APPENDIX TRK – INCLINED ORBIT TRACKING

Last Revised: 10 August 2017

This appendix describes the additional capability provided by the Inclined Orbit Tracking option. It is provided as a supplement to the RC4500 baseline manual.

1 Introduction

1.1 Overview

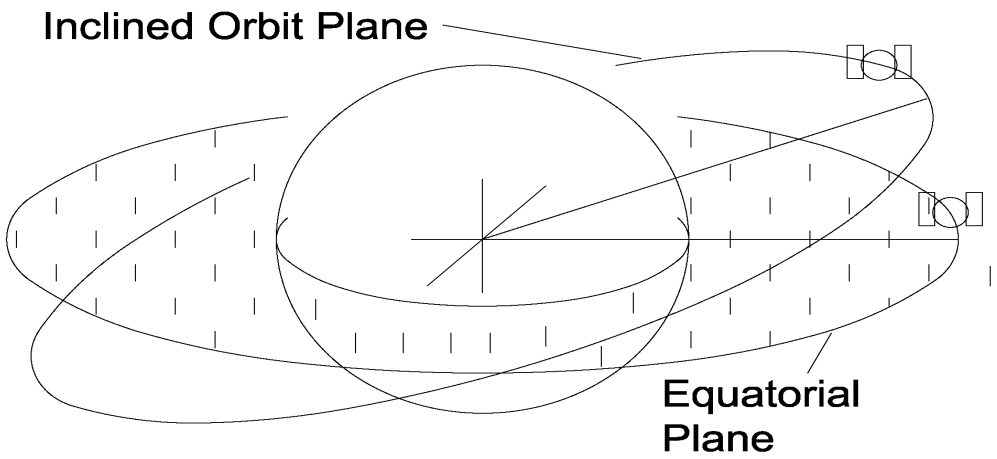
This option provides the RC4500 with the ability to perform basic STEP and MEMORY tracking of inclined orbit satellites. This option requires high resolution sensors on the azimuth and elevation axis.

1.2 Theory of Operation

A geostationary satellite must expend propellant and perform station-keeping maneuvers to maintain an orbit at the proper position. East-West station-keeping maneuvers are performed to maintain the satellite's longitudinal position and North-South station-keeping maneuvers are performed to keep the satellite's orbital plane aligned with the earth's equatorial plane.

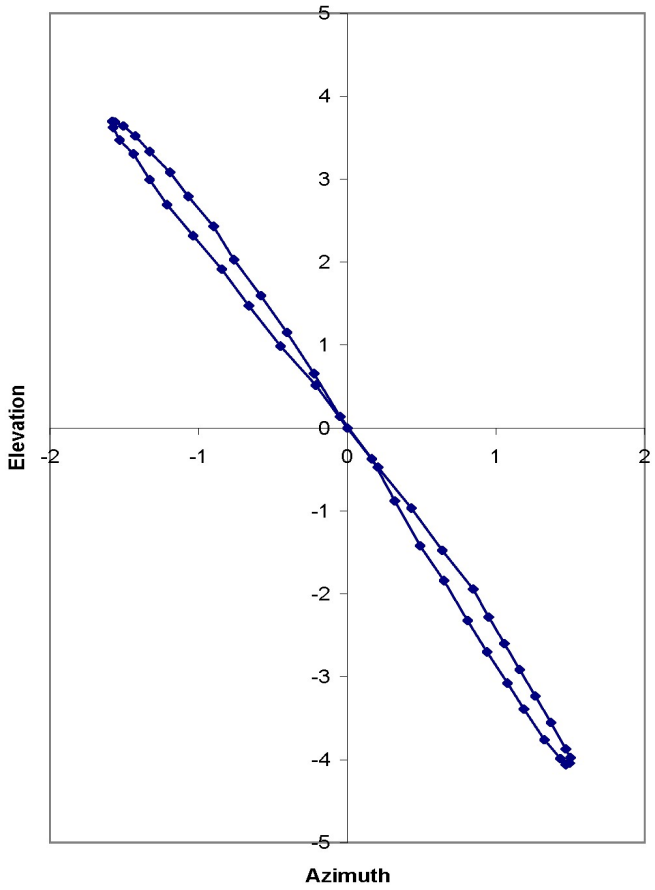
Approximately 90 percent of the propellant is expended for North-South station-keeping activities. If these activities cease and the satellite is allowed to drift into an inclined orbit, the operational life of a satellite can be greatly extended.

The following diagram shows that the orbital plane of an inclined orbit satellite is 'inclined' with respect to the earth's equatorial plane. In this illustration, the inclination angle between the inclined orbit satellite's orbital plane and the earth's equatorial plane is greatly exaggerated. Typical inclination angles are less than 10 degrees.



Whereas a geostationary satellite appears fixed in space, the apparent position of a satellite in an inclined orbit varies. If viewed by an observer located at the center of the earth, the motion of an inclined orbit satellite would be a figure eight centered on the earth's equatorial plane with a total height of twice the inclination angle.

These relationships are strictly valid only if the motion is viewed from the center of the earth. The apparent motion is slightly greater and somewhat skewed when viewed from the surface of the earth. The exact shape of the pattern varies with the longitudinal position of the satellite and the place on the earth from which the satellite motion is viewed. As shown in the following graph, the apparent motion of is now oriented in a direction perpendicular to the “arc” of satellites.

