APPENDIX TLE – TWO-LINE ELEMENT TRACKING

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This appendix is provided as a supplement to the baseline RC4000 manual and the inclined orbit tracking option appendix (Appendix TRK). Sections in the baseline manual are referred to when data specific to the TLE/Ephemeris tracking option is described.

Applicable to RC4000 software version 2.0x and higher.

1.0 THEORY OF OPERATION

1.1 Overview

The TLE tracking option provides additional capabilities to the RC4000's satellite LOCATE and inclined orbit TRACK modes. All functions of the basic step/memory track option are retained.

Software Configuration. If the TLE tracking option is purchased, the software will be designated as "E" instead of "T" for basic step/memory tracking.

Example: the software for a RC4000 purchased with GPS and Fluxgate, TLE tracking and remote control capability would be designated 4K-xx-G**E**RNN

1.2 System Interface Requirements

The same interface requirements needed by the basic tracking option are required to mechanize ephemeris tracking. Most notable is the requirement for high resolution sensors (such as resolvers) on the azimuth and elevation axes.

1.3 Operational Overview

The ephemeris tracking option provides enhanced performance for the LOCATE and TRACK features of the RC4000.

When performing a LOCATE function, the ephemeris option allows the RC4000 to predict the current azimuth and elevation of an inclined orbit satellite.

When TRACKing, the ephemeris option allows the RC4000 to follow an inclined orbit satellite even if a signal strength indication is not present.

1.4 Antenna Pointing Solution

The enhanced LOCATEing and TRACKing capabilities are accomplished by predicting satellite position based on the satellite's current NORAD Two Line Element (TLE) ephemeris data set.

NOTE: current ephemeris data for the satellite must be loaded into the ACU for the TLE option to perform correctly.

1.5 Tracking Inclined Orbit Satellites

The ephemeris tracking option introduces an additional tracking sub-mode designated as EPHEM_TRACK. With the basic tracking option, when signal strength was lost during STEP_TRACK the RC4000 would either no longer move the antenna until signal strength returned or it would enter a search pattern. With EPHEM_TRACK, the position of the satellite is predicted for the current date and time and the RC4000 continues to move the antenna until signal strength returns.

2.0 INSTALLATION

Ephemeris tracking mechanizes an “open-loop” pointing of the antenna. No signal strength feedback is used to follow the inclined orbit satellite’s path through the sky.

The need to open loop point the antenna makes correct calibration of the antenna sensors even more critical. The calibration steps detailed in the baseline manual and basic tracking appendix must be followed in addition to the few unique steps for ephemeris tracking that are discussed next.

2.3.2 Elevation Calibration

The ephemeris tracking option will estimate the tilt (pitch and roll) of the antenna platform by comparing the elevation angle determined from the inclinometer with the angle from the elevation resolver. The inclinometer will always read the elevation angle relative to the local horizontal while the resolver reads the elevation angle relative to the antenna platform.

In order to correctly estimate the platform’s tilt, the elevation axis must be calibrated while the platform is level. From this level position, the elevation inclinometer and the elevation resolver sensors must be calibrated such that they read the same angle. This requirement is discussed in the following examples where the antenna will be pointed to look at the same satellite.

If the antenna’s platform is setting level with respect to the local horizontal, the elevation angle reported from the inclinometer and the angle reported from the resolver should be the same and the RC4000 can determine that there is no tilt. If the antenna’s platform is not level with the local horizontal (as if it is setting on a hill), the elevation angle from the inclinometer will be the same as in the first case but the resolver angle will be different since the antenna had to be rotated differently to achieve the same RF look angle. This difference in the two angles can be used to characterize the tilt of the platform.

It is important that the resolver elevation angle be calibrated such that it indicates true elevation with the platform absolutely level.

The TILT maintenance routine (see 3.2.2.7.4 of this appendix) should be performed to check the correctness of the elevation calibration.

3.0 DETAILED OPERATION

3.2.2.3 Locate

If a satellite that doesn't have ephemeris data associated with it is selected, the LOCATE mode will perform exactly as described in the baseline manual.

If a satellite with ephemeris data associated with it is selected (see 3.2.2.3.1 below), LOCATE mode will perform an operation to characterize the tilt of the antenna platform. Additionally LOCATE will calculate the azimuth and elevation pointing solution based on the current date/time and ephemeris data rather than assuming that the satellite is in a geostationary (non-inclined) orbit.

