ATTITUDE DETERMINATION PROGRAM FOR PERSONAL COMPUTER (PC/ADP)

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November 20th, 1987

TABLE OF CONTENTS

1.0 PREFACE

Aim of this document is to describe the implementation on an IBM PC/AT of an Attitude Determination System for spinning satellites, according to the agreement between CAST and CNUCE.

An Attitude Determination Program (ADP) for spinning satellites is already existing at CNUCE. Its reliability has been stated during many years of operations as far as the use of the mathematical model, the implementation environment and the operating strategy are concerned; this existing System has been conceived to run on main-frames.

The purpose of our work has been to modify ADP to run on Personal Computer and to accomplish only no real-time S/C attitude determination. ADP has been simplified and a new system (PC/ADP) more flexible has been implemented.

The operating strategy, models and methods which are used in the Attitude Determination Program, (See [1]), (See [2]), are not discussed, while the adapting work done in a systemistic way, stressing only that parts of the existing System usefull for a better understanding of our job, is presented.

2.0 PC CHARACTERISTICS AND PRELIMINARY TESTS

To implement the system, an IBM PC/AT (whose characteristics are shown in tab.1) has been selected.

Hardware	Software
RAM 1152 KB	PC/VM 370 Operating System
CPU Intel 80286 6 MHz	
Math-Coprocessor Intel 80287	
Hard-Disk 20 MB	
Floppy Disk 1.2 MB	
Floppy Disk 360 KB	
Two Expansion AT/370 Cards	

TABLE 1 - PC/AT CHARACTERISTICS

The VM/PC 370 Operating System running on PC/AT makes it possible:

1. to link the 3081 disk where ADP resides, to load it in the PC memory and to run it locally;

2. to mantain also on the PC the interactivity of the ADP System.

The first possibility enabled us to test preliminarly the 3081/ADP System on PC/AT; the second one was very usefull because the user has to make decisions while the program runs and shows partial results. These results are to be evaluated by the user himself to continue the proper execution of the program.

Exploiting the characteristics just outlined, it was possible to evaluate the execution time for the 3081/ADP System on the PC/AT, simulating an attitude determination for SIRIO Satellite. Since the elapsed time for the execution was of about 40 minutes (an acceptable time taking into account the no-real time application of the System), we have decided to continue the implementation work.

3.0 THE 3081/ADP SYSTEM AND THE PRELIMINARY WORK

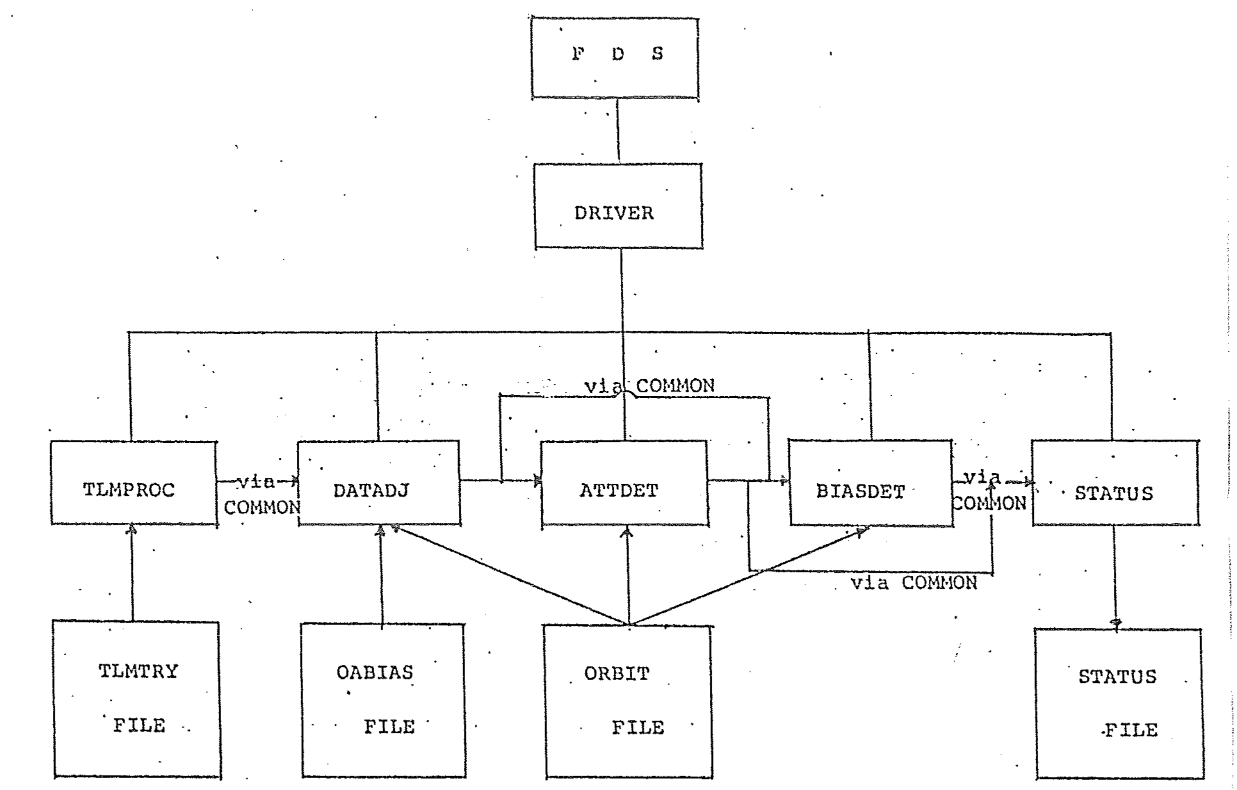

FIG. 1 - 3081/ADP BLOCK DIAGRAM

In fig. 1 the 3081/ADP Block Diagram is shown; with reference to this figure, the following blocks can be evidenced:

