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Joint Augmented Reality Visual Informatics System Project

HID Prototype System Goals for FY22

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November 2021

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This report is available in electronic form at

https://nasa-ext.box.com/s/u0chu6g94l79l8m2f77zt4uqob3pakyq

Change Record

Rev.	Date	Originator	Approvals	Description
Basic	November 2021	Briana Krygier		Initial Release

Verify this is the correct version before use

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Project Intent and Expectations

The Joint AR project goals at the broadest level aim to realize a design that can place as much full color on a spacesuit helmet bubble surface area at a legible viewing distance and focal point as possible. This would be considered the most ambitious end solution. In other words: we should be able to place content of any type: text, graphical, images, video etc. and color anywhere on the bubble and it remains legible for a crewmember to read from within the suit. This ambitious end solution will undoubtably be challenged and impacted the closer we try to integrate with the constraints of an actual spacesuit but for the purposes of this document, MIT should strive to realize as much of this ideal state as possible.

Section 1 and 2 of this document detail goals for the Joint AR prototype for FY22. Section 3 of this document includes considerations for the flight version of Joint AR. While, these are not included in the goals for the FY22 prototype, the system designers should not make design decisions that would preclude the design from meeting the flight considerations in the future. This partnership will focus on MIT designing optical components, while NASA integrates and provide feedback to MIT on limitations to the design to maintain compatibility with the suit constraints. MIT should generate a design that utilizes an existing image source technology. NASA has baselined and selected a TI DLP3010 as the image source through prior trade studies and environmental testing. If MIT identifies a better technology to use in place of the DLP, NASA is open to discussion regarding design changes.

Definitions

Field of view (FOV) is what the eye can see at one point while the head remains static.
Field of regard is the sum of what the eye can see when you move your eyes around and when you move your head around.
Horizontal line of sight is parallel with the angle of elevation with an inclination of 0 degrees.
Normal line of sight is defined -15 degrees below the 'horizontal line of sight.'
See Figure 1 and 2 for visual summary of these definitions.
TBR is 'to be refined'.
HID is 'heads-in-display.'

