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Report
To The
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
-AMES RESEARCH CENTER -
FINAL REPORT
for
GRANT NAG 2-700
SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE/
HIGH RESOLUTION MICROWAVE SURVEY
TEAM MEMBER

Paul G. Steffes, Principal Investigator

Report Period: March 1, 1991 through August 31, 1994

Submitted by

Professor Paul G. Steffes
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332-0250
telephone: (404) 894-3128
e-mail: ps11@prism.gatech.edu

(NASA-CR-196478) SEARCH FOR
EXTRATERRESTRIAL INTELLIGENCE/HIGH
RESOLUTION MICROWAVE SURVEY TEAM
MEMBER Final Report, 1 Mar. 1991 -
31 Aug. 1994 (Georgia Inst. of
Tech.) 21 p

N95-13026

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G3/55 0019818

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I. INTRODUCTION AND SUMMARY

This Final Report summarizes activities conducted by the Principal Investigator and his students during the three years of the NASA High Resolution Microwave Survey (HRMS). As a (HRMS) Team Member with primary interest in the Sky Survey activity, this investigator attended nine Investigator Working Group (IWG) meetings and traveled independently to conduct experiments or present results at other meetings (See Table 1). As a member of the IWG, the investigator's major activity involved evaluating the effects of spaceborne radio frequency interference (RFI) on both the SETI Sky Survey and Targeted Search. A key accomplishment has been development of a database of all unclassified earth or biting and deep space transmitters, and development of accompanying search software, which provides to the observer information about potential sources of interference and gives complete information regarding the frequencies, positions and levels of interference generated by these spacecraft. A complete description of this search system (called HRS, or HRMS RFI Search) is given in Section II of this report. Other key accomplishments have included development of a 32,000 channel Fast-Fourier-Transform Spectrum analyzer for use in studies of interference from satellites (Tatem and Steffes, 1993) and in a 1.4 mm SETI observational study (Steffes and DeBoer, 1994). The last revision of HRS has now been distributed to the extended radio astronomy and SETI community. Its usefulness has been demonstrated by the large number of users (see Appendix A).

Table I
MAJOR ACTIVITIES
GRANT NAG 2-700

<u>DATE</u>	<u>MEETING & LOCATION</u>	<u>DESCRIPTION</u>
3/91	SETI/MOP-IWG NASA Ames, R.C.	-Motivations for conducting SETI searches at wavelengths shorter than "the water hole".
6/91	SETI/MOP-IWG JPL (Pasadena, CA)	-Plan for developing database of spaceborne RFI sources
8/91	USA-USSR Joint Conference on SETI/(Santa Cruz, CA)	-Presented paper on millimeter - wavelength SETI (Steffes, 1993)
10/91	SETI/MOP-IWG NRAO (Greenbank, WV)	-Demonstrated first version of spaceborne RFI database
2/92	Sky Survey Engineering Development (Goldstone, CA)	-Worked independently with EDM to characterize Magellan spacecraft downlinks and other spaceborne RFI..
3/92	SETI/MOP-IWG NASA Ames, R.C.	-Report results of Feb. 1992 experiments at Goldstone.
6/92	SETI/MOP-IWG JPL (Pasadena, CA)	-Update on including Low Earth Orbiters (LEO's) in database
8/92	JPL (Pasadena, CA)	-Reviewed S-Band data from Sky Survey EDM and compared with spaceborne RFI database
1/93	National Radioscience Meeting and HRMS-IWG (Boulder, CO)	-Described new RFI database search system (HRS). (DeBoer and Steffes, 1993)
4/93	NRAO-Kitt Peak, AZ	-Conducted SETI observation at 203 GHz (Steffes and DeBoer, 1994)
4/93	HRMS-IWG NASA Ames R.C.	-Reported results from Kitt Peak observations
7/93	Georgia Tech Woodbury Research - Facility (Woodbury, GA)	-Conducted measurements of effects of interference from C-Band (3.7-4.2 GHz) communications satellites (Tatem and Steffes, 1993)

