A MICRO-COMPUTER-BASED SYSTEM TO COMPUTE MAGNETIC VARIATION*

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A micro-computer-based implementation of a magnetic variation model for the continental United States is presented. The implementation computes magnetic variation as a function of latitude and longitude for general aviation receivers such as Loran-C.

I. INTRODUCTION

A mathematical model of magnetic variation in the continental United States (COT48) has been implemented in the Ohio University Loran-C receiver. The model is based on a least squares fit of a polynomial function. The implementation on the micro-processor based Loran-C receiver is possible with the help of an Am 9511 math chip, manufactured by Advanced Micro Devices, which performs 32 bit floating point mathematical operations. A Peripheral Interface Adapter (M6520) is used to communicate between the 6502 based micro-computer and the 9511 math chip. The implementation provides magnetic variation data to the pilot as a function of latitude and longitude. This report briefly describes the model and the real time implementation in the receiver.

II. THE MATHEMATICAL MODEL

The model was developed at the United States Geological Survey (USGS) by Fabiano et al. [1], by performing least squares analysis on more than 34,000 data measurements taken between 1900 and 1974. The analysis provides an analytical model of the magnetic field which is used to compute the magnetic variation.

For the actual magnetic variation calculation the COT48 region is partitioned into five, 12 degree longitudinal bands from 66 degrees West to 126 degrees West. A set of coefficients for each of the five bands is determined by the analytical model. A seventh order polynomial function of the analytical model is applied to compute the magnetic variation. The secular change is calculated in a similar way, the only difference being that a sixth order polynomial function is used. Also, the secular change case is not partitioned into bands and therefore the same set of coefficients is used for the entire COT48 region.

The polynomial function adapted for the procedure is

\[ \sum_{i=0}^{n} \sum_{j=0}^{l} a_{ij} (\theta_c)^{i-j} (\lambda_c)^j \]

- \( a_{ij} \) - coefficients
- \( \theta_c \) - normalized latitude
- \( \lambda_c \) - normalized longitude
- \( \lambda = \gamma \)
- \( \gamma \) - Table 1 - east longitude normalizing factor
- \( \theta \) - co-latitude = 90°-latitude
- \( \lambda \) - east longitude = 360°-longitude

The limits on each band and other constants are specified in Table 1 [2].
For the magnetic variation calculation \( n = 7 \), and thus 36 coefficients are specified for each band in the COT48 region, while in the secular change calculation \( n = 6 \), therefore only 28 coefficients are required for the whole COT48 region. All the coefficients are given in Appendix A.

The model was simulated in FORTRAN on an IBM 370 computer at Ohio University and a contour plot was made of the magnetic variation in the COT48 region (figure 1). The FORTRAN program listing is included in Appendix B. A copy of an actual magnetic variation chart published by the Defense Mapping Agency (DMA) is shown in figure 2. Comparisons between actual published values of the magnetic variation and values calculated by the model were made and are described later in this report.

III. MICRO-COMPUTER IMPLEMENTATION

The magnetic variation model was implemented on a 6502 based Super-Jolt micro-computer. The 6502 microprocessor has only an 8-bit data bus, so the processor needs a large amount of memory and rapid access. The calculations in the implementation of the model require complex floating point operations of exponents. It is therefore desirable to use an external hardware device to support the microprocessor in these calculations.

The Am9511 was chosen to be implemented with the Super-Jolt system. It is a peripheral math processor which performs the necessary floating point mathematical operations. The Am9511 is designed to be used in conjunction with microprocessor systems that have an 8-bit data bus. The stack oriented processor can handle 16 and 32-bit floating point operands and performs arithmetic and trigonometric functions. An instruction set of the Am9511 is included in Appendix C [3].

Additional hardware is necessary to allow the microprocessor to communicate with the math processor. An M6520 peripheral Interface Adapter (PIA) is used for handshaking with the microcomputer. The PIA consists of two 8-bit ports and several control registers for interface with external support devices. The overall design of the microcomputer, which is a part of the Ohio University Loran-C project is shown in figure 3.

IV. INTERFACING SOFTWARE

Special software is needed to allow the hardware components to interact with one another. The four subroutines 'PINT', 'PUSH', 'POP' and 'CMND' were written by Fischer [4] with this particular goal in mind. 'PINT' initializes the Am9511 and the PIA and, also, the scratchpad RAM locations. 'PUSH' is used to copy a four byte number from RAM to the stack of the Am9511. 'POP' does exactly the opposite by copying a four byte floating point number from the stack of the Am9511 to scratchpad RAM. 'CMND' sends an instruction byte to the Am9511 to perform the desired operation. It also checks the status register of the math processor to determine the outcome of the operation. Flow charts of the above subroutines are given in figure 4.

The actual magnetic variation program 'MAGVAR', occupies about 800 bytes of memory including scratchpad RAM locations. The coefficients 36
for each of the five bands, occupy 900 bytes of memory. Each of the coefficients is converted into a 32-bit floating point format compatible with the Am9511 representing four bytes. The secular variation calculation is not included in the real time implementation for reasons which shall be addressed later in this report. The complete program listing is given in Appendix D at the end of this report. The 'MAGVAR' program takes about 1.5 seconds in execution time. However, since the magnetic variation does not change rapidly in a small geographic region, it does not need to be computed every time navigation position information is updated, when included in the actual navigation receiver such as the Ohio University Loran-C. For example a small change in the software can allow computation of the magnetic variation every 30 miles, or a one degree change in geographic position or any other interval desired.

V. RESULTS AND CONCLUSIONS

Initially, the values for the magnetic variation were computed by the FORTRAN simulation and compared to values published by National Geophysical Data Center.* The results obtained were accurate to a large degree. Table 2 summarizes two points in each band, of which comparisons were made in the COT48 region. The reason for the discrepancy in the values could arise from the differences between the data and the model. Fabiano and others [1] evaluated the model and compared it to surveyed data for 1,450 points. From these measurements an overall root mean squared deviation of 0.5 degrees was found in the magnetic variation in the COT48 region. Also, a probable cause for the larger discrepancy in the region of bands 2 and 3 could indicate magnetic variation anomalies in the Great Lakes region.

