12 | 6  | 3  | 8  | 7  | 5  | 5  | 2  | 13 | 55 | 17 | 14 | 9  |
| 4  | 8  | 4  | 2  | 6  | 14 | 5  | 2  | 12 | 7  | 3  | 7  | 7  | 4  | 4  | 2  | 13 | 29 | 57 | 12 | 7  |
| 9  | 7  | 8  | 3  | 11 | 10 | 7  | 4  | 11 | 5  | 6  | 10 | 8  | 5  | 4  | 4  | 12 | 11 | 5  | 53 | 7  |
| 14 | 6  | 5  | 2  | 12 | 11 | 6  | 3  | 18 | 8  | 6  | 23 | 16 | 29 | 18 | 3  | 14 | 11 | 5  | 12 | 55 |

Figure 2. Listing of the Average Response Vector for Each Prescribed Challenge.

Table 1. Listing of the Prolongable Phonemes  
in the English Language<sup>a</sup>

| <u>Ident<br/>Number</u> | <u>Alpha<br/>Description<sup>b</sup></u> |
|-------------------------|--|
| 1                       | OH                                       |
| 2                       | EE                                       |
| 3                       | EH                                       |
| 4                       | SS                                       |
| 5                       | AA                                       |
| 6                       | ZZ                                       |
| 7                       | AY                                       |
| 8                       | FF                                       |
| 9                       | OU                                       |
| 10                      | LL                                       |
| 11                      | KH                                       |
| 12                      | AH                                       |
| 13                      | RR                                       |
| 14                      | OO                                       |
| 15                      | AW                                       |
| 16                      | SH                                       |
| 17                      | VV                                       |
| 18                      | II                                       |
| 19                      | ZH                                       |
| 20                      | UH                                       |
| 21                      | NN                                       |

---

<sup>a</sup>Omitted because of out-of-context indistinguishability are TH (thin vs fin), DH (this vs vis), and the MM and NG sounds rum vs run vs rung).

<sup>b</sup>The listed sequence of 21 sounds are those contained in the sentence "Oh, yes, as a full car wash vision."

Table 2. Hazard Ranking<sup>1</sup> of Perceptions

| <u>Rank</u> | <u>Sound</u> | <u>Hazard</u> | <u>Errors in 12 Challenges</u> |
|-------------|--------------|---------------|--------------------------------|
| 1           | UH           | 0.109         | 0                              |
| 2           | KH           | 0.133         | 0                              |
| 3           | SH           | 0.143         | 0                              |
| 4           | SS           | 0.149         | 0                              |
| 5           | FF           | 0.191         | 0                              |
| 6           | AH           | 0.233         | 0                              |
| 7           | AA           | 0.242         | 0                              |
| 8           | OH           | 0.245         | 0                              |
| 9           | AY           | 0.248         | 0                              |
| 10          | II           | 0.258         | 0                              |
| 11          | AW           | 0.267         | 0                              |
| 12          | ZZ           | 0.272         | 0                              |
| 13          | EH           | 0.283         | 0                              |
| 14          | ZH           | 0.325         | 0                              |
| 15          | OO           | 0.350         | 1                              |
| 16          | NN           | 0.381         | 0                              |
| 17          | EE           | 0.388         | 0                              |
| 18          | VV           | 0.467         | 0                              |
| 19          | RR           | 0.847         | 0                              |
| 20          | OU           | 1.024         | 1                              |
| 21          | LL           | 3.600         | 5                              |

---

<sup>1</sup>Hazard matrix elements range from 0.058 to 3.600.



Table 3. Nature of the Perception Errors

| <u>E<sup>a</sup></u> | <u>K<sup>b</sup></u> | <u>Challenge</u> | <u>Response Choices</u> |    |    |    |    |
|----------------------|----------------------|------------------|-------------------------|----|----|----|----|
| 9                    | 1                    | OU               | VV                      | OU | RR | AA | ZZ |
| 10                   | 1                    | LL               | OU                      | VV | LL | RR | ZZ |
| 10                   | 5                    | LL               | OU                      | LL | RR | VV | ZZ |
| 10                   | 6                    | LL               | OU                      | LL | RR | VV | ZZ |
| 10                   | 7                    | LL               | OU                      | LL | RR | VV | ZZ |
| 10                   | 8                    | LL               | OU                      | LL | RR | VV | ZZ |
| 14                   | 1                    | 00               | NN                      | OO | AH | OU | AW |

---

<sup>a</sup>The original numerical code for the challenge sound is E.

