Lunar Adaptive Solid-State Lighting Assembly

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As plans for NASA's Lunar Gateway start to take shape, never-before-seen challenges surrounding its construction and maintenance are on the horizon. Most notably, astronauts will perform a record number of physically and mentally taxing extravehicular activity (EVA) hours during the Lunar Gateway's creation. This brings about issues when considering the Moon's unique day-night cycle, which lasts nearly thirty-times longer than that of Earth. Astronauts' internal clocks, which are centered around sunlight patterns on the Earth's surface, will be drastically changed during critical, lengthy spacewalks if not accounted for, significantly impacting crew energy levels. As such, a novel method of adaptable dynamic lighting systems, mimicking the Earth's daylight cycle, must be implemented to mediate astronauts' circadian rhythms and ensure quality upkeep and development of the Lunar Gateway.

In October 2012, NASA began the use of dynamic lighting systems aboard the International Space Station (ISS), which utilize a rigid schedule of varying light levels to simulate Earth-like sunlight patterns (NASA, 2016). High and low-intensity light—corresponding to feelings of alertness and relaxation—is shone in mornings and evenings, respectively, with regular white light being used during the day (Lockley et al., 2013; Lockley & Brainard, 2016). It was discovered that variable light-emitting-diode (LED) assemblies of this nature are more effective than their fluorescent, single-intensity counterparts in mediating the ISS crew's circadian rhythms and daily energy levels (Whitmire et al., 2015). However, critical late-night tasks and experimentation conducted by crew members do not make use of the shifting LED system due to its inflexibility, and thus are at greater risk of circadian fatigue (Scott et al., 2024). Implementation of a task-adaptable dynamic lighting system is crucial in solving this issue for the Lunar Gateway; the number of late-hour, emergency EVAs conducted is likely to be higher than that of the ISS, putting astronauts at risk of circadian misalignment.

Due to the Moon's month-long daylight cycle, the Lunar Gateway's construction and day-to-day operations will benefit greatly from a three-part dynamic lighting solution. Similar to the ISS, Solid-State Lighting Assemblies (SSLAs) housing LEDs, with an electrical current running through each diode's microchip, will be used to provide white light in varying intensities, with blue wavelengths being increased or reduced according to the set twenty-four-hour schedule (Maida, 2016; Whitmire, et al., 2015; Wright, 2014). SSLA technology will be modified to better adapt to astronauts' tighter working schedules, which are caused by extensive EVAs taking place alongside regular experimentation. These Lunar-Adapted Solid-State Lighting Assemblies (LASSLAs) will feature external Bluetooth antennas in place of regular remote connectors, allowing for connection with Lunar Gateway computers (Maida, 2016). During the Moon's dark period, which lasts approximately two weeks, passengers will be gradually awoken by blue-enriched white light beginning at 6:00, providing a boost in alertness prior to beginning the day's tasks (Motamedzadeh et al., 2017). From 7:45 to 19:45 (when most tasks, experiments, and EVAs will occur) regular white light will be used. Mimicking a sunset, the LEDs' blue-wavelength content will then progressively decrease and eventually plateau; this blue-reduced, warm white light will remain in place until 21:30, when all LEDs will fade to black. Lunar days will follow the same schedule at a lower overall intensity, accounting for natural light from the Sun. Manual lighting controls located on the LASSLA's faceplate will indicate whether this "Lunar Daytime" setting is on.

Flexibility in the system's schedule, for use before and during prolonged EVAs and experimentation at atypical hours, will be provided by the Dynamic Lighting System Software

(DLSS), which will be used to control the LASSLAs' LEDs remotely using the external Bluetooth antenna attached to each LASSLA's power interface assembly (Greaney, 2023; Maida, 2016). Lunar Gateway crew members and the mission control center (MCC) will have access to two different, interlinked forms of the DLSS. Through the right-hand side of the application's interface, passengers will be able to request specific changes to the regular lighting plan using basic numerical and button-based input in the “Send Request” menu, consisting of the timeframe of altered lighting and desired LED preset (blue-enriched, regular, or blue-reduced white light). Astronauts can also provide written input in the form of a short description of the reason for the requested change (e.g., “EVA, robot arm maintenance”). An outgoing request's information and acceptance status will be visible on the left-hand side of the interface under the “Request Status” menu, along with any comments provided by the MCC. A standard request must be made prior to 7:00, leaving time to discuss with fellow crew members and the MCC. Requests made after this time will be directly viewed by mission control through the “Incoming Requests” tab on the left-hand side of their version of the DLSS without outside interaction between crewmates, allowing for leeway in emergency, late-notice situations. Specifically, after selecting a request in the “Incoming Requests” tab, the “Reviewing Request” menu will display all data fields inputted by the astronaut. A two-button system (approve and reject) will be used beneath this overview of the request. Radio frequency signals will be sent from one of the Gateway's main computers to each LASSLA's Bluetooth component upon the acceptance of a lighting suggestion (Greaney, 2023). Altered schedules will still feature gradual transitions between modes of lighting, and a timeline with color-coded blocks will display the current, real-time updated dynamic lighting plan in the center of the software's interface, labeled “Current Schedule”.

To prepare for the system's usage, along with its corresponding software, astronauts would be given a copy of the DLSS and a sample LASSLA. Multiple mock-up situations would be presented to the crew, including creating both on-time and emergency requests for different lighting types. Prior to conducting mock EVAs during Gateway simulations, astronauts would be expected to fill out a request on the DLSS if needed. For example, a group of astronauts seeking to make repairs to the Gateway's exterior from 19:45 to 20:30 in blue-enriched white light would specify this timeframe and lighting mode, along with describing the EVA in their request; when inside the real Lunar Gateway, the awareness-promoting light would enhance the crew's productivity during this task. Due to schedule changes taking effect throughout the entire Gateway, timeliness and understanding of a request's implications would be emphasized during training. The MCC would also be presented with examples, including early, late-notice, and conflicting requests. As mission control has the power to approve or deny outgoing requests, a multitude of situations with difficult decisions would be proposed, with critical thinking being the focal point of training.

Developing and executing an adaptive dynamic lighting system is key to achieving the Lunar Gateway's ambitious goals, especially those surrounding EVAs in its construction and maintenance. Accessible, request-based software, used to quickly and remotely control light schedules station-wide, allows for increased circadian alignment in astronauts aboard the Gateway in spite of unexpected, late-night tasks. Improved alertness, awareness, and productivity makes circadian lighting paramount to human comfort systems in lunar orbit and justifies extra training for its proper usage.

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