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COMMERCIAL KU-BAND SATCOM ON-THE-MOVE USING A HYBRID TRACKING SCHEME

ABSTRACT

The US Army has an unfulfilled requirement to provide long range communications to lower echelon Tactical Operations Centers (TOCs) On-The-Move (OTM). Currently, the Battalion (BN)-Level TOCs can communicate only by terrestrial radios, which are severely range-limited. This MITRE Mission Oriented Investigation and Experimentation (MOIE) calls for the design and prototyping of an affordable satellite communications (SATCOM) terminal that can support reduced data rate SATCOM OTM (SOTM) and Medium Data Rate (MDR) SATCOM On-The-Pause (SOTP) communications. Extended range communications by means of small aperture, low cost satellite terminals is anticipated to be greatly valued by the Army's digitization transformation. The platform stabilization subsystem is a key component of this MITRE program.

We propose a new hybrid-tracking scheme for antenna stabilization for Line-of-Sight (LOS) communications to a commercial satellite operating at Ku-band. Harsh terminal platform dynamic conditions while communicating with the satellite necessitate the use of tracking antennas and stabilized platform pedestals. The tracking system will be a hybrid design, which includes open loop tracking with periodic closed loop updates to correct for drifting of the inertial system. It combines the use of Fiber Optic Gyroscopic (FOGs) sensors with RF-based conical gimbal/step scan feedback. While the gyros compensate for the fast vehicle motion, the lower bandwidth RF tracking loop corrects for the low rate/DC drift errors associated with the ephemeris and gyrosensors. The novelty in our dual loop approach consists of combining these two tracking loops to minimize the tracking scan-loss.

The highly desired low-cost aspect of our platform stabilization design is credited to the use of FOG sensors as a key part of the tracking system. The hybrid design relies heavily on the use of high quality FOGs to track in a "Selective-Open loop (RF-wise) Pointing mode".

Introduction

The anticipated data rate required by the Battalion (BN)-Level Warfighter is 32 kbps and 256 kbps for SOTM and SOTP operation, respectively. This program is intended to develop a prototype terminal mounted on a High Mobility Multipurpose Wheeled Vehicle (HMMWV) that will be subjected to various unimproved road conditions to characterize the terminal's ability to faithfully track the satellite under extreme conditions. To keep the cost of the prototype terminal below an objective target of $150K, we elected to develop the terminal using commercial off-the-self (COTS) equipment designed for Ku-band SATCOM operation.

I. Description/Antenna

Our SOTM terminal consists of a modified commercial reflector antenna mounted on an elevation over azimuth pedestal. The pedestal/ radome design is based on a modified KVH Industries G6 model. The modified G6 antenna (Figure 1), employs a center-fed horn feed matched appropriately with an OrthoMode Transducer (OMT). It is mechanically steered in both the azimuth and elevation axes. The azimuth range is 720 degrees and the elevation range is 10 to 90 degrees.

Figure 1. Modified KVH G6 pedestal: 0.6 meter circular aperture center fed antenna.

The radome/ pedestal support assembly has been designed to specifically match the HMMWV shelter structure, but that can be easily modified to fit other vehicle mounting configurations. Linearly polarized signals are received by the Americom K2 satellite, which require a skew angle adjustment in our polarization. The receive 3dB beamwidth at the Ku-band downlink frequency of 11.75GHz is 2.2 degrees. Conversely, the transmit half-power (-3dB) beamwidth, at the Ku-band uplink frequency of 14.25 GHz, is 2.05 degrees for he effective aperture diameter of 0.6 meters. The feed has been matched to the reflector and is showing a max. In-band VSWR of 1.2:1(TBD) with sidelobe levels at least 20 dB from the peak.

II. Tracking System

The antenna tracking mechanism is required to maintain pointing within 1.5-2 dB, off the peak of the beam, based on recent link budget allocations. Pointing is to be maintained throughout the various driving phases of the HMMWV (except severe fade-out and direct blockage conditions, over extended periods of time exceeding 1 hour). The antenna's most stringent (narrow) beamwidth (2.05 degrees on transmit) requires fine pointing accuracy throughout the dynamic motion profile that the pedestal is subjected (Figure 2).