Table I
MAJOR ACTIVITIES
GRANT NAG 2-700

<u>DATE</u>	<u>MEETING & LOCATION</u>	<u>DESCRIPTION</u>
8/93	Bioastronomy Symposium on SETI and HRMS - IWG (Santa Cruz, CA)	-Presented results from Kitt Peak observations (Bioastronomy Symposium, Steffes and DeBoer, 1993) and presented results from study of interference from C-Band satellites (HRMS-IWG)
9/93	HRMS-Owens Valley Radio Observatory Deployment Review - JPL (Pasadena, CA)	-Presented priorities for L-Band observations based on imminent blockage by various satellite services.
1/94	HRMS - IWG (Final Meeting)	-Presented plans for final updates to satellite RFI databases and search system.

II. DEVELOPMENT OF DATABASE OF SPACEBORNE TRANSMITTERS

Over the 3 year life of the NASA-HRMS Investigator Working Group (IWG), the Georgia Tech group developed a database of all non-classified satellites, giving frequencies and orbital parameters on each. The data was derived and is maintained from eight sources:

- 1) "World Satellite Annual", and the quarterly "World Satellite Transponder Loading Reports" (published by Mark Long Enterprises, Inc.). This includes all geostationary, and many low-earth orbiting (LEO) commercial satellites.
- 2) "The Satellite Situation Report" (published by Project Operations Branch, NASA/GSFC). This document includes all earth orbiting spacecraft, but has only limited information on transmitting frequencies.
- 3) "The Space Frequency Coordination Group (SFCG) Database." Maintained by Dr. Luis Vadillo (INTA/Spain), this includes both earth orbiting and deep-space spacecraft which are governmentally owned.
- 4) The "Communications Center" (Clarksburg, MD) database. This includes all governmental and non-governmental geostationary spacecraft.
- 5) "AFIT Satellite Data Base", maintained by T.S. Kelso, Air Force Institute of Technology. Contains orbital elements for all spacecraft, available electronically via internet.
- 6) "Space 2000" Database, produced by Space Analysis and Research, Inc., Colorado Springs, CO.
- 7) "The NRAO Database", maintained by Dr. Wesley Sizemore, NRAO-Green Bank, WV.
- 8) Published updates in journals such as "Satellite Communications" and "Via Satellite."

All of the above information (except for #3) has been integrated into a single database known as

GEOSAT. GEOSAT currently contains 551 satellites, including 241 geostationary and 310 low earth orbiting satellites. Since the orbital parameters for the low-earth orbiting satellite do change, we have updated all of the "two-line orbital elements" using the NASA-Goddard database.

A second database, known as SSDB is derived from the Space Frequency Coordination Group (SFCG) database (#3, above). It contains 219 government-owned spacecraft. Searches of both GEOSAT and SSDB are conducted with a top-level search system called HRMS RFI Search (HRS). HRS search parameters consist of a sky window in right ascension/declination or azimuth/elevation, and a frequency range. The observer's location, as well as the date and time (UT) of the observation, are likewise entered. The spacecraft found to lie within the search space are written to an ASCII output file, along with the search parameters and the spacecraft characteristics. The latest edition of HRS (together with the databases) was sent to the user group (approximately 25 users, see Appendix A) in June 1994. Its revisions are significant, especially with the increasing number of L-Band mobile satellite systems, which will pose a definite obstacle to future radio astronomical and SETI observations.

III. INVOLVEMENT IN PLANNING AND CONDUCT OF OBSERVATIONS

During the September 1993 exercise of planning for the HRMS Sky Survey/Summer 1994 OVRO campaign (L-Band), it became clear how important knowledge of the developing spaceborne RFI problem would be in scheduling observations. While the Sky Survey has now been cancelled, many of the lessons learned about approaches to scheduling will be important for Project Phoenix, the private-sector continuation of the Targeted Search. For example, the Optus B1 satellite has now been launched and provides an L-Band transponder with total downlink flux levels reaching 3.7×10^{-12} watts per square meter in the 1545-1559 MHz band, over the entire continent of Australia. This can be 60 dB to 120 dB above the detection threshold of the Targeted Search, depending on how much spectral spreading is used. Since studies conducted under this grant by Tatem and Steffes (1993) have shown that such transmissions are detectable when the receiving antenna is pointed over 150 beamwidths away from the satellite, the risk of complete spectral blockage is significant. Usage of the Optus B1 L-Band system is currently quite low, but is expected to grow quickly. It will be necessary to evaluate the usage levels, and decide whether this spectral range can be observed BEFORE the usage level becomes excessive, and the ability to observe is lost forever. Likewise, if the usage level is excessive, this should be determined before scheduling of future observations, since the number of detections would probably overwhelm a