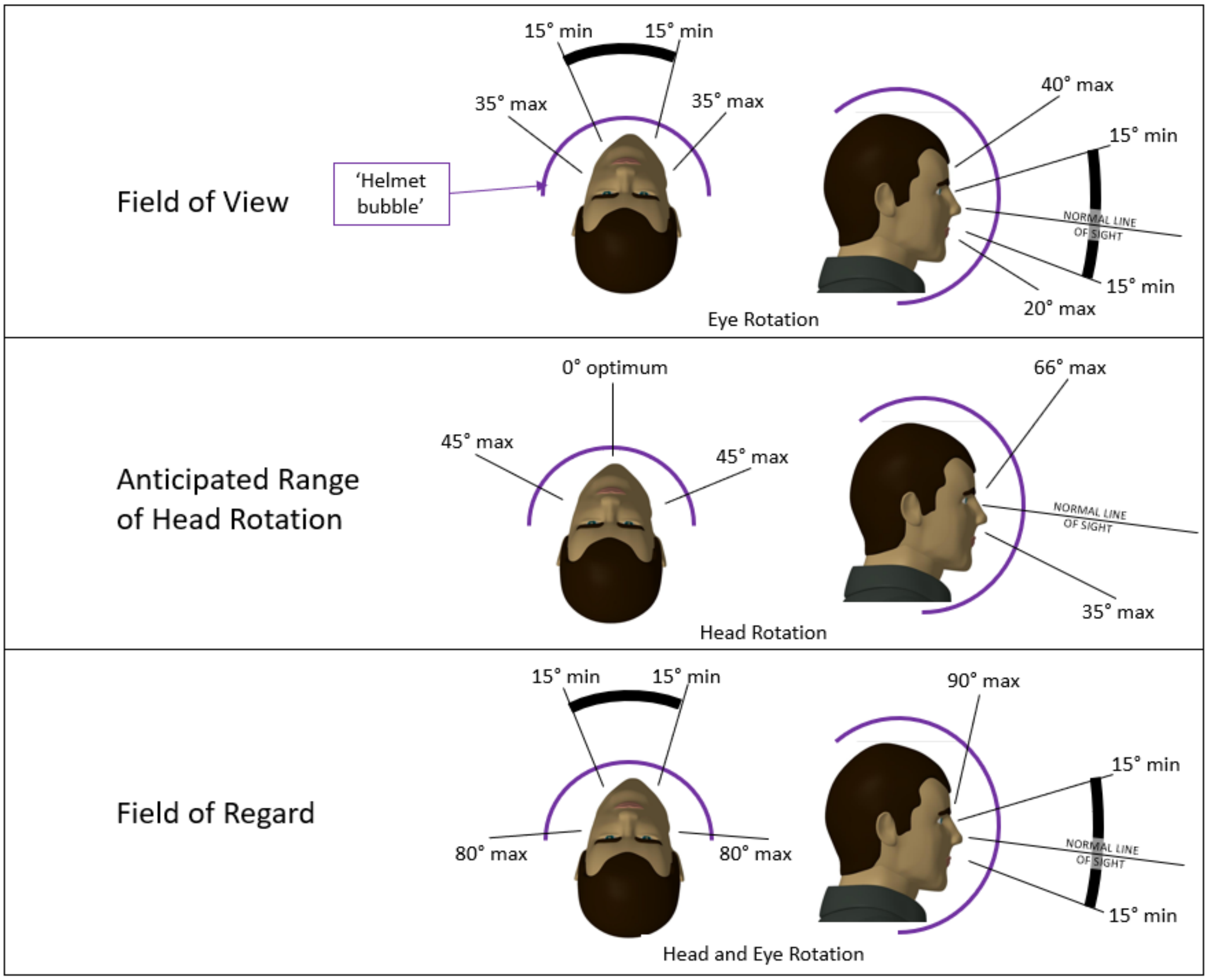

Figure 1 – Helmet Field of View and Field of Regard Definitions

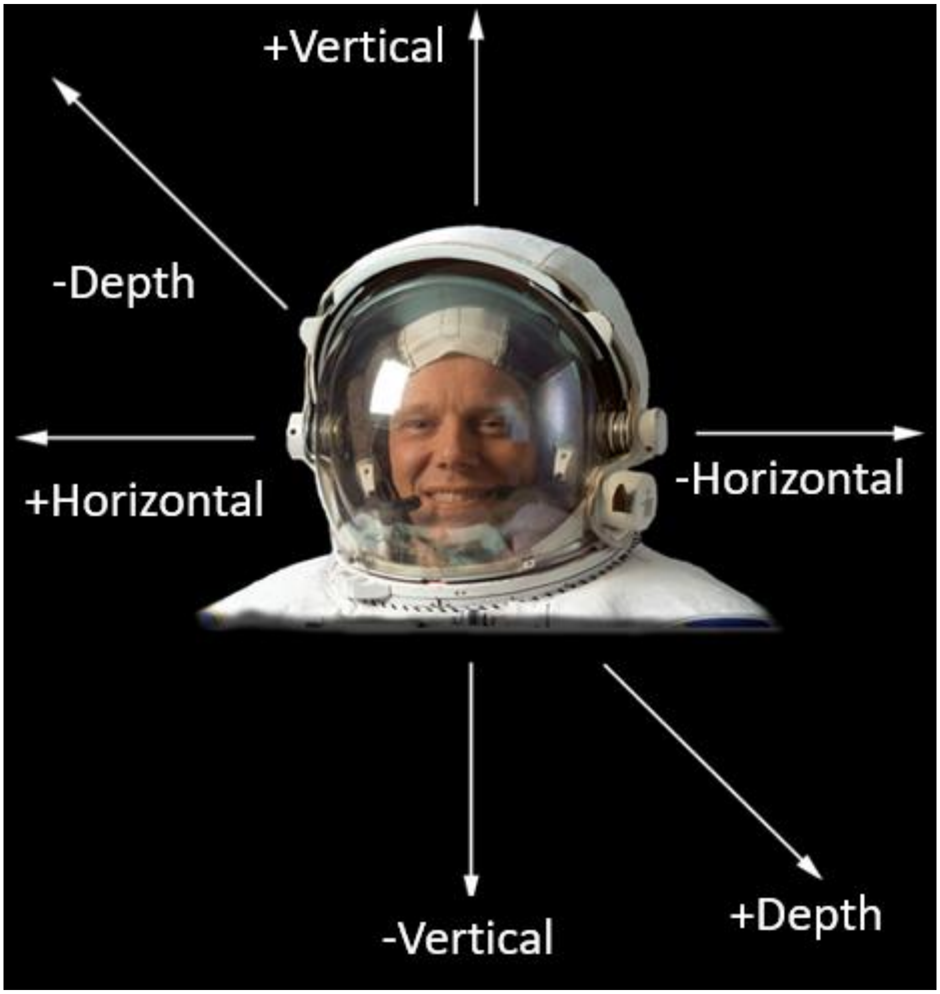

Figure 2 - Helmet FOV Coordinate System Definitions

1. Functional / Mechanical

1.1. Display Configuration

Goal: The display system should be helmet-mounted and decoupled from the user's head.

