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DESI Camera Specification

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1 Scope of Document

This document specifies requirements for the DESI spectrograph camera units and is a supporting document to a request for proposal to fabricate the cameras. It is not intended for construction of the spectrograph.

2 Description

2.1 Background

The DESI project will field a set of ten multi-object spectrographs at the Mayall 4m telescope at Kitt Peak. The spectrographs will be located in a remote, stable, temperature controlled laboratory environment (i.e. not attached to the telescope). Each spectrograph, shown schematically in **Error! Not a valid bookmark self-reference.**1, includes three independent spectral channels, 'Blue', 'Red', and 'NIR' mounted onto a common optical bench. A common collimating mirror and dichroic beam splitters feed light to the channels. The spectrograph objects are a linear array of 500 optical fibers arranged into a V-groove array on a convex surface. The spherical *collimator* mirror approximately collimates a fiber's f/4.0 output beam. The fibers' collimated beams then strike a flat fold mirror and are directed into three different color channels via two dichroic beam splitters. Each channel consists of an independent sub-bench whereon light is dispersed by a volume phase holograph grating (VPHG) into a transmissive *camera unit* and then focused onto a CCD sensor residing in a windowed cryogenic vacuum chamber. Each camera unit's optics is divided into a *lens barrel assembly* and a *field lens assembly* wherein the lens is mounted as the hermetic window for the sensor chamber. The end result on each sensor is to record a separate spectrum for each fiber object where the spectral direction is parallel to VPHG dispersion and the imaging direction is parallel to the object array.

Notional optical designs for the camera units are described in the Applicable Documents. These notional designs include complete spectrograph configurations for the cameras' illumination and are detailed in a Zemax parameter file. The notional design Zemax file constitutes a specification of the optical input function provided to the cameras.