In general, the results were found to be satisfactory and the decision was made to implement the model on the Ohio University Loran-C receiver. The results computed by the microcomputer were within 0.1 degrees of the values computed by the FORTRAN simulation. As indicated earlier, the secular change was not implemented on the receiver. The magnetic variation in the COT48 region changes less than 11 minutes of arc annually at its worst case. This translates to a change of less than one degree over a period of five years at its worst case. Since the Ohio University Loran-C receiver is a research tool, not implementing the secular change function would not have a crucial impact on the outcome of future research. The coefficients for the model are derived every five years by the USGS, and can be updated very easily to keep the model current.

The overall performance of the implementation proves to be satisfactory. The major advantages are that the magnetic variation is available all the time to the pilot to allow accurate determination of the compass heading. It is computed automatically and is one less adjustment or source of error during a flight, thus also reducing the chances of pilot error.

VI. ACKNOWLEDGMENTS

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*National Geophysical Data Center, Boulder, Colorado.
The author would like to acknowledge the help of Dr. Robert Lilley, Associate Director and Mr. James Nickum, project engineer at Avionics Engineering center, whose suggestions proved invaluable in all stages of this research. Special thanks is also due to Dr. Hugh Bloemer, Department of Geography, whose advice was indispensable.

VII. REFERENCES


[2] Ibid., Fabiano, Jones and Peddie.


VIII. APPENDICES

A. Co-efficients for the 5-band and secular change in COT48.

B. FORTRAN Program Listing of "MAGVAR".

C. Instruction Set for the Am9511.

D. 6502 Assembly Language Program Listing of the Magnetic Variation Implementation on the Ohio University Loran-C Receiver.
Table 1. Limits on Five Bands and the East Longitude Normalizing Factor.

<table>
<thead>
<tr>
<th>Band</th>
<th>Partition °W longitude</th>
<th>λ(degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>66-77</td>
<td>289</td>
</tr>
<tr>
<td>2</td>
<td>78-89</td>
<td>277</td>
</tr>
<tr>
<td>3</td>
<td>90-101</td>
<td>265</td>
</tr>
<tr>
<td>4</td>
<td>102-113</td>
<td>253</td>
</tr>
<tr>
<td>5</td>
<td>114-125</td>
<td>241</td>
</tr>
</tbody>
</table>
Table 2. Comparisons Between Actual and Computed Values of Magnetic Variation.

<table>
<thead>
<tr>
<th>Band</th>
<th>Latitude Deg. N</th>
<th>Longitude Deg. W</th>
<th>Magnetic Variation Actual</th>
<th>Magnetic Variation Computed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>77</td>
<td>7.72°W</td>
<td>7.40°W</td>
</tr>
<tr>
<td>66°W - 78°W</td>
<td>40</td>
<td>73</td>
<td>13.05°W</td>
<td>12.71°W</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>81</td>
<td>3.98°W</td>
<td>2.78°W</td>
</tr>
<tr>
<td>78°W - 90°W</td>
<td>40</td>
<td>87</td>
<td>1.12°W</td>
<td>0.51°W</td>
</tr>
<tr>
<td>3</td>
<td>34</td>
<td>93</td>
<td>4.37°E</td>
<td>5.90°E</td>
</tr>
<tr>
<td>90°W - 102°W</td>
<td>38</td>
<td>101</td>
<td>9.05°E</td>
<td>10.84°E</td>
</tr>
<tr>
<td>4</td>
<td>36</td>
<td>103</td>
<td>9.93°E</td>
<td>10.91°E</td>
</tr>
<tr>
<td>102°W - 114°W</td>
<td>40</td>
<td>107</td>
<td>12.62°E</td>
<td>13.54°E</td>
</tr>
<tr>
<td>5</td>
<td>38</td>
<td>123</td>
<td>16.18°E</td>
<td>16.59°E</td>
</tr>
<tr>
<td>114°W - 126°W</td>
<td>32</td>
<td>113</td>
<td>12.58°E</td>
<td>13.25°E</td>
</tr>
</tbody>
</table>
Figure 1. Continental U.S. magnetic variation.
Figure 2. Magnetic variation in the United States from world declination chart (source Defense Mapping Agency).
Figure 3. Block diagram for the microcomputer system.
Figure 4. Logic flow diagrams illustrating steps control program executes to communicate with 9511.
Figure 4. Concluded.
Appendix A. Co-efficients For the 5-band and Secular Change in COT48.

The coefficients \((a_{ij})\) for the magnetic variation in the conterminous United States (5 bands).