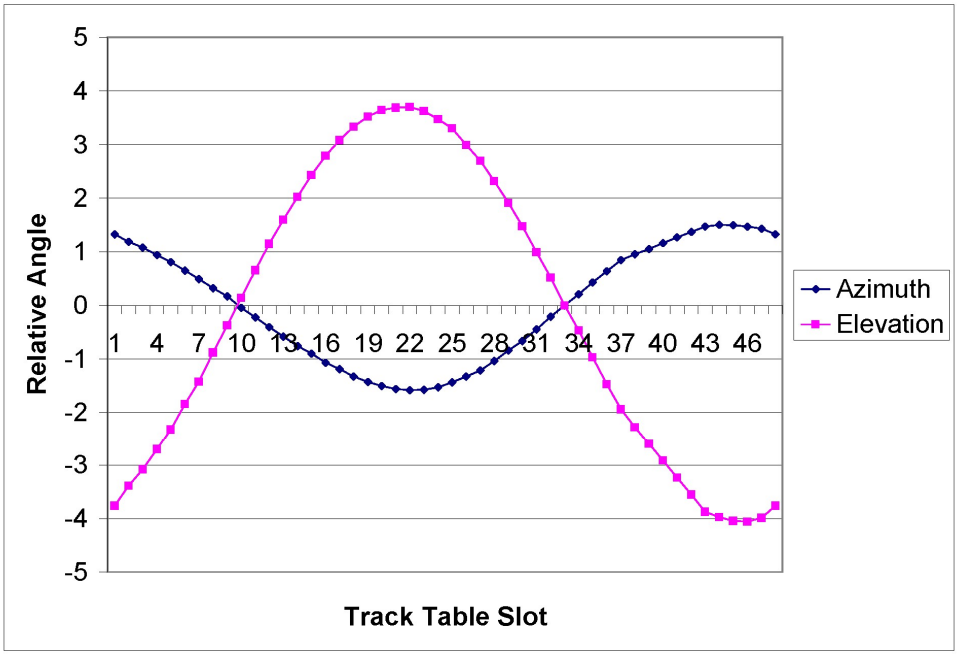


The motion of the satellite is periodic – the figure eight repeats itself every 23 hours, 56 minutes, and 4 seconds. This period is referred to as a sidereal day, or the time it takes the earth to complete exactly one revolution.

1.3 Tracking Algorithm

The tracking algorithm can be divided into multiple parts: STEP_TRACK, MEMORY_TRACK, TRACK_SEARCH, and TRACK_ERROR. These parts are implemented as sub-modes of TRACK mode.

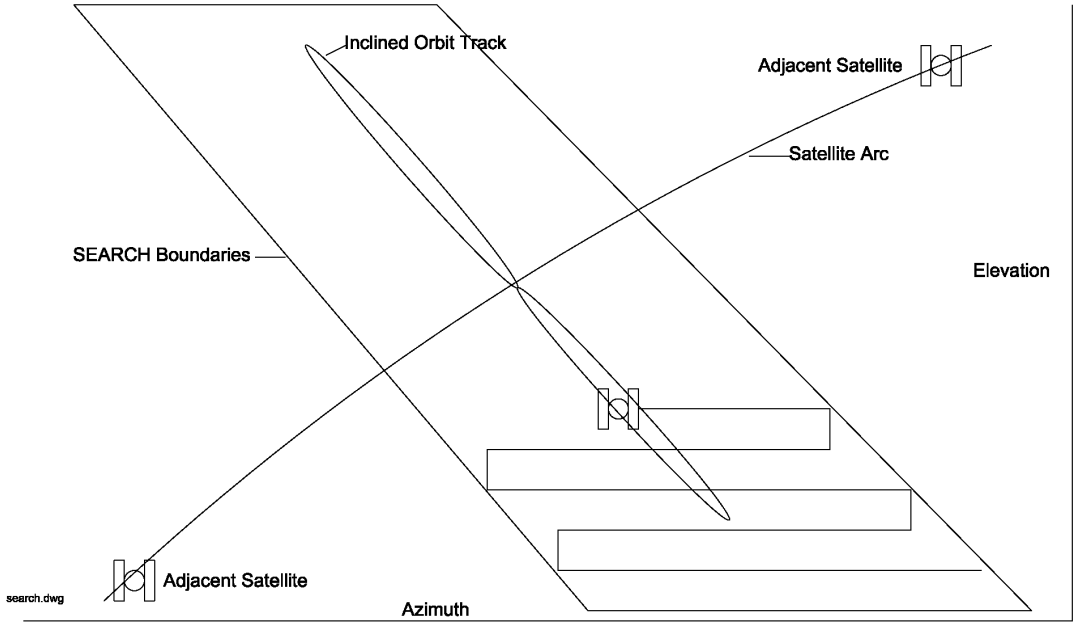
In the STEP_TRACK sub-mode, the ACU periodically performs peak-ups on an inclined orbit satellite. Whenever the current sidereal time equals the one-of-48 time-segments, a peak-up occurs and the antenna azimuth and elevation values are stored into a track table. A completed track table becomes a map of the satellite's apparent motion as seen by the antenna. The following graph shows an example set of track table points.