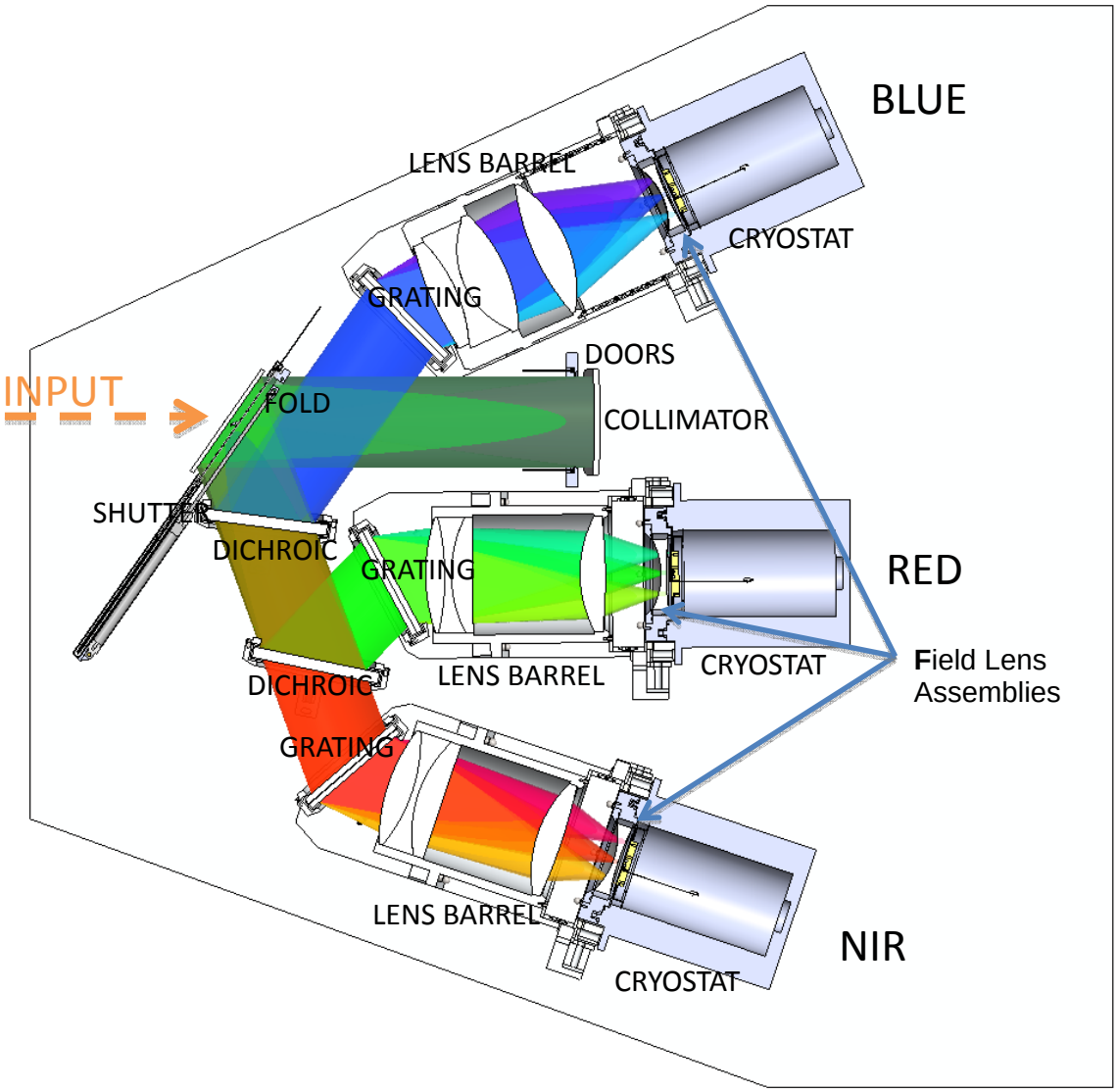

Figure 1 DESI Spectrograph Schematic. Gravity is perpendicular to illustration plane.

3 Applicable Documents

Requirement specified in this document shall take precedence over requirements referenced in other documents.

3.1 Government Documents

Portions of the following documents are referred to in this document.

DOCUMENT #	DATE/REV.	SUBJECT (TITLE)
IEST-STD-CC1246D	2002	Product Cleanliness Levels & Contamination Control Program

3.2 Project-level Publications

The following system documents form a part of this specification.

FILENAME	DESCRIPTION
DESI-0211-v2.zip	DESI Notional Design Zemax Archive File
DESI-0212-v2.pdf	DESI Camera Mechanical ICD
DESI-0213-v2.zip	DESI Alternate Glass Combination Zemax Archive File
DESI-0215-v2.pdf	DESI Spectrograph Lens Bond Strength Analysis

4 Optical Performance

4.1 Pass band

The operating pass bands for the camera unit channels are shown in Table 1.

Channel	**Blue**	**Red**	**NIR**
$\lambda_{minimum}$ (nm)	360	566	747
$\lambda_{maximum}$ (nm)	593	772	980

Table 1 Pass-Band Specification

4.2 Throughput

The end-to-end throughput requirements for each of the three camera units are shown in Table 2. These values refer to average performance over the entire camera field and band pass, presuming unpolarized light.

Item	**Specification**
Blue Camera Throughput	>86 % for λ = 360 nm >90 % for λ =600 nm
Red Camera Throughput	>92.5% for λ = 560 nm >92 % for λ = 650 nm >93 % for λ = 780 nm
NIR Camera Throughput	>92.4% for λ = 740 nm >91 % for λ = 980 nm
Linear between specified wavelengths and applied to the pass band of Table 1	

Table 2 Throughput Specification

4.3 Camera Unit Imaging

The imaging specifications are shown in Table 3. Each channel's diffraction grating disperses nearly parallel-beam incident light at an approximate pupil to the camera. Imaging performance requirements are chromatic in the dispersion dimension. Stated differently, the camera design will only achieve geometric blur requirements when tested at the actual wavelength associated with a given location on the detector.

Imaging requirements shall be met with compensated manufacturing tolerances. The manufacturing tolerances and compensation technique shall be described. These performance requirement values presume that a uniform f/4.0 beam emanates from a point source and illuminates the spherical Collimator to feed the camera, as detailed per the referenced Zemax file. The Maximum Optical RMS radius is the maximum allowed RMS radius of the optical spots (for all field angles).

	Channel	**Channel**	**Channel**
Parameter	**Blue**	**Red**	**NIR**
Maximum Optical RMS Radius	< 12 µm	< 12 µm	< 12 µm
Angular field size (degree) *	7.72°	7.72°	7.72°
Spectral field (nm)	360- 593 nm	566- 772 nm	747- 980 nm
Spectral field size (degree) **	8.06°	8.03°	8.03°
* At the central field angle. See the Notional Design for details			
** At the central wavelength. See the Notional Design for details			
Table 3 Imaging Specifications			

4.4 Focal Length

The effective focal length specifications are shown in Table 4.
The focus axial location shall not change by more than 5 µm/C for temperatures from 18-22C

Item	**Specification**
Blue Camera Focal Length	212.8 +/- 1 mm
Red Camera Focal Length	213.6 +/- 1 mm
NIR Camera Focal Length	214.0 +/- 1 mm
Specified at the band pass central wavelength, over temperatures from 18-22C	
The CCD active area is 60.26 mm in the spectral direction and 60.02mm in the imaging direction	
Table 4 Effective Focal Length, CCD Area Specifications	

5 Camera Unit

The Camera Unit ICD DESI-0212 shows interface requirements necessitated by the spectrograph and by the use of the Lens Barrel Assembly together with the Field Lens Assembly. The ICD defines proposed boundaries for the Camera mechanical elements, their relation to the focal plane, material specifications, metrology features, and interface details.