<table>
<thead>
<tr>
<th>Band 1</th>
<th>Band 2</th>
<th>Band 3</th>
<th>Band 4</th>
<th>Band 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a_{00} )</td>
<td>-0.12544E 02</td>
<td>-0.26754E 01</td>
<td>0.66671E 01</td>
<td>0.13031E 02</td>
</tr>
<tr>
<td>(a_{10} )</td>
<td>0.47404E 00</td>
<td>0.30498E 00</td>
<td>0.73577E 02</td>
<td>-0.24981E 00</td>
</tr>
<tr>
<td>(a_{11} )</td>
<td>-0.79262E 00</td>
<td>-0.85269E 00</td>
<td>-0.62856E 00</td>
<td>0.94568E 02</td>
</tr>
<tr>
<td>(a_{20} )</td>
<td>-0.14935E-01</td>
<td>-0.11933E-01</td>
<td>-0.75537E-02</td>
<td>0.84073E-03</td>
</tr>
<tr>
<td>(a_{21} )</td>
<td>0.47508E-02</td>
<td>0.18570E-01</td>
<td>0.23621E-01</td>
<td>0.19160E-01</td>
</tr>
<tr>
<td>(a_{22} )</td>
<td>0.73049E-02</td>
<td>0.19648E-01</td>
<td>-0.99456E-02</td>
<td>-0.17215E-01</td>
</tr>
<tr>
<td>(a_{30} )</td>
<td>0.28976E-03</td>
<td>0.64489E-03</td>
<td>0.57882E-03</td>
<td>0.14505E-03</td>
</tr>
<tr>
<td>(a_{31} )</td>
<td>0.46111E-03</td>
<td>0.31737E-04</td>
<td>0.54348E-04</td>
<td>0.13665E-04</td>
</tr>
<tr>
<td>(a_{32} )</td>
<td>-0.15079E-02</td>
<td>-0.16286E-02</td>
<td>0.70147E-03</td>
<td>0.35821E-03</td>
</tr>
<tr>
<td>(a_{33} )</td>
<td>0.12536E-02</td>
<td>-0.10931E-02</td>
<td>0.58517E-04</td>
<td>0.12490E-02</td>
</tr>
<tr>
<td>(a_{40} )</td>
<td>-0.29623E-04</td>
<td>0.46667E-04</td>
<td>0.10017E-04</td>
<td>-0.63934E-05</td>
</tr>
<tr>
<td>(a_{41} )</td>
<td>-0.18112E-04</td>
<td>-0.51048E-04</td>
<td>0.77275E-04</td>
<td>0.10816E-03</td>
</tr>
<tr>
<td>(a_{42} )</td>
<td>0.55077E-04</td>
<td>-0.72203E-04</td>
<td>0.14306E-03</td>
<td>-0.50373E-04</td>
</tr>
<tr>
<td>(a_{43} )</td>
<td>0.62795E-04</td>
<td>0.55063E-03</td>
<td>0.31817E-04</td>
<td>-0.51783E-04</td>
</tr>
<tr>
<td>(a_{44} )</td>
<td>0.23134E-06</td>
<td>-0.19467E-05</td>
<td>-0.40952E-05</td>
<td>-0.82114E-06</td>
</tr>
<tr>
<td>(a_{45} )</td>
<td>-0.15270E-05</td>
<td>0.60160E-05</td>
<td>0.60160E-05</td>
<td>0.21843E-05</td>
</tr>
<tr>
<td>(a_{50} )</td>
<td>0.14304E-05</td>
<td>-0.59918E-05</td>
<td>-0.88037E-05</td>
<td>-0.89843E-05</td>
</tr>
<tr>
<td>(a_{51} )</td>
<td>0.53560E-05</td>
<td>0.38753E-04</td>
<td>-0.14001E-04</td>
<td>0.58428E-05</td>
</tr>
<tr>
<td>(a_{52} )</td>
<td>-0.76365E-05</td>
<td>0.44242E-04</td>
<td>0.19349E-04</td>
<td>0.18777E-04</td>
</tr>
<tr>
<td>(a_{53} )</td>
<td>-0.62672E-07</td>
<td>-0.76459E-07</td>
<td>-0.12533E-06</td>
<td>-0.20612E-07</td>
</tr>
<tr>
<td>(a_{54} )</td>
<td>0.79694E-07</td>
<td>-0.62486E-07</td>
<td>0.17499E-07</td>
<td>-0.41744E-09</td>
</tr>
<tr>
<td>(a_{55} )</td>
<td>0.15540E-06</td>
<td>0.17782E-06</td>
<td>0.39251E-07</td>
<td>-0.10090E-06</td>
</tr>
<tr>
<td>(a_{60} )</td>
<td>0.97851E-07</td>
<td>-0.30012E-07</td>
<td>-0.27612E-07</td>
<td>0.57044E-07</td>
</tr>
<tr>
<td>(a_{61} )</td>
<td>0.11556E-06</td>
<td>0.24909E-06</td>
<td>0.15699E-06</td>
<td>0.84960E-06</td>
</tr>
<tr>
<td>(a_{62} )</td>
<td>-0.76126E-06</td>
<td>0.74355E-06</td>
<td>0.18538E-05</td>
<td>0.62532E-06</td>
</tr>
<tr>
<td>(a_{63} )</td>
<td>0.23144E-07</td>
<td>0.48778E-05</td>
<td>-0.38992E-06</td>
<td>-0.45290E-07</td>
</tr>
<tr>
<td>(a_{64} )</td>
<td>0.16860E-09</td>
<td>0.24723E-08</td>
<td>0.84712E-08</td>
<td>0.10184E-08</td>
</tr>
<tr>
<td>(a_{65} )</td>
<td>0.43030E-09</td>
<td>0.38370E-08</td>
<td>0.44108E-08</td>
<td>0.11497E-07</td>
</tr>
<tr>
<td>(a_{66} )</td>
<td>-0.69117E-08</td>
<td>0.19785E-07</td>
<td>0.77909E-08</td>
<td>0.16786E-07</td>
</tr>
<tr>
<td>(a_{70} )</td>
<td>0.33027E-08</td>
<td>-0.76731E-08</td>
<td>0.37480E-09</td>
<td>0.64112E-09</td>
</tr>
<tr>
<td>(a_{71} )</td>
<td>0.93928E-08</td>
<td>-0.40025E-07</td>
<td>0.88535E-07</td>
<td>0.27692E-07</td>
</tr>
<tr>
<td>(a_{72} )</td>
<td>0.91628E-08</td>
<td>0.52668E-07</td>
<td>0.12561E-06</td>
<td>-0.93332E-07</td>
</tr>
<tr>
<td>(a_{73} )</td>
<td>0.22806E-07</td>
<td>-0.21183E-06</td>
<td>0.14212E-06</td>
<td>0.52297E-08</td>
</tr>
<tr>
<td>(a_{74} )</td>
<td>0.56746E-08</td>
<td>-0.29999E-06</td>
<td>-0.15083E-07</td>
<td>-0.54997E-07</td>
</tr>
</tbody>
</table>
Appendix A Concluded.

The coefficients $(a_{ij})$ for the secular change in the cor48 region.

| $a_{00}$ | $-0.95533E+01$ |
| $a_{10}$ | $0.11582E+00$ |
| $a_{11}$ | $0.93474E-01$ |
| $a_{20}$ | $0.13750E+01$ |
| $a_{21}$ | $0.22416E+01$ |
| $a_{22}$ | $0.12437E+01$ |
| $a_{30}$ | $0.27558E+05$ |
| $a_{31}$ | $0.53560E-03$ |
| $a_{32}$ | $0.70816E+03$ |
| $a_{33}$ | $0.32333E-03$ |
| $a_{40}$ | $0.49965E+04$ |
| $a_{41}$ | $0.18579E+04$ |
| $a_{42}$ | $0.38544E+05$ |
| $a_{43}$ | $0.11451E+04$ |
| $a_{44}$ | $0.63005E+05$ |
| $a_{50}$ | $0.23992E+06$ |
| $a_{51}$ | $0.35195E+06$ |
| $a_{52}$ | $0.26724E+06$ |
| $a_{53}$ | $0.53815E+06$ |
| $a_{54}$ | $0.44979E+06$ |
| $a_{55}$ | $0.12145E+06$ |
| $a_{60}$ | $0.85465E+07$ |
| $a_{61}$ | $0.70500E+07$ |
| $a_{62}$ | $0.26013E+07$ |
| $a_{63}$ | $0.30705E+09$ |
| $a_{64}$ | $0.12121E+07$ |
| $a_{65}$ | $0.15529E+08$ |
| $a_{66}$ | $0.29462E+08$ |
FORTRAN Program Listing of "MAGVAR".