3.2.2.3.1 Satellite Selection

To enable ephemeris tracking operation, a satellite must be described as having ephemeris data associated with it. If no ephemeris data is associated with the satellite, the LOCATE operation will be the same as described in the baseline manual.

NOTE: a satellite may be described as having an inclined orbit (inclination greater than 0) without having ephemeris data associated with it. In this case, the LOCATE and TRACK modes will operate as if the ephemeris option is not present.

Only satellites programmed via the user preset list may have ephemeris data associated with them. In LOCATE mode, manual entry of ephemeris data is not provided since so much additional information is required. Likewise SATLIST data will not contain ephemeris data since the ephemeris data becomes obsolete in a matter of only weeks.

Associating ephemeris data with a preset satellite is discussed in section 3.3.1.1.4

Preset Satellite List

When the preset satellite list is selected, the EPHEM field describes whether or not the satellite has ephemeris data associated with it.

The following screen shows a satellite that has Two Line Element (TLE) set data associated with it.

```
                                        LOCATE
 #   NAME       LON  INC  BAND  EPH
 1 BRASIL A1   79.0W  2    C     Y
<SCR>THRU LIST <ENTER>SELECT  <MODE>EXIT
```

The EPHEM field may also indicate "NONE" if no ephemeris data is associated with the satellite.

Selecting a satellite with associated ephemeris data will trigger unique actions described below.

3.2.2.3.2 LOCATE Automatic Movement

When the LOCATE screen initially displays a target for a satellite with ephemeris data, the AZIM and ELEV targets are those calculated as if the satellite has no inclination (nominal position).

After the polarization selection (if applicable), the LOCATE function will perform a series of movements to estimate the tilt of the platform. If tilt was previously estimated this routine will not be accomplished.

TILT ESTIMATE

As discussed in section 2.3.2 of this appendix, the elevation angle derived from the inclinometer (referenced to local horizontal) and the elevation resolver angle (referenced to the platform) may be compared to determine tilt of the platform.

The first step of this process will move the antenna to the DEPLOY position. Comparing the inclinometer and resolver angles will essentially determine the pitch of the platform.

A second movement will rotate the antenna in azimuth in order to characterize the roll of the platform. How the azimuth moves is based on the nominal azimuth target initially calculated. In order to save time, azimuth will move in the direction (clockwise or counterclockwise) of the nominal azimuth target. If the nominal azimuth target is greater than 45 degrees, then the movement will be to the azimuth target. If the target is less than 45 degrees, azimuth will move to the 45 degree position in order to obtain enough rotation to adequately characterize roll.

EPHEMERIS POINTING SOLUTION

After the tilt calculation, the LOCATE function will recalculate a target azimuth and elevation for the satellite at the current date and time. While this calculation is being done, the azimuth and elevation targets inside parenthesis will flash "TLE" as the current target is being calculated. The following shows how the screen will appear as a TLE orbit prediction is being calculated.

```
AZIM:   0.0 (  TLE )            LOCATE
ELEV: -61.7 (  TLE )      SAT:GALAXY 7
 POL:   0.0 ( -45.0)
MOVING TO (TARGETS) <STOP>HALT MOTION
```

The orbital prediction calculation may take several seconds. After the calculation is performed, the calculated azimuth and elevation targets for the current time of day will be displayed within the parenthesis. Immediately following the calculation the automatic movement to the predicted targets will begin.

<u>3.2.2.3.4 Spiral Search Autopeak</u>

Having ephemeris data available allows the RC4000 to predict where an inclined orbit satellite should be at the current time of day. Having this knowledge allows the controller to perform a more efficient search for the inclined orbit satellite.

When ephemeris data is available, the RC4000 will perform a "flat spiral" search instead of the expanding spiral search used for an inclined orbit satellite that does not have ephemeris data associated with it. Rather than moving to the nominal target and beginning the expanding spiral, the RC4000 will move to the target elevation (for the current time of day) and search the full range in azimuth before adjusting elevation. As described in the baseline manual, the azimuth search will account for errors in the azimuth pointing target mainly due to error from the compass' heading reading. This movement will be referred to as a "flat spiral" search pattern.

The flat spiral search pattern always starts at the CCW edge of the pattern's limits. As with the expanding spiral search, the flat spiral search will terminate when a signal strength indication above the search threshold is found. The flat spiral search may be manually stopped at any time by pressing the MODE or STOP keys.