system and waste valuable telescope time. Such studies have been a major part of this investigation.

In addition, a SETI search of 40 solar-type stars was conducted at the 203 GHz positronium, hyperfine resonance using the NRAO-Kitt Peak, AZ 12-meter radio telescope (Steffes and DeBoer, 1994). Many of the techniques used in studying the problem of spaceborne RFI were used in this observation.

IV. CONCLUSION

Despite the premature cancellation of the NASA-HRMS Program, the techniques and databases developed by this investigation will serve to make future SETI observations, and other radio astronomical observations, more effective by predicting potential sources of spaceborne radio frequency interference (RFI). Its future use in radio astronomy and SETI will be a lasting legacy of the HRMS Program. Similarly, the one journal paper and four conference publications will serve to document both the observational work and RFI studies conducted to date, and will be very useful to future programs.

V. REFERENCES

DeBoer, D.R. and P.G. Steffes 1993. The Georgia Tech Spaceborne Transmitter Database and its uses in SETI and Radio Astronomy. International Union of Radio Science Programs and Abstracts: 1993 National Radio Science Meeting, pg. 224. (Presented January 8, 1993; Boulder, CO)

Steffes, P.G. 1993. The Potential for Millimeter-Wave SETI. Third Decennial USA-USSR Conference on SETI - A.S.P. Conference Series vol. 47, pp. 367-371. (Presented August 9, 1991; Santa Cruz, CA)

Steffes, P.G. and D.R. DeBoer 1993. A SETI Search of Nearby Solar-type Stars at the 203-GHz Positronium Hyperfine Resonance. Program of the Bioastronomy Symposium: Progress in the Search for Extraterrestrial Life, pg. 30. (Presented August 17, 1993; Santa Cruz, CA)

Steffes, P.G. and D.R. DeBoer 1994. A SETI Search of Nearby Solar-Type Stars at the 203-GHz Positronium Hyperfine Resonance. Icarus107, pp. 215-218.

Tatem, R.B. and P.G. Steffes 1993. Impact of Satellite Radio Frequency Interference (RFI) on the High Resolution Microwave Survey (HRMS) Sky Survey at C-Band Frequencies. Appendix to Semiannual Status Report #5 for Grant NAG2-700 to the NASA Ames Research Center. Appendix C.

APPENDIX A

*** DISTRIBUTION LIST ***

HRMS RFI SEARCH DATABASE

Bill Brundage
Frequency Coordinator
IRAO
P.O. Box 0
Socorro, NM, 87801

e-mail: wbrundag@polaris.cv.nrao.edu
Notes: Version 2.2 on 9/9/1993

Richard Lacasse
Digital Engineer
IRAO
P.O. Box 2
Green Bank, WVA 24944-0002
(304) 456-2109

Notes: Version 2.2 on 9/9/1993

Guillermo Lemarchand
Physicist
University of Buenos Aires
c.c. 8 - Suc. 25,
1425-Bs. As., Argentina

e-mail: lemar@dcfcen.edu.ar
34-1-774-0667
34-1-786-8114

Notes: Version 2.2 on 9/9/1993

Dan Werthimer
Assoc. Development Engineer
Astronomy Dept. and Space Sciences Lab.
University of California at Berkeley
Berkeley, CA 94720
(415) 642-9222
(415) 642-6997
(415) 848-2179

Notes: Version 2.2 on 9/9/1993

Wayne L. Bowman, Jr.
Project Engineer
660 Engineering Drive, Technology Park/Atlanta
P.O. Box 7700
Norcross, GA 30091-7700
(404) 263-9200 Ext. 4315