This program computes the magnetic variation as a function of latitude and longitude. The secular change is also calculated. It is based on the USD 80 polynomial model developed by Fabiano and others at the United States Geological Survey in Denver Co. Please consult USGS Circular No. 810 for details.

Rajan Kaul - 3/84

The input variables are ALAT, ALON, and YEAR representing latitude, longitude, and year. Variables A and A1 are the coefficients to be read.

```
DIMENSION A(8,8),A1(8,8)
DATA EAST/'EAST'/,WEST/'WEST'/
```

Read latitude and longitude

```
WRITE(6,9)
9 FORMAT(1X,'TYPE LAT. AND LONG., AS NNN.NN NNN.NN (F6.2,1X,F6.2)')
READ(7,8) ALAT,ALON
8 FORMAT(F6.2,1X,F6.2)
```

Determine which band the point is in to load correct set of coefficients corresponding to particular band.

```
IF(ALON.GE.66.0.AND.ALON.LT.78.0) K=11
IF(ALON.GE.78.0.AND.ALON.LT.90.0) K=12
IF(ALON.GE.90.0.AND.ALON.LT.102.0) K=13
IF(ALON.GE.102.0.AND.ALON.LT.114.0) K=14
IF(ALON.GE.114.0.AND.ALON.LT.126.0) K=15
```

Read normalized longitude for particular band and the coefficients.

```
READ(K,7) DLON
7 FORMAT(F6.2)
DO 5 NN=1,8
DO 6 II=1,NN
READ(K,3,END=13) A(NN,II)
3 FORMAT(E12.5)
5 CONTINUE
6 CONTINUE
```

Define colatitude and normalized east longitude

```
DLA=90.0-ALAT
DLO=360.0-ALON
```

Initialize magnetic variation and perform calculation

```
AK=0.0
DO 1 N=1,8
DO 2 I=1,N
KK=IABS(N-I)
JJ=IABS(I-I)
DL=DLO-DLON
IF(DL.EQ.0.0) DL=360.0
AK=AK+(A(N,I)*((DLA-52.01)**KK)*((DL)**JJ))
2 CONTINUE
1 CONTINUE
```

Read coefficients for secular change calculation

```
DO 15 NN=1,7
DO 16 II=1,NN
READ(16,23,END=14) A1(NN,II)
15 CONTINUE
16 CONTINUE
```

101
DEFINE COLATITUDE AND NORMALIZED EAST LONGITUDE

DLA=90.0-ALAT  
DLO=360.0-ALON

INITIALIZE SECULAR CHANGE AND PERFORM CALCULATION

SV=0.0  
DO 11 N=1,7  
DO 12 I=1,N  
KK=IABS(N-I)  
JJ=IABS(I-I)  
DL=DLO-DLON  
IF(DL.EQ.0.0) DL=360.0  
SV=SV+(A(N,I)*((DLA-52.01)**KK)*((DL)**JJ))

CONTINUE

CONTINUE

READ YEAR

WRITE(6,17)  
FORMAT(5X,'TYPE YEAR AS NN.N (F4.1) E.G. JUN 84 = 84.5')

READ(7,18) YEAR  
FORMAT(F4.1)

COMPUTE SECULAR VARIATION ANNUAL AND TO PRESENT DATE.

ALSO COMPUTE MAGNETIC VARIATION

SECVAR=SV*(YEAR-85.0)/60.0  
SS=SV/60.0  
VAR=AK+SECVAR  
IF(VAR.LT.0.0) DIR=WEST  
IF(VAR.GT.0.0) DIR=EAST  
V=ABS(VAR)  
WRITE(6,4) ALAT,ALON,V,DIR,SS  
FORMAT(5X,'LATITUDE = ',F6.2/,5X,'LONGITUDE = ',F6.2/,5X,'MAGNETIC & VARIATION = ',F6.2/,5X,'SECULAR CHANGE (ANNUAL) = ',F6.2)

STOP

END
### Command Summary

<table>
<thead>
<tr>
<th>Command Code</th>
<th>Command Mnemonic</th>
<th>Command Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 6 5 4 3 2 1 0</td>
<td>FIXED-POINT 16-BIT</td>
<td></td>
</tr>
<tr>
<td>w 1 1 0 1 1 0 0 0</td>
<td>SAUX</td>
<td>Add TOS to NOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 1 1 0 1 1 0 1 1</td>
<td>SSUX</td>
<td>Subtract TOS from NOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 1 1 0 1 1 1 0 0</td>
<td>SMLU</td>
<td>Multiply NOS by TOS Lower half of result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 1 1 0 1 1 1 1 0</td>
<td>SMUL</td>
<td>Multiply NOS by TOS Upper half of result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 1 1 0 1 1 1 1 1</td>
<td>SDIV</td>
<td>Divide NOS by TOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td></td>
<td>FIXED-POINT 32-BIT</td>
<td></td>
</tr>
<tr>
<td>w 0 1 0 1 1 0 0 0</td>
<td>DADD</td>
<td>Add TOS to NOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 0 1 0 1 1 0 1 1</td>
<td>DSUB</td>
<td>Subtract TOS from NOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 0 1 0 1 1 1 0 0</td>
<td>DMUL</td>
<td>Multiply NOS by TOS Lower half of result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 0 1 0 1 1 1 1 0</td>
<td>DMUL</td>
<td>Multiply NOS by TOS Upper half of result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 0 1 0 1 1 1 1 1</td>
<td>DDIV</td>
<td>Divide NOS by TOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td></td>
<td>FLOATING-POINT 32-BIT</td>
<td></td>
</tr>
<tr>
<td>w 0 0 0 0 0 0 0 0</td>
<td>FADD</td>
<td>Add TOS to NOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 0 0 0 0 1 0 0 0</td>
<td>FSUB</td>
<td>Subtract TOS from NOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 0 0 0 0 1 1 0 0</td>
<td>FMUL</td>
<td>Multiply NOS by TOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td>w 0 0 0 0 1 1 1 0</td>
<td>FDIV</td>
<td>Divide NOS by TOS Result to NOS Pop Stack</td>
</tr>
<tr>
<td></td>
<td>DERIVED FLOATING-POINT FUNCTIONS</td>
<td></td>
</tr>
<tr>
<td>w 0 0 0 0 1 0 0 0</td>
<td>SQRT</td>
<td>Square Root of TOS Result in TOS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DATA MANIPULATION COMMANDS</td>
<td></td>
</tr>
<tr>
<td>w 0 0 0 0 0 0 0 0</td>
<td>NOP</td>
<td>No Operation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Notes
1. TOS means Top of Stack NOS means Next on Stack
2. AMD Application Brief Algorithm Details for the Am9511
3. Many commands destroy one stack location (bottom of stack) during development of the result. The derived functions may destroy several stack locations. See Application Brief for details.
4. The Inverse Trigonometric functions handle angles in radians, not degrees.
5. No remainder is available for the fixed-point divide functions.
6. Results will be undefined for any combination of commands coding that is not specified in this table.