TLMPROC:

- retrieve, from telemetry file, data relevant to attitude computation;

DATADJ:

- selects telemetry data and computes the corresponding ephemeris data;

BIASDET:

- computes attitude and systematic errors applying batch least- squares filtering methods;

ATTDET:

- computes the attitude vectors, frame by frame, using deterministic methods.

The shown sub-systems share informations by COMMON BLOCKS and are managed by the DRIVER in a single module. In order to make the program more flexible and to transfer it to the personal computer, the 4 sub-systems have been separated into 4 different modules. Therefore it has been necessary to select for each sub-system:

1. the tree diagram;

2. the common blocks;

3. the shared data variables within each common block.

The above listed items permit respectively, to define the different modules, to select all variables shared between original subsystems, and to identify the variables shared between the new modules.

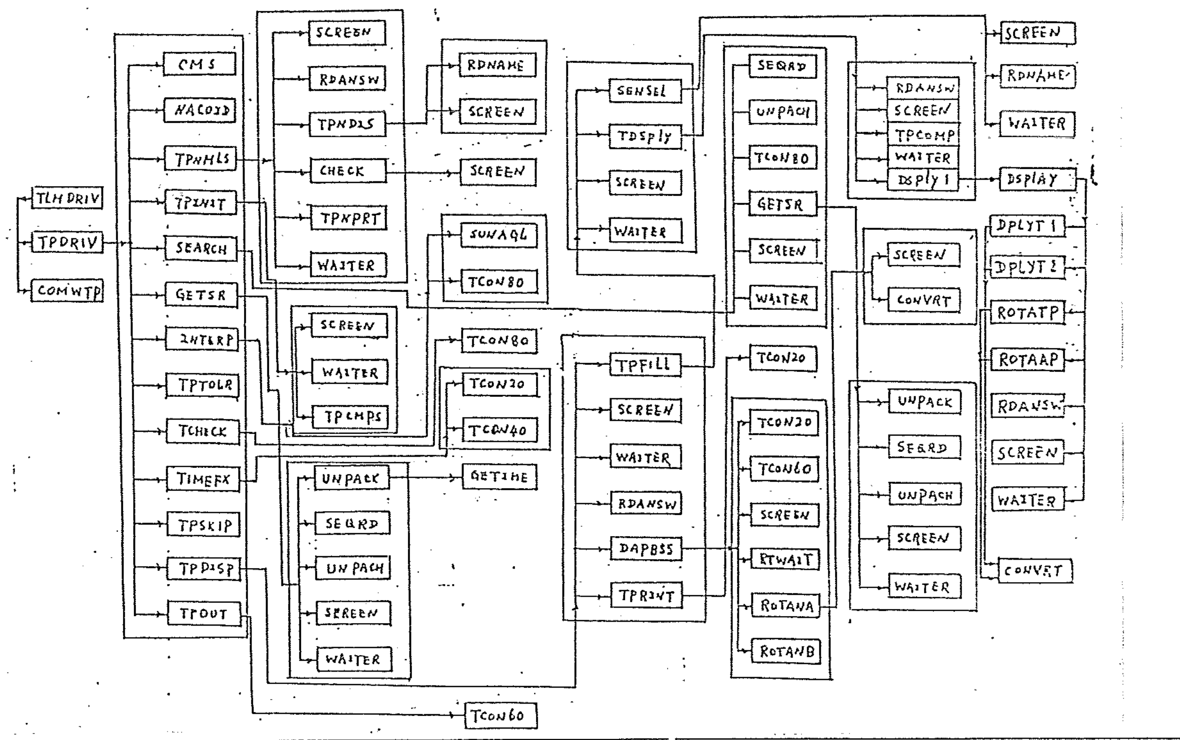

FIG. 2 - TLMPROC TREE DIAGRAM

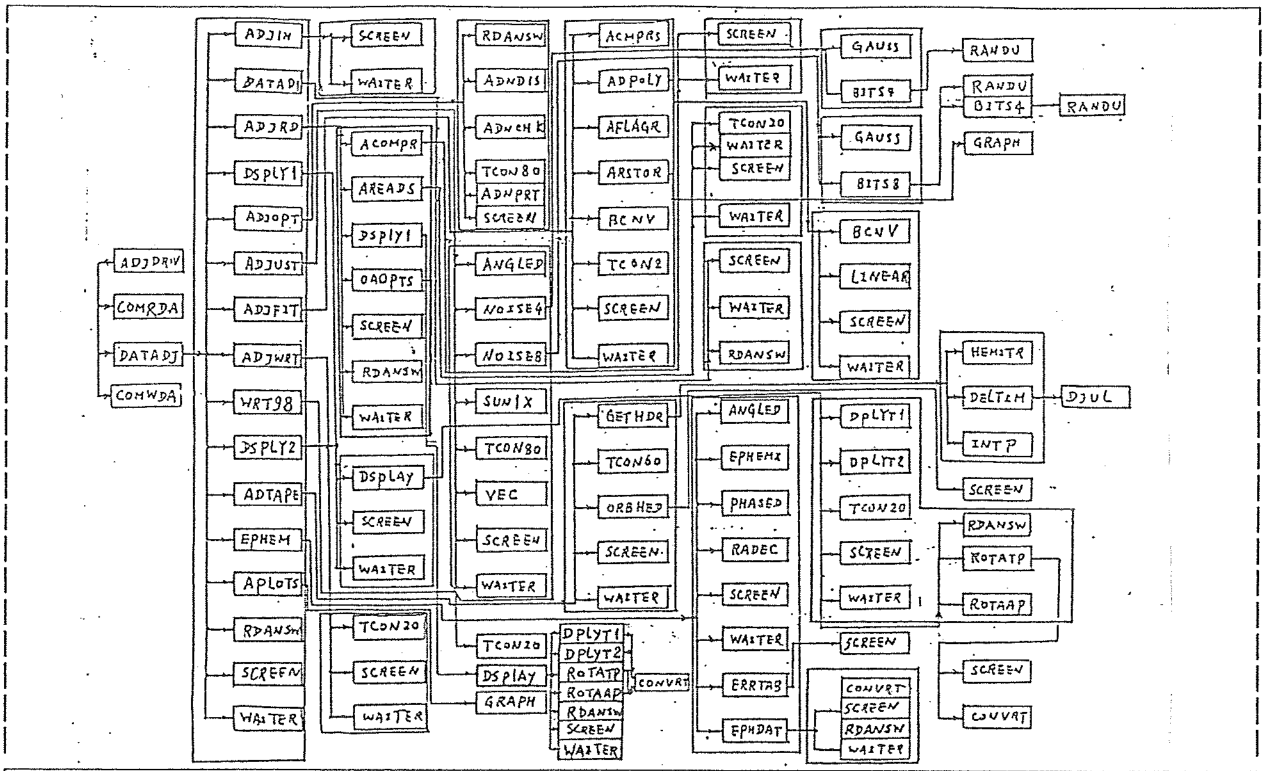

FIG. 3 - DATADJ TREE DIAGRAM

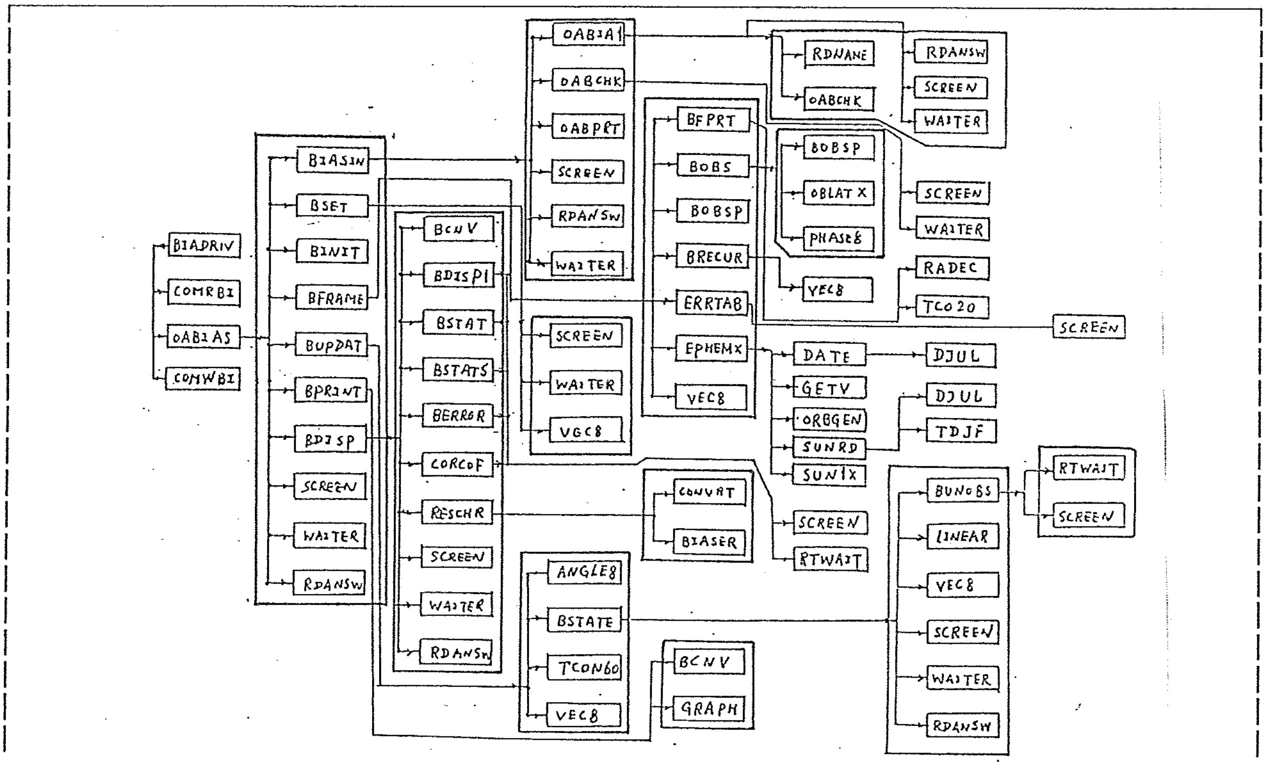

FIG. 4 - BIASDET TREE DIAGRAM

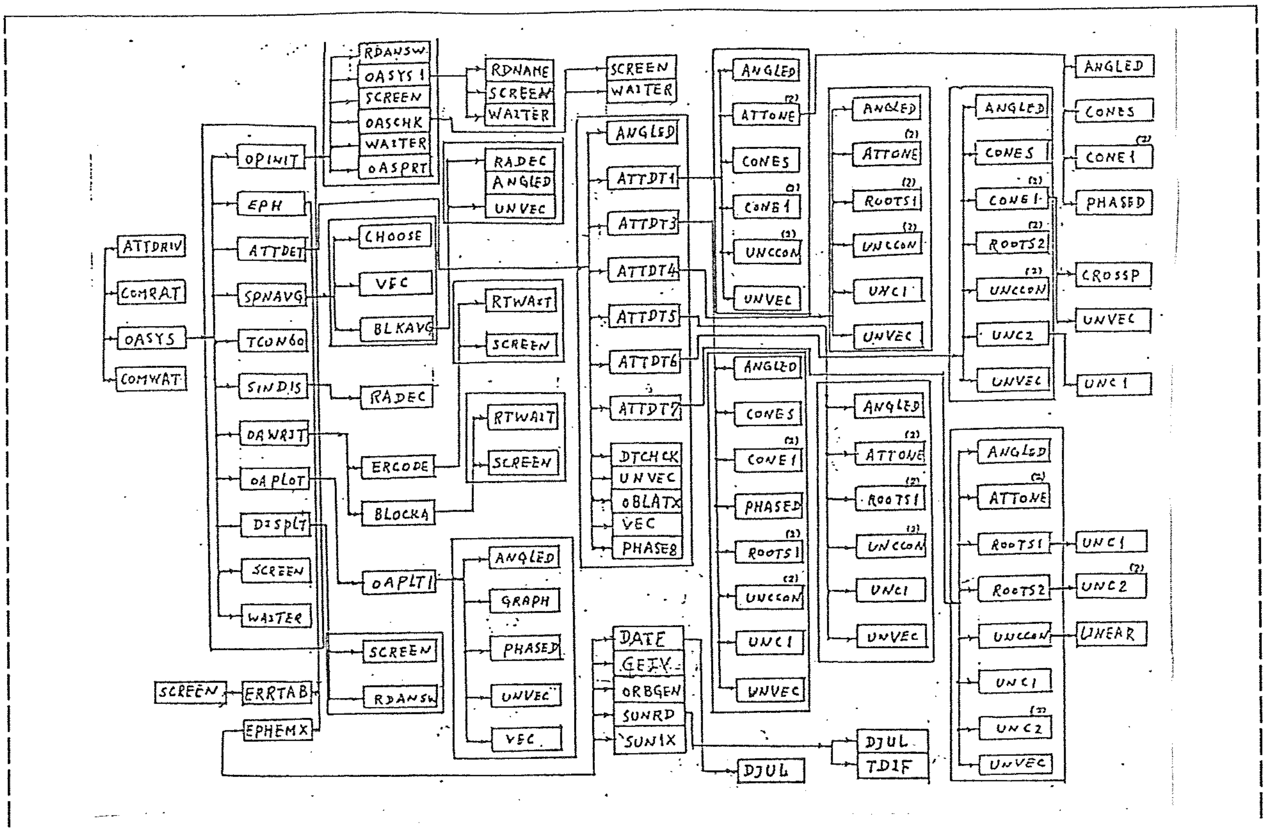

FIG. 5 - ATTDET TREE DIAGRAM

Figs. 2-5 show respectively the tree diagrams corcerning the TLMPROC, DATADJ, BIASDET, and ATTDET; At the top of each tree the subroutines created to share data in the new system are reported.

FILE NUMBER	RELATIVE COMMON DATA NAME	VARIABLES	MODULE NAME	READ OR/AND WRITE
21	TPGESS	SUNTIM(250) SUNANG(250) OMEGA(250) CONFIG(250) IREJ(250) ETIME(2,2,250)	TLMPROC DATADJ	WRITE READ
22	SYSLST	SENANG(2) ANOM(4)	TLMPROC DATADJ ATTDET BIASDET	WRITE READ READ READ
