APPENDIX TLE – TWO-LINE ELEMENT TRACKING

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This appendix is provided as a supplement to the baseline RC4500 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.

1.0 THEORY OF OPERATION

1.1 Overview

The TLE tracking option provides additional capabilities to the RC4500's inclined orbit TRACK mode. All functions of the basic step track/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 an RC4500 purchased with TLE tracking and Ethernet remote control capability would be designated 45R-xx-N**E**INN

1.3 Operational Overview

The ephemeris tracking option provides enhanced performance for the TRACK feature of the RC4500.

When TRACKing, the ephemeris option allows the RC4500 to follow an inclined orbit satellite even if a signal strength indication is not present.

1.4 Antenna Pointing Solution

The enhanced 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 RC4500 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 RC4500 continues to move the antenna until signal strength returns.

3.0 ELECTRICAL INSTALLATION

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

4.0 CALIRATION

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.

4.2.3.1 Elevation Calibration

It is important that the resolver elevation angle be calibrated such that it indicates true elevation.

DETAILED OPERATION

5.1.2.1 TLE tracking via SETUP

In addition to the normal data associated with a SETUP 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.

```
NAME:BRASIL A1                        SETUP
LON: 79.0W          INCLIN: 2
BAND:KU           TRACKING: 4         SIG:1
<0>NONE <1>MEM <2>STEP <3>STP/TLE <4>TLE
```

TRACKING <0> NONE <1>MEM <2>STEP <3>STP/TLE <4>TLE

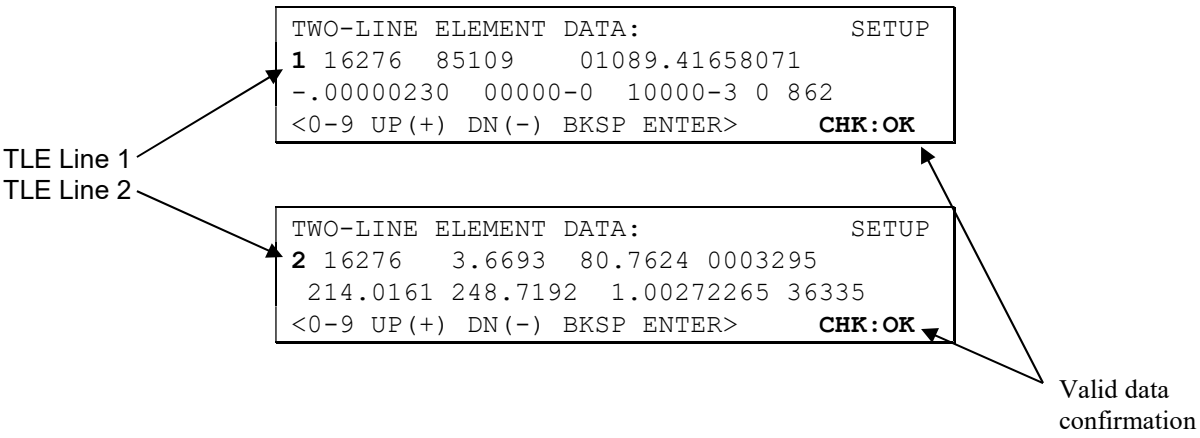
This field signals whether there is TLE data available for the preset satellite.

The following two screens are included in SETUP only when TLE is designated for the satellite. The RC4500 uses one screen dedicated for each of the two lines of data (TLE1 and TLE2.) When the TLE screen is first initialized, all entries are blank except for the first character of the line that is automatically filled in.

```
TWO-LINE ELEMENT DATA:              SETUP
1

<0-9 UP(+) DN(-) BKSP ENTER>
```

After proper TLE data is entered, the screens will look like the following examples:



Data may be entered when the cursor is shown. After a character is keyed, the cursor will advance to the next character. The cursor may be moved backward by using the BKSP key. To enter data, the “0” through “9” number and the “.” are available directly from the RC4500 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.

Space “ ” characters and alphabetic characters are not entered by the user (the display shows blank spaces where these characters would normally exist in the TLE data sets.)

After entering the last character, the RC4500 will calculate the data's checksum and compare it to the last character. If the calculated and entered checksums match, then "CHK:OK" will be displayed on the bottom-right corner of the display to validate to the user that the checksum match was ok. If the checksums don't match, then "CHK:ERR" will be displayed to indicate an error in the data that was typed. The user may use the BKSP key to delete entries back and allow the data to be retyped.

