The INTRAC Algorithm

In the mid 1970's the British Post Office, (now British Telecom International) decided that there was a need to develop a new antenna control algorithm to overcome the weaknesses of steptrack algorithms. These weaknesses tended to result in mis-pointing of the antenna and loss of track when operating with scintillating or fading satellite beacons, high inclination orbit, and/or narrow 3-dB groundstation antenna beamwidths. BPO therefore funded a detailed study of the applicability of optimal filtering techniques to overcome these limitations. The study proposed a new tracking algorithm based on orbit modelling. The BPO funded the development of prototype tracking equipment using this algorithm and undertook trials of the equipment on operational 32 metre C-band Intelsat Std A antennas and on an experimental 8 metre K_u-band antenna. The trials were performed over several years at both typical (30^o) and low (5^o) elevation on clear-sky, scintillating and fading channels. The trials confirmed the effectiveness of the new algorithm. They showed that its performance was on par with monopulse control, that it was fully compliant with Intelsat pointing specifications and that it overcame the problems associated with step track controllers. This algorithm was the first antenna control algorithm to use orbit modelling and became known as Smoothed Step Track (SST).

The SST algorithm was licensed to Signal Processors Ltd (SPL), on an exclusive basis, in 1983. Since than SPL has continued developing the algorithm, enhancing its capabilities and adding new features and interfaces. The result is the INTRAC enhanced orbit modelling algorithm (INTRAC is an acronym for INtelligent TRacking Antenna Controller). Many special variants have also been developed at SPL as required by customers. The algorithm has consequently been subject to continuous improvement for fifteen years and incorporates the results of much experience in the application of orbit modelling algorithms in a wide range of conditions. As would be expected from this lengthy period of proving and enhancement, the algorithm is also extremely rugged and reliable, both in concept and in coding.

The time-honoured conventional steptrack and its more recently introduced variants operate by nodding the beam back and forth and sideways at predetermined intervals or when the signal level drops, making a correction at each nod until the signal level across the nod becomes balanced, thus indicating that the beam is peaked. Such algorithms consequently use the step cycle to attempt to point the beam at the satellite directly. While this may appear to be the obvious and correct method of pointing the beam, the method suffers from severe disadvantages when the beacon signal power fluctuates during a step cycle. Under these conditions the derived pointing will be incorrect and the antenna will not be pointed directly at the satellite. The result is that such algorithms are prone to lose track if the beacon signal is fluctuating too much.

Such fluctuations in the received beacon signal can result from rain fades and from tropospheric and ionospheric scintillation. Tropospheric scintillation is particularly severe in tropical climates and when the satellite beam traverses a long path through the atmosphere, which occurs when antennas are operated at low angles of elevation. Ionospheric scintillation effects can also be severe in tropical regions, particularly during the Equinoxes and at sunset. Ionospheric scintillation is relatively independent of the angle of elevation of the antenna and, unlike tropospheric scintillation, whose main effect is on tracking at low elevation angles, is also liable to interfere with the tracking of dishes operated in the tropics at high angles of elevation. Under such scintillation conditions conventional steptrack controllers can suffer large pointing errors or simply lose track completely.

To overcome these problems INTRAC uses its acquired history of individual step-cycle measurements not to point the antenna directly but, instead, to build an accurate model of the satellite track as viewed from the particular antenna and in doing so also incorporates any systematic nonlinearities in the antenna position transducers, etc. The resulting orbital model is then used to control the antenna pointing. By the use of optimal signal processing INTRAC removes the sensitivity to errors in individual step cycle measurements and provides a robust control algorithm which can point the antenna very accurately, even under severe scintillation conditions. The pointing accuracy of the algorithm is independent of the orbital inclination of the satellite being tracked up to inclinations of at least 10^o.

The key to deriving a reliable and accurate orbital model is the ability to derive accurate estimates of the many parameters involved in the model. Much specialised noise processing expertise and experience has been applied in the design of the INTRAC algorithm to ensure that INTRAC can build an accurate model and can maintain it even when the beacon signal is subject to severe fluctuations.

The INTRAC algorithm uses a robust steptrack pointing error estimator to obtain the raw satellite position estimate, normally at 10 minute intervals. The raw satellite position estimate is filtered with a narrow noise-bandwidth tracking filter to produce the basic, multi parameter, orbital model. To correct short-term errors in the basic model resulting from modelling error, windage and satellite station keeping manoeuvres, the difference between the raw satellite position estimate and the orbital model is filtered with another tracking filter (known as the "relationship algorithm") capable of tracking and correcting transients. This is then combined with the basic model to form a reliable predictor that tracks mean windage, refraction and stationkeeping manoeuvres without error.