<sup>b</sup>The sample number of the challenge sound is K.

Table 4. Cochlear First-Moment Statistics

| <u>Phoneme</u> | <u>Max</u> | <u>Min</u> | <u>Ave</u> | <u>Dev</u> |
|----------------|------------|------------|------------|------------|
| OH             | -63.84     | -77.42     | -73.59     | 2.09       |
| EE             | -30.14     | -48.38     | -39.78     | 3.78       |
| EH             | 22.23      | 8.43       | 15.11      | 4.41       |
| SS             | 91.84      | 81.91      | 86.54      | 2.96       |
| AA             | 13.09      | - 4.63     | 4.32       | 4.32       |
| ZZ             | -14.96     | -46.52     | -33.70     | 5.68       |
| AY             | 10.70      | -12.50     | - 1.93     | 7.11       |
| FF             | 79.42      | 70.25      | 75.64      | 2.10       |
| OU             | -50.50     | -71.35     | -64.38     | 4.21       |
| LL             | -69.38     | -83.98     | -77.20     | 3.42       |
| KH             | 71.58      | 39.63      | 63.40      | 7.61       |
| AH             | - 2.44     | -23.05     | -13.28     | 5.73       |
| RR             | -26.34     | -56.40     | -38.98     | 9.25       |
| OO             | -76.40     | -93.03     | -91.05     | 2.62       |
| AW             | -38.10     | -57.23     | -46.11     | 4.06       |
| SH             | 92.80      | 87.03      | 90.74      | 1.24       |
| VV             | -48.75     | -76.19     | -63.08     | 5.34       |
| II             | 9.92       | -29.11     | -11.95     | 11.51      |
| ZH             | - 2.63     | -39.76     | -27.73     | 9.47       |
| UH             | -30.14     | -55.07     | -38.05     | 6.53       |
| NN             | -65.47     | -88.90     | -83.71     | 4.21       |

Table 5. Permanent Equipment Items (USAF Property)

| <u>Manufacturer</u> | <u>Item</u>                              |                               | <u>Serial No.</u> |
|---------------------|--|-------------------------------|-------------------|
| Hewlett-Packard     | HP9830A                                  | Programmable Controller       | 1303403812        |
| Hewlett-Packard     | HP 11276                                 | 7904-Word Memory              | 1303A03812        |
| Hewlett-Packard     | HP 11270                                 | Matrix Operations ROM         | --                |
| Hewlett-Packard     | HP 11272                                 | Extended I/O ROM              | --                |
| Hewlett-Packard     | HP 11274                                 | String Variables RO,          | --                |
| Hewlett-Packard     | HP 11279B                                | Adv Prog I ROM                | 57329             |
| Hewlett-Packard     | HP 11289B                                | Adv Prog II ROM               | 57269             |
| Hewlett-Packard     | HP 11283B                                | Printer Control ROM           | 58539             |
| Hewlett-Packard     | HP 11336A                                | Printer Interface             | 00777             |
| Hewlett-Packard     | HP 11202A                                | TTL I/O Interface             | 04871             |
| Hewlett-Packard     | HP 11202A                                | TTL I/O Interface             | 04924             |
| Hewlett-Packard     | HP 11202A                                | TTL I/O Interface             | 04925             |
| Hewlett-Packard     | HP 9871A                                 | Printer/Plotter               | 1537A01161        |
| Hewlett-Packard     | HP 9162                                  | Burst-Read Cassette           | 9162-0050         |
| Tektronix           | R5103N                                   | Oscilloscope                  | B046837           |
| Tektronix           | 5A15N                                    | Amplifier, with X1 Probe      | B042153           |
| Tektronix           | 5A15N                                    | Amplifier, with X1 Probe      | B042192           |
| Tektronix           | 5B10N                                    | Time Base, with X1 Probe      | B044051           |
| Tektronix           | C-5                                      | Oscilloscope Camera           | CB369385          |
| Ward                | Pwrkrft                                  | 10-Drawer Cabinet             | --                |
| Powertec            | XR Series                                | 3D5-3.0 Pwr Supplies (2)      | --                |
| Powertec            | XR Series                                | 3D15-1.2 Pwr Supplies (2)     | --                |
| Continental         | QT59B,S                                  | Bus (30) & Socket (82) Strips | --                |
| Turner              | 35A                                      | Microphone, 150 ohms, flat    | --                |
| Hardware            | Chassis Box, Meter, Jacks, 5-Board Stack |                               | --                |