23	SATDP2	INTRNL(32)	TLMPROC DATADJ	WRITE READ
24	ADGESS	STIME(250) BETA(250) SPINRA(250) KONFIG(250) REJ(250) ETIM(2,2,250)	DATADJ ATTDET BIASDET	WRITE READ READ
25	ADGESS	SUN(3,250) R(3,250) V(3,250)	DATADJ ATTDET BIASDET	WRITE R/W R/W
26	ADJSIZ	IFILLA	DATDJ ATTDET BIASDET	WRITE READ READ
27	IRFLAG	BTIMEV IOASYS	DATADJ ATTDET BIASDET	WRITE R/W R/W
28	ORBIT1	ZEPOCH ZA ZE ZEYE ZEMO ZWO ZRANOD IZSUN IZSPC IZMOON	DATADJ ATTDET BIASDET	WRITE R/W R/W
29	OASYSC	ALFAVG DELAVG	ATTDET BIASDET	WRITE READ
30	OAGESS	INDX(12,250) SREJ(3000) CHOICE(3000)	ATTDET BIASDET	WRITE READ
31	OASSIZ	IFILL2	ATTDET BIASDET	WRITE READ

TABLE 2 - SHARED FILES

Tab. 2 shows the file numbers created to share data, the common block name they belong to, the names of the variables and the modules using them in read/write mode.