*Original not available at time of publication.*
Appendix D. 6502 Assembly Language Program Listing of the Magnetic Variation Implementation on the Ohio University Loran-C Receiver.

ORG $A8
BASE BSS 2
ORG $55
CTRN BSS 1
CTRI BSS 1
COFCTR BSS 1
* USED IN LEAST SQUARES ALGORITHM
COFTAB BSS 2
MTEMP BSS 1
MTEMP1 BSS 1

* EQUATES TO SUBROUTINE CALLS
* PUSH EQU $28AC SUBROUTINE TO PUSH NUMBER ON TO 9511 STACK
POP EQU $28DC SUBROUTINE TO POP NUMBER FROM 9511 STACK
CMND EQU $290C SUBROUTINE TO ISSUE COMMAND TO 9511 TO PERFORM
* OPERATION

* EQUATES TO VARIABLE ADDRESSES USED IN RNAV
* PHGS EQU $E0 LATITUDE OF RECEIVER
THGS EQU $DC LONGITUDE OF RECEIVER
P18 EQU $2C 180.0/PI
PA12 EQU $30 2*PI
F90 EQU $24 PI/2
* AM5111A COMMANDS.

PWR EQU SOB
FADD EQU $10
FSUB EQU $11
FMUL EQU $12
FDIV EQU $13
SQRT EQU $15

* CONSTANTS AND VARIABLES
BAND EQU $0 ADDR FOR NORMALIZED LONGITUDE FOR PARTICULAR BAND
* FOLLOWED BY 36 CO-EFFICIENTS FOR EACH BAND AT LOCATION
* $C800 TO $CFFF - ONE PAGE FOR EACH OF 5 BANDS.
* CONSTANTS FOR DIVISION IN LEAST SQUARES ALGORITHM FOR MAGVAR.
MZERO EQU $0 -0.0
MONE EQU MZERO+4 - 1.0
MTWO EQU MONE+4 -2.0
MTHREE EQU MTWO+4 -3.0
MFOUR EQU MTHREE+4 -4.0
MFIVE EQU MFOUR+4 -5.0
MSIX EQU MFIVE+4 -6.0
MSEVEN EQU MSIX+4 -7.0
* CONSTANTS THAT DEFINE LIMITS IN BANDS OF COT48 TO DETERMINE
* WHICH SET OF CO-EFFICIENTS NEED TO BE USED IN THE ALGORITHM
* TO DETERMINE MAGNETIC VARIATION.
A78 EQU MSEVEN+4
A90 EQU A78+4
A102 EQU A90+4
A114 EQU A102+4
A5201 EQU A114+4
F180 EQU A5201+4
ATEMP EQU F180+4
NDL EQU ATEMP+4
MDLA EQU NDL+4
MDLA52 EQU MDLA+4
MAGVAR EQU MDLA52+4
RLTEMP EQU MAGVAR+4
MAGVD EQU RLTEMP+4

ORG $C000

104
* * MOVE CONSTANT NUMBER TABLE IN SCRATCH SPACE
* *
  LDA =1
  STA BASE+1    BASE = $0100
  LDA =0
  LDY =0
  MO
  LDA TABLE1,Y
  STA (BASE),Y
  INY
  CPY =56
  BNE MO
*

* MAGNETIC VARIATION CALCULATION
*
* CALCULATE MDLA
*  INC BASE+1    BASE = $0300
  INC BASE+1
  LDY =F90
  JSR PUSH
  DEC BASE+1    BASE = $0200
  LDY =PHGS
  JSR PUSH
  LDA =FSUB
  JSR CMDN
  INC BASE+1    BASE = $0300
  LDY =P18
  JSR PUSH
  LDA =FMUL
  JSR CMDN
  DEC BASE+1
  DEC BASE+1    BASE = $0100
  LDY =MDLA
  MDLA = 90-PHGS
  JSR POP
*

* CALCULATE MDLO
*  INC BASE+1    BASE = $0300
  INC BASE+1
  LDY =A12
  JSR PUSH
  DEC BASE+1    BASE = $0200
  LDY =THGS
  JSR PUSH
  LDA =FSUB
  JSR CMDN
  INC BASE+1    BASE = $0300
  LDY =P18
  JSR PUSH
  LDA =FMUL
  JSR CMDN
  DEC BASE+1
  DEC BASE+1    BASE = $0100
  LDY =MDLO
  MDLO = 360-THGS
  JSR POP
*