Table 6. Expendable Supplies

A. Controller/Printer Use

- 8 Printer Ribbons
- 30 Digital Tape Cassettes
- 2 Printer Drive Chains
- 4 Print-wheel Triads
- 2 Tape Head Cleaner Fluids
- 3 Boxes Printer Paper (Plain)
- 3 Boxes Printer Paper (Carbon)
- 1 TTL I/O Interface Card

B. Hybrid Electronic Use

- 2 Power Supplies 5V, 3A
- 2 Power Supplies, 15V, 1.2A
- 1 Turner 35A Microphone
- 1 Master Circuit Board
- 10 Hand Tools (for Ckt Changes)
- 30 Rolls Hook-up Wire, #22-1/C PVC
- 200 DIP Chips, Digital Type
- 100 DIP Chips, Analog Type
- 300 Capacitors, CK05BX Type
- 400 Resistors, 0.25W, Carbon

Table 7. Phoneme Structure of Typical Words

| <u>Phoneme<br/>Sequence</u> <sup>1</sup> | <u>English<br/>Equivalent</u> |
|--|-------------------------------|
| RR TH                                    | Earth                         |
| SS UH NN                                 | Sun                           |
| MM OO NN                                 | Moon                          |
| RR II VV RR                              | River                         |
| OO SH UH NN                              | Ocean                         |
| SH AW RR                                 | Shore                         |
| OO EH DH RR                              | Weather                       |
| SS UH NN EE                              | Sunny                         |
| RR AY NN                                 | Rain                          |
| SS NN OH                                 | Snow                          |
| AH EE SS                                 | Ice                           |
| SS EE LL II NG                           | Ceiling                       |
| NN AW RR TH                              | North                         |
| SS AH OO TH                              | South                         |
| LL EH VV LL                              | Level                         |
| AA ZZ II MM OU TH                        | Azimuth                       |
| EH LL EH VV AY SH UH NN                  | Elevation                     |
| RR AY NN ZH                              | Range                         |
| FF EE OO SS EH LL AH ZH                  | Fuselage                      |
| OO II NG                                 | Wing                          |
| AY LL RR AH NN                           | Aileron                       |
| NN OH ZZ                                 | Nose                          |
| KH AA NN UH NN                           | Cannon                        |
| FF LL AA KH                              | Flak                          |
| MM AH EE NN                              | Mine                          |
| RR AH EE FF LL                           | Rifle                         |
| SS LL II NG                              | Sling                         |
| EH RR OH                                 | Arrow                         |
| RR UH SH EE UH                           | Russia                        |
| FF RR AA NN SS                           | France                        |
| II ZZ RR AY LL                           | Israel                        |
| RR OH MM                                 | Rome                          |
| KH AH EE RR OH                           | Cairo                         |
| MM AH EE AA MM EE                        | Miami                         |
| AH RR MM EE                              | Army                          |
| NN AY VV EE                              | Navy                          |
| MM UH RR EE NN                           | Marine                        |
| EH RR                                    | Air                           |
| FF AW RR SS                              | Force                         |
| MM II LL II SH UH                        | Militia                       |
| RR OH LL                                 | Roll                          |
| SS KH OO EE ZZ                           | Squeeze                       |
| KH RR UH SH                              | Crush                         |
| SH UH VV                                 | Shove                         |
| SS OO KH                                 | Soak                          |
| TH RR OH                                 | Throw                         |

<sup>1</sup>The equalities TH = FF, DH = VV, and MM = NG = NN are made automatically as this 2-column dictionary is loaded into memory.

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APPENDIX A

Reprint Requests

**IBM**

LOS ANGELES SCIENTIFIC CENTER  
1930 Century Park West  
Los Angeles, California 90067

Oct. 29, 1975

Dear Prof. Victor W. Bolie

I would greatly appreciate a reprint/preprint of your paper/abstract

**Computer Optimization of Cochlear  
Design Parameters**

which appeared in the

**Interim Report AFOSR**, and related papers.

Thank you for this courtesy.