SUNTIM(N)	SUN TIME FROM 0 HOURS UT, SEPT. 1, 1957 (SECONDS)
SUNANG(N)	SUN ANGLE (DEGREES)
OMEGA(N)	SPIN RATE (DEGREES/SECOND)
ETIME(2,2,N)	EARTH SENSOR TIME (SECONDS FROM SUN TIME)
CONFIG(N)	CONFIGURATION FLAG
IREJ(N)	REJECTION FLAG
SENANG(2)	NOMINAL SENSOR MOUNTING ANGLES, MEASURED BETWEEN SPIN AXIS AND SENSOR
ANOM(4)	NOMINAL AZIMUTH ANGLES(DEGREES)
INTRNL(32)	FILL SIZE OF TP ARRAYS AFTER SENSOR SELECTION
STIME(M)	SUN CROSSING TIME (SEC)
BETA(M)	SUN ANGLE (DEG)
SPINRA(M)	SPIN RATE (DEG/SEC)
ETIM(2,2,M)	RELATIVE HORIZON XING TIM(SEC)
KONFIG(M)	SUN SENSOR INDICATOR (2 SENSORS)
REJ(M)	EARTH SENSOR FLAG (2 SENSORS)
SUN(3,M)	UNIT SUN VECTOR AT SUN TIME(3 COMPONENTS)
R(3,M)	S/C POSITION VECTOR AT SUN TIME(3 COMPONENTS)(KM)
V(3,M)	S/C VELOCITY VECTOR AT SUN TIME(3 COMPONENTS)
IFILLA	NUMBER OF ENTRIES IN THE ADJUSTMENT ARRAYS -- STIME,BETA,SPINRA,ETIM,KONFIG,REJ
BTIMEV	TIME ADJUSTMENT (SECONDS) ADDED TO STIME(I) BEFORE EPHEMERIS VECTORS WERE ACCESSED. (SET TO ZERO IN THE DATA ADJUSTER, CHANGED IN ATTDET OR OABIAS IF THE VECTORS ARE REACCESSED)
IOASYS	FLAG INDICATING CALLS TO ATTDET SINCE LAST CALL TO DATA ADJUSTER (USED TO DETERMINE WHETHER OABIAS CAN USE REJECTION FLAGS FROM ATTDET)
ZEPOCH	EPOCH TIME OF ORBITAL ELEMENTS (SECONDS FROM SEPTEMBER 1, 1957, 0 HOURS UT)
ZA	SEMI-MAJOR AXIS (KM)
ZE	ECCENTRICITY (UNITLESS)
ZEYE	INCLINATION (DEG)
ZEMO	MEAN ANOMALY (DEG)
ZWO	ARGUMENT OF PERIGEE (DEG)
ZRANOD	RIGHT ASCENSION OF ASCENDING NODE (DEG)
IZSUN	METHOD FOR OBTAINING SUN POSITION
IZSPC	METHOD FOR OBTAINING S/C POSITION
IZMOON	METHOD FOR OBTAINING MOON POSITION
ALFAVG	COMBINED BLOCK AVERAGE RIGHT ASCENSION (DEG)
DELAVG	COMBINED BLOCK AVERAGE DECLINATION (DEG)
INDX(12,N)	INDEX IN ARRAYS WHICH FOLLOW, FOR 12 METHODS
CHOICE(K)	CHOICE FLAG, INDICATES CHOICE OF AMBIGUOUS SOLUTION
SREJ(K)	REJECTION FLAG
IFILL2	NUMBER OF ATTDET RESULTS

TABLE 3 - THE MEANING OF VARIABLES USED IN FILES 21 TO 31

Tab. 3 defines the meaning of the variables; figs. 2-5 and tabs. 2-3 are referred to the new modules.