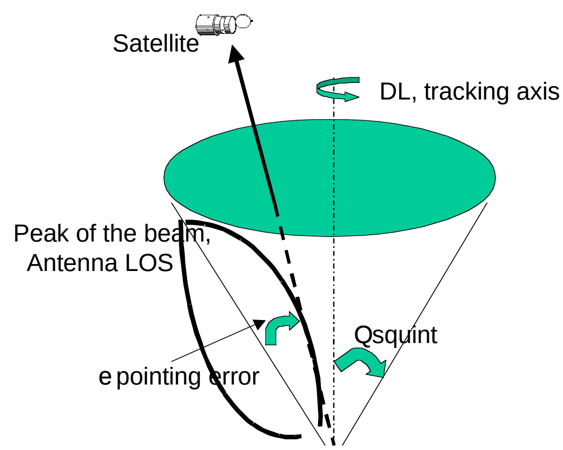

Figure 2. Gimbal scan geometry

As stated earlier, the positioner mechanism uses an elevation over azimuth pedestal driven by a pair of microstepping stepper motors, one in each axis, with precision better than 7 thousands of a degree (at 256 microsteps). The positioner is controlled by digital signal processors (DSPs) (Figure 3), implementing a set of tracking algorithms that utilize four distinct sources of information:

a) a dual axis Fiber Optic Gyro (FOG) Rate Sensor
b) an inertial measurement/attitude reference unit (IMRU)
c) a pair of optical incremental encoders to close position loops and mainly detect stepper stall-out conditions, and finally
d) a DC–voltage output proportional to the amplitude modulated scanning carrier by the pointing error to the satellite downlink beacon.

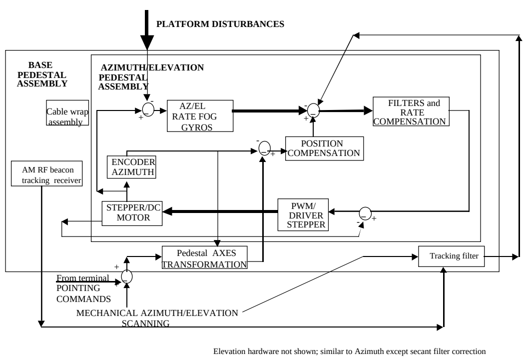

Figure 3. Digital Signal Processing Tracking loop Implementation: Topology

The FOG rate sensor has an effective 100 Hz bandwidth and it is mounted behind the main reflector having one of its axis aligned with the antenna elevation axis while the second one is sensing the cross-elevation rates being effectively perpendicular to the LOS to the satellite. On the other end of the spectrum, a very low bandwidth (1-2 Hz), small displacement (0.5-1 degree; optimized at 0.82 degrees) gimbal scan is used to null out any low rate gyro drift rates and dc/slowly varying errors such as in Ephemerides, etc. The commercial off-the-shelf IMRU is primarily used for satellite acquisition, as well as, during its reacquisition procedure that might occur due to an extended fade-out /blockage condition or during excessive dynamic motion conditions.

The overall tracking system is expected to sustain tracking rates 85 degrees/sec and accelerations up to 45 degrees/sec^2, in both the Azimuth and Elevation axes. By integrating a high quality, low drift rate gyro (2.5 degrees/hr) over temperature, it eases the requirement that is typically placed upon the traditional continuous scanning tracker, in at least two ways:

1) By allowing us the option to selectively turn on/off the scanning mechanism, it essentially eliminates the induced scan track loss (~1.5-2 dB), which is gained in favor of added link resource utilization. Given the tight link margins this translates to higher sustained throughput rates and/or smaller effective aperture antenna sizes for the same sustained rates.
2) Reduces effective drive loads placed on the mechanical drives/power, especially under the conditions of low-to-negligible dynamic motion profile, as seen by the vehicle.

In the case, where the gimbal scan is turned off the pedestal/antenna stabilization system relies solely upon the inertial reference to maintain pointing toward the satellite, i.e. operating in an “Open-Loop pointing mode”. Conversely, when the accumulated drift errors (slowly varying components due to Ephemeris errors, gyro rate sensors, etc.) surpass a time/ DC -beacon “level threshold, then the RF-based conical gimbal scan is engaged, i.e. operating in a “Closed-Loop RF-Pointing mode”. This continues long enough as to null these errors prior to switching back to the “Open Loop mode” once again. The novelty in our approach lies in the fact that FOG based rate sensor technology is becoming far more affordable commercially ($3k/axis, in Y2K). Additionally this tracking technique avails itself, to other RF techniques beyond the conventional reflector antennas. Even in cases where one might be considering to use electronic switching, for instance, in the case of a phased array system for a ground mobile system as a means to tracking, still inertial rate sensors provide long extended inertial pointing stability despite fade outs and extended blockage conditions.