Rationale: Decoupling the display from the head will eliminate the possibility of the display becoming misaligned from the user's eye. Also, crewmembers have expressed a strong desire to keep head-mounted systems to a minimum.

1.2. Helmet Mounted Optics Weight

Goal: The display system optics should be designed with the intent of minimizing mass of the system.

Rationale: System mass is a priority for system evaluation even at the early design stages. Thus the helmet mounted display system must exhibit a low mass even in this initial design stage. Associated support electronics mass is separate from Helmet Mounted Optics Weight.

1.3. Durability

Goal: System should be mobile, ruggedized and be able to maintain functionality during daily usage.

Rationale: System will be used in field tests and needs to survive multiple users and numerous hours of human testing.

1.4. Testing Platform

Goal: The display system prototype should mount to the wearable 3D printed technology demonstrator suit upper torso. 3D printed technology demonstrator suit upper torso is NASA provided hardware, the contractor will be provided CAD models of a non-export-controlled suit for context awareness. Disclaimer: The non-export-controlled suit models are publicly available and are not being endorsed by NASA as accurate models of xEMU. MIT will need to provide mounting specifications that NASA will then integrate into the 3D printed technology demonstrator suit. NASA will be responsible for determining specific mounting locations on the suit.

Rationale: The 3D printed suit upper torso is the closest available analogous suit for testing a helmet mounted display.

1.5. Eye Relief

Goal: The display should have an eye relief suitable for eye positions with a large range of 'near eye' to several inches from the eye.

Rationale: The eye relief needs to allow the display to be mounted on the helmet and viewed with the user's head angled toward the display. Exact positioning of optical components will be jointly developed through this research endeavor this fiscal year.

1.6. Optical Element Volume Envelope Regarding Protrusion into Helmet Bubble

Goal: The display's final optical elements should maintain a slim profile similar to the surface of the helmet bubble. Referencing figure 3 – the optics volume for elements outside the user's field of view is larger than for the element's in the user's field of view.

Rationale: Keeping the display optics close to the helmet bubble will prevent the display from impeding upon the suit volume of the user. Large optics elements inside the user's central field of view would be very intrusive while performing tasks, but would interfere less with tasks if placed outside the user's central field of view.