The step tracking operation positions the antenna to maximize the received signal strength. Signal strength is also used to determine whether or not a satellite transponder is currently active. If the signal strength reading falls below a threshold, the ACU assumes that a satellite signal is not present. If the satellite signal is lost while step tracking, the SEARCH sub-mode receives control. When the MEMORY_TRACK sub-mode is active, the presence of a satellite signal governs whether or not track table update operations are performed.

The MEMORY_TRACK sub-mode is active whenever a satellite's track table contains valid satellite position data for the current sidereal time. When MEMORY_TRACK is active the antenna smoothly tracks the satellite by interpolating between track table azimuth and elevation position entries. Once a complete track table has been established for a satellite, the ACU will remain in the MEMORY_TRACK sub-mode.

The SEARCH sub-mode is active when the satellite signal is lost and track table data is not available. In this sub-mode the ACU performs a search for the satellite in the region where it calculates the satellite will be found, based on its knowledge of the satellite's apparent motion. If the satellite is found while the ACU is performing a search, the STEP_TRACK sub-mode will receive control. If the satellite is not found while performing the search, the ACU will wait *Search Retry Interval* minutes and perform another search. If while waiting for the *Search Retry Interval* to expire, the sidereal time advances to a time for which valid track table data is available, the MEMORY_TRACK mode will become active.



The automatic search may be disabled via the Search Enable CONFIG mode item. If the automatic search is disabled, the user is prompted to manually position the antenna on the satellite.

The TRACK_ERROR sub-mode becomes active whenever an error occurs. Some of the errors which can occur are: antenna jammed, antenna limit reached while tracking, antenna runaway, track table data corrupted, system CONFIG data corrupted, or a peak limit error has occurred (while peaking the antenna the ACU had to move too far - possibly peaking on an adjacent satellite).

2 Configuration

High-resolution sensors must work correctly to achieve repeatable, precise movements during tracking. It is suggested that small automatic movements made using the MOVETO mode. If the ACU struggles to make good repeatable movements, then tracking performance will not be optimal.