5.1 Lens Barrel and Field Lens Assemblies Relative Location

The Camera Unit consists of two separate subassemblies, the lens barrel assembly and the field lens assembly, which shall be aligned and tested together as a single optical camera unit. Following delivery, the customer will attach the LBA to the channel bench and the FLA to a sensor cryostat. Each attachment may include multi-axis adjustment features that can be used to tune the assembly's precise relative location.

The barrel and field lens assemblies shall include accessible fiducial reference points to allow for the correct and aligned relative positioning of the units as determined by the manufacturer and reported with a precision of 20μm (TBC) at 20C +/- 0.5C. Proposed fiducial features are shown in the ICD drawings. Alternate schemes and references for this metrology purpose may be used.

5.2 Lens Barrel and Field Lens Assemblies Materials

The Camera Unit ICD drawings show the sequence of intervening materials between the LBA mounting flange plane and the FLA mounting planes and between the FLA mounting plane and the CCD sensor focal plane. The presumed type and thickness of the materials are shown. This information may be used to design thermal compensation for the Camera units so that optical performance over the specified thermal operation range will be satisfied.

The majority of the intermediate structure between the LBA and the FLA is the channel bench, preferably to be made of aluminum 6061-T6. The optical bench may be made of an alternate material with a thermal expansion coefficient similar to that of common and readily machinable metals. The FLA mounting surface is made of stainless steel 304L. The FLA mount shall be made of similar material.

5.3 Focus Method & Access

The Camera Unit design shall allow for adjustment of the optical focus on the CCD sensor to compensate for as-built spherical wavefront errors in the spectrograph feed optics, and possibly for as-built compensation within the Camera optics. The spectrograph feed optics errors will not exceed 5 waves (TBC) (λ=632 nm) for the Blue channel and 9 waves (TBC) (λ=632 nm) for the Red and NIR channels.

The method and range of focal adjustment is TBD and may include (a) the axial positioning as a single unit of either the FLA and CCD sensor together, or equivalently the LBA, or (b) the axial adjustment of a lens internal to the camera barrel. In the case (b), the focus mechanism and its accessibility and fixation following adjustment shall be detailed.

5.4 Optical Scattering, Baffling & Cleaning

The camera design shall minimize stray light propagation and scattering.

The outer edges of lenses, lens barrel and lens clamp surfaces visible to the focal surface shall be coated with low reflectivity and low scatter material having < 5% TIS (e.g. Z306 paint) that is compatible with adjacent materials such as optical coupling oils or gels.

Glass optical elements shall be polished to a low scatter surface roughness (<20Å RMS isotropic).

CaF2 optical elements shall be polished to a low scatter surface roughness (<50Å RMS isotropic).

The field lens shall include a planar extension of at least 10 mm in radius beyond the working clear aperture. The extension and lens edges shall be coated with low reflectivity and low scatter material having < 5% TIS (e.g. Z306 paint).

Particulate cleanliness Level 300 shall be maintained within the lens barrel assembly.

Particulate cleanliness Level 500 shall be maintained on external optical surfaces.

Ghost reflections within the working image field shall not exceed an irradiance of 10^{-5} (TBC) relative to the incident object irradiance, over more than 1% (TBC) of the image field area.

Cleaning procedures for supplied components shall be compatible with materials, cleanliness levels, and vacuum exposure, where required. Cleaning procedures shall be specified prior to production.

5.5 Clear Aperture

Optics and mounts within the lens shall be oversized so that no vignetting occurs if the chief ray at the entrance pupil, compared to its ideal location, is shifted laterally by +/- 2.0 mm (TBC) and in angle by +/-6 arc minutes (TBC).

6 Camera Lens Barrel Assembly (LBA)

6.1 Optical & Mechanical Interface

The Camera Unit ICD DESI-0212 shows the Lens Barrel Assembly interface requirements necessitated by the spectrograph and the Field Lens Assembly. ICD constraints include the allowed envelope, structural mounting and positioning features, baffle mounting interfaces (8x M3 holes at detector end), the optical axis location, and alignment and metrology features.

Bidders may request departures from the ICD specifications and should be aware of close mechanical constraints at the optical entrance to the LBA.

The LBA shall include protective covers installed over both input and output apertures.

Bidders shall estimate the LBA mass.

7 Field Lens Assembly (FLA)

7.1 Optical & Mechanical Interface

The Camera Unit ICD DESI-0212 shows the Field Lens Assembly interface requirements necessitated by the spectrograph, the cryostat and the Lens Barrel Assembly. ICD constraints include the allowed envelope, structural mounting and positioning features, the interface material, high vacuum features, the optical axis location, and alignment and metrology features.