Notes: Version 2.2 on 9/9/1993

Wesley A. Sizemore
NRAO
P.O. Box 2
Green Bank, W VA 24944-0002
(304) 456-2107

e-mail: wsizemore@polaris.cv.nrao.edu
Notes: Version 2.2 on 9/9/1993

Larry Van Horn
Grove Enterprises
P.O. Box 98
Brasstown, NC 28902
(704) 837-9200

Notes: Version 2.2 on 9/15/1993

Jim Cordes
Astronomy Department
Space Science Building
Cornell University
Ithaca, NY 14853-6801
(607) 255-0608

e-mail: cordes@astrosun.tn.cornell.edu
Notes: Version 2.2 on 9/16/1993

Mike Davis
Director, Arecibo Observatory
P.O. Box 995
Arecibo, PR 00613
(809) 878-2612

e-mail: mike@aosun.naic.edu
e-mail: mdavis@naic.bitnet
Notes: Version 2.2 on 9/16/1993

Dayton Jones
Mail Code 238-700
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-7774

e-mail: djabl@ac.jpl.nasa.gov

Jill C. Tarter
SETI Project Scientist
NASA Ames Research Center
Mail Stop 244-1
Moffett Field, CA 94035-5830
(415) 604-5727

e-mail: tarter@bkyst.berkeley.edu
Notes: Version 2.2 on 9/16/1993

Dick Thompson

e-mail: athomps@polaris.cv.nrao.edu
Notes:

Tom Gergely

e-mail: tgergely@note.nfs.gov
Notes:

William Baan

e-mail: willema@naic.edu
Notes:

Dewey Ross

e-mail: dross@polaris.cv.nrao.edu
Notes:

R.S. Roger

e-mail: rsr@drao.nrc.ca
Notes:

Vivek Dhawan

e-mail: vdhawan@polaris.cv.nrao.edu
Notes:

Ted Selig

e-mail: tvs@deimos.caltech.edu
Notes:

ORIGINAL PAGE IS
OF POOR QUALITY

Georgia Institute of Technology
Atlanta, Georgia 30332-0250
USA
Fax 404•853•9171

Tel: (404) 894-3128

June 8, 1994

Dear Colleague:

Enclosed is a diskette and an updated instruction manual for the Georgia Tech database of spaceborne transmitters known as HRS (HRMS BFI Search). The database has been substantially updated since last year's revision, and the search software itself has been made more easy to use. Contained in the database are over 750 spacecraft, with updated orbital elements for those not in geostationary orbits. While the diskette has been set up in a DOS format, the software can be run in almost any environment (UNIX, etc.). Installation can be accomplished by simply typing "install".

Development of this database has been made possible by the NASA - Search for Extraterrestrial Intelligence/High Resolution Microwave Survey Program under Grant NAG2-700 from NASA Ames Research Center. Since NASA's SETI activity has now terminated, this will be the last update for a while. However, we expect the usefulness of this software for planning both radio astronomical and SETI observations to remain strong for at least a year or more. In the future, we hope to obtain support to continue the maintenance and upgrades of this database, from other sources.

Questions regarding HRS can be directed to myself, or students, Dave DeBoer and Lewis Roberts, who have worked very diligently on its development.

Sincerely,



Paul G. Steffes
Professor

PGS: sr

Enclosures

HRMS RFI Search (HRS)

David R. DeBoer, Lewis Roberts

June 1, 1994

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1 Introduction

This document contains the manual for HRMS RFI Search (HRS). HRS is a database search program that utilizes data (primarily commercial geostationary) compiled at the Georgia Institute of Technology (hereafter referred to as GEOSAT) and a database of government owned satellites compiled by the Space Frequency Coordination Group (hereafter referred to as SSDB).

