Navigational Satellite Programs

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Introduction

The following set of programs are those currently in use at N.I.C. for various aspects of satellite navigation. The date of this report is 28.8.1969. The on-line process programs are liable to have various modifications introduced without change of name, so note should be taken of the modification date.

The programs fall naturally into two sections, those involved in the on-line reduction of data from the satellite and those involved in the analysis both on-line and off-line.

Program Names

On-line reduction: SATIN, SATCL, SATVT, INSAT, SATCH

On-line analysis: SATD1, SATD2, SATD3

Off-line analysis: SATC1, SATC2, SATC3, SAT

Subroutine: BCD, SETBT, BITIN, BITST

On-line Reduction

Data: The satellite receiver detects the presence of a navigational satellite above the horizon and receives and decodes phase modulated signals on 150 and 400 mHertz. The decoded signals are presented at the computer output terminals of the receiver as a sequence of 15 bit messages the presence of a message being signalled by a 50 μs pulse on a separate interrupt line. For the 1300 a hardware pulse lengthener is required to provide a 10 mS interrupt. Further hardware features of the receiver that must be operative are the 'between pass inhibit' line and the '4·6 second enable' line. These are controlled by switches on the main distribution board in the computer room - (see satellite receiver manual for further details).

The format of the decoded message from the receiver is as follows. Every two minutes 25 groups of 3 15 bit words are transmitted. The pass may last for 19 minutes. The first 3 bits of each word of all receiver messages is a code as follows

110(6) 1st word of group of 3 message words
111(7) 2nd or 3rd word of any group of 3 words
010(2) 1st word of group of 3 400 Mc 2 minute counts
100(4) 1st word of group of 3 150 Mc 2 minute counts
011(3) 1st word of group of 3 400 Mc 4·6 second counts
101(5) 1st word of group of 3 150 Mc 4·6 second counts

(See below for the last 4 entries).

The remaining 12 bits of each word are 3 4 bit BCDXS3 coded numbers e.g. 1001 1000 0011 are BCDXS3 983 which translates to straight BCD by subtracting 3 from each number to give BCD 650. (The number system in BCDXS3 is extended to A=10, B=11, C=12.)

Thus each of the 25 groups of 3 words after decoding and removal of code bits becomes a group of 9 decimal numbers. These provide all the information required to determine the position of the satellite at the beginning of the 2 minute period and is the sum total of digital information from the satellite. If the receiver

loses lock BCD zeros are transmitted with the code (not BCDXS3 zero).

The receiver also counts the doppler frequency shift of both the 400 and 150 MH signals and presents these as integrated doppler counts over the 2 minute intervals. Partial counts during the minutes are presented at 4.6 second intervals (code 3 and 5) interleaved with the satellite message data. The counts are presented again as 3 15 bit words. When the code bits are removed the 9 numbers are BCDXS3 except for the first 2 which are always BCD Ø. If lock is lost on either 400 or 150 MH channel then BCDXS3 Ø are transmitted in place of the 7 BCDXS3. numbers.

Thus in summary; approximately every 4.6 seconds (with a longer gap at the end of a 2 minute period) the following are transmitted

1. 3 groups of 15 bits of 400 MH Doppler
2. 3 groups of 15 bits of 150 MH Doppler
3. 3 groups of satellite message.

The first 400 and 150 MH Doppler of a 2 minute period is the accumulated doppler count over the preceeding 2 minutes (the first Doppler count after the satellite receiver locks on is always zero).

The first interrupt of a 2 minute period provides an accurate time signal.

Operational Requirements for satellite navigation with current systems - August '69

Hardware receiver should be in the mode that enables 4.6 second doppler data transfer and disables between pass interrupts. Switches for both these functions are on the left hand of the main computer distribution board.

The receiver oscillator requires several hours after being plugged in on standby for the oscillator to stabilise.

The interrupt pulse lengthening circuit must be on. This requires both ± 12 volt supplies.

Software should not require manual intervention. Fix is printed out on the 1816 and is also written to file SATF.

Skeleton common variables ISW(5), ISW(6) have an effect on the programs.

If ISW(5) is non-zero then P/T output on punch 2 should be expected. If P/T 2 is not ready the whole system will hang up. This output is really for analysis of data in case things go wrong with the automatic solution of the problem, some of it is not immediately intelligible without first hand acquaintance with the satellite data.

If ISW(6) is non-zero then P/T output following any output as a result of ISW(5) and separated from it by blank tape and run-out is put out in a form ready for input to an off-line program CFSAT. ISW(6) is automatically set non-zero if the program detects a more than 15 minute error between the computers internal clock and the in skeleton common variable IMINT. This allows a fix to be obtained even if the external clock malfunctions. The ISW(6) option should be available early September.

ISW(5) and ISW(6) can be conveniently set 0 or 1 by the/DO function of CIPRO.