* CALCULATE MDLA52
*  LDY =MDLA
  JSR PUSH
  LDY =A5201
  JSR PUSH
  LDA =FSUB
  JSR CMDN
  JSR CMDN
  LDY =MDLA52
  MDLA52 = MDLA-52
  JSR POP
* INC BASE+1 BASE = $0200
  LDY =THGS
  JSR PUSH
  DEC BASE+1 BASE = $0100
  LDY =RLTEMP
  JSR POP
  PUT THGS IN RLTEMP FOR COMPARISION PURPOSES IN THE NEXT SEGMENT TO DETERMINE WHICH BAND TO USE
  TO CALCULATE MAGVAR.
  DETERMINE WHICH BAND IT IS TO CALCULATE MAGVAR.
  *
  LDY =A78
  JSR PUSH
  LDY =RLTEMP
  JSR PUSH
  LDA =FSUB
  JSR CMND
  LDY =ATEMP
  JSR POP
  ATEMP = 78*PI/180 - THGS
  LDY =ATEMP
  LDA (BASE),Y
  BPL M1
  IF ATEMP IS +VE -- BAND 1, IF NOT TRY FOR BAND 2
  *
  LDY =A90
  JSR PUSH
  LDY =RLTEMP
  JSR PUSH
  LDA =FSUB
  JSR CMND
  LDY =ATEMP
  JSR POP
  ATEMP = 90*PI/180 - THGS
  LDY =ATEMP
  LDA (BASE),Y
  BPL M2
  IF ATEMP IS +VE -- BAND 2, IF NOT TRY FOR BAND 3
  *
  LDY =A102
  JSR PUSH
  LDY =RLTEMP
  JSR PUSH
  LDA =FSUB
  JSR CMND
  LDY =ATEMP
  JSR POP
  ATEMP = 102*PI/180 - THGS
  LDY =ATEMP
  LDA (BASE),Y
  BPL M3
  IF ATEMP IS +VE -- BAND 3, IF NOT TRY BAND 4
  *
  LDY =A114
  JSR PUSH
  LDY =RLTEMP
  JSR PUSH
  LDA =FSUB
  JSR CMND
  LDY =ATEMP
  JSR POP
  ATEMP = 114*PI/180 - THGS
  LDY =ATEMP
  LDA (BASE),Y
  BPL M4
  IF ATEMP IS +VE -- BAND 4
  JMP M5
  MUST BE BAND 5
  *
  SET CO-EFFICIENT TABLE ADDRESS TO CORRESPOND WITH PARTICULAR BAND
  *
  M1
  LDY =MDLO
  JSR PUSH
  LDA =$C8
  STA BASE+1
  STA COFTAB+1 BAND 1
  JMP M6
  *
  M2
  LDY =MDLO
  JSR PUSH
  LDA =$C9
STA BASE+1
STA COFTAB+1
JMP M6

M3
LDY #MDLO
JSR PUSH
LDA #$CA
STA BASE+1
STA COFTAB+1
JMP M6

M4
LDY #MDLO
JSR PUSH
LDA #$CB
STA BASE+1
STA COFTAB+1
JMP M6

M5
LDY #MDLO
JSR PUSH
LDA #$CC
STA BASE+1
STA COFTAB+1
JMP M6

M6
LDA =0
STA COFTAB
LDY =BAND
JSR PUSH
LDA #FSUB
JSR CMND
LDA =1
STA BASE+1
LDY =NDL
JSR POP
LDA =4
STA COFCTR
CLC
LDA CTRN
LOAD OUTER LOOP COUNTER
ROL A
ROL A
POINT TO LOCATION FOR EXPONENTS FOR LEAST SQUARE
STA MTEMP
LDY MTEMP
JSR PUSH
LDA CTRI
LOAD INNER LOOP COUNTER
ROL A
ROL A
POINT TO LOCATION FOR EXPONENTS
STA MTEMP
LDY MTEMP
JSR PUSH
LDA #FSUB
JSR CMND
N-I
LDY #RLTEMP
JSR POP
LDY #MDLA52
JSR PUSH
LDY #MDLA52
LDA (BASE),Y
BPL C6
LDA =1
STA MTEMP1
LDA =CHSF
JSR CMND
JMP C9

C6
LDA =0
STA MTEMP1
LDY #RLTEMP
JSR PUSH
LDA #PWR
JSR CMND
MDLA52**(N-I)
CLC
LDA CTRN
SBC CTRI
AND =1
EXponent EVEN?
BNE C4  
LDA MTEMP1  
BEQ C4  
LDA =CHSF  
JSR CMND  
MDLA52**(N-I)  
CLC  
LDA CTRI  
ROL A  
STA MTEMP  
LDA MTEMP  
JSR PUSH  
LDA =RLTEMP  
JSR POP  
LDY =NDL  
JSR PUSH  
LDY =NDL  
LDA (BASE),Y  
BPL C7  
LDA =0  
STA MTEMP1  
LDA =CHSF  
JSR CMND  
JMP C8  
C7  
LDA =1  
STA MTEMP1  
C8  
LDY =RLTEMP  
JSR PUSH  
LDA =Pwr  
JSR CMND  
NDL**1  
*  
IN THIS NEXT SEGMENT A TEST IS DONE TO MAKE SURE THE CORRECT SIGN  
* IS ATTACHED WITH THE RESULT AFTER THE EXPONENT CALCULATION.  
*  
LDA CTRI  
AND =1  
BEQ C5  
LDA MTEMP1  
BNE C5  
LDA =CHSF  
JSR CMND  
C5  
LDY =ATEMP  
JSR CMND  
MDLA52**(N-I)*NDL**1  
LDA COFTAB+1  
STA BASE+1  
LDA COFCTR  
JSR PUSH  
LDA =FMUL  
JSR CMND  
A(N1)*NDL**(1)*MDLA52**(N-I)  
LDA =1  
STA BASE+1  
LDA =MAGVAR  
JSR PUSH  
LDA =FADD  
JSR CMND  
ADD TO ACCUMULATE THE VALUE OF MAGVAR  
LDA =MAGVAR  
JSR POP  
MAGVAR=MAGVAR+A(N1)*NDL**(1)*MDLA52**(N-I)  
INC COFCTR  
INC COFCTR  
INC COFCTR  
INC COFCTR  
INC COFCTR  
INC COFCTR  
INC COFCTR  
LDA CTRN  
CMP CTRI  
BEQ C1  
INC CTRI  
JMP C2  
LDA CTRN  
CMP =7  
BEQ C3  
YES, LOOP OUT  
NO, IS NEGATIVE FLAG SET ?  
NO, FLAG NOT SET -- LOOP OUT  
EXPONENT WAS ODD AND NEGATIVE FLAG WAS SET -- THEREFORE CHANGE SIGN AGAIN  
MDLA52**(N-I)  
LOAD INNER LOOP COUNTER FOR LEAST SQUARES PROCED  
POINT TO LOCATION FOR EXPONENTS  
BASE = $0100  
PUT CO-EFFICIENT TABLE ADDRESS IN BASE  
POINT TO CO-EFFICIENT COUNTER  
A(N1)*NDL**(1)*MDLA52**(N-I)  
BASE = $0100  
ADD TO ACCUMULATE THE VALUE OF MAGVAR  
MAGVAR=MAGVAR+A(N1)*NDL**(1)*MDLA52**(N-I)  
POINT TO NEXT SET OF CO-EFFICIENTS  
IF THEY ARE EQUAL INNER LOOP DONE, CHECK IF OUTE  
IF NOT, GO BACK AND COMPLETE OUTER LOOP  
CHECK TO SEE IF OUTER LOOP COMPLETE  
OUTER LOOP ALSO DONE, BRANCH OUT
INCREASE OUTER LOOP COUNTER
LDA =0
STA CTRI
JMP C2
RTS

* TABLE OF CONSTANTS USED BY MAGNETIC VARIATION STORED
* STARTING AT $0100 IN SCRATCHPAD RAM LOCATION.