2 Installation and Operation

To install HRS and the associated databases (SSDB and GEOSAT) onto your hard drive insert the diskette labeled 'COMPLETE INSTALLATION' into your disk drive and simply type 'install' at the drive prompt (A:\ or B:\). This will invoke an installation utility routine which will allow the user to place a copy of HRS in a chosen directory. The default directory is C:\HRMS. This will place a copy of HRS in the directory C:\HRMS\HRS, a copy of SSDB in

C:\HRMS\SSDB, and a copy of GEOSAT in C:\HRMS\GEOSAT. Note that this requires 3.6 Mbytes of memory on your hard disk. If you just wish to place HRS on your hard drive (which requires 740 kbytes) then insert the diskette labeled 'HRS ONLY' and type 'install' at the drive prompt. This will put a copy of HRS in the directory C:\HRMS\HRS. These directories will be created by the install programs.

Once installed, HRS is executed by typing 'HRS' in the HRS directory. See the literature on SSDB and GEOSAT for their operating instructions (README for SSDB and README.DOC for GEOSAT). When you type 'HRS' the following menu will appear:

HRMS RFI Search

Main Menu

- 1.) Location: .0 .0
- 2.) Date: / / 3.) Time: : 4.) Mission date: ENABLED
- 5.) Low frequency (MHz): .000 MHz
- 6.) High frequency (MHz): .000 MHz
- 7.) Right Ascension of search window:
 Azimuth of search window:
- 8.) Declination of search window:
 Elevation of search window:
- 9.) Continue 10.) Other 11.) Help 12.) End

Input selection (1-12).

As you can see, HRS consists of 12 main menu selections:

- 1.) Location This is the latitude and longitude of the observer. A library of locations is included and may be selected. This library can be edited by the first menu selection under the 'Other' menu.

The convention followed throughout is to enter positive values for degrees W and N and negative values for degrees E and S.

- 2.) **Date** The date of observation is input in the format MMDDYYYY, e.g. 01031992 for January 3, 1992. You will be asked if you wish to use today's date and if so this will be read from the DOS utility.
- 3.) **Time** The time (Universal Time) of the observation is input in the format HHMM, e.g. 2030 for 8:30 p.m.. You will be asked if you wish to use the current time and if so this will be read from the DOS utility. The number of hours to get UT from local time will automatically be added. This function will state what the conversion to UT is and ask if that is correct--if not you may change it.
- 4.) **Mission date** The mission date option has two settings: ENABLED and DISABLED. If enabled it will read the SOM (Start Of Mission) and EOM (End Of Mission) from the database and only include the satellites currently operational (or at least those that the database *thinks* are currently operational). For DISABLED it obviously does not. Note for GEOSAT there is only an SOM entry so EOM is assumed eternity. Also, this function checks the year only.
- 5.) **Low frequency (MHz)** The lower limit of the frequency search window is entered at this choice, in MHz. Each database entry has a lower and upper frequency value for each transponder (a center and bandwidth for SSDB) and if any portion of this range falls within the search window it is passed to the next criterion of position.
- 6.) **High frequency (MHz)** The upper limit of the frequency search window is entered at this choice.
- 7.) **Right Ascension of search window/Azimuth of search window** When this selection is chosen you will be prompted to select either a window in RA/Dec or Az/El. The appropriate parameters for minimum and maximum values are then entered in HHMMSS for RA min/max or decimal degrees for Az min/max. If no orbital parameters exist within the database (or no subsatellite points for geostationary satellites) then frequency is the only criterion.
- 8.) **Declination of search window/Elevation of search window** The Declination or Elevation minimum and maximum values are entered upon this choice in decimal degrees. If a window in RA/Dec or Az/El has not yet been chosen you will be prompted to choose at this time. Note that for declination, degrees south are entered as a negative number and degrees north as a positive number.
- 9.) **Continue** This option will begin the database search with the given parameters. The output will be written to an ASCII file named as the search time with the tag OUT, e.g. the output file for a search at 8:30 pm would be 2030.OUT. There is a header with the search parameters followed by a list of the satellites found to match the criteria. As a match is found the satellite name is written to the screen.
- 10.) **Other** Other contains various helpful astrometric routines and the location library editing facility. See Section 3 for more information.

11.) Help HRS maintains an on-line help with this option. The user may add to it by editing the HRS.HLP file with an ASCII editor. See Section 3 for more information.