Sincerely yours,

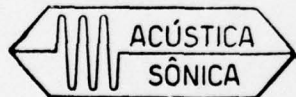
*A. Inselberg*  
**A. Inselberg**

Dear **Dr. BOLIE**

I would appreciate it very much if you would be so kind as  
to send me a reprint of your article

**COMPUTER OPTIMIZATION OF COCHLEAR DESIGN  
PARAMETERS**

**Feb. 1975**



ACÚSTICA E SÔNICA S/C/L  
01000 São Paulo Brasil  
P. O. Box 12,946

Thank you for your courtesy,

*L. X. Nepomuceno*  
Prof. L. X. Nepomuceno

*John F Jarvis*

*2/12/76*

*HEGLO Bell Labs*

*Holmdel NJ 07733*

*ear modeling,*

*Mossbauer Reference*

THE UNIVERSITY OF NEW MEXICO

DATE: September 22, 1975

TO: File

FROM: V. W. Bolie, Principal Investigator

SUBJECT: Report on September 14-20, 1975 Trip to California

The multiple purposes of the above trip were the following:

1. Visit with personnel at the Stanford Artificial Intelligence Institute on problems of automatic speech recognition.
2. Attend WESCON in San Francisco, with particular emphasis on microprocessors and new mini-computer equipment of value in automatic speech recognition.
3. Visit with personnel at the Speech Communications Research Laboratory in Santa Barbara, on problems of automatic speech recognition.

At SAI, automatic speech recognition research was said to be reduced in scope. Some research is continuing in automatic recognition of three-dimensional objects using TV images.

At WESCON it was found that the new Hewlett-Packard Printer/Plotter (soon to be marketed) is ideally suited for use with the H-P 9830A now being acquired at UNM for USAFOSR speech signal research studies. It was also learned that IBM has finally joined the mini-computer builders by coming into the market with a new portable (5100 series) mini-computer. This represents a major policy shift by IBM.

At SCRL, the interest continues in automatic speech recognition, with emphasis on the fundamental properties of real-time speech. An 11-minute segment of natural male speech has been taped, digitized, and densely labelled for long-range studies. The SCRL President, Dr. June Shoup-Hummel, expressed high interest in the results of my research on computer simulation of the human cochlea. Several of her colleagues asked that I send to them a report on my work thus far. It appears that their PDP/11 computer facilities are well suited for addition of the UNM/USAF cochlear model as a subroutine.

In summary, this trip was highly beneficial to the UNM/USAFOSR research project, and it is hoped that one or two additional trips can be scheduled to develop future cooperative projects with SCRL.



PRINTED CIRCUIT BOARD TECHNIQUE\*

by

David N. Hulsbos

UNM EECS Dept.

Summer 1976

\* This work done under the direction of Dr. Victor W. Bolie,  
Principal Investigator, USAFOSR Grant No. 72-2178B.

## MAKING PATTERN OF CIRCUIT AND PHOTO WORK

The first step of printed circuit board production is circuit design and layout. The circuit is laid out on white poster board. Bishop Graphics drafting and layout aids and Centron Drafting Aids are used for the pattern. Pattern may be made in actual (1X) size or double (2X) size. Using 2X size will reduce amount of error on finished board. Keep poster board free of dirt and pencil marks, as these will appear on the negative if left on poster board. Removal of all pencil marks from board is essential. The actual photo work is done at Roy M. Riedl, Co., 1647 2nd St. N.W., 243-1957. Work can usually be done in 6 hrs. Be careful with negatives, keeping foreign matter and fingerprints off surface.

Table 1

### Materials Needed

Poster Board  
Bishop Graphic Drafting Aids  
Kodak Photo Resist Type 3  
Kodak Photo Resist Thinner  
Kodak Ortho Resist Developer

#### CLEANING BOARD

1. Shear copper-clad boards to proper size. Drill small hole in corner of board for hanging board for drying later. Clean board with steel wool, SOS pads, and scouring powder. Remove all grease, oxidation, and foreign matter from the copper surface. Board MUST be cleaned down to the copper. Rinse well with water and dry with air hose. Cleaned board should be coated with Kodak Photo Resist within an hour (before reoxidation of board occurs). A clean board is essential.