NOTE: if the track signal source (3.3.1.3.12) is set to “NONE”, the user will need to identify that the antenna is pointing at the satellite by some other means.

After finding a signal strength indication, a peaking function will perform an operation very similar to a step track movement in order to position the dish more precisely on the satellite.

3.2.2.7 Position

If the ephemeris tracking option is present, the POSITION screen will also display information about the pitch and roll of the antenna platform. For the RC4000, pitch and roll is defined with respect to the local horizontal plane.

Pitch is considered rotation about the platform’s lateral axis (from –90 degrees azimuth to +90 degrees azimuth). Positive pitch values indicate a “nose up” (0 degrees azimuth higher than 180 degrees azimuth) orientation.

Roll is considered rotation about the platform’s longitudinal axis (from 180 degrees azimuth to 0 degrees azimuth). Positive roll values indicate a “right wing up” (90 degrees azimuth higher than -90 degrees azimuth) orientation.

```
L/L:38°56N  94°44W GPS           POSITION
ANT BEARING:225.0 FLUXGATE     NOT SAVED
P: -1.7 R: 3.1    AUTO           <4>SAVE
<1>LAT/LON <2>HEADING <3>TILT <MODE>EXIT
```

P: -1.7 R: 3.1 AUTO

The P: field displays the current calculated pitch and the R: field displays the current roll.

If pitch and roll have not been calculated the fields will display “*****”. Whenever a position component (lat/lon or heading) is changed, the current pitch and roll will be considered invalid and the “*****” displayed.

Pressing the “3” key will put the controller into TILT mode. TILT mode allows for initiating tilt calculations and is mainly intended as an aid in checking calibration.

3.2.2.7.4 TILT

The TILT mode automatically moves the antenna, gathers elevation data (from the inclinometer and resolver) and calculates apparent pitch and roll of the platform.

```
AZIM:   0.0 (       )              TILT
ELEV: -61.7 (       )
P1:      P2:       PITCH:     ROLL:
                      <4>START TILT
```

The movement sequence is similar to that described for the TILT ESTIMATE section of the LOCATE movement.

Initially the mount is moved to the DEPLOY position. From there, pitch is determined based on the difference between the elevation inclinometer and elevation resolver angles. After calculating pitch, azimuth is moved to the 45 degree position and again elevation angles are sampled and roll is calculated.

3.2.2.9 Track

How the basic TRACK mode sequences through sub-modes is described in the Inclined Orbit Tracking appendix (APP-TRK). The ephemeris tracking option supplies a new TRACK sub-mode called “EPHEM TRACK”.
The following paragraphs describe how the existing tracking sub-modes are modified and details the EPHEM TRACK sub-mode in section 3.2.2.9.6.

When TRACK mode is first entered, the track_signal_source configuration item determines whether or not TRACK will initially enter STEP TRACK sub-mode or not.

If the track_signal_source is set to SS1 or SS2, TRACK mode assumes there will a signal strength indication available and will enter STEP TRACK to peak up on the signal strength. Section 3.2.2.9.1 describes how the STEP TRACK mode operates differently if the satellite being tracked has ephemeris data associated with it.

If the track_signal_source is set to NONE (only available with the EPHEM option), TRACK will initially enter a manual jog screen.

3.2.2.9.1 Step Track

In order for ephemeris tracking to be enabled, at least one initial step track operation must be performed to determine azimuth and elevation offsets. After the first step track peakup, the current azimuth and elevation positions are compared to the positions calculated by the ephemeris model. These differences will be used as offsets if the TRACK mode switches to EPHEM_TRACK.

The STEP_TRACK sub-mode will pass control to the EPHEM_TRACK sub-mode if signal strength is lost (and the azimuth and elevation offsets have been initialized).

3.2.2.9.2 Memory Track

If TRACK is in EPHEM_TRACK when it is time to store a track table entry, that table entry will be annotated with an "e" when viewed from the TRACK MENU screen.

3.2.2.9.3 Track Search

When ephemeris data is available, there will be no need to transition to the TRACK SEARCH sub-mode. The NORAD model will predict the azimuth and elevation positions.

3.2.2.9.4 Track Menu

<1>PEAKUP NOW

If TRACK MENU is entered from EPHEM, this action will reposition the dish according to the calculated targets for the current date and time.