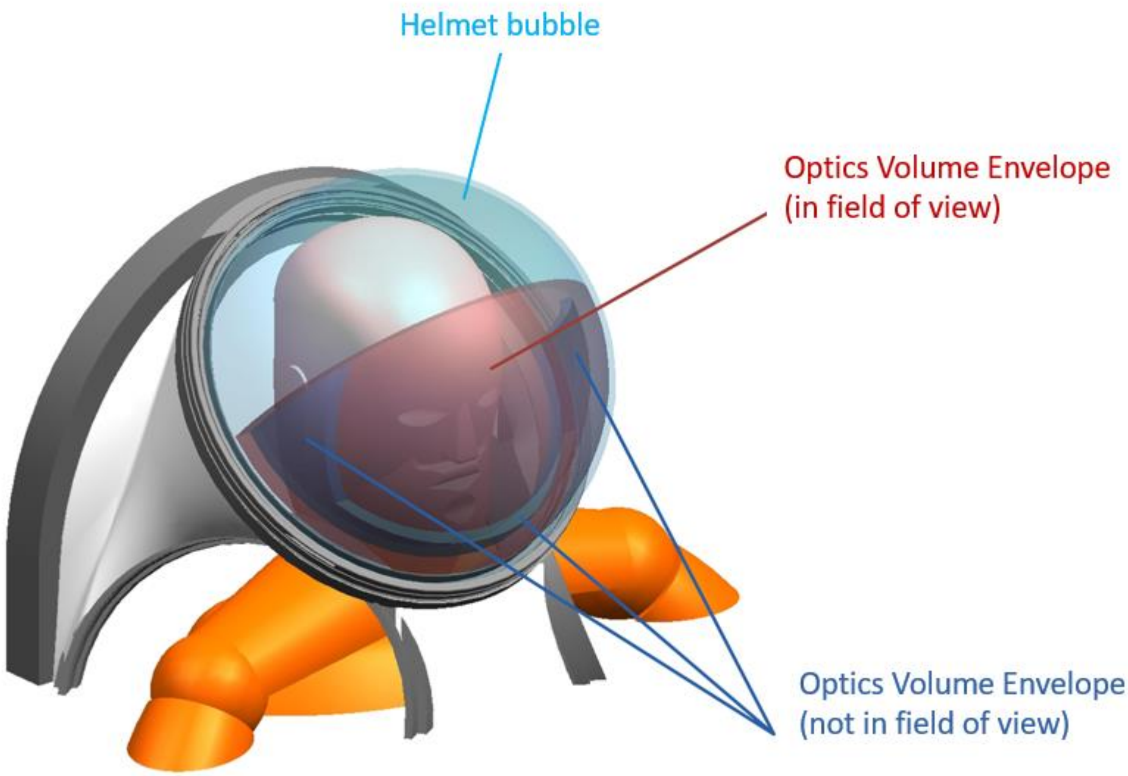

Figure 3 - Optical Volume Envelopes

2. Optical

2.1. Optics See-Through Transmission

Goal: The display system should be highly see-through. Transmission of the system should meet a minimum of 50%, but have a goal of 80% or better.

Rationale: The display system will be in the user's field of regard and needs to be highly see-through to avoid interference with EVA tasks. 50% would be similar to conventional HUD beam combiner. 80% is a level that is relatively hard to detect for typical user.

2.2. Eye Box

Goal: The display system should have a large eye box. Minimum of 25mm x 25mm x 25mm. Goal of vertical 85mm x horizontal 25mm x depth 60mm would accommodate a variety of users, while an ideal goal of vertical 130mm x horizontal 100mm x depth 125mm of would accommodate head movement within the suit. Eye box numbers are assuming a monocular display, for binocular display the eye box size is replicated for either eye.

Rationale: This will allow for the display system to be tolerant of head movement as well as accommodate the large anthropomorphic range of users. This will also allow the display image to be easily located.

2.3. Color Depth

Goal: The display system should be a full color display, but a monochrome display is acceptable as an initial intermediate solution.

Rationale: The helmet mounted display should be capable of displaying crew procedures and instructions, consumables and system information, and photos and video view.

2.4. Apparent Distance

Goal: As a minimum, the display system should have a fixed focus display with an apparent image distance that reduces strain between accommodating reading the display with viewing the user's surroundings. Apparent image distance should be 13 inches at a minimum. An adjustable focus display is highly desirable with an apparent image distance of 13 inches to infinity.

Rationale: Having an adjustable focus will allow the user to tailor the display for their most comfortable viewing distance. As a minimum, the display should be focused at a comfortable reading distance.

2.5. Pixel Density

Goal: The display system virtual image should have a pixel density of at least 47 pixels per degree (ppd).

Rationale: NASA 3001 standard requires minimum 32 ppd, 60 ppd would be nearing the upper limit of what the human eye can resolve, meanwhile typical AR helmets are around 47 ppd. 47 ppd would give a middle ground between having a large display for information while also providing clarity for the user to clearly resolve the image.

2.6. Apparent Image Field of View

Goal: The apparent image field of view should be located within the reasonable range of head rotation. The apparent image field of view should be located within the normal range of line of sight for the vertical field of regard. This is depicted in Figure 1 – this figure details minimum and maximum expectations - minimum field of view of 30 degrees and maximum of 70 degrees. Note the vertical field of view is referenced from the 'normal line of sight' in figure 1 (see also Definitions).

Rationale: A 95th percentile human has limited head rotation while in the suit which limits usable horizontal field of regard – they cannot completely rotate their head without interfering with the suit structure. For ease of viewing the display, this image location was selected to keep the display in the user's reasonable line of sight.

2.7. Field of Regard Interference

Goal: The display should not interfere with the central horizontal field of regard. Figure 1 and 2 define the field of regard coordinate system.

Rationale: The display should not interfere with visuals necessary for core operation of the suit e.g. the DCU display, the display should not interfere with central field of regard.