For proper operation of the satellite programs the cold start program CCLD2 should have been executed at some stage.

Messages on typewriter

1. SATCL - Spurious Interrupts on satellite line

   Usually means either that receiver has just been switched on or off, voltage low on pulse lengthener circuit or noise getting in from some other circuitry onto the satellite interrupt line.

2. SATCL - Satellite Pass Finish at

   Approximate time of end of satellite pass and start of data analysis.

3. SATCL - invalid word count

   SATFF record length in error, program terminates.

4. SATCH - invalid doppler codes

   Usually means that the input data to SATFF has got out of sequence probably through spurious interrupts or through missing first interrupt of pass. Check with WCTFL to see if first 6 words of SATFF are 2003 7333 7333 4003 7333 7333. If not then suspect interrupt circuitry.

5. SATCH - no time parameter available

   Program unsuccessful in decoding variable parameters - program terminates.

6. SATCH - not enough good dopplers

   Less than 3 non-zero dopplers available for fix.

7. SATD3 - 150 MC Doppler only
   SATD3 - 400 MC Doppler only

   To indicate fix quality.

8. SATD3 - Frequency
   Satellite Fix Day - Time -
   Lat. - Long.

Data Files associated with on-line satellite programs

	Name	Log No.	Length	Record Length
1.	SATFF	20	75 sectors	320

This contains in the first 45 words of each record the raw satellite data from the receiver output socket. Words 46-55 contain additional information required for fix but external to the receiver. Word 48 always has antenna height in metres, 55 always has word count of number of data words available in this record. This will always be 45 except on the last record. Words 47 and 49-54 are written only when the start of a 2 minute period occurs in the data of the record concerned (see SATIN). Words 56-320 are never used.

2.	RDOP4	21	3 sectors	3 word

This has 400 MH raw doppler data in 3 word records sorted out from SATFF on the assumption that the first 3 word group of SATFF is the first 400 Mc doppler count.

3.	RDOP1	22	3 sectors	3 word

150 MH raw doppler as for RDOP4.

4.	RMESS	23	3 sectors	3 word

Satellite message raw data as for RDOP4, RDOP1.

5.	RMIN2	24	1 sector	10 word

Words 46-55 of those SATFF records in which a 2 minute message starts. This should be records 1, 6, 11, 16 etc.

6. BDOP4 25 3 sectors 3 word

400 MH Doppler data converted from BCD to decimal but still with code number attached to front of each word (i.e. making a 4 digit decimal from code + 3 BCD numbers).

7. BDOP1 26 3 sectors 3 word

150 MH Doppler as for BDOP4

8. DOP4 27 3 sectors 3 word

400 Mc Doppler now converted from BDOP4 form to extended precision floating point without code.

9. DOP1 28 3 sectors 3 word

150 MH Doppler as for DOP4.

10. SATF 1 2 sectors 6 word

Day No., time (1/10 minute), Lat. (deg.), Lat. (1/100 min), Long. (deg.), Long. (1/100 min.) of fix. The minutes part of Lat. and Long. take sign of degrees part.

Common Variables for on-line programs

NMESS	No. of 2 minute marks in pass, including that at lock time
IERR	A parameter for error information
IDAY1	Day number at start of pass
JFIX(51) JVAR(39)	Fixed and Variable majority voted 3 word message groups in decimal but with code parameters still attached
FFIX(11)	Floating point decoded physical values of fixed parameters
ITIM(12)	The time parameters extracted from the variable message parameters
DELE(12)	The floating point eccentric anomaly correction
DELA(12)	The floating point major axis correction
IDELN(12)	The out of plane correction before combination into physical parameters.
(The above 4 arrays all start at the 2 minute period before lock on)	
DOP42(10) DOP12(10)	The physical floating point 400 and 150 MH doppler 2 minute counts starting with the zero counts at lock time
DOP(10)	The doppler count used in analysis (maybe vacuum, 400 or 150 MH). This does not include the zero count at lock time.
ANTH	Antenna Height above ellipsoid in metres
VE VN	East and North velocities in kts.

EPDEG ETDEG	D.R. Latitude and Longitude in degrees
DELN(12)	Physical out of plane correction as for DELE, DELA
JTIM	Lock on time in minutes from midnight.

All variables are implicitly typed.