3.2.2.9.6 Ephemeris Track

The EPHEM_TRACK sub-mode may be entered via two conditions:
1 – while STEP tracking, signal strength is lost or
2 – at TRACK initialization, the track_signal_source item is set to NONE

For the second case where no signal source is available, TRACK will enter a manual jog screen which allows the user to jog the antenna until it is determined it is pointed at the satellite.

```
AZIM: 33352    3.2    RF: 487      TRACK
ELEV: 40938   44.9   SAT:SBS 4      (Ku)
 POL:   0.3         STEP:IDLE      18:19
WAITING FOR NEXT PEAKUP...      <0>-MENU
```

When the user presses the ENTER key, the controller will assume it is peaked up on the satellite. The controller will then predict the azimuth and elevation position of the satellite and calculate offsets to be used by EPHEM TRACK. This offset calculation is the same as is done when the first STEP TRACK is done (if signal strength is available).

After entering EPHEM TRACK, the controller's actions will sequence in a very similar manner as STEP TRACK. When it is time to move the antenna, EPHEM TRACK will predict the azimuth and elevation position for the current date and time. The controller will move the antenna the appropriate amount and again be in IDLE until the next required move.

The EPHEM_TRACK sub-mode will pass control to these TRACK sub-modes upon the following conditions:

STEP_TRACK – receives control when signal strength returns (if track_signal_source is set to SS1 or SS2)

MEMORY_TRACK – when track table data is available

3.3.1.3.12 Track Factors

```
SEARCH ENABLE: 1           CONFIG-TRACK
    MAX ERROR:  3   HOLDOFF: 120
 SEARCH WIDTH:  4       SIG: 0   TIME: 2
```

SIG: **SIGNAL SOURCE <0>NONE <2>SS1 <3>SS2**

The TLE option allows the track signal source to be specified as "NONE". If this value is specified, TRACK mode will initially go to TRACK-MANUAL instead of STEP TRACK. From TRACK-MANUAL the user will be required to initiate ephemeris tracking.

3.3.1.1.3 Preset Satellites

In addition to the normal data associated with a preset satellite, an additional field is provided to signal whether or not there is TLE data available for the satellite. If there is TLE data available, the preset number will be used as the index to the ephemeris data described in 3.3.1.1.4.

```
SAT#: 3   NAME:BRASIL A1     CONFIG-SATS
 LON: 79.0W PO:  0.0     EPH:1
INCL: 2 BAND:0 POL:1
EPHEMERIS DATA <0>NONE <1>TLE
```

EPH: **EPHEMERIS DATA <0>NONE <1>TLE**

This field signals whether there is TLE data available for the preset satellite.

3.3.1.1.4 Two Line Element Set Data

As the name implies, Two Line Element set data is described by two lines of data each with 69 characters. The RC4000 uses one screen to show each line of data. The top line of each screen identifies which line is being displayed (TLE1 or TLE2). The top line will also show the index number and satellite name from the preset satellite screen. The user may scroll through index numbers via the SCROLL UP or SCROLL DN keys.

When a TLE data screen is initialized it shows the existing TLE data stored.

Index Number Satellite Name TLE Line 1 or 2

```
SAT#: 3  SAT K2             CONFIG-TLE1
1 16276  85109    01089.41658071
-.00000230  00000-0  10000-3 0   862
<SCR> THRU LIST, <ENTER> TO MODIFY DATA
```

Example TLE data from www.celestrak.com:

```
INTELSAT 30 (IS-30)
1 40271U 14062A   16272.42736112 -.00000180  00000-0  00000+0 0  9990
2 40271   0.0163 216.5508 0001383   3.7128 206.1658   1.00271611  7182
```

Alphabetic characters are not entered, instead a space " " should be used.

```
SAT#: 1  INTELSAT 30         CONFIG-TLE1
1 40271  14062    16272.42736112
-.00000180  00000-0  00000+0 0  9990
<SCR> THRU LIST, <ENTER> TO MODIFY DATA
```

Example line 1 data:

```
SAT#: 3  SAT K2              CONFIG-TLE1
1 16276  85109    01089.41658071
-.00000230  00000-0  10000-3 0   862
<SCR> THRU LIST, <ENTER> TO MODIFY DATA
```

Example line 2 data:

```
SAT#: 3  SAT K2              CONFIG-TLE2
2 16276   3.6693  80.7624 0003295
 214.0161 248.7192 1.00272265 36335
<0-9 . SCR UP+/DN- ENTER( ) BKSP> COL: 1
```

After scrolling to the desired index, the user may begin to edit data by pressing the ENTER key. The cursor will then be placed on the first data character for the line. This character will be “1” for the first line and “2” for the second line. NOTE: see the tables that follow this section for further description of the data contained in each line.