2.8. Brightness

Goal: The apparent brightness of the display should be adjustable from 149 cd/m^2 to 7448 cd/m^2 minimum (TBR).

Rationale: A bright display will allow it to be viewed in a variety of lighting conditions. These values were calculated given a minimum contrast ratio of 1.2 for the range of lighting conditions on the lunar surface and assumed a bubble/display transmission of 80%. See Appendix A for discussion on how these values were determined. These values will be refined and limited by the Joint AR allocated power budget.

2.9. Contrast

Goal: The display system should have a high contrast ratio of greater than or equal to 100 to 1, while viewed with an unlit black ambient background scene.

Rationale: A high contrast ratio, when combined with the other system specifications, will allow the display to clearly depict images and text to the user without causing eye strain.

2.10. Contrast Transfer Function

Goal: Using the user viewed display zones in Figure 4, the display system should have a contrast transfer function better than 60% in Zone 1 at the display source resolution.

Rationale: The display system's optical performance will be a priority in evaluation of the system, thus the system design must be designed to achieve a high contrast transfer function.

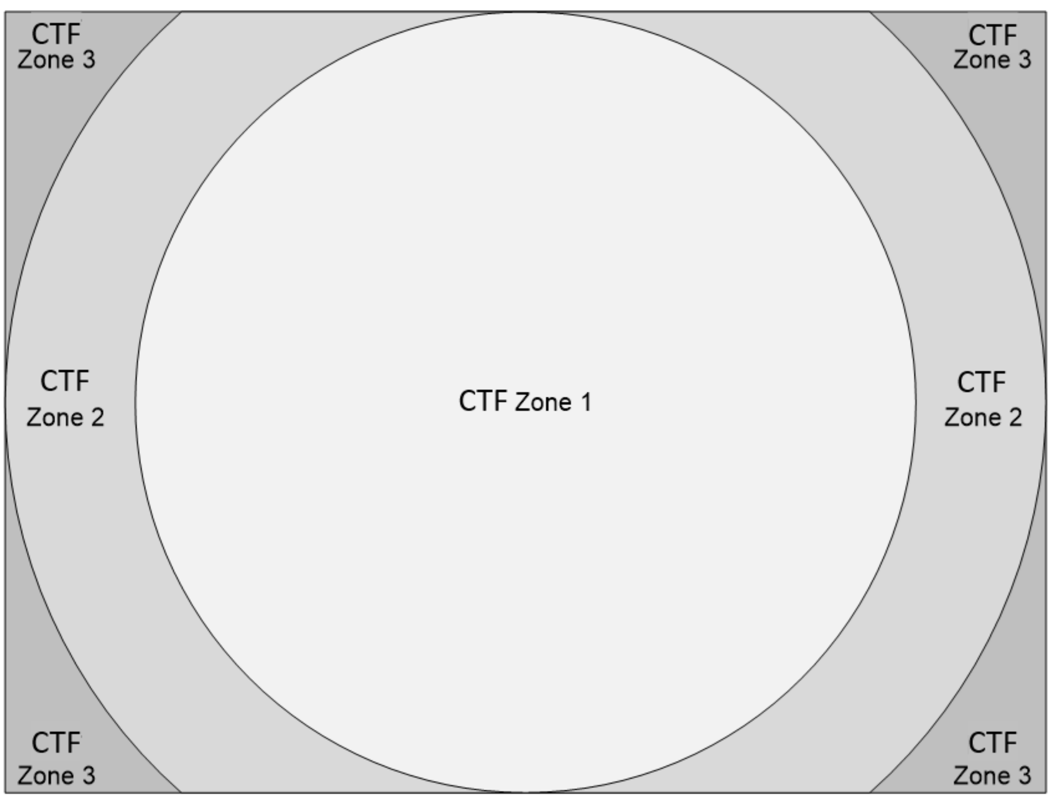

Figure 4 - CTF Zones

2.11. Illumination Uniformity

Goal: The display system should have highly uniform illumination across the field of view. Illumination uniformity is most important in the center of the display and may be lower towards the display edges.

Rationale: The display system's optical performance will be a priority in evaluation of the system, thus the system design must minimize illumination non-uniformity across the field of view.