3 Detailed Operation

3.1 Setup Mode

A track is initiated after SETUP mode based on the value of the TRACKING field.

```
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

- NONE – This value specifies no tracking should be done on this satellite.
- MEM – The MEMORY/STEP mode is the nominal tracking method. When this mode is selected, MEMORY_TRACK will be active as long as track table data is available. The track system will fall back to STEP_TRACK when no data is available.
- STEP – The STEP/MEMORY mode should be used to constantly peak-up the antenna. When this mode is selected, STEP_TRACK will remain active as long as signal is present. The track system will fall back to MEMORY_TRACK when signal is lost if track table data is available.

3.2 Track Mode

TRACK mode consists of several sub-modes: STEP_TRACK, MEMORY_TRACK, TRACK_SEARCH, TRACK_ERROR, and TRACK_MENU.

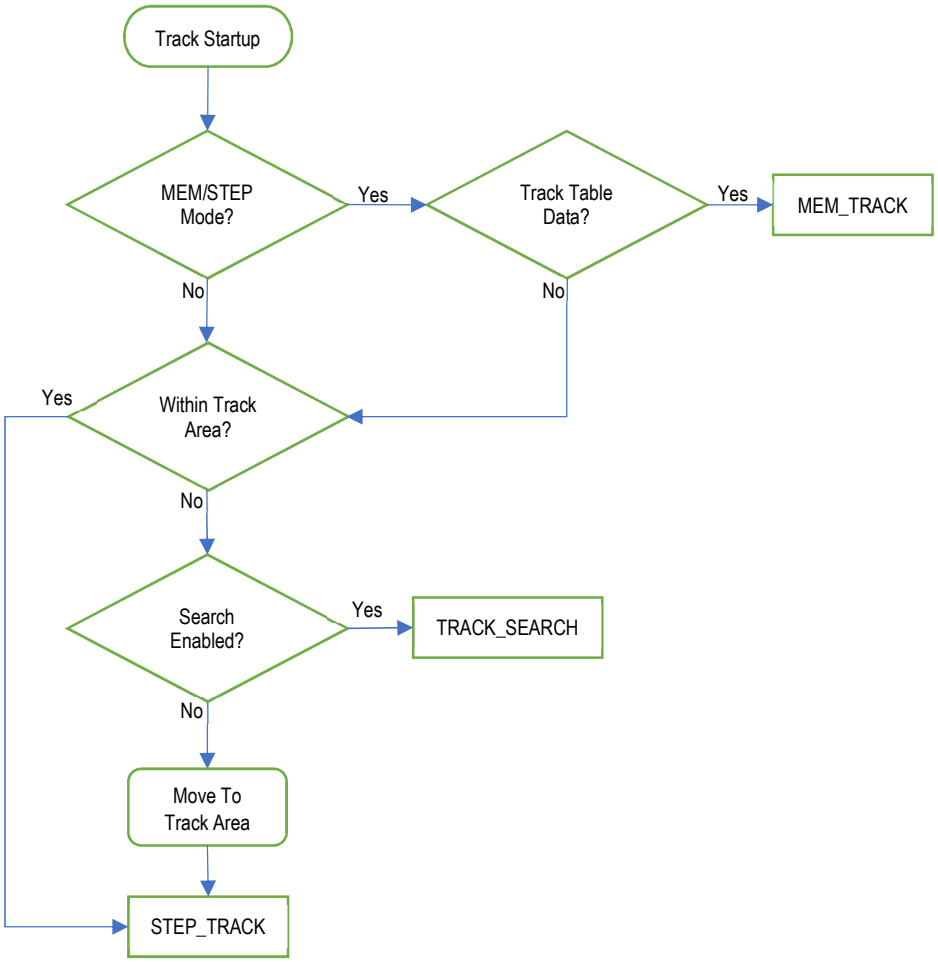
```
AZ:  31561  340.44   EXT:2730       TRACK
EL:  11060   49.27   SAT:BRASIL A1   (KU)
PL:  26517    6.54   STEP:IDLE      22:18
WAITING FOR NEXT PEAKUP...       <0>-MENU
```

Whenever a track sub-mode is IDLE:

1) The current system time is displayed in an HH:MM format.
2) The CW, CCW, H, and V keys may be used to adjust the polarization.
3) The TRACK_MENU prompt is displayed (if expert access is enabled).

3.2.1 Track Startup

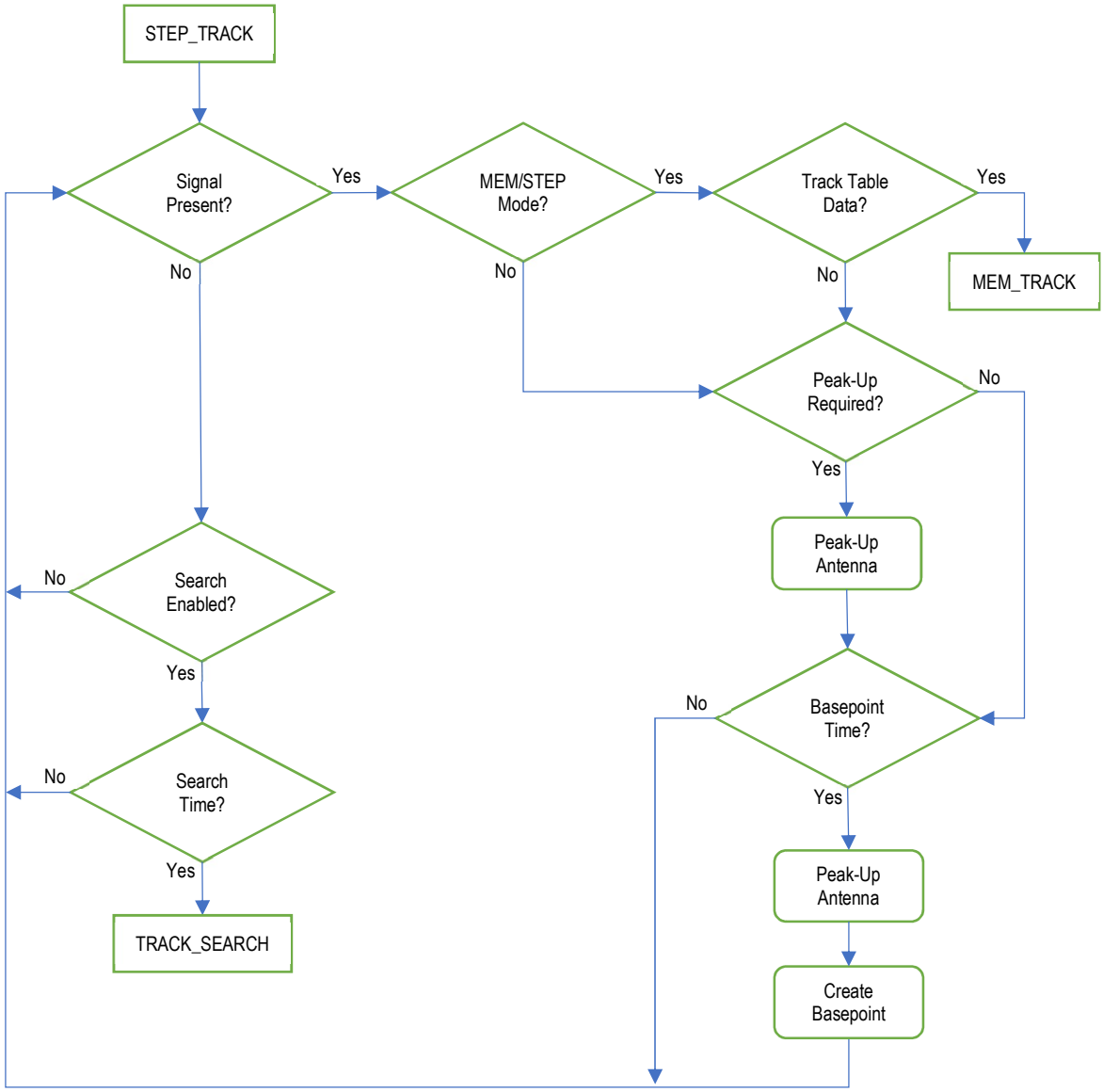
TRACK mode can be entered from either SETUP or RECALL mode. On startup, the ACU will perform any needed data initializations and switch to the initial sub-mode according to the following diagram.



If a move into the track area is required, the ACU will first scan forward through the track table looking for an available basepoint. If a basepoint is found, the ACU will move to that position. If no basepoint is found, the ACU will move to the nominal position on the “arc” of satellites. Either of these positions should be a point where the satellite will eventually arrive.

3.2.2 Step Track

In the STEP_TRACK sub-mode, the ACU will periodically jog the antennas to peak-up the received signal strength. This sub-mode is active whenever there is no track table data available for the current sidereal time and a satellite signal is present. The following diagram illustrates this procedure.



Two events can trigger a peak-up. The first is when the calculated antenna pointing error exceeds the maximum tracking error (Peak-Up Required). The second is when the current sidereal time reaches one of the 48 track table entries (Basepoint Time).

The pointing error is calculated based on the antenna's beamwidth and radiation pattern. The maximum tracking error is determined by the Max Track Error configuration item. This item should be assigned to a value that balances pointing error with wear on the antenna's motors and actuators. Decreasing this value reduces the error but increases the movement frequency.

The following status messages may be displayed in this sub-mode:

STEP:IDLE
WAITING FOR NEXT PEAKUP

This state indicates that satellite signal strength is present and the ACU is waiting to perform the next peaking operation.

STEP:PEAKING
JOGGING ANTENNA TO FIND MAXIMUM SIGNAL

The antenna is currently being jogged to find the azimuth and elevation position which corresponds to the maximum received signal strength.

STEP:SIGNAL LOST
WAITING FOR SIGNAL TO RETURN

A satellite signal is not present and the ACU is waiting for the signal to return.

This sub-mode will pass control to another TRACK sub-mode in the following circumstances:

MEMORY_TRACK

MEMORY_TRACK receives control when the current sidereal time equals a time for which track table data is available.

TRACK_SEARCH

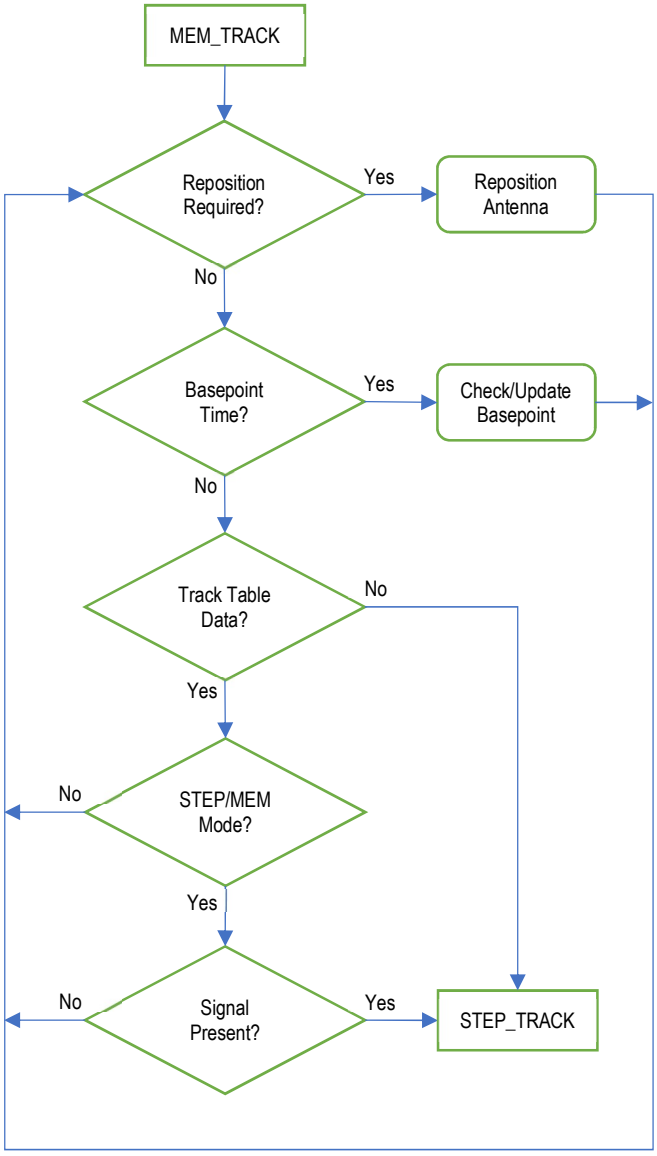
TRACK_SEARCH receives control if search is enabled and the signal has not returned after 5 minutes. If search is not enabled, the current sub-mode retains control.

TRACK_ERROR

TRACK_ERROR receives control if an error occurs.

3.2.4 Memory Track

In the MEMORY_TRACK sub-mode, the ACU periodically repositions the antenna to positions derived from the track table. This sub-mode is active whenever track table data is available, regardless of whether a satellite signal is present or not. The following diagram illustrates this procedure.