Inskel Common Variables are as for cruise 29 of Discovery

N.I.O. SUBPROGRAM -39

Name	SATIN, secondary entry points SATIM, PGINT
Type	Skeleton Interrupt Routine
Language	1800 Assembler
Calls	Level 3, SATCL
Data File	SATFF - 75 sectors
Skeleton Common	2 x 57 word buffer IMINT - minutes and tenths time of day IDAY - Day number ISPD - Speed in 1/100 kts. IHDNG - 1/10 Degrees IANTH - Antenna Height in metres IPDEG - D.R. Latitude in ^{o} North positive ITDEG - D.R. Longitude in ^{o} East positive IPROG - Pass in Progress indicator Note that SATIN expects these to be in certain defined places in skeleton and current listing is as for skeleton common of cruise 29. Moreover SATIN requires an equate giving the address of the top end of skeleton common (currently SKEL EQU /0F1D).
Purpose	To respond to interrupt from receiver and accept 15 low order bits of DIV on DIV 72. If the interrupt is the first of a 2 minute period the following satellite common variables are put inwords 46-55 of the common buffer. Word 47 Day No. 48 Antenna Height 49 Course 1/10 degree 50 Speed 1/100 kt. 51 D.R. Lat. degrees 52 D.R. Long. in degrees 53 Time in 1/10 minutes 54 Position of 1st data word after 2 minute mark 55 No. of data words in the sector Words 48 and 55 are transferred to disk on every disk transfer not just those with a 2 minute mark. The data from the receiver is entered sequentially into words 1-45 of the buffer which when full is transferred by PGINT at level 3 to a sector of SATFF, meanwhile data is streamed to the 2nd buffer. There are two words in front of each

buffer containing a word count and sector address. Disk transfers take place every 23 seconds.

When no interrupts have been detected for 15 seconds program timer 3 times out and SATIM is called if no further interrupts occur after 15 more seconds the pass is assumed ended, the skeleton buffer written to SATFF, common variables initialised for next pass and SATCL is queued.

This program is a direct adaption of one by E. Caughran of IBM at Scripps.

N.I.C. PROGRAM 183

Name	SATCL
Type	Mainline Core-Load
Language	Fortran
Calls	SATVT
Called From	SATIM
Data Files	SATFF, RDCP4, RDCP1, RMESS, RMIN2
Skeleton Common	ISW(5), ISW(6), IMINT, IDAY
Purpose	To sort file SATFF

A check is first made that more than 1 sector of data has been written. If not, it is assumed that the interrupts are spurious a message is typed and program ends. Sign on messages are typed saying that satellite pass has finished. If ISW(5) is non-zero the message is also punched on P/T 2. If the skeleton time IMINT does not agree with internal clock ISW(6) is set non-zero to provide off-line output and termination of program SATCH.

The 400 MH doppler data is stored in 3 word records in RDCP4. Similarly 150 MH data is in RDCP1 and satellite message in RMESS. RMIN2 has the 10 word records from words 46 to 55 of SATFF whenever there is a 2 minute mark. A count is kept of the number of these records to give the total number of messages received.

The sorting process also rearranges the data in form of Fortran arrays reversing the original SATFF order which is assembler ordered. It is also assumed that the first interrupt is for the first word of 400 Mc doppler and that subsequent data is strictly in the expected order.

N.I.C. PROGRAM 184

Name	SATVT
Type	Mainline Core-Load
Language	Fortran
Calls	INSAT
Called by	SATCL
S/R's	BITMN, SETBT, BITST, BCD
Data Files	RMESS, RDCP4, RDCP1, BDCP4, BDCP1
Skeleton Common	ISW(5)
Purpose	To convert the satellite BCD data to decimal integer. This program checks that there are at least 3 complete 2 minute messages. It then majority votes bit by bit both the fixed and variable parameters and converts from BCD to decimal code, leaving the code parameters attached to the front of each word. e.g. an original hexadecimal bit pattern 7B93 will be decoded to 7860, and integer. BCDXS3 zeros are treated as indication of loss of lock and the whole of the group of 3 words concerned are set to zero. Next the 4.6 second dopplers are converted from BCD to decimal. If ISW(5) is non-zero the decoded decimal values of the fixed and variable parameters, 400 and 100 Mc doppler and the information from words 46 - 55 of those sectors of SATFF containing a 2 minute mark are punched to P/T 2.

N.I.C. PROGRAM 135

Name	INSAT
Type	Mainline Core-Load
Language	Fortran
Calls	SATCH
Called by	SATVT
Data Files	BDOP4, BDOP1, DOP4, DOP1
Skeleton Common	None
Purpose	To check that fixed and variable parameters have right code and if not flag an error. Then the fixed parameters are scaled to physical units. The variable corrections to eccentric anomaly and major axis are found, starting with the correction of the 2 minutes before lock and continuing for 3 2 minute intervals beyond the last one received. The out of plane parameter is decoded line by line but not fully evaluated at this stage. The integer doppler data from INSAT is converted to physical units by combination of the 3 word groups into a single floating point word. 4.6 second doppler is filed on disk and 2 minute data written to COMMON.

