An In-Vacuum X-ray Exposure Device for CCD Characterization

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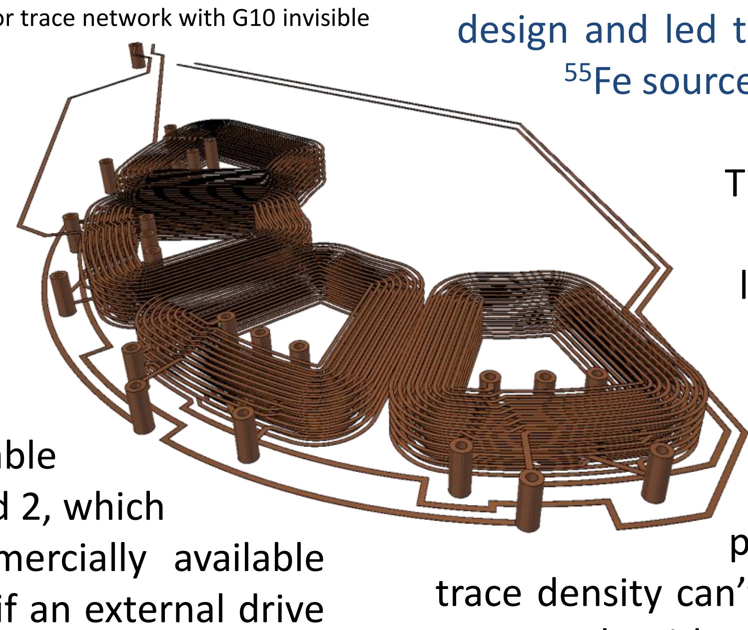
Introduction:

The usefulness of x-rays for measuring charge diffusion and CTE in CCDs is well established. A practical limitation of working with the kα and kβ energies of one of the more common and useful x-ray sources for CCD characterization, ^{55}Fe, is that objects are very opaque to this light. Experimental setups that operate astronomical CCDs always require a vacuum vessel, which immediately precludes the possibility of illuminating the sensor with an external ^{55}Fe source. Methods for realizing this diagnostic method typically fall into one of three categories:

1. A dedicated ^{55}Fe vacuum cover which replaces the vacuum window just for the measurement.
2. A motion vacuum feedthrough which allows the source to be positioned as desired with respect to the CCD.
3. An electric motor or actuator within the vacuum with a mechanism to deploy or uncover the source.

PCB stator trace network with G10 invisible



The labor intensive nature of method 1, which is not amenable to automation, and the mechanical complication of method 2, which generally needs significant space to realize with commercially available vacuum components and is similarly expensive, especially if an external drive mechanism is used for automation, led us to consider deploying an electronic exposure device within the vacuum environment.

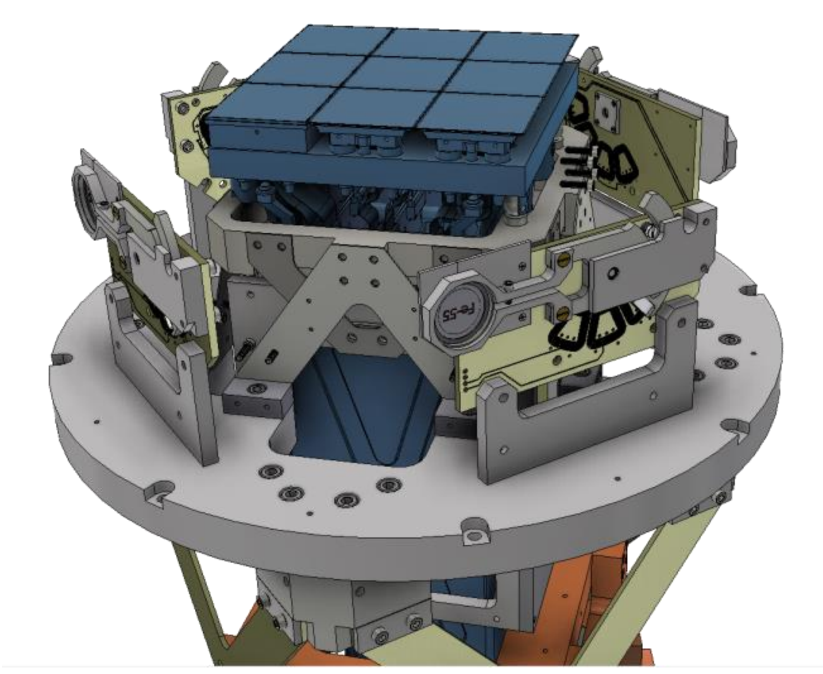
Background:

In the context of Large Synoptic Survey Telescope CCD development, the first version of an in-vacuum electronic x-ray exposure device was designed in 2007 by S. Plate using a commercially available ultra-high vacuum motor and a cam mechanism attached to an arm which carried the x-ray source for deployment. This system was used successfully for several years, until intermittent reliability issues arose from the cam mechanism, which would occasionally bind when the device was in certain orientations.

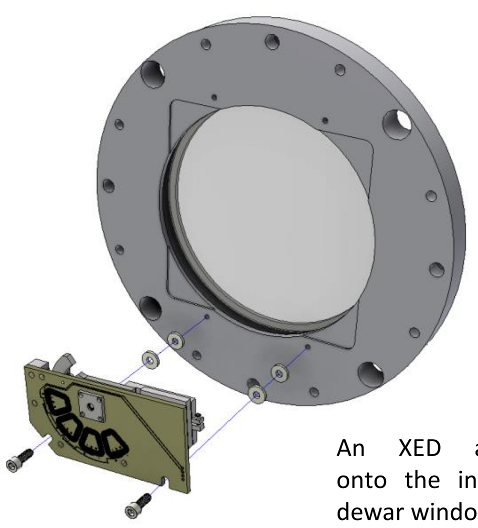
The allure of designing a more reliable and elegant solution led to the apparatus presented here.

Design:

Conventional electric motors are usually incompatible with high vacuum environments. The stator windings entrap air and machine oil and the bearings require lubricant. Many of the common materials are also prone to oxidation. High-vacuum-compatible motors are commercially available but tend to be expensive and weak for their mass.



Four XEDs installed in a large cryostat (the LSST Commissioning Camera) in an orientation which exposes the CCD array near grazing incidence. A variation on the source carrier design is implemented in this arrangement which places the standard isotope packaging as close to the mechanical extent of the carrier mechanism as possible to minimize the gap needed between the CCDs and chamber window. P. Kuczewski designed a version of the controller that handles four XEDs simultaneously.

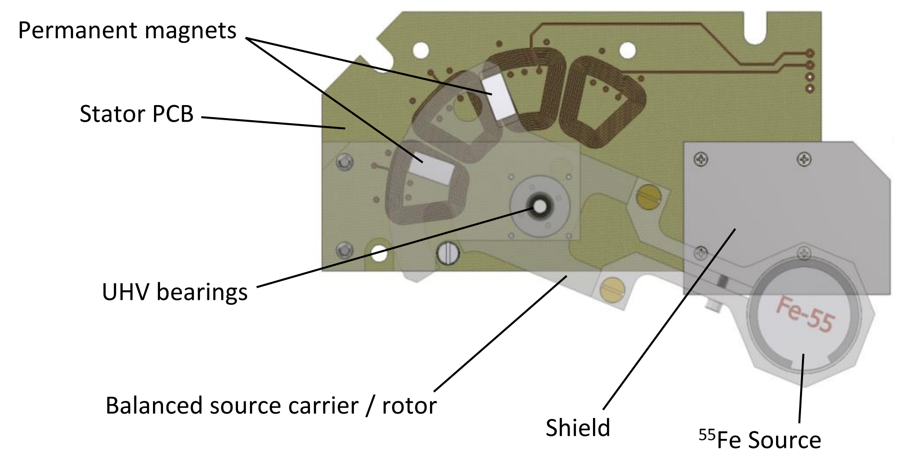


An XED assembled onto the inside of a dewar window cover

The principle of operation for any such device is that the radioisotope, mounted to an actuated carrier arm, can be positioned over either the CCD under test or out of the optical path behind a shield. The **X-ray Exposure Device (XED)** presented comprises an original actuator motor that was fabricated at the BNL Instrumentation Division using conventional printed circuit board manufacturing methods. To eliminate the possibility of virtual leaks from normal motor windings unconventional stator coils were designed into a monolithic PCB, thus making an intrinsically vacuum-compatible foundation for the rest of the device. The flat nature of the stator drove the design and led to a direct-drive scheme in which the rotor doubles as the ^{55}Fe source carrier; the only moving part.

The motor formed can be described as a flattened permanent magnet synchronous motor. The stator is a 6 layer PCB, thick enough also to function as the mechanical baseplate. It is tempting to visualize each coil element as an electromagnet, but in reality the motive force is generated when the permanent magnets on the rotor pass over the radial traces on the coil elements. The primary disadvantage of using a PCB in this way is that the trace density can't approach that of a conventional winding, so the motor is very weak with a torque of only 3.8*N-Cm*. This makes the balance of the rotor/source carrier critical, as well the friction inherent in the bearings.

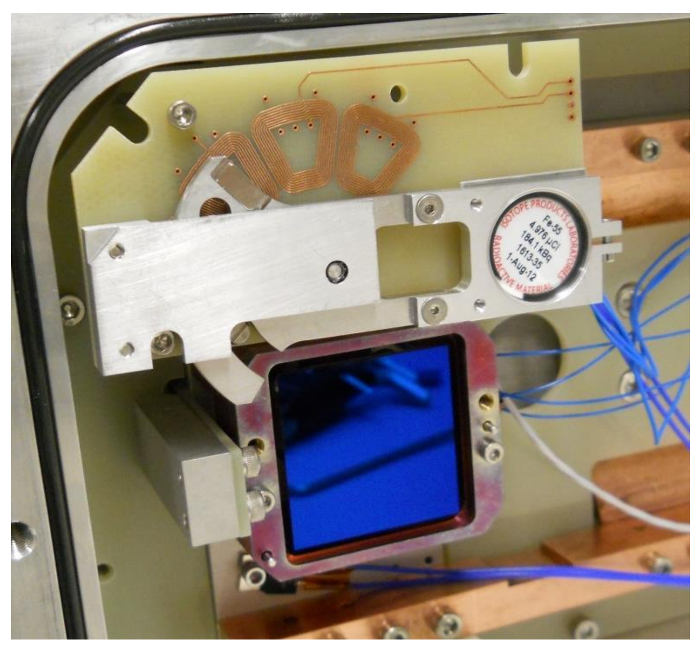
The source carrier/rotor assembly pivots on two Dicronite (tungsten disulfide) coated UHV-compatible ball bearings. The rotor piece is made from austenitic stainless steel, holding the permanent magnets without adhesives and counter-balancing the source carrier, which is necessarily a lighter, aluminum piece.



The parts of the X-ray Exposure Device

The four stator coils are wired in twos, terminating at a four-pin header. A custom controller based on a $5 PICAXE microcontroller sitting outside vacuum provides the necessary three-phase firing sequence to power the XED. Triggering is via RS-232, TTL, or pushbutton.

A nice characteristic of the design is its low-profile form factor, measuring ~111mm x 56mm x 13mm. A good example of installation into a tight space is shown at right, where the distance from the CCD's surface to the inner surface of the cryostat's cover is 25mm.



XED in operation for the LSST Raft Optimization And Readout Program

Summary:

The XED is a compact, simple, affordable solution to in-vacuum automatic exposure of ^{55}Fe x-rays for CCD characterization. Several copies have been made with more planned for various cryostats in various configurations. Having refined the original design, the units in use have proved reliable and un-affected by mounting arrangements in a range of orientations.

Acknowledgements:

P. Kuczewski, P. O'Connor

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