Two events can trigger a reposition. The first is when the calculated antenna pointing error exceeds the maximum tracking error (Reposition Required). The second is when the current sidereal time reaches one of the 48 track table entries (Basepoint Time).

The pointing error is calculated based on the antenna's beamwidth and radiation pattern. The maximum tracking error is determined by the Max Track Error configuration item. This item should be assigned to a value that balances pointing error with wear on the antenna's motors and actuators. Decreasing this value reduces the error but increases the movement frequency.

This sub-mode periodically performs peak-ups to check the accuracy of track table entries. If the discrepancy between the peak-up position and the track table position is greater than Max Track Error, the update flag for all entries in the track table is set. The frequency at which these track table accuracy checks occur is determined by the Update Check Interval.

A normal peak-up will occur if the update flag of the current table entry is set. Following a successful peak-up, the track table entry will be updated and the update flag will be reset. The update flag remains set if a satellite signal is not present.

The following status messages may be displayed in this sub-mode:

MEM:IDLE
WAITING TO REPOSITION

The ACU is waiting to reposition the antenna.

MEM:REPOSITION
MOVING TO STAY WITHIN MAX TRACK ERROR

The ACU is currently repositioning the antenna to a position derived from the track table.

MEM:PEAKING
CHECKING TRACK TABLE ENTRY

The ACU is performing a step track operation to check the accuracy of a track table entry.

MEM:PEAKING
UPDATING TRACK TABLE ENTRY

The ACU is performing a step track operation to update a track table entry.

This sub-mode will pass control to another TRACK sub-mode in the following circumstances:

STEP_TRACK

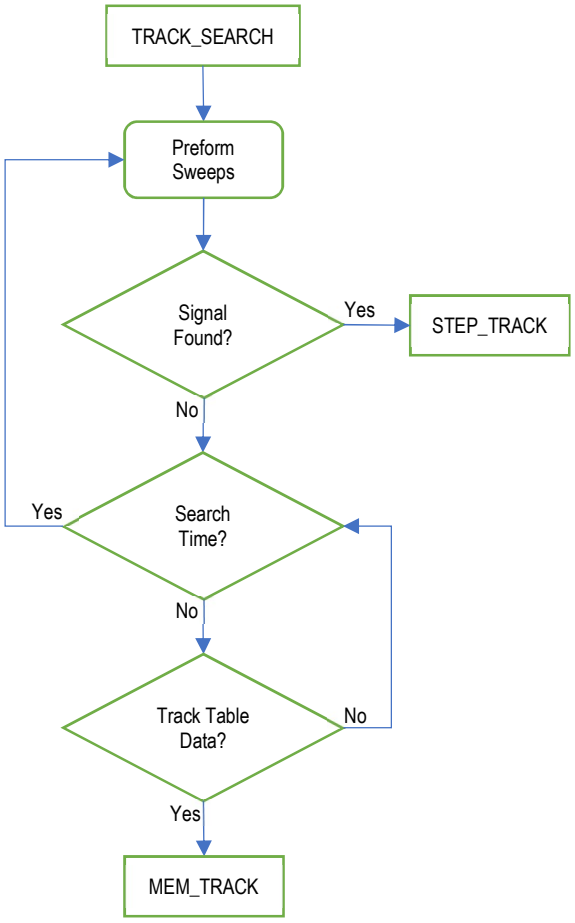
STEP_TRACK receives control when the current sidereal time equals a time for which no valid track table data is available. STEP_TRACK also receives control if the tracking mode is STEP/MEMORY and a satellite signal is present.

TRACK_ERROR

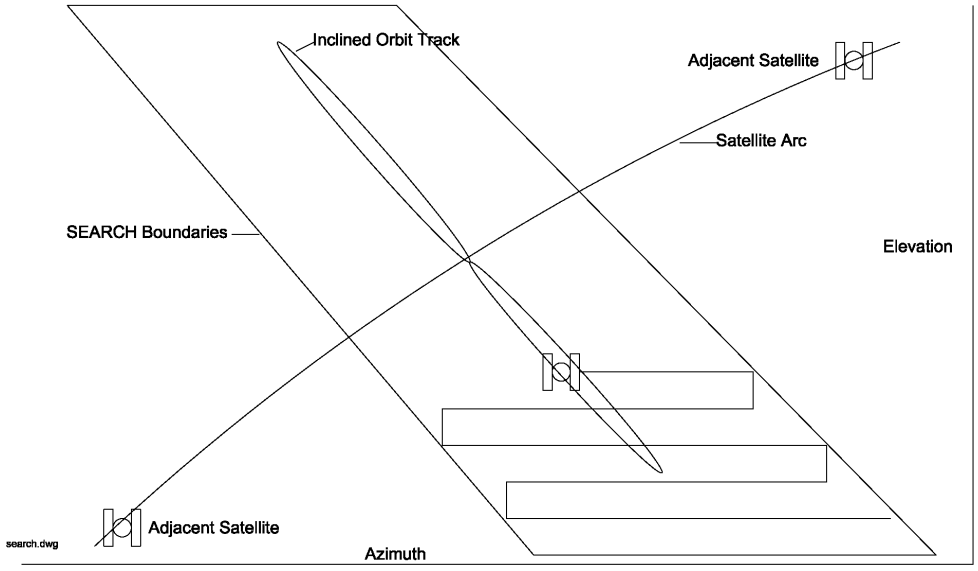
TRACK_ERROR receives control if an error occurs.

3.2.5 Track Search

In the TRACK_SEARCH sub-mode, the ACU periodically performs a search for the satellite using the Intelli-Search algorithm. This sub-mode is active whenever the satellite signal is lost and the track table does not contain position data for the current sidereal time. The following diagram illustrates this procedure.



The ACU will sweep the antenna in a serpentine-shaped pattern over the region where it has calculated the satellite will be found. The extent of the search region is based on the antenna latitude/longitude, the satellite longitude/inclination, the antenna beamwidth, and the Search Width configuration item. In most cases, the search region is shaped like a parallelogram.



The following status messages may be displayed in this sub-mode:

SEARCH:DOING SWEEP #
PERFORMING MAX SIGNAL SEARCH PATTERN

A search is in progress.

SEARCH:IDLE
WAITING TO SEARCH AGAIN

A search has been performed and a satellite signal was not found. The ACU is waiting to perform another search.

SEARCH:PEAK FOUND
MOVING TO PEAK POSITION

A search has been performed and a satellite signal was found. The ACU is returning to the position with the greatest signal strength.

This sub-mode will pass control to another TRACK sub-mode in the following circumstances:

STEP_TRACK

STEP_TRACK receives control if a satellite signal was found.

MEMORY_TRACK

MEMORY_TRACK receives control if the current sidereal time equals a time for which track table data is available.

TRACK_ERROR

TRACK_ERROR receives control if an error occurs.

3.2.7 Track Error

In the TRACK_ERROR sub-mode, all tracking operations are halted. This sub-mode is active whenever an error is detected.

The only way to exit from the ERROR sub-mode is to exit TRACK mode by hitting the MODE key, or by sending a Track Reset remote command.