The following screen allows the user to peak up on the satellite if necessary. Once the satellite position is peaked, press the ENTER key to save the AZ/EL positions.

```
AZ:  54.13            RF: 509     SETUP
EL:  48.95
PL: -84.74           SPD:FAST
<ENTER>SAVE AZ/EL POSITION    <MODE>EXIT
```

The user will next be asked to store values for horizontal and vertical polarization positions. While this screen is displayed, the keypad may be used to jog the polarization axis in order to peak. The "5" key is also active to initiate a 90 degree "cross polarization" movement. Note that the user will need to tune the receiving equipment to correct frequencies for the different polarizations.

```
AZ:  54.13            RF: 509     SETUP
EL:  48.95
PL: -84.74           SPD:FAST
<ENTER>SAVE H-POL POSITION    <MODE>EXIT
```

```
AZ:  54.13            RF: 509     SETUP
EL:  48.95
PL:   5.26           SPD:FAST
<ENTER>SAVE V-POL POSITION    <MODE>EXIT
```

The next screen prompts the user to select which polarization (horizontal or vertical) to use for RX (receive.)

```
H-HORIZONTAL: -84.74
V-  VERTICAL:   5.26  SAT:BRASIL A1

<H/V>SELECT RX POLARIZATION   <MODE>MENU
```

The RC4500 will then automatically enter TRACK mode.

```
AZ:                                TRACK
EL:                 SAT:BRASIL A1
PL:
INITIALIZING TRACK PARAMETERS...
```

5.1.2.2 TLE tracking via RECALL

Satellites which have been stored in the controller's non-volatile memory (via SETUP) can be recalled from the RECALL mode.

```
                                        RECALL
#   NAME         LON   INCL BAND TRK  TBL
1   BRASIL A1    79.0W   2   KU  TLE 100%
<SCR>THRU LIST <ENTER>SELECT  <MODE>EXIT
```

Use the Scroll Up and/or Scroll Dn keys to scroll through the list of satellites stored in non-volatile memory. Press the ENTER key to select the desired satellite.

If no satellites are currently stored the following screen will appear.

```
                                        RECALL
 *       NO SATELLITES IN MEMORY       *
 *     USE SETUP MODE TO STORE NEW     *
                             <MODE> TO EXIT
```

After a satellite has been selected, the controller will prompt the user to specify the desired polarization.

```
H-HORIZONTAL: -84.74                RECALL
V-  VERTICAL:   5.26  SAT:BRASIL A1

<H/V>SELECT RX POLARIZATION   <MODE>MENU
```

Antenna movement can be stopped at any time by pressing the Stop key.

The RC4500 will then automatically enter TRACK mode.

```
AZ:  36847  202.41   EXT:2731       TRACK
EL:  37899   28.18   SAT:BRASIL A1  (Ku)
PL:      0  -84.74   TLE:REPOSITION
MOVING TO STAY WITHIN MAX ERROR...
```

5.2.1.1.2 Two Line Element 1 Data

As the name implies, Two Line Element set data is described by two lines of data each with 69 characters. The RC4500 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.

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>MODIFY DATA
```

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 RC4500 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.

Space “ ” characters and alphabetic characters are not entered by the user (the display shows blank spaces where these characters would normally exist in the TLE data sets.)

After entering the 69th character the RC4500 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.

5.2.1.1.3 Two Line Element 2 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
<SCR>THRU LIST, <ENTER>MODIFY DATA
```

The format for entering data into TLE 2 is the same as in TLE 1 (see section 5.2.1.1.2.)

3.2.2.3.4 Spiral Search Autopeak

Having ephemeris data available allows the RC4500 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 RC4500 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 RC4500 will move to the target elevation (for the current time of day) and search the full range in azimuth before adjusting elevation. 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.

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.

5.1.2.5 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 describes 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 5.2.1.3.10 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.

5.1.2.5.1 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 peak-up, 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).

5.1.2.5.2 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.

5.1.2.5.3 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.

5.1.2.5.4 Track Menu

<1> ALIGN 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.

5.1.2.5.6 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:   8.3  32974                TRACK
ELEV:  35.3   8824 SAT:SBS 4
 POL:  71.1 V    SPEED:SLOW
PEAK-UP MANUALLY <ENTER>TLE TRACK
```

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

5.2.1.3.10 Track Factors

```
   SEARCH: 3                CONFIG-TRACK
MAX ERROR: 3  TIME: 2
  HOLDOFF:120  LOG:0    AZDP:1.0
<0-MANUAL,1-NARROW,3-NOMINAL,10-WIDE>
```

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 +	0	
	22	Fraction of Day	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	0	
	46	Motion	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		In Degrees
	19	Ascending Node	8	
	20		2	
	21		.	
	22		3	
	23		7	
	24		3	
	25		8	
	26			Blank Line
2.5	27	Eccentricity	0	Decimal point assumed
	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 RC4500 via the remote control port and web interface when those options are available.