Research Concepts Inclined Orbit Tracking Satellite Antenna Controllers

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The RC1500B, RC2000C, and RC2500 are inclined orbit satellite tracking antenna controllers manufactured by Research Concepts, Inc. (RCI). Although these antenna controllers are designed to interface with different types of antennas and antenna mounts, the inclined orbit satellite tracking algorithms employed by these controllers are nearly identical. This paper describes the tracking algorithms employed by the these antenna controllers.

The RC1500 is a single axis antenna controller designed to interface with antennas powered by 36 volt DC actuators with integral limit switches and pulse type position sensors. The RC1500's solid state drive can supply up to 5 amps at 36 volts to the antenna actuator.

The RC2000C is a dual axis antenna controller designed to interface with antennas powered by a pair of 36 volt DC actuators. The RC2000C is available in a number of different configurations depending on the antenna mount type. The RC2000C AZ/EL is designed to work with antennas which employ elevation over azimuth type mounts. The RC2000 POLAR is designed to work with polar mount's with either a motorized elevation (latitude angle) adjustment or a motorized declination adjustment. The RC2000 EL/AZ is designed for azimuth over elevation type mounts.

The RC2500B is designed to interface to elevation over azimuth type antenna's which employ resolver type azimuth, elevation, and polarization sensors, discreet limit switches, and an antenna interface unit (AIU) located on the antenna pad. The AIU contains the motor drives and accepts control outputs from the RC2500 which activates the antenna motors.

All of these controllers monitor received signal strength via analog inputs (called AGC - automatic gain control - inputs since the signal strength voltage is often derived from receiver AGC circuits). The controller AGC inputs accept a DC voltage (0 to 10 volts for the RC1500 and RC2000C, -10 volts to +10 volts for the RC2500) which is proportional to signal strength. The controllers can be programmed to accept AGC voltages of either polarity - positive polarity AGC inputs increase in magnitude as the received signal strength increases while negative polarity AGC inputs decrease in magnitude as the received signal strength increases. These controllers also include an RS-422 serial interface which is compatible with the SA Bus specification.

To understand the operation of these controllers it is helpful to review the characteristics of inclined orbit satellites.

Inclined Orbit Satellites

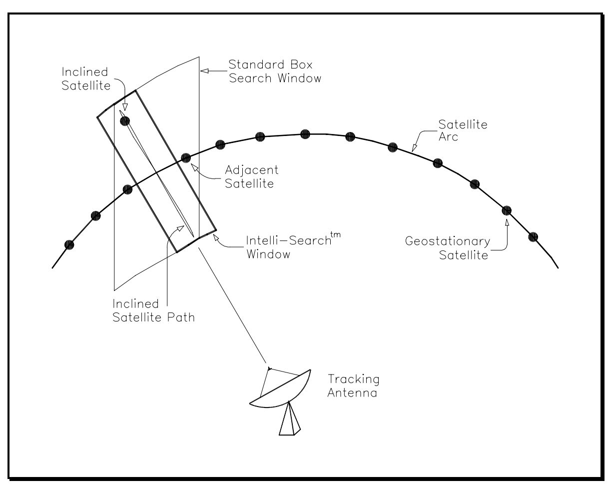
Satellites are allowed to drift into an inclined orbit to save satellite station-keeping propellant. East-West station-keeping maneuvers must be performed to keep the satellite in its assigned orbital position. North-South station-keeping is performed to keep the satellite in the earth's equatorial plane. Natural forces tend to cause the satellite's orbital plane to tilt, or become inclined to the earth's equatorial plane. By suspending North-South station-keeping maneuvers (while continuing East-West station-keeping), a significant savings of propellant can be realized. Typically, for a geostationary satellite, 90 percent of the total propellant usage is due to North-South station-keeping maneuvers.

A satellite in an inclined orbit has certain known characteristics (to a close approximation). The inclination of the satellite's orbital plane relative to the earth's equatorial plane increases at a rate of between 0.6 and 0.9 degrees per year. The rate varies from year to year. The apparent motion of the satellite is periodic with time, the period is approximately 23 hours, 56 minutes, 4 seconds. The apparent motion of the satellite about a nominal position as viewed from the center of the earth is a figure eight pattern, as described by the following equations.

Height of the figure eight (North-South): $2 * i$ degrees

Width of the figure eight (East-West): $(i^2) / 115$ degrees

... where i is the inclination of the satellite's orbital plane to the earth's equatorial plane in degrees.