Bidders may request departures from the ICD specifications and should be aware of close mechanical constraints between the rear face of the FLA and the CCD sensor within the cryostat.

The FLA shall include protective covers installed over both input and output apertures.

Bidders shall estimate the FLA mass.

7.2 Radioisotope Content

The FLA lens shall limit the use radioactive coatings or materials. Coatings shall have U ≤ 80 ppm, Th ≤ 250 ppm, and K ≤ 3.0 % (by weight), assuming a total coatings thickness of 100 µm. This will likely rule out using ThF4 and ThOF2. Glass materials shall not include elements with significant natural radioactive isotope content, such as K,U and Th.

7.3 Cryo-Vacuum operation

The camera optical performance requirements shall be met when the FLA is subject to vacuum and the CCD is operating at cryogenic temperatures.

The field lens operates under a pressure difference from external atmospheric pressure on the lens barrel side to high vacuum (10^{-6} mbar) on the sensor cryostat side. The field lens may also be subject to internal pressurization during cryostat venting operations, not exceeding 1.33 atmospheres. Consequently, the field lens assembly shall include high-vacuum sealing features to the cryostat and to the field lens and shall accommodate the possibility of internal overpressure.

The FLA vacuum total vacuum seal leak rate shall not exceed 10^{-8} mbar liter sec^{-1} (TBC) under 1 atm external pressure.

The field lens assembly shall be made with best practice for safe cryogenic vacuum or pressure operations and shall be verified by analysis or test to survive the pressure conditions. The lens shall not have any internally radiused steps, and all surfaces shall be polished or acid-etched. Analysis shall show the lens to have a maximum principal stress less than 4.5MPa under 1.0 atm (101kPa) external pressure and a maximum principal stress less than 6.7Mpa under 1.33 atm (135kPa) internal pressure. Alternatively, testing shall show the lens to survive 101kPa external pressure and 135kPa internal pressure, each for 24 hours at room temperature.

The vacuum side of the field lens will likely be located close to but no less than 3 mm from the cryogenic CCD active face that operates at about -100C. Consequently the field lens will operate substantially below ambient temperature. The mounting surface to which the field lens assembly is attached will operate at a temperature of approximately 20 C.

Field lens performance in the Notional Design is not significantly affected by the anticipated temperature, temperature gradient, or pressure gradient environment, according to UCB analysis. Alternative field lens designs shall consider these effects.

8 Environmental Specification

The environmental specifications are given in Table 5.

All specifications (throughput, imaging, etc.) must be met over the operational environmental range.

The cameras must still be able to perform to specifications when returned to operational ranges after being exposed to the survival environmental range.

The throughput must meet the specifications after being exposed to the operational environments for 10 years.

The camera unit as packed for shipment may be subject to shock, thermal and pressure conditions. The camera units shall be handled & shipped in such a way as to not exceed the specified survival environment. The survival range may be modified to reflect expected shipping conditions.

Lenses must use densified coatings or equivalent to ensure satisfaction of operational vacuum and humidity requirement. MgF_2 coatings shall not be used in 100% humidity conditions.

Bonded lenses shall be subject to an analysis and test program for like materials, configuration and environmental conditions as expected for the Camera lens elements. Bonded or oil-coupled lens assemblies shall be verified as environmentally sound by test using three temperature cycles through the survival temperature range at a minimum temperature slew rate of 20 C/hour, with each cycle including thermal soaks at the extreme temperature limits of no less than 12 hours.

Table 5 Environmental Specifications

Environment	**Specification**
Operational Temperature	20°C ± 2°C
Operational Humidity	0 to 85% RH
Operational Humidity, FLA, exit surface	0 % RH
Operational Pressure	0.7 to 1.0 atm
Operational Pressure, FLA, exit surface	10^{-6} mbar
Lifetime	10 years
Assembly Natural Harmonic Frequency	> 100 Hz
Survival Temperature*	-20°C to +40°C
Survival Temperature Rate of Change*	20 °C / hour
Survival Humidity, FLA entry surface	100% RH (condensation)
Survival Humidity	95% RH
Survival Pressurization*	0.13 to 1.0 atm in 45 minutes
Design Limit Load, any axis*	10 g
* As packed for shipment. Alternate levels may be considered	

9 Acronyms

Acronym	Definition
ASSY	Assembly
BBAR	Broad Band Anti Reflection (Coating)
CCD	Charge Coupled Device
CFE	Customer Furnished Equipment
FLA	Field Lens Assembly
FWHM	Full Width at Half Maximum
LBA	Lens Barrel Assembly
NIR	Near Infrared
RH	Relative Humidity
TBC	To Be Confirmed
TBD	To Be Determined
TIS	Total Integrated Scatter
UCB	University of California, Berkeley
VPHG	Volume Phase Holographic Grating