Data may be entered in an overwrite type of editing style. After a character is keyed, the cursor will advance to the next character. The cursor may be moved backwards by the BKSP key. To enter data, the 0 through 9 numbers, the “.” are available directly from the RC4000 keypad. To enter a “+” use the SCROLL UP key and to enter a “-“ use the SCROLL DN key. Pressing the ENTER key will record a space and advance the cursor.

Alphabetic characters will not be entered, instead a single space “ ” should be entered in place of the alphabetic character.

The COL: field will show the present column number of the cursor.

After entering the 69th character the RC4000 will calculate the data's checksum and compare it to the last character. If the calculated and entered checksums don't match, an error will be flagged.

3.3.1.1.4.1 Line 1 Data

FIELD	COL	DESCRIPTION	EXAMPLE	COMMENTS
1.1	1	Line number of Element Set	1	
	2			Blank line
1.2	3	Satellite Number	1	
	4		6	
	5		2	
	6		7	
	7		6	
1.3	8	Security Classification	U	
	9	blank		Blank line
1.4	10	ID*-Launch Year	8	
	11		5	
1.5	12	ID*-Launch Number of Year	1	
	13		0	
	14		9	
1.6	15	ID*-Piece of Launch	D	
	16			
	17	* International Designator		
	18			Blank line
1.7	19	Epoch Year	0	Last two digits of year
	20		1	
1.8	21	Epoch Day of Year + Fraction of Day	0	
	22		8	
	23		9	
	24		.	
	25		4	
	26		1	
	27		6	
	28		5	
	29		8	
	30		0	
	31		7	
	32		1	
	33			Blank line
1.9	34	First Time Derivative of Mean Motion	-	“BallisticCoefficient”
	35		.	
	36		0	
	37		0	
	38		0	
	39		0	
	40		0	
	41		2	
	42		3	
	43		0	
	44			Blank line
1.10	45	Second Time Derivative of Mean Motion	0	
	46		0	
	47		0	
	48		0	
	49		0	
	50		-	
	51		0	
	52			
	53			Blank line
1.11	54	BSTAR drag term		“Radiation Pressure Coefficient”
	55		1	
	56		0	
	57		0	
	58		0	
	59		0	
	60		-	
	61		3	
	62			Blank line
1.12	63	Ephemeris Type	0	Always 0 for distributed elements
	64			Blank line
1.13	65	Element Number		
	66			
	67		8	
	68		6	
1.14	69	Checksum	2	Modulo 10

3.3.1.1.4.2 Line 2 Data

FIELD	COL	DESCRIPTION	EXAMPLE	COMMENTS
2.1	1	Line Number of Element Set	2	
	2			Blank Line
2.2	3	Satellite Number	1	
	4		6	
	5		2	
	6		7	
	7		6	
	8			Blank Line
2.3	9	Inclination		In Degrees
	10			
	11		3	
	12		.	
	13		1	
	14		2	
	15		4	
	16		0	
	17			Blank Line
2.4	18	Right Ascension of the Ascending Node		In Degrees
	19		8	
	20		2	
	21		.	
	22		3	
	23		7	
	24		3	
	25		8	
	26			Blank Line
2.5	27	Eccentricity	0	Decimal point assummed
	28		0	
	29		0	
	30		2	
	31		4	
	32		7	
	33		7	
	34			Blank Line
2.6	35	Argument of Perigee	3	
	36		2	
	37		7	
	38		.	
	39		3	
	40		8	
	41		0	
	42		1	
	43			Blank Line
2.7	44	Mean Anomaly	2	
	45		0	
	46		7	
	47		.	
	48		0	
	49		4	
	50		9	
	51		1	
	52			Blank Line
2.8	53	Mean Motion		
	54		1	
	55		.	
	56		0	
	57		0	
	58		2	
	59		7	
	60		0	
	61		4	
	62		2	
	63		4	
2.9	64	Revolution Number at Epoch		
	65		3	
	66		3	
	67		8	
	68		8	
2.10	69	Checksum	4	Modulo 10

There are additional ways to bring in TLE data into the RC4000 via the remote control port and web interface when those options are available.