12.) End This option leaves the HRS system and returns the user to DOS.

The first eight menu selections constitute your search parameters. After making those selections, and for a window in RA/Dec, the main menu will look something like this:

HRMS RFI Search

Main Menu

- 1.) Location: 84.4 W 33.8 N
- 2.) Date: 10/13/1992 3.) Time: 13:42 4.) Mission date: DISABLED
- 5.) Low frequency (MHz): 1000.000 MHz
- 6.) High frequency (MHz): 2500.000 MHz
- 7.) Right Ascension of search window: 01h 00m 00s - 22h 00m 00s
- 8.) Declination of search window: 15.00 S - 15.00 N
- 9.) Continue 10.) Other 11.) Help 12.) End

Input selection (1-12).

A typical output file will look something like this:

HRMS RFI Search

Date of search: 12-16-92 Time of search: 14:16:32

Date: 12/16/1992 UT: 18:15 LST: 18h 18m 53s
Location: 84.4 W 33.8 N Mission Date: ENABLED
Low frequency: 1000.000 MHz
High frequency: 1500.000 MHz
Azimuth Search Window: .00 - 360.00
Elevation Search Window: 15.00 - 65.00

Frequency entry

Spacecraft: Inmarsat II F1

Launch Date: 10 /1991

Downlink 1:

1500.000 - 1550.000 MHz EIRP: 39 dBw Polarization: RH

Downlink 2:

3600.000 - 3621.000 MHz EIRP: 24 dBw Polarization: LH

Downlink 3:

4180.000 - 4200.000 MHz EIRP: 24 dBw Polarization: LH

Downlink 4:

.000 - .000 MHz EIRP: dBw Polarization:

Antenna Coverage: Global beam

Comments: Orbit to be determined

Geostationary

Spacecraft: Gstar 3

Launch Date: 9 /1988

Subsatellite point: 93.0 W

Azimuth: 195.2 Elevation: 49.6

Right Ascension: 17h 39m 35s Declination: 5.5 S

Downlink 1:

11700.000 - 12200.000 MHz EIRP: 38.5-50 dBw Polarization: H/V

Downlink 2:

1500.000 - 1650.000 MHz EIRP: 17 dBw Polarization:

Downlink 3:

.000 - .000 MHz EIRP: dBw Polarization:

Downlink 4:

.000 - .000 MHz EIRP: dBw Polarization:

Antenna Coverage: CONUS, Alaska, Hawaii, Caribbean, and Central
America

Comments: Currently in an inclined orbit.

In addition to this output file, a file mirroring what is printed to the screen during a search will be written to a file appended by .SCR (for example, 2030.SCR).

If something untoward happens while calculating the location of the spacecraft (for instance, no orbital parameters are present for a low earth orbiter) that spacecraft will get written to a file appended by .INV (for example, 2030.INV) if it satisfies the frequency criteria and will be tagged "Invalid Orbital Parameters".

A typical output file will look something like this:

HRMS RFI Search

Date of search: 12-16-92 Time of search: 14:16:32

Date: 12/16/1992 UT: 18:15 LST: 18h 18m 53s
Location: 84.4 W 33.8 N Mission Date: ENABLED
Low frequency: 1000.000 MHz
High frequency: 1500.000 MHz
Azimuth Search Window: .00 - 360.00
Elevation Search Window: 15.00 - 65.00

Low Earth Orbit

Spacecraft (Invalid Orbital Parameters): EOS
Agency: NASA
Objective: Earth Observing System
Start of mission: 01/16/1991 End of mission: 01/16/1998

Azimuth: .0 Elevation: .0
Right Ascension: Oh Om Os Declination: .0 S

Drs-to-User:
Frequency: 1227.6000 MHz BW (99.9%): 20.000 MHz
EIRP: 199.8 Polarization: CIR

User-to-Drs:
Frequency: .0000 MHz BW (99.9%): .000 MHz
EIRP: 199.8 Polarization:

Orbit Comments: Circular. Sun-Synchronous

End-of-file.

In general, the philosophy has been to be overly inclusive, if anything, and let the operator discriminate the data.