4.0 THE IMPLEMENTED SYSTEM AND THE FINAL TESTS

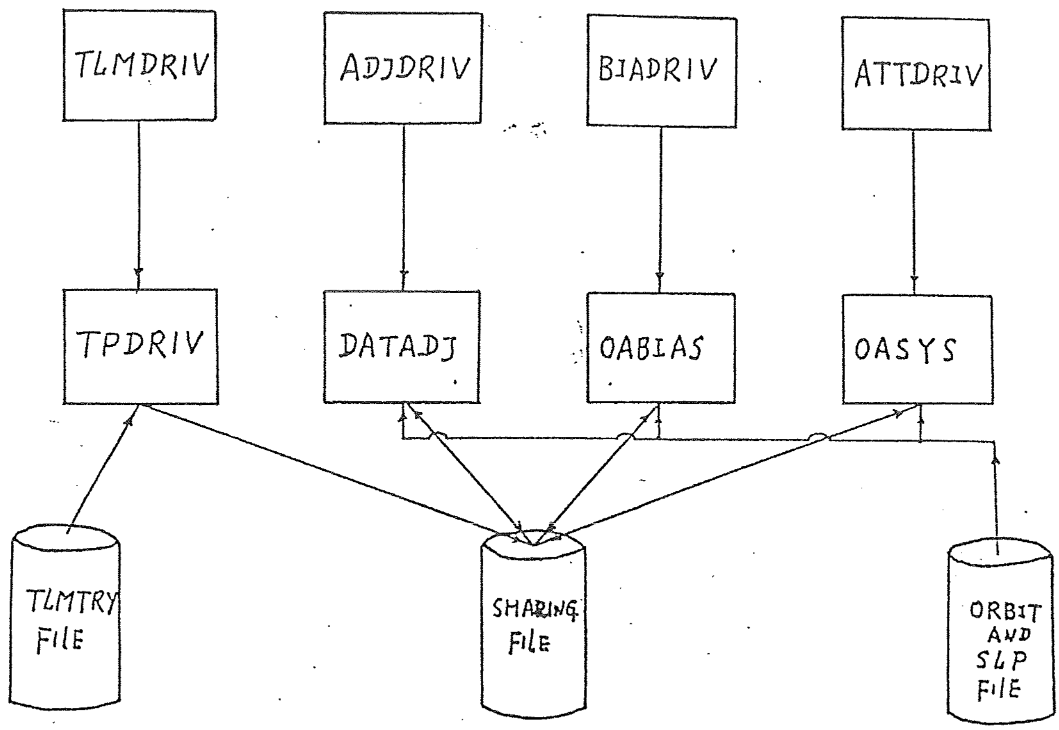

FIG. 6 - PC/ADP BLOCK DIAGRAM

Fig. 6 shows the block diagram of the Attitude Determination System implemented on the PC, where it has been evidenced data shared among generated modules and how they use telemetry data files, planets and spacecraft ephemeris. On request, the last two files can be generated by the System.

```
&CONTROL OFF
ERASE FILE TLMPROCC A1
SCREEN
&BEGTYPE
                *****************************
                *  TLMPROC IS LOADING NOW   *
                *                           *
                *     PLEASE    WAIT        *
                *****************************

&END
-FLD FILEDEF 1 TERM
FILEDEF 2 DISK ADP NAMLST A1
FILEDEF 5 TERM
FILEDEF 6 DISK FILE TLMPROCC A1(RECFM VBA LRECL 137 BLKSIZE 141
FILEDEF 14 DISK TLMTRY FILE D1 (RECFM FB LRECL 312 BLKSIZE 312
FILEDEF 21 DISK FILE FT21F001 B1
FILEDEF 22 DISK FILE FT22F001 B1
FILEDEF 23 DISK FILE FT23F001 B1
-GO TLMPROC
```

TABLE 4 - TLMPROC EXEC

```
&CONTROL OFF
ERASE FILE DATADJJ  A1
SCREEN
&BEGTYPE
                *****************************
                * DATADJ  IS LOADING NOW    *
                *                           *
                *     PLEASE    WAIT        *
                *****************************

&END
-FLD FILEDEF 1 TERM
FILEDEF 2 DISK ADP NAMLST A1
FILEDEF 5 TERM
FILEDEF 6 DISK FILE DATADJJ A1(RECFM VBA LRECL 137 BLKSIZE 141
FILEDEF 16 DISK ORBIT FILE E4(RECFM VS LRECL 1096 BLKSIZE 1100
FILEDEF 88 DISK SLP FILE F1 (DSORG DA XTENT 400 LRECL 2264 BLKSIZE 2264)
FILEDEF 98 DISK FILE FT98F001 A1 (RECFM F LRECL 80 BLKSIZE 80
FILEDEF 21 DISK FILE FT21F001 B1
FILEDEF 22 DISK FILE FT22F001 B1
FILEDEF 23 DISK FILE FT23F001 B1
FILEDEF 24 DISK FILE FT24F001 B1
FILEDEF 25 DISK FILE FT25F001 B1
FILEDEF 26 DISK FILE FT26F001 B1
FILEDEF 27 DISK FILE FT27F001 B1
FILEDEF 28 DISK FILE FT28F001 B1
-GO DATADJ
```