Examination of the equations show that the figure eight is much taller than it is wide. For example, a 5 degree inclination results in an apparent East-West position variation of 0.217 degrees. The apparent motion of the satellite is practically a straight line oriented in a North-South direction. This knowledge of the satellite's period and apparent motion is exploited by the RCI antenna controllers.

These relationships are strictly valid only if the motion is observed 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 earth from which the satellite motion is viewed. To estimate the height and width of an inclined orbit satellite's motion as viewed from the surface of the earth, a good approximation is to multiply the results of the above equations by a factor of 1.2. The long axis of the figure eight is parallel to the antenna's declination axis. The declination axis is perpendicular to the geostationary arc of satellites. Please refer to the figure.

Tracking Algorithm

The tracking algorithm used by the RC2000B and RC2000C antenna controllers can be divided into 3 distinct parts - STEP_TRACK, PROGRAM_TRACK, and SEARCH. The process will be described in chronological order as seen by a user initiating a track on a satellite for the first time. To initiate the track process the user jogs the antenna to the satellite and verifies the identity of the satellite. The system then enters STEP_TRACK mode.

In STEP_TRACK mode the controller periodically peaks the receiver's AGC signal strength by jogging the antenna. The time and position are recorded in a track table maintained in the controller's non-volatile memory. The interval between peakups is determined by antenna size, the frequency, and a user-specified maximum allowable error (in dB). STEP_TRACK mode is active until a time is reached that corresponds to a segment of the satellite's motion which has previously been stored in the track table. When this occurs PROGRAM_TRACK mode is activated.

In PROGRAM_TRACK mode the controller smoothly moves the antenna to the positions stored (or derived from) entries in the track table. The time between movements is determined by the same factors which govern the time between peakup operations in STEP_TRACK mode. In particular, the user can specify the maximum allowable error between the antenna's actual position and the position specified by the track table. By increasing the maximum allowable error, antenna movements can be performed less frequently, thus avoiding unnecessary wear on the antenna actuators. In PROGRAM_TRACK mode the accuracy of the track table is monitored by periodically peaking up the receiver AGC signal. If the error exceeds a level set by the user, all entries in the track table are flagged for update. The period between these accuracy checks is specified by the user and typically varies from once a day to once a week.

SEARCH mode is entered from STEP_TRACK mode when the satellite signal has been lost. (AGC level drops below a user set threshold) In this mode, the controller periodically searches over a parallelogram shaped region where the controller has calculated that the satellite will be found. The use of the *Intelli-Search* algorithm relieves the user of the task of specifying the coordinates of this search area. The RC2000 series tracking controllers determine the dimensions and position of the search parallelogram from the user-entered target satellite longitude and inclination as well as the previously stored positions of adjacent satellites. By searching over a narrowly-defined region of space, false tracks are virtually eliminated. When the satellite is located, the controller enters the STEP_TRACK mode. With the RC2000C it is possible to disable the automatic search. When the search is disabled the user is prompted to manually position the antenna on the satellite.

Single-Axis Tracking

When using a modest-sized antenna in which the beam may be steered along the declination axis, (perpendicular to the geostationary arc) a satellite that is in an inclined orbit may be tracked with the RC1500B, a single-axis antenna controller. The angular width of the figure eight pattern of the satellite's apparent motion is, in general, very small. From the previously shown equations, and taking into account the factor of 1.2, the width is 0.26 degrees for a satellite with an inclination of 5 degrees. If the antenna beamwidth is much larger than the width of the figure 8, the satellite can be tracked with single-axis, declination motion. An 11.5m C-band or a 3.8m Ku-band antenna has a 3dB beamwidth of about 0.6 degree. Properly aligned, these antennas could track the satellite above with less than 3dB error.

In conclusion, the tracking algorithms of the RC2000 series offer the following unique features....

Ease of setup. In other tracking controllers the user must specify a rectangular search window. The satellite must be observed for 24 hours to insure that the search window is large enough to provide the antenna movements necessary to track the satellite but small enough so that an adjacent satellite is not within the search window. With the 2000 series, the user is relieved of these chores. The geostationary satellites of interest are located first, then the desired inclined orbit satellite is found, identified and logged into memory. The setup data which must be entered is straight forward - antenna size, satellite longitude, satellite band - C or Ku (L band also for the RC2000C), antenna latitude and longitude, and maximum tracking error (in dB).

Accuracy. The accuracy of the system is determined by the resolution of the position sensors, backlash in the mount, and a user-defined variable which specifies the maximum allowable error.

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