N.I.C. PROGRAM 186

Name	SATCH
Type	Mainline
Language	Fortran
Calls	SATD1
Called by	INSAT
Data Files	RMIN2
Skeleton Common	None
Purpose	Checks that at least one of 400 MH and 150 MH doppler has right code. Gets parameters (antenna height lat and long) from RMIN2 record 1. Checks if out of plane parameters available. If they are it combines the 2 single digits from successive message groups into one physical out of plane parameter. Uses time moduls 30 minutes from satellite variable parameters to line up computer clock time with satellite time moduls 1440 minutes. Next the two minute dopplers are edited to remove counts less than 2,800,000 and greater than 4,700,000 and also non-increasing counts. If both 400 and 150 mc doppler are available these are checked for differences greater than 1200 which it found lead to a rejection of those doppler counts (they are set to zero). The number of non-zero doppler counts available for a fix is then found and program terminates if there are less than 3. Finally the course and speed are read from the last record of RMIN2 and converted to velocity east and north in knots.

N.I.C. PROGRAM 187

Name	SATD1
Type	Mainline
Language	Fortran
Calls	SATD2
Called By	SATCH
Data Files	None
Skeleton Common	None
Purpose	Accepts satellite fixed and variable parameters and 2 minute doppler passed through COMMON from SATCH. At this stage all data must have been verified and perfect. Zero doppler counts will be accepted as an indication of missing data. SATD1's main job is to calculate satellite positions every 2 minutes from lock on until the end of the pass. The coordinates are placed in arrays XS, YS, ZS which are cartesian inertial coordinates - XS through 1st point of Aries YS at right angles and in equatorial plane and ZS through the N. Pole the 3 forming a right handed system. SATD1 is similar to the non-process program SATC1.

N.I.C. PROGRAM 188

Name	SATD2
Type	Mainline
Language	Fortran
Calls	SATD3
Called by	SATD1
Data Files	None
Skeleton Common	None
Purpose	To perform iterative solution of the navigation problem. A D.R. position at lock time is assumed and ships position at succeeding 2 minute intervals is calculated in X, Y, Z coordinates (see SATD1). Assuming a velocity for the ship. Distances of satellite from D.R. positions are calculated. The change in distance every 2 minutes is compared with the true change in distance given by the integrated doppler count. Allowing a small error in D.R. residual equations are formed for the latitude and longitude errors. Solving these equations for a new D.R. the solution is iterated until the latitude and longitude residuals are less than 10^{-6} radian and satellite offset frequency residual (a 3rd unknown parameter of the problem) is less than 0.1 cycle/2 minutes. If the solution doesn't converge after 30 iterations a flag is set.

N.I.C. PROGRAM 189

Name	SATD3
Type	Mainline
Language	Fortran
Calls	VIAQ
Called By	SATD2
Data Files	SATF
Skel Common	None
Purpose	To output to typewriter and disk file SATF the results of SATD2. It also informs user of type of fix, e.g. 400 Mc only means that vacuum doppler wasn't used in the fix calculation. Latitudes North and Longitudes East are Positive. SATF has 6 word records of DAY NO., TIME OF FIX (1/10 minute), Latitude (deg.), Latitude (1/100 minute), Longitude (deg.), Longitude (1/100 minute). The minutes part of the positions take the sign of the degrees part. The file is a process file and used in conjunction with S/R FULL. SATC3 is the non-process equivalent of SATD3.

N.I.C. PROGRAM 190

Name	SATC1
Type	Non-Process Program
Language	Fortran
Calls	SATC2
Called by	None
Purpose	To input off-line data for satellite fix.

Data	// JOB
	// XEQ SATC1 FX
	(Day Number I3 format)
	(11 fixed parameters E15.8/format)
	(N = No. of Doppler counts + 1, I1 format)
	(N sets of 3 variable parameters in E15.8/format. Eccentric Anomaly first, major axis correction and finally out of plane correction)
	(N - 1 Doppler counts E15.8/format)
	(Lock on time in minutes from midnight E15.8/)
	(D.R. Latitude degrees E15.8/, North positive)
	(D.R. Latitude minutes part, always +)
	(D.R. Longitude degrees E15.8/, east positive)
	(D.R. Longitude in minutes E15.8/, always +)
	(Antenna height above geoid in metres E15.8/)
	(Velocity east E15.8/)
	(Velocity north E15.8/)
	(M = number of 2 minute intervals from lock time at which fix is required. I1 format)
	// END
	Note that if doppler counts are not available for a particular 2 minute period then they may be set zero in the data above and a fix still be obtained providing there are at least 3 good dopplers.

N.I.C. PROGRAM 191

Name	SATC2
Type	Non-Process Program
Language	Fortran
Calls	SATC3
Called by	SATC1
Purpose	Iterative solution of satellite navigational problem. Identical with SATD2.

N.I.C. PROGRAM 192

Name	SATC3
Type	Non-Process Program
Language	Fortran
Calls	EXIT
Called by	SATC2
Purpose	Output to lineprinter the results of SATC2. Calculations similar to SATD3. No disk files written.