3 More on OTHER and HELP

OTHER contains several helpful (hopefully) routines to assist you in your RFI search. The OTHER menu looks like:

OTHER menu

- 1.) Edit location list
- 2.) Calculate Local Sidereal Time from UT
- 3.) Calculate UT from Local Sidereal Time
- 4.) Calculate RA/Dec from Az/El
- 5.) Calculate Az/El from RA/Dec
- 6.) Calculate Az/El-RA/Dec from subsatellite point
- 7.) Calculate Az/El-RA/Dec from orbital parameters
- 8.) Calculate position of the sun
- 9.) Calculate positions of the planets
- 10.) Precess RA and Dec to new epoch
- 11.) Return to Main Menu

Input selection (1-11).

These are all pretty much self-explanatory and you are prompted for inputs, so using it shouldn't be a problem. Most of the routines were adapted from Peter Duffett-Smith's "Astronomy With Your Personal Computer" (Cambridge University Press, 1985). OTHER is fairly well insulated from the MAIN menu functions with the exception of option 7, which will change the value of latitude and longitude of the observer in the MAIN menu.

The on-line help was included for completeness since HRS is pretty simple and straight-forward to use. However, there are a few helpful tips in there. For instance, an Az search window cannot straddle 360 degrees. Also, if you wish to view something ASCII while running HRS you could include it in the ASCII HRS.HLP file.

To include something in HRS.HLP, just bracket it between two '*b' characters and include the name as the first line. Then place the name in the list near the top of the file. For example, to include the text

This is a test to include text in HRS.HLP
between the entries for Date and Time and name it as 'TEST', that section of the file would look like:

08011992. Today's date can be selected.

*b
TEST
This is a test to include text in HRS.HLP
*b
time

Then you include TEST in the list after

More help on the following topics may be found by typing the appropriate name:

Placement of the word within the list doesn't matter.

Note that HRS searches for a verbatim match, and it is case sensitive. Also, the line width must be 80 characters or less.

4 Incorporating New Data Into HRS

As with any database, this search system is only as good as the data it uses. Given the fluid nature of spaceborne transmitter parameters, out-of-date entries can become a problem. Though updates of GEOSAT and SSDB will be issued upon request, the user may wish to update HRS personally.

As the data accessed by HRS is in ASCII format, the user may edit the data using any ASCII editor. The GEOSAT.DAT and the SSSAT.DAT files contain the names of the accessed data files as well as their format for GEOSAT and SSDB respectively. Indeed, one may start their own data file, say MY-DATA.HRS, format it in either GEOSAT or SSDB format and include the filename in the appropriate .DAT file.

The other way to access the data is to use GEO or SS and change the data within the dBase or Clipper databases. Two executables have been included to facilitate changing them to HRS format: DCGEO.EXE and DCSS.EXE. These two programs require ASCII versions of the GEOSAT and SSDB databases. To get these choose option 5, 'Make Text Files', in GEOSAT or choose option 6, 'File Maintenance/Copy' then option 2, 'Copy to SS.SDF' in SSDB. DCGEO will prompt you for an input filename (the file in GEOSAT format) and an output filename (the file to be written in HRS format). The convention used

is to change the tag to .HRS from .TXT. DCSS assumes an input filename of SS.SDF and writes the output to SS.HRS.

Note that SSDB does not have a way to edit the orbital parameters as needed for HRS. This must be done with an ASCII editor and, again, the format may be found in the SSSAT.DAT file. GEOSAT includes orbital parameters in the comment sections. For any orbital parameter editing see section 5.

5 COM1 And COM2 Orbital Specifications

5.1 Keywords and Format

5.1.1 GEOSAT

GEOSAT was primarily designed to include geostationary spacecraft and therefore all that was needed was the one subsatellite point to completely characterize the location of the spacecraft. In order to incorporate other types of spacecraft such as low earth orbiters or deep space probes however we need further specifications. The fields in the database which will contain this information are the two COMMENT lines (referred to as COM1 and COM2, respectively). The COM lines are formatted to hold only 50 characters so if you have to lose any numbers make sure that they are the least significant digits. These fields will have several reserved keywords and/or symbols as specified below.