TABLE 5 - DATADJ EXEC

```
&CONTROL OFF
ERASE FILE BIASDETT A1
ERASE FILE FT07F001 A1
ERASE FILE FT08F001 A1
ERASE FILE FT09F001 A1
SCREEN
&BEGTYPE
                 ****************************
                 *                          *
                 *  BIASDET IS LOADING NOW  *
                 *                          *
                 *     PLEASE    WAIT       *
                 *                          *
                 ****************************
&END
-FLD FILEDEF 1 TERM
FILEDEF 2 DISK ADP NAMLST A1
FILEDEF 5 TERM
FILEDEF 6 DISK FILE BIASDETT A1(RECFM VBA LRECL 137 BLKSIZE 141
FILEDEF 7 DISK FILE FT07F001 A1(RECFM VBA LRECL 137 BLKSIZE 141
FILEDEF 8 DISK FILE FT08F001 A1(RECFM VBA LRECL 137 BLKSIZE 141
FILEDEF 9 DISK FILE FT09F001 A1(RECFM VBA LRECL 137 BLKSIZE 141
FILEDEF 16 DISK ORBIT FILE E4 (RECFM VS LRECL 1096 BLKSIZE 1100
FILEDEF 88 DISK SLP FILE F1 (DSORG DA XTENT 400 LRECL 2264 BLKSIZE 2264)
FILEDEF 22 DISK FILE FT22F001 B1
FILEDEF 24 DISK FILE FT24F001 B1
FILEDEF 25 DISK FILE FT25F001 B1
FILEDEF 26 DISK FILE FT26F001 B1
FILEDEF 27 DISK FILE FT27F001 B1
FILEDEF 28 DISK FILE FT28F001 B1
FILEDEF 29 DISK FILE FT29F001 B1
FILEDEF 30 DISK FILE FT30F001 B1
FILEDEF 31 DISK FILE FT31F001 B1
-GO BIASDET
```

TABLE 6 - BIASDET EXEC

```
&CONTROL OFF
ERASE FILE ATTDETT  A1
SCREEN
&BEGTYPE
               *****************************
               *  ATTDET  IS LOADING NOW   *
               *                           *
               *     PLEASE    WAIT        *
               *****************************
&END
-FLD FILEDEF 1 TERM
FILEDEF 2 DISK ADP NAMLST A1
FILEDEF 5 TERM
FILEDEF 6 DISK FILE ATTDETT A1 (RECFM VBA LRECL 137 BLKSIZE 141
FILEDEF 16 DISK ORBIT FILE E4 (RECFM VS LRECL 1096 BLKSIZE 1100
FILEDEF 88 DISK SLP FILE F1 (DSORG DA XTENT 400 LRECL 2264 BLKSIZE 2264)
FILEDEF 99 DISK FILE FT99F001 A1 (RECFM F LRECL 128 BLKSIZE 128
FILEDEF 22 DISK FILE FT22F001 B1
FILEDEF 24 DISK FILE FT24F001 B1
FILEDEF 25 DISK FILE FT25F001 B1
FILEDEF 26 DISK FILE FT26F001 B1
FILEDEF 27 DISK FILE FT27F001 B1
FILEDEF 28 DISK FILE FT28F001 B1
FILEDEF 29 DISK FILE FT29F001 B1
FILEDEF 30 DISK FILE FT30F001 B1
FILEDEF 31 DISK FILE FT31F001 B1
-GO ATTDET
```

TABLE 7 - ATTDET EXEC

Tabs. 4-7 show the exec commands for each new System modules; five different type of files have been defined, residing on five different logical storage devices:

- PC/ADP Input Namlist and user's Output Files
  - to be modified by the general users or by the program itself;
- PC/ADP Data Sharing Files
  - to be modified only by the program;
- Modules and Execs,
- Telemetry File,
- Satellite Ephemeris, Solar/Lunar/Planetary (SLP) Ephemeris
  - to be modified only by Specialists authorized for the System maintenance.

To be stressed that the last two files have been allocated in different disks to take into account the frequency of their updating (usually one month for S/C ephemeris and a few years for SLP); the maximum space required for each disk type is respectively 3201KB, 165KB, 1357KB, 1685KB, 858KB, 999KB.

Tabs. 8-9 and 10-11 show the numerical results of an attitude determination on 3081/ADP and PC/ADP, using the same input data simulated for the preliminary tests.

BIASDET ITERATION SUMMARY		
ITERATION NO. 6		
CONVERGED= YES	COMBINED WEIGHTED RMS = 0.292288	
PARAMETER	CURRENT VALUE	STANDARD DEVIATION
ALPHA(1)	347.459968	0.000606
DELTA(1)	-89.578805	0.000198
DSUN-1	-0.058968	0.000608
DGAMMA-1	0.236876	0.000382
AZIM-1	1.806663	0.000289
DGAMMA-2	-0.921108	0.000292
AZIM-2	1.798406	0.000252

TABLE 8 - STATISTICAL RESULTS FROM 3081/ADP

BLOCK AVERAGE RESULTS

M = METHOD OF ATTITUDE COMPUTATION
= 1, 84, SUN ANG/EARTH-IN
= 2, 84, SUN ANG/EARTH-OUT
= 3, 84, SUN ANG/EARTH-WIDTH
= 4, 84, SUN ANG/DIHEDRAL ANG
= 5, 84, DIHEDRAL ANG/EARTH WIDTH
= 6, 96, SUN ANG/EARTH-IN
= 7, 96, SUN ANG/EARTH-OUT
= 8, 96, SUN ANG/EARTH-WIDTH
= 9, 96, SUN ANG/DIHEDRAL ANG
=10, 96, DIHEDRAL ANG/EARTH WIDTH
=11, SUN ANG/DUAL SCANNER WIDTHS
=12, DIHED ANG/DUAL SCANNER WIDTHS
=13, 84, AVERAGE (METHODS 1-5)
=14, 96, AVERAGE (METHODS 6-12)
=15, TOTAL AVERAGE (METHODS 1-12)