#### COATING BOARD WITH KODAK PHOTO RESIST TYPE 3(KPR)

2. With air hose, blow the dust out of the glass tray used for coating boards with KPR. Pour KPR into glass tray. Cleaned board should be air blown with hose to remove any dust and dirt that may have settled upon board. Attach wire to board. Using paper towel, coat board with KPR. Coat MUST be of uniform thickness and cannot contain any air bubbles. Various techniques may be tried to achieve this. (1) Use paper towel as a "spoon" and pour KPR onto board, overlapping pours. Then, using wire, spin rapidly. This will help to throw off excess KPR on board. However, this technique may result in ridges of KPR formed on board as a result of excess KPR flowing to the edge of the board and drying before it reached the edge of the board to be spun off. This ridge is unacceptable. (2) Again, using



paper towel as a spoon, pour the KPR over the board. Let the KPR run to one edge of the board and drip off. Hold the board in this position until the KPR ceases to drip off the board. This technique works well if the edge that the KPR drips from is not needed. A thicker coat will be formed on this edge, but will not interfere with etching process unless this edge is to be left copper-clad. If the printed-circuit pattern uses the entire board, then it is suggested that a slightly larger board than needed be sheared. Drill the hanging hole in the unneeded portion along one edge and allow the KPR to flow to this edge also. Therefore, the portion needed for the finished product will be coated with KPR of a uniform thickness and will not have any holes bored in it. If the coating is satisfactory, hang the board in the light-tight closet to dry for 12 hours. Save unused KPR and clean glass tray. All KPR residue must be removed from glass tray. If not, chunks of dried KPR will come loose from tray during later KPR coatings, thereby contaminating KPR solution and ruin coating of board.

#### EXPOSURE OF BOARD TO UV

3. If the board is to be exposed, developed, and etched the same day, the automatic etcher heater should be turned on when exposure is begun. Heater should be set for approximately 120°F. Coolant hose should be turned on (green hose to left of sink by west door). Before exposure, negative should be cleaned with 95% alcohol if there is any grease on negative

surface (i.e., fingerprints, etc.) Use cotton swab dipped in alcohol. Care should be taken in cleaning emulsion (dull) side of negative. Some emulsion will be removed with the alcohol, therefore, do not press hard with swab or clean excessively long or often. If negative becomes wet, dry as soon as possible. If water spots do form, cleaning with 95% alcohol should remove them. Do not allow the negative to become scratched, as this makes the negative useless. Using the air hose, blow dust particles off copper-clad board and negative. Place copper clad board copper side up in exposure tray. Place negative emulsion (dull) side down on copper-clad board. Clean (if necessary) the plexiglass cover for exposure tray and air blow dust from surface. Align negative on board and place plexiglass cover over exposure tray. Turn vacuum pump on and recheck alignment of negative on board. Slide tray into box. Check U-V light circuits. Turn switch on with rotary switch in desired position. Far counterclockwise will turn all lights on. Push pushbutton switch and release. Lit pilot lights indicate which U-V lamp circuits are not activated. Expose board for 25-30 minutes. Exposure initiates polymerization of KPR-3 thereby making it unaffected by developer.

#### DEVELOPMENT OF BOARD

4. Blow dust out of 2nd glass tray. Pour KODAK ORTHO RESIST DEVELOPER (KOR) into glass tray. Place board in tray. Agitate occasionally. If developer is fresh, develop for 3-5 minutes. If developer has been previously used, development for 5-8 minutes may be necessary to remove all unexposed KPR-3 from board. Rinse board with water. Pour developer back into can. With air hose, dry glass tray.

#### Etching of Board

5. Place board in automatic etcher. Automatic etcher uses ferric chloride solution and oxidation-reduction reaction to remove exposed copper from board. Etcher will work faster when solution is warm. Make sure heater has been on at least 30 minutes, preferable 45-60 minutes to insure warm solution. Etch board for 3-7 minutes, depending upon temperature of solution and freshness of solution. Rinse with water. If not all exposed copper is removed, continue etching. Rinse with water and dry. Remove KPR-3 from copper-clad remaining on board with steel wool. This also roughens up the copper surface for easier soldering.

While etching, if it appears that all of the unexposed KPR-3 was not removed from board while developing, board may be rinsed with water, dried, and developed longer. Care should be taken, however, not to develop for too long as edges of exposed KPR-3 will begin to be developed away.



If a board is etched too long, the straight edges of the copper strips will be eaten into by the ferric chloride, leaving ragged edges.

If a wide board is being etched, it may be noticed that the outside edges do not etch as rapidly as the center portion. Also, the lower edge of the board will not etch as rapidly as the portion a few inches higher. This should be taken into account when considering positioning of board during etching.

HINT: When cleaning KPR-3 from glass tray, do not use water. You will have a mess. Clean tray using paper towel and KPR-3 Thinner. When KPR-3 has been removed, the thinner may be rinsed out with water. Air dry with hose.

⑨ Final rept 1 Sep 75 - 31 Aug 76,

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