```
AZIM: 32974    8.3   SS1:756       TRACK
ELEV:  8824   35.3   SAT:SBS 4      (Ku)
 POL:  71.1 V      ERROR:PEAK_LIMIT
* ERROR - TRACKING HALTED *   <MODE>EXIT
```

The possible track mode errors are described below:

ERROR: PEAK_LIMIT

This error indicates that the antenna moved too far in either azimuth or elevation while attempting to peak the antenna. This error is described in Section 5.1, “Peak Limit Errors”.

ERROR: ACU ALARM

This error indicates that a system alarm is active. Check the alarm line to see what has occurred. For drive alarms, go to MAINT > DRIVE to reset the axis that was shut down.

ERROR: BAD TRACK DATA

This error indicates the track table or header has been corrupted. The only way to correct this error is to restart the track via RECALL mode.

ERROR: UNDEFINED

This error is a catch-all for any other unexpected condition. The only way to correct this error is to restart the track via RECALL mode.

3.2.8 Track Menu

In the TRACK_MENU sub-mode, data relating to the satellite being tracked can be viewed and modified. This sub-mode is activated by depressing the 0-key while in the IDLE state of any other TRACK sub-mode.

The following screen shows the main TRACK_MENU on the lower display lines. The current sidereal time is shown in the lower right corner.