2.12. Optical Aberrations

Goal: The display system should be designed to minimize optical aberrations

Rationale: The display system's optical performance will be a priority in evaluation of the system; thus the system design must minimize observable aberrations. Aberrations include but are not limited to geometric distortion and field non-uniformity. Geometric distortion is defined as the percent deviation of a point from its paraxial location. The aberrations should not interfere with the user's ability to discern text, symbology, and image content from the display.

2.13. Ghost Reflections

Goal: The display system should be designed to minimize ghost reflections.

Rationale: The display system's optical performance will be a priority in evaluation of the system; thus the system design must minimize observable reflection. The display system must not create reflections that interfere with the crew's ability to view the display and the environment. Reflections should not interfere with user's ability to discern text, symbology, and image content from the display.

2.14. Optical System Power Efficiency

Goal: The combined power efficiency of the optical components in the system should be highly efficient.

Rationale: The suit is power limited; thus, the Joint AR display system is power limited. In order to reduce Joint AR system power, the optical system needs to be efficient with the light provided by the projector. A majority of the projected light should be passed to the user's eyes.

3. Future Compatibility

3.1. Materials Compatibility

Goal: The system materials should be able to withstand the expected environment inside and outside of the EVA suit on the lunar surface.

Rationale: Inside the suited environment is 100 percent oxygen. All components interior to the suit must be compatible with this environment in the final design stage thus this must be a factor in system evaluation in the early design stages. Components outside the suit should withstand environmental factors including but not limited to ultraviolet light, extreme temperatures, and vacuum pressures. As parts of this system will be exposed to the lunar environment, the system should be resilient to particulate contamination with limited impact to the optical properties of the system and electronic components. While this initial development phase system is not required to operate in a lunar environment, the later development phase designs will need to be compatible with the lunar environment.

3.2. Users with glasses

Goal: The system should accommodate users who requires prescription eye glasses to perform daily functions.

Rationale: Given the general population need for prescription eye glasses and proximal age of crew members for future spaceflights, the use of prescription and/or reading glasses will become an increasing factor in normal spaceflight operations.

Appendix A – Luminance

The reference paper by Foote, B. (1998) Design guidelines for advanced air-to-air helmet-mounted display systems. *Proceedings of the SPIE, Helmet- and Head-Mounted Displays III,* presents a notional HMD configuration closely analogous to a Space Suit HMD. A minimum contrast ratio (CR) of 1.2 is required (using formula CR = (Lo + Lhmd)/Lo, Where Lo is background Luminance, and Lhmd is luminance of the HID).

With the 1.2 minimum CR for Joint AR, on worst case lunar lighting scenarios:

1) Assuming lunar asset with large thermal blanket that has 90% diffuse reflection, the Luminance coming off it is 130000 lux / pi = 41380 cd/m2
2) Assuming a bubble transmission of 80% (more realistic) the required luminance is **7448 cd/m2**

It could argue that in these scenarios, the crew would have to have their sun visors, down:

1) Assuming same lunar asset with 41380 cd/m2 coming off the surface, no viewed through sun visor (approx. 15% transmission) the apparent luminance is now 6207 cd/m2.
2) Assuming a bubble transmission of 80%, the required luminance is **993 cd/m2**

The low ambient lighting condition for lunar surface operation with sun visor down:

1) Assuming same solar illumination of 130000 lux lunar surface (15% reflectance) the surface has a luminance of 6207 cd/m2, now viewed through sun visor (approx. 15% transmission) the apparent luminance is now 931 cd/m2.
2) Assuming a bubble transmission of 80%, the required luminance is **149 cd/m2**

Above values should be recalculated if the transmission of the system changes from 80%.

These calculations are not without caveats. The above values for HID luminance are “apparent luminance”, meaning the luminance reaching the user eye. Our configuration with the image source outside the bubble, means the display source will need to produce higher luminance levels, such that by the time the image gets through the bubble and/or sun visor, meta lens, nanoparticles, etc., with the resulting attenuation, yields a luminance level listed above. Also, in the sun visor down configuration, because our image source is outside the bubble and sun visor, the sun visor would need to be fabricated to be wavelength sensitive (ie. effectively a narrow band pass filter that allows display wavelength to pass through, while attenuating all other visible wavelength). Otherwise the sun visor is simply attenuating both the ambient background and the display image equally, which won’t help contrast. The wavelength sensitive sun visor is something the Joint AR team will be looking into recommending for the xEMU design, but this may not be possible depending on xEMU design maturity.