

**Short Abstract (submission requirement):**

The ISS is an outstanding platform for developing, testing and refining laser communications systems for future exploration. A recent ISS project which improved ISS communications satellite acquisition performance proves the platform's utility as a laser communications systems testbed.

## **Abstract: ISS Efforts to Fully Utilize its Target Acquisition Capability Serves as an Analog for Future Laser Pointing Communications Systems**

In 2001, the ISS took on a new high-capacity Ku-band communications system to return payload science data and crew video to the ground. Examination of today's baseband capacity in 2017 makes the 2001 Ku-band capability seem primitive by comparison: 1) today's return link is six times faster, 2) increased video capacity by 50% while adding high-definition cameras and 3) increased number of payload data channels by more than 10 times the original capacity. All of those baseband capacity improvements occurred while utilizing the same old pointing system we installed on-orbit back in 2001. That fact is a testimony to the outright resilience of the pointing system hardware and to the forward-thinking of ISS Program leadership that acquired the Ku-band antenna, a six-foot-diameter parabolic dish, long before on-orbit operations.

But, higher baseband capacities demand greater pointing accuracy. That is, as baseband size increases, there is less transmitted power per data bit in the baseband, which immediately leads to decreased communications link performance margin. Decreased performance margin demands higher-precision pointing to maintain link reliability. The original Ku-band pointing and automated tracking system had the characteristic accuracy necessary to support baseband increases over these sixteen years but the targeting accuracy of the navigation system was conservatively estimated when the ISS mission began. The original Ku-band operations concept was based on uncertainty about the navigation system which resulted in long target search times. In the beginning of Ku-band operations, the uncertainty on the acquisition time of for the system was on the order of three minutes. A demand went out from the operations and payload community for greater accuracy regarding the start of Ku-band service. In response, the ISS flight control team undertook a careful performance analysis of the navigation system accuracy to determine whether navigation could support smaller target acquisition times. That effort resulted in a reduction of the Ku-band target acquisition time by more than 500%, adding more than 200 hours of scheduled Ku-band service per year.

To achieve this improvement in acquisition time, the team began with a critical examination of the target acquisition process for communications satellites. Each time a satellite is available for communications service, the ISS navigation system provides a pointing vector to the Ku-band antenna. This vector is a navigation computer's version of "start looking here." The Ku-band slews to that orientation represented by the pointing vector and begins a "spiral search" period to attempt to find the signal from the communications satellite. After the spiral search time ends, the Ku-band independently activates its transmission and tracks the communications satellite without any input from the navigation computer. The Ku-band's tracking represents an independent measurement of state that is so accurate that it can be used as a unique, independent ISS attitude measurement. But, that prior spiral search time is uninteruptable and in the early days, because of uncertainties in navigation system performance, that search time was quite long. However, the flight control team noticed an interesting event at the beginning of each spiral search: the Ku-band received signal level would spike to a useable level. That spike meant that the navigation computer was pointing the Ku-band at the communications satellite right at the very beginning of the spiral search period, but by design, Ku-band must undergo its own independent search. The team's analysis results indicated that the navigation system was so accurate that the Ku-band search time period could be reduced by 400%. Additional 100% time

reduction was achieved by reducing the wait time between the start-up of each satellite spiral search sequence. As with all spacecraft systems at the beginning of a mission, performance estimates are conservative so that unexpected margins don't prevent the accomplishment of mission objectives. It is quite common to discover that a spacecraft system performs much "better than advertised" – especially when you fly the vehicle for more than sixteen years. While that fact is usually true, another facet of long-duration flight control is that the team learns more and more about how to glean the most performance out of a durable system. As a result of this effort, the uncertainty on the start of Ku-band service time has been reduced from more than three minutes to roughly fifty seconds – up to three days in advance of the scheduled service.

The elements of this process improvement project represent precepts that should be applied while using the ISS as a testbed for future laser communications systems. A part of the ISS effort to improve Ku-band performance included taking inventory of the system measurement error for the various inputs. This step was necessary because the navigation system measures its state using the Global Positioning System (GPS) and integrates attitude knowledge with ring laser gyroscopes but it also receives measured states for the communications satellites from the ground. Hence, the pointing vector used by Ku-band antenna represents a propagated relative state between ISS and the communications satellite – with measurement error. The team had to determine how well the navigation system knew its location in inertial space, its orientation in inertial space and how well it understood the location of the communications satellites. Such characteristics as the physical alignment of the Ku-band antenna with respect to the ISS body had to be accounted. Then, to assess the navigation system's pointing performance, the team had to convert resultant measurement error into Ku-band pointing angles.

One method for increasing communications link baseband capacity is to increase the operating carrier frequency. Ultimately, light frequencies are used because they offer the greatest possible baseband capacity. For deep-space laser communications links, transmitters are lasers and the most common receivers are a focal plane of electronic pixels behind a focusing lens, basically a telescope. Pointing precision requirements for laser communications systems are ten to one-hundred times greater than those needed for ISS Ku-band. However, the ISS team developed a real-time pointing performance assessment tool that can be used as a foundation for a "learning system" that constantly assesses how well it is pointing. The team is considering development of a realtime feedback system that empowers "the machine" to make adjustments based on how well it is performing. Such a system will be essential to improving pointing performance in the next-generation communications systems. The ISS represents an ideal testbed for developing and testing laser pointing systems that support human deep-space communication. One recent laser communications experiment on-board the ISS resulted in a report that the ground could "see" vibrations in the ISS truss – from more than 200 miles. Such sensitivities illustrate the utility of the ISS for this type of technology development. With its constant local-vertical-local-horizontal (LVLH) attitude and long periods of control-moment gyro control (micro-gravity phases), human crew attendees for servicing, visiting vehicle operations, and example human demands on baseband, the ISS represents an excellent testbed for laser pointing systems. The pioneering work that has already been accomplished to improve our Ku-band pointing performance illustrates the possibilities for development, test and improvement that ISS represents for future laser communications systems.