```
AZ:  31561  340.44   EXT:2730      TRACK
EL:  11060   49.27   SAT:BRASIL A1  (KU)
TRACK MENU:<1>PEAKUP NOW <2>VIEW TABLE
<3>MODIFY FACTORS <BKSP>EXIT       83216
```

The action performed by selecting option <1> depends on the last TRACK sub-mode:

<1>PEAKUP NOW

This action returns control to the STEP_TRACK sub-mode and performs a peak-up operation if signal strength is available.

<1>ALIGN NOW

This action returns control to the MEMORY_TRACK sub-mode and repositions the antenna based on the current sidereal time.

<1>SEARCH NOW

This action returns control to the TRACK_SEARCH sub-mode and causes the ACU to initiate another search operation.

Selecting option <2> displays the track table data.

<2>VIEW TABLE

The track table fields are the table entry number (0-47), sidereal time (in seconds), azimuth pulse count, elevation pulse count, and update flag status. The user may scroll through the 48 table entries by using the Scroll Up/Down keys.

```
AZ:  31561  340.44   EXT:2730      TRACK
EL:  11060   49.27   SAT:BRASIL A1  (KU)
TRACK TABLE <SCROLL>UP/DOWN <BKSP>EXIT
47 84365 33124 10312 *  <1>DELETE  83234
```

The asterisk next to the elevation count indicates that the update flag for that table entry is set. A blank in that field indicates that the update flag for that entry is reset (or not set).

Selecting option <1> at this point deletes all data from the currently displayed entry.

Selecting option <3> allows track factors to be modified.

<3>MODIFY FACTORS