M	ALPHA (DEG)	DELTA (DEG)	NO-OBS BEFORE	NO-OBS AFTER
1	347.491	-89.579	107	106
2	347.394	-89.579	129	94
3	347.613	-89.580	107	107
4	347.552	-89.579	107	104
5	347.220	-89.581	107	77
6	347.417	-89.579	139	138
7	346.952	-89.576	149	118
8	347.511	-89.579	139	139
9	347.308	-89.578	139	135
10	347.287	-89.582	138	104
11	0.0	0.0	0	0
12	0.0	0.0	0	0
13	347.469	-89.579	557	488
14	347.306	-89.579	704	634
15	347.377	-89.579	1261	1122

BEFORE = BEFORE SIGMA REJECTION
AFTER = AFTER SIGMA REJECTION

TABLE 9 - DETERMINISTIC RESULTS FROM 3081/ADP

BIASDET ITERATION SUMMARY

ITERATION NO. 6

CONVERGED= YES COMBINED WEIGHTED RMS = 0.292288

PARAMETER	CURRENT VALUE	STANDARD DEVIATION
ALPHA(1)	347.459968	0.000606
DELTA(1)	-89.578805	0.000198
DSUN-1	-0.058968	0.000608
DGAMMA-1	0.236876	0.000382
AZIM-1	1.806663	0.000289
DGAMMA-2	-0.921108	0.000292
AZIM-2	1.798406	0.000252

TABLE 10 - STATISTICAL RESULTS FROM PC/ADP

BLOCK AVERAGE RESULTS

M = METHOD OF ATTITUDE COMPUTATION
= 1, 84, SUN ANG/EARTH-IN
= 2, 84, SUN ANG/EARTH-OUT
= 3, 84, SUN ANG/EARTH-WIDTH
= 4, 84, SUN ANG/DIHEDRAL ANG
= 5, 84, DIHEDRAL ANG/EARTH WIDTH
= 6, 96, SUN ANG/EARTH-IN
= 7, 96, SUN ANG/EARTH-OUT
= 8, 96, SUN ANG/EARTH-WIDTH
= 9, 96, SUN ANG/DIHEDRAL ANG
=10, 96, DIHEDRAL ANG/EARTH WIDTH
=11, SUN ANG/DUAL SCANNER WIDTHS
=12, DIHED ANG/DUAL SCANNER WIDTHS
=13, 84, AVERAGE (METHODS 1-5)
=14, 96, AVERAGE (METHODS 6-12)
=15, TOTAL AVERAGE (METHODS 1-12)

M	ALPHA (DEG)	DELTA (DEG)	NO-OBS BEFORE	NO-OBS AFTER
1	347.491	-89.579	107	106
2	347.394	-89.579	129	94
3	347.613	-89.580	107	107
4	347.552	-89.579	107	104
5	347.220	-89.581	107	77
6	347.417	-89.579	139	138
7	346.952	-89.576	149	118
8	347.511	-89.579	139	139
9	347.308	-89.578	139	135
10	347.287	-89.582	138	104
11	0.0	0.0	0	0
12	0.0	0.0	0	0
13	347.469	-89.579	557	488
14	347.306	-89.579	704	634
15	347.377	-89.579	1261	1122

BEFORE = BEFORE SIGMA REJECTION
AFTER = AFTER SIGMA REJECTION

TABLE 11 - DETERMINISTIC RESULTS FROM PC/ADP

Comparing tabs. 8-9 with 10-11, we can state that results are exactly the same ones.

Tab. 12 shows for each PC/ADP module the I/O and the execution time; the minimum Virtual Memory (V.M.) size to run the new System is reported too.

With reference to the following table:

- the total I/O time (80 seconds) necessary to share data is irrelevant with respect to the total CPU time (42 minutes) which is close to that accounted during the preliminary test (40minutes);
- the virtual memory size needed to run PC/ADP is 752 KB to be compared with 1300 KB required by the 3081/ADP (See [1]).

PC/ADP V.M. SIZE 752 KB		
MODULE	I/O (SECONDS)	EXECUTION TIME (MINUTES)
TLMPROC	14.0	29.48
DATADJ	25.5	2.13
BIASDET	15.5	4.86
ATTDET	25.5	5.13

TABLE 12 - PC/ADP: I/O AND EXECUTION TIME

5.0 CONCLUSIONS

- The 4 sub-systems of 3081/ADP have been splitted into 4 modules (fig. 1) and used to implement an Attitude Determination System on the PC/AT.
- The implemented System is reliable as the existing one (tabs. 8-11) and it is more flexible and easier to adapt to a varity of space missions.
- The variables shared between the modules have been reduced to the ones strictly necessary for proper operations; in this way the I/O time has been lowered down to about 2 minutes.
- The maximum time of 42 minutes required for the total execution is widely acceptable, taking into account that the System is not intended for real-time attitude determination.
- The use of micros means low cost, high software portability, possibility of local and autonomous processing.

All these are the important advantages that justify the effort to adapt on micros the existing software and to extend the use of such computers in the flight dynamics area.

6.0 REFERENCES

[1] G. Faconti, M. Lucchesi, G. Pasquinelli "Sirio Attitude Determination Program (ADP)", CNUCE/Istitute of CNR - Pisa, July 1979.

[2] G. Faconti, "Flight Dynamics System (FDS)", CNUCE/Institute of CNR - Pisa, August 1977.