<table>
<thead>
<tr>
<th>TABLE1</th>
<th>HEX</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00,00,00,00</td>
<td>0.0 (MZERO)</td>
<td></td>
</tr>
<tr>
<td>01,80,00,00</td>
<td>1.0 (MONE)</td>
<td></td>
</tr>
<tr>
<td>02,80,00,00</td>
<td>2.0 (MTWO)</td>
<td></td>
</tr>
<tr>
<td>03,80,00,00</td>
<td>3.0 (MTHREE)</td>
<td></td>
</tr>
<tr>
<td>03,A0,00,00</td>
<td>5.0 (MFIVE)</td>
<td></td>
</tr>
<tr>
<td>03,CO,00,00</td>
<td>6.0 (MSIX)</td>
<td></td>
</tr>
<tr>
<td>03,E0,00,00</td>
<td>7.0 (MSEVEN)</td>
<td></td>
</tr>
<tr>
<td>01,AE,40,F1</td>
<td>-78*PI/180 (A78)</td>
<td></td>
</tr>
<tr>
<td>01,C9,06,DA</td>
<td>-90*PI/180 (A90)</td>
<td></td>
</tr>
<tr>
<td>01,E3,DE,C4</td>
<td>-102*PI/180 (A102)</td>
<td></td>
</tr>
<tr>
<td>01,FE,AD,AE</td>
<td>-114*PI/180 (A114)</td>
<td></td>
</tr>
<tr>
<td>06,DO,0A,30</td>
<td>-52.01*PI/180 (A5201)</td>
<td></td>
</tr>
<tr>
<td>79,8E,FA,35</td>
<td>-PI/180.0 (F180)</td>
<td></td>
</tr>
</tbody>
</table>

* CO-EFFICIENTS FOR THE FIVE BANDS OF THE COT48
* THE DATA LABELED BAND(N) IS THE NORMALIZED
* LONGITUDE FOR EACH BAND. THE CO-EFFICIENTS
* ARE STORED IN ONE PAGE CHUNKS STARTING AT
* $3800 TO $3CFF.

ORG $C800

<table>
<thead>
<tr>
<th>BAND1</th>
<th>HEX</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>09,90,81,48</td>
<td>289.01</td>
<td></td>
</tr>
<tr>
<td>84,C9,82,96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7F,F2,96,07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80,CA,E9,68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA,F4,B3,9C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>79,9B,AC,C4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>79,EF,5E,07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75,97,EB,10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75,F1,CO,9A</td>
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<td></td>
</tr>
<tr>
<td>F7,C5,A5,66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>77,A2,06,A6</td>
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<td></td>
</tr>
<tr>
<td>71,D4,E9,7F</td>
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<td></td>
</tr>
<tr>
<td>F1,F8,7E,1B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1,97,02,15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>72,7E,02,28</td>
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<tr>
<td>73,83,80,EB</td>
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<td>6A,F8,66,41</td>
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<tr>
<td>ED,CC,F2,4A</td>
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<tr>
<td>6D,BF,FC,83</td>
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<td>6F,B9,FC,17</td>
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<td>F0,80,1E,7A</td>
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<td>E9,86,96,3E</td>
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<tr>
<td>69,AB,24,13</td>
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</tr>
<tr>
<td>6A,AE,DO,20</td>
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<td></td>
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<tr>
<td>69,02,22,6E</td>
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<tr>
<td>69,F8,29,08</td>
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<tr>
<td>EC,CC,59,1D</td>
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<tr>
<td>67,C6,0D,89</td>
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</tr>
<tr>
<td>E0,B9,62,17</td>
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</tr>
<tr>
<td>61,EC,8F,0F</td>
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</tr>
<tr>
<td>E3,ED,7C,38</td>
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<tr>
<td>64,E2,F5,2F</td>
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<td></td>
</tr>
<tr>
<td>66,A1,5E,31</td>
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<td></td>
</tr>
<tr>
<td>66,9D,6A,60</td>
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<td></td>
</tr>
<tr>
<td>67,C3,E7,CE</td>
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<td></td>
</tr>
<tr>
<td>65,C2,FA,4F</td>
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ORG $C900

<table>
<thead>
<tr>
<th>BAND2</th>
<th>HEX</th>
<th>Description</th>
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<tbody>
<tr>
<td>09,8A,81,48</td>
<td>277.01</td>
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<tr>
<td>82,AB,39,97</td>
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</tr>
<tr>
<td>7F,9C,26,0D</td>
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</tr>
<tr>
<td>80,DA,0A,06</td>
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</tr>
</tbody>
</table>
HEX FA,C3,82,A1
HEX 7B,9b,1F,46
HEX 7B,A0,F5,0D
HEX 76,A9,80,F8
HEX F6,C0,C6,EB
HEX F7,D5,7C,74
HEX F7,8F,48,07
HEX 72,85,1D,21
HEX 72,FC,B0,09
HEX F2,06,1C,5F
HEX F3,97,6B,8F
HEX F6,9F,AC,25
HEX EE,B2,A3,89
HEX EF,B2,1F,27
HEX EF,00,00,58
HEX EF,C3,E7,79
HEX 72,AE,8A,81
HEX 72,89,60,7C
HEX EA,A4,31,6A
HEX 6A,8B,80,51
HEX 6A,BE,EF,E4
HEX 68,00,66,8B
HEX 6B,35,5A,65
HEX 6C,91,98,81
HEX 6F,A3,AC,94
HEX 64,A0,E4,CF
HEX EF,83,06,58
HEX 67,09,4F,1D
HEX EF,83,03,0F
HEX EA,88,EC,48
HEX 68,AE,35,1A
HEX EA,AE,72,9A
HEX EB,1A,00,6C
ORG $CA00