```
AZ:  31561  340.44   EXT:2730      TRACK
EL:  11060   49.27   SAT:BRASIL A1  (KU)
FACTORS MENU <SCROLL>UP/DOWN <ENTER>EXIT
MAX ERROR (1/10 dB) <1-30>: 3
```

The following track factors can be modified. Use the Scroll Up/Down keys to move through the list.

MAX ERROR (1/10 Db) <1-30>

Specifies the maximum tracking error in tenths of a dB. Default value is 3.

SEARCH WIDTH <1-NARROW, 10-WIDE>:

Specifies a normalized scaling factor that increases or decreases the width of the search window. Values greater than 3 increase it, less than 3 decrease it. Default value is 3.

TRACK TABLE <1-CLEAR>:0

Press 1 to clear the track table entries, or 0 to leave as is. Be careful with this one!

UPDATE FLAGS <1-CLEAR, 2-SET>:0

Press 1 to clear the UPDATE flags for all track table entries.

Press 2 to set UPDATE flags for all track table entries.

UPDATE TIME <0-999 HOURS>: 33

The period of time between track table basepoint update checks. Default value is 33 hours.

SEARCH RETRY <0-999 MINS>: 10

The period of time between successive SEARCH attempts when no signal is present and track table data is not available. Default 10 minutes.

SIGNAL THRESHOLD <0-4095>: 200

During Step Track operations, this value refers to the minimum signal strength required to indicate that the antenna is pointing at the satellite.

3.3 Configuration

The CONFIG > TRACK FACTORS screen is used to configure track system operation.

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

SEARCH: <0-MANUAL,1-NARROW,3-NOMINAL,10-WIDE>

This field specifies the sweep width of the Intelli-Search algorithm. Setting this value too large may cause mistaken alignment on an adjacent satellite. Setting this value too small may not sweep over a region which is wide enough to find the satellite.

The search is disabled by setting the value to zero (0). The search should be disabled for transmit applications or for antennas which move very slowly.

MAX ERROR: ENTER MAX ERROR IN TENTHS OF A dB <1-30>

This field specifies the maximum antenna tracking error in tenths of a dB. This value determines the step sizes and the frequency of peak-up operations. This value should not be made smaller than 3 (0.3 dB) for most antennas.

HOLDOFF: SET PEAKUP HOLDOFF TIME <1 - 999 SECONDS>

This field specifies the number of seconds before a track-table entry during which a peaking operation should not occur. The reason for this holdoff is to avoid a situation where a regular peak-up takes too long and the track table entry time is missed.

TIME: SIGNAL SAMPLE TIME <2-99 SECONDS>

This field specifies the number of seconds that will be spent sampling signal strength following each peak-up move. Increasing this value will improve the ability to determine the position of higher signal but will also make total peak-up time proportionately longer.

LOG: <0>DISABLE <1>ENABLE TRACK DATA LOGGING

This field is used to enable the output of diagnostic data to the ACU log system. A factory technician may request this data while troubleshooting track system performance.

AZDP: AZ/EL DELTA FACTOR <0.5 – 1.5>

This field specifies the step size delta factor. This value is used to compensate non-uniform antenna diameters. The default value of 1.0 will calculate steps assuming the antenna's azimuth and elevation diameters are the same. A value of 1.1 will increase elevation steps by 10% and decrease azimuth steps by 10%. A value of 0.9 will decrease elevation steps by 10% and increase azimuth steps by 10%.

4 Optimizing Performance

The Max Track Error parameter has more influence over the operation of the tracking system than any other. It decides when to peak the antenna and how big the step sizes should be.

Some users conclude that the smallest Max Track Error leads to the tightest track. However, the ACU cannot peak-up properly when the value of this parameter yields step sizes are close to the mechanical hysteresis (slop) of the antenna mount. This can lead to PEAK LIMIT errors or the antenna peaking itself off of the satellite.

Here is the mechanism which can lead to this undesirable result:

1) The Max Track Error is set to a low value which results in an elevation peak-up step size of just one position count.
2) When a peak-up occurs, the ACU measures the signal strength at the current antenna position, and then moves the antenna up or down in elevation in an attempt to find the strongest satellite signal. For this example, the ACU records the signal strength and moves the antenna up in elevation by one position count.
3) Due to mechanical hysteresis, the antenna's pointing angle does not change even though the antenna's position has moved one position count.
4) Noise, variance, or changing atmospheric conditions result in the ACU measuring a stronger signal at the “new” antenna position.
5) The ACU concludes that the satellite has moved up. The ACU will again move up by one position count. At the new position, the ACU will measure the signal strength again to determine if the signal is stronger at the new position than at the starting position. This process will continue until a weaker signal strength is recorded. When that occurs, the ACU will back up one step and conclude that it has found the elevation peak.

The problem occurs when the ACU makes the wrong decision at step 4. Any time the ACU step size is comparable in magnitude to the antenna's mechanical hysteresis, a problem WILL eventually occur.

The solution to this problem is simple. The Max Track Error must be set large enough that a single step results in a clear change in signal strength. For most antennas, a Max Track Error greater than 3 (0.3dB) is appropriate.

5 Troubleshooting

This section discusses the most-common problems that can occur while tracking an inclined orbit satellite.

5.1 Peak Limit Errors

The maximum movement of the antenna during a peaking operation is limited to prevent the antenna from ending on an adjacent satellite. A Peak Limit Error indicates that the ACU wanted to move the antenna too far from the starting position.

A number of situations can cause this error:

1) Incorrect antenna diameter or satellite band. This causes the ACU to calculate too narrow of an apparent antenna beamwidth, which is used to determine the maximum movement allowed. During a peak-up, the antenna may move beyond this maximum amount.
2) Specified satellite inclination too small. This causes the ACU to not peak-up often enough. During a peak-up, the antenna may have to move beyond the maximum amount allowed.
3) Specified update check interval too large. During an update peak-up, the antenna may move beyond the maximum amount allowed.
4) Signal threshold is too low. If the threshold value is set too low, the signal of the receiver may be above the threshold when the antenna is looking at noise. The ACU would mistakenly assume that the satellite signal is present, and attempt to peak-up on the noise.
5) Play or looseness between an antenna axis and the sensor. This results in the antenna's pointing angle remaining the same even though the sensor has changed.

5.2 Track Table Gaps

This problem can arise if a Max Track Error-inspired peak-up is in progress when the track table update should occur – the ACU will not perform the track table update. This causes gaps in the track table data.

The solution is to adjust the Peakup Holdoff Interval configuration value to be longer than the worst-case time that it takes to perform a peaking operation. The worst-case time corresponds to the time when the satellite is passing through the earth's equatorial plane.