III. FOG Gyro Tracking/Rate loops

The gyro rate loops (two of them, one in each axis), essentially integrate angular rates sensed in their respective axes, yaw rate for instance, after the needed secant correction (cross-elevation axis, only) is applied. These generate cumulative angular displacements that become the reference signals around which the micro-stepping signals are formed (open loop-RF).

In the closed loop case, the micro-steppers are still driven by the rate sensors, but this time the angular pointing error displacement is sensed physically (closing the feedback), via a measurement of the DC modulated error signal that is measured by a) turning on the scanning rate that creates the modulated error, and b) by providing a Beacon DC-signal proportional to the modulated error as measured, hence the closed loop is closed. Figure 3, above depicts these two algorithms both from their relative locations on the pedestal, as well as, from a DSP coding modular segmentation. Figure 4, below shows the same algorithms but as seen from a physical/conceptual perspective to further enforce the concepts outlined here.

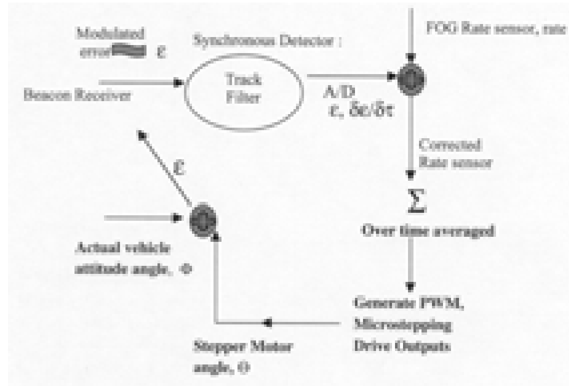

Figure 4. Slow Track-loop feedback closed around the Beacon Receiver error modulated signal.

Finally it is important to view the same architecture, from the perspective of the actual physical hardware/firmware implementation, which is heavily weighted on an architecture made up primarily of COTS components (Figure 5).

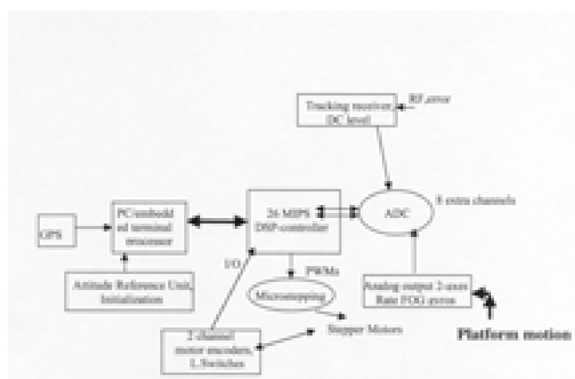

Figure 5. Architecture Layout showing functionality mapped to a mix of COTS/developed components.

IV. Results/Conclusions

Results based on the integration efforts and derived operational performance will be made available upon testing completion this coming June, 2001. The optimal squint tracking (scan loss) was analytically derived for the case of 0.6 meters, and was shown to be 0.82 degrees. It is the value that maximizes the slope of the error modulated signal, at a value of approximately, ~0.4 * _b, or namely, 0.82 degrees (equivalently, -1.92 dB), tracking scan loss. This squint angle will be used in our DSP tracking loop implementation to set the scan loss/squint angle (which in turn generates the modulated pointing error), while the antenna is operating in its Closed Loop RF-tracking mode. Alternatively, this is set to zero in the case of the Open RF-loop mode.

V. Future Work

Future work should involve the coordinated efforts leading up to an integrated terminal controller that accommodates status inputs not only from the antenna controller but also from other relevant modules. These modules are the modem, the link layer protocol terminal processor and the input sensors that we have discussed in this treatise. Incremental improvements are expected to take place in numerous areas, especially as lessons learned come in after each demonstration effort.

References

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