BAND03
HEX 09,84,81,48 = 265.01
HEX 03,05,38,CD
HEX 79,F1,19,1D
HEX 80,A0,E9,70
HEX FF,EE,84,81
HEX 79,1C,81,09
HEX FA,A2,F3,EB
HEX 76,97,BB,AF
HEX F5,9A,33,6F
HEX 76,87,E2,A7
HEX 72,F5,70,94
HEX 72,E5,F3,4B
HEX 70,A0,0F,1E
HEX 73,A2,0E,7C
HEX 74,96,25,2F
HEX 72,E6,F3,5C
HEX EF,89,82,28
HEX EE,A8,01,DA
HEX F0,35,B3,7A
HEX F0,89,EE,A9
HEX F0,EA,EE,68
HEX EF,97,89,6C
HEX EA,83,01,11
HEX 67,96,50,EE
HEX 68,88,95,5F
HEX E7,ED,2E,80
HEX ED,EB,BA,5A
HEX ED,FB,00,15
HEX EB,01,56,79
HEX 66,91,88,02
HEX 65,97,80,FC
HEX 66,85,38,91
HEX E1,CE,0C,45
HEX 69,BE,20,A2
HEX 6A,86,DF,80
HEX 6A,98,99,19
HEX 77,81,8F,33
ORG $C000
BAND4

HEX 08,FD,02,8F - 253.01
HEX 04,00,80,90
HEX FF,FF,CE,74
HEX FF,8A,80,0B
HEX 76,9C,64,B4
HEX 7B,9C,F5,DA
HEX FB,80,07,85
HEX 74,96,19,1A
HEX F7,8C,58,C3
HEX 75,86,CE,22
HEX F7,A3,B4,25
HEX 70,E5,A2,BA
HEX EF,6E,86,8B
HEX 73,CE,02,E2
HEX F2,03,47,EB
HEX 72,B5,73,91
HEX EC,DC,6C,A8
HEX 6F,09,DD,4E
HEX F0,96,9B,67
HEX 6F,DA,90,74
HEX 6F,04,00,19
HEX 71,A2,48,72
HEX E7,B1,0E,70
HEX E1,E5,70,20
HEX E9,CE,AD,43
HEX 68,F5,00,52
HEX EC,E4,10,69
HEX 6C,A7,0C,02
HEX E8,02,84,06
HEX 63,88,48,78
HEX E6,05,86,8A
HEX 67,90,31,EF
HEX 62,B0,38,29
HEX 67,ED,DE,B1
HEX E9,CE,AD,43
HEX 65,83,81,5E
HEX E8,EC,36,48
ORG $C000

BAND5

HEX 08,F1,02,8F - 241.01
HEX 04,FF,F4,F1
HEX FF,CE,02,29
HEX FE,00,F4,93
HEX 7A,89,50,CC
HEX 79,9B,89,C9
HEX F9,05,2C,60
HEX 75,8C,F5,25
HEX ED,00,40,A4
HEX 74,86,6B,73
HEX 78,96,8C,74
HEX F0,F1,E6,21
HEX F2,AA,AC,0F
HEX 73,89,FF,23
HEX 71,9C,AD,69
HEX F2,D9,31,E5
HEX EE,07,CO,F0
HEX 6E,92,95,4D
HEX EA,83,02,45
HEX F0,E9,1C,DA
HEX 71,8A,7C,2A
HEX F2,9E,31,E4
HEX ED,02,85,5A
HEX ED,F8,00,15
HEX E8,01,56,79
HEX 66,91,88,02
HEX 65,97,8D,FC
HEX 66,85,08,91
HEX E1,CE,0C,45
HEX 6A,86,DF,80
HEX E8,99,99,19
HEX E7,81,8F,35
ORG $C800

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BAND4

HEX 08,FD,02,8F - 253.01
HEX 04,00,80,90
HEX FF,FE,00,CE,74
HEX FF,BA,BB,CB
HEX 76,0C,64,84
HEX 78,9C,F5,0A
HEX FB,80,07,85
HEX 74,98,19,1A
HEX F7,B8,8B,03
HEX 75,BB,CE,22
HEX F7,A3,84,25
HEX 70,EA,42,8A
HEX EF,06,86,88
HEX 73,EA,02,22
HEX FA,03,47,EB
HEX 72,85,73,91
HEX EC,DC,5C,AA
HEX 6F,09,DD,3E
HEX F0,96,8B,67
HEX 6F,0A,9C,74
HEX 6F,CA,00,19
HEX 71,A2,4F,72
HEX E7,B1,0E,70
HEX E1,E5,7D,20
HEX E9,08,AD,43
HEX 68,F5,00,52
HEX EC,E4,10,59
HEX 6C,AE,DC,02
HEX E8,02,84,06
HEX 63,8B,0B,78
HEX E5,C5,86,8A
HEX 67,90,31,E7
HEX 62,B0,3B,29
HEX 67,ED,DE,31
HEX E9,C8,6D,45
HEX 65,B3,B1,5E
HEX E8,EC,36,48
ORG $CC00

BAND5

HEX 08,F1,02,8F - 241.01
HEX 04,FE,F4,8F
HEX FF,CE,B2,29
HEX FE,00,F4,95
HEX 7A,89,50,CC
HEX 79,8B,69,CC
HEX 9F,D5,2C,6D
HEX 75,BC,F5,25
HEX ED,E0,20,44
HEX 74,66,68,73
HEX 78,96,8C,74
HEX F0,01,F6,21
HEX F2,AA,AC,0F
HEX 73,89,FF,23
HEX 71,9C,AD,69
HEX F2,DF,31,E3
HEX EE,07,CD,F0
HEX 8E,92,95,4D
HEX EA,B3,02,45
HEX F0,E9,1C,DA
HEX 71,8A,7C,2A
HEX F2,9E,31,E4
HEX 67,DA,A5,80
HEX 6A,8F,5A,F3
HEX EB,ED,0D,25
HEX 6D,98,6D,AB
HEX ED,00,43,7B
HEX EC,B1,2A,FE
HEX 6D,92,4C,1D
HEX 65,DF,30,34
HEX 66,82,9E,74
HEX 66,E7,39,8F
HEX 69,B5,F0,07
HEX 64,95,10,7C
HEX 67,FE,63,A2
HEX E9,BB,99,80
HEX 6A,CF,F8,04
END