1.) If the first character of COM1 is the '@' character this will mean the spacecraft is a low earth orbiter. Following @ in COM1 should be the orbital parameters of:

- Epoch in format YYDDD.ddddddd
- First derivative of mean motion / 2
- Second derivative of mean motion / 6
- Ballistic coefficient
- Inclination in degrees

and COM2 should contain the rest of the needed orbital parameters:

- Right ascension of ascending node in degrees
- Eccentricity
- Argument of perigee in degrees
- Mean anomaly
- Mean motion

(See section 5.2 for the meanings of these parameters.) They should be delimited by a comma and preceded by a colon. For example,

Q92045.70925411,-6.0E-8,4.5E-5,.10672E-4,99.1388:
110.7968,9.485E-5,158.7714,201.3836,13.83679338:

- 2.) If the first ten characters of COM2 are 'Deep Space' then this is a deep space probe. HRS then only checks the frequency but states in the output that it is a deep space probe.
- 3.) If the first four characters of COM2 are 'Freq' then this is only a frequency entry and HRS only checks the frequency and states this in the output. If the COM2 entry is none of the above but the direction entry is the '*' character instead of 'E' or 'W' then this is also only a frequency check and will be stated as such in the output.
- 4.) If none of these cases apply then the satellite is a geostationary satellite.

5.1.2 SSDB

SSDB has an orbit specification symbol (ORBIT) where

- G = Geostationary
- A = Low Earth Orbit
- B = Deep Space
- F = Frequency entry

which determines what sort of orbit the spacecraft is in. The 'G', 'A' and 'B' designations are internal to SSDB but 'F' is unique to HRS and would have to be included by using an ASCII editor in the SS.HRS datafile (SSDB will not allow it). If the spacecraft is a low earth orbiter (A) then the parameters are included in two COM statements identical to the two COM statements in GEOSAT, which should be appended to the end of the data line in the SS.HRS file. Note that these are also formatted to be 50 characters apiece and that the format is the same as the low earth orbit format for GEOSAT. You should ignore the orbital parameter entries in the SS program itself.

5.2 Low Earth Orbit Parameters

These numbers follow the NORAD/NASA 2-Line model. These numbers are generated by the SGP4/SDP4 model. The two line format is:

```

          EPOCH          XNDT20      1  2  BSTAR 3
          /-----\ /-----\ /---\ \ /---\ \
1 11080U 78098 A 92215.70925411 -.00000006 00000-0 10672-4 0 9841
2 11080 99.1388 110.7968 0009485 158.7714 201.3836 13.83679338695555
          \-----/ \-----/ \---\ / \---\ / \-----/
          XINCL  XNODEO  EO  OMEGAO  XMO  XNO

```

1 = XNDD60 (significant) 2 = IEXP (XNDD60 exponent)
3 = IBEXP (BSTAR exponent)

For quantities in scientific notation, an implied decimal point is located just before the significant. In the example above, BSTAR = .10672E-4.

EPOCH = YYDD.ddddddd, where 92001.00000000 = 1992 Jan 1 0h UTC
XNDT20 = (1st derivative of mean motion) / 2
XNDD60 = (2nd derivative of mean motion) / 6
BSTAR = ballistic coefficient (mass/cross section)
XINCL = inclination
XNODEO = right ascension of ascending node
EO = eccentricity
OMEGAO = argument of perigee
XMO = mean anomaly
XNO = mean motion

Note that in the 2-line format the decimal is assumed for BSTAR, XNDD60 and for the eccentricity (EO) and that the exponents for BSTAR and XNDD60 are separate. This is not the case for the COM1/COM2 specifications—they are "real" numbers. That is:

$$\text{XNDD60} = [\text{XNDD60}] \times 10^{|\text{IEXP}|-5}$$

$$\text{BSTAR} = [\text{BSTAR}] \times 10^{|\text{IBEXP}|-5}$$

$$\text{EO} = [\text{EO}] \times 10^{-7}$$

where the square brackets refer to NORAD/NASA variables. The rest of the numbers can be entered as typed in the 2-line format.