The INTRAC tracking filters are designed in such a way as to enable the model to provide the required accurate pointing prediction at all times. Even when not verified by step-cycle measurements, as for example occurs with loss of beacon, the tracking filters are capable of accurately predicting the satellite orbit for many days. Under INTRAC control, pointing is always controlled from the internal satellite orbit model. When a step-cycle is performed, it is always done as a perturbation with respect to current pointing. Thus, unlike conventional steptrack, INTRAC is always on track when a step-cycle is performed. INTRAC never uses the step-cycle for the purpose of directly bringing the beam on track. INTRAC simply performs one step-cycle in each axis every 10 minutes in order to up-date the parameters used in the orbital model and for the rest of the time keeps the beam correctly pointed.

As a result of the combination of thermal noise, fade, scintillation, random windage-induced platform-reference motion, and other noise sources, the beacon signal will, during a step-cycle, contain noise additional to that directly attributable to the step-cycle itself. Careful algorithm design ensures that this noise has zero mean value and has a value of standard deviation such that it is equivalent to thermal noise of a certain effective value of C/No. By special design of the step-cycle the INTRAC system minimises this effective value of C/No in a way that is not possible with conventional steptrack methods. Furthermore the INTRAC step-cycle design discriminates so effectively against the slow component of received beacon signal power fluctuation, caused for example by rain fades, that it almost completely suppresses errors caused by linear beacon ramps of all practicable slopes.

The INTRAC algorithm also incorporates adaptive compensation for imperfections in the antenna drives. As a result its performance is largely unaffected by servo backlash, AC track motor drive rate and transportation rate (motor to axis rate) and coast, because of the specific choice of step-pattern and the use of high resolution position transducers. The INTRAC servo algorithm dynamically calibrates the mechanical coast of the antenna and automatically compensates for it if it is within reasonable limits (less than 1/20 beamwidth).

During initial acquisition the INTRAC algorithm tracks the satellite using a third order, unbiased tracking filter. This algorithm dynamically adjusts the period between step-cycles to match the perceived orbit inclination and received beacon signal power fluctuations and noise level. During this initial period the tracking accuracy achieved is about 80% of the normal INTRAC tracking accuracy. INTRAC can also accept Intelsat IESS-412 and NORAD data to establish its initial model and eliminate the learning period altogether. It then modifies the data from this model to take account of the actual conditions at the antenna and optimise the model.

Wind affects tracking in two ways. Windage shifts the position reference by an amount that depends on the antenna design. This component of beam shift is not visible to the position transducers. The mean of the reference shift is tracked by the INTRAC algorithm in a similar way to a stationkeeping manoeuvre.

The component of beam shift that is visible to the position transducers is entirely tracked by INTRAC within a 10 mHz noise bandwidth. When the position transducers accurately reflect beam pointing in windage, INTRAC continuously tracks the windage at 16 sec updates. To support tracking of visible wind-induced beam deflection between step-cycles, the INTRAC servo control algorithm maintains a short-term average of beam pointing. When deciding whether to update beam pointing, INTRAC references this average rather than the current pointing. A further small deadband is also applied to suppress unnecessary hunting.

The INTRAC tracking filter distinguishes received beacon signal power fluctuations, fades and noise from the mean component of windage-induced beam-pointing, orbit changes and beam refraction. The effect of the fluctuations, fades and noise on the INTRAC tracking filter is as if these were a zero mean position random noise source. The variance of these is brought within specification by tracking the position estimates with a narrow noise bandwidth tracking filter. The mean components of windage-induced beam-pointing, orbit changes and refraction are seen as transients to be tracked by the INTRAC relationship algorithm. The design of the relationship algorithm is a carefully evolved working compromise between transient performance and noise suppression which provides high accuracy tracking under all conditions likely to be encountered in practice.

Summary

The INTRAC algorithm operates by maintaining a model of the satellite ephemeris which enables it to point the antenna accurately at the satellite at all times. At intervals of about 10 minutes the INTRAC algorithm briefly perturbs current pointing with a stepcycle to enable satellite pointing to be checked. These measurements are used to update the orbital model. The optimal filtering used by INTRAC processes the satellite pointing measurements and can discriminate against noise and uncertainties on these measurements caused by beacon level fluctuations and thermal noise or windage-induced beam deflection, as well as scintillations caused by atmospheric effects and perturbations caused by stationkeeping manoeuvres. This ability of the INTRAC filter to discriminate against these effects enables the controller to produce an accurate prediction of true satellite ephemeris. The INTRAC algorithm characterises and adaptively compensates for moderate imperfections in the antenna drive mechanisms. INTRAC is specifically designed to discriminate against beacon fluctuations, fades and noise and INTRAC controllers track with the same high accuracy for any inclination of orbit.