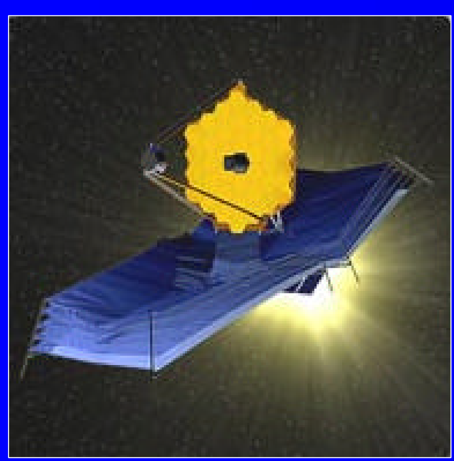
A New Approach: Electromagnetic Actuation of JWST Microshutters

Alyssa A. Rzeszutko: 2003 NASA Academy Research Associate, Code 543

George Voellmer: Principal Investigator, Code 543



Introduction to JWST

The James Webb Space Telescope, formerly known as the Next Generation Space Telescope, will depart for an L2 orbit in August 2010. JWST will succeed the Hubble Space Telescope to look further into space than ever attempted before. The origins and composition of the universe will be studied to gain information on the formation of galaxies and stellar evolution. Scientists hope to unveil some of the mysteries of dark matter as well as the size of the universe. [1] [2]

Fast Facts

- Launch Date: August, 2010
- Launch Vehicle: Ariane 5
- Mission Length: 5-10 years
- Orbit: L2
- Travel Time to L2 Orbit: 3 months
- Operating Temperature: 30 K
- Telescope Mass: 6200 kg
- Primary Mirror Diameter: 6 m
- Wavelength Range: Visible to mid infra-red (0.6-28 μm)
- Flight Instruments:
  - Near Infrared Camera (NIRCam)
  - Near Infra-Red multi-object Spectrometer (NIRSpec)
  - Mid Infra-Red Instrument (MIRI) [2]

Microshutter Actuation Diagram

NOTE:
Pre-magnetized microshutters want to align themselves with the B-Field

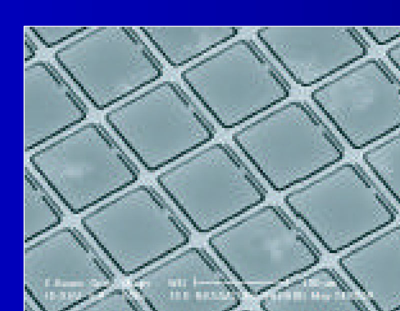
Microshutters for NIRSpec

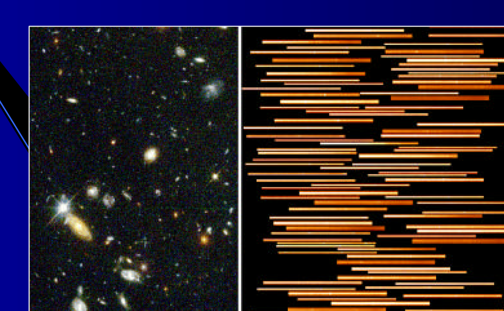
What are Microshutters?

- Magnetically actuated programmable masks
- Used in observing primordial galaxies
- Block overlapping spectra
- 1 microshutter is 100 x 200 μm
- 1 array is composed of 2000 x 1000 shutters

What are they Made of?

- Shutters and Hinges: Silicon nitride
- Array Frame: Silicon
- Deposited CoFe, magnetic material, on each shutter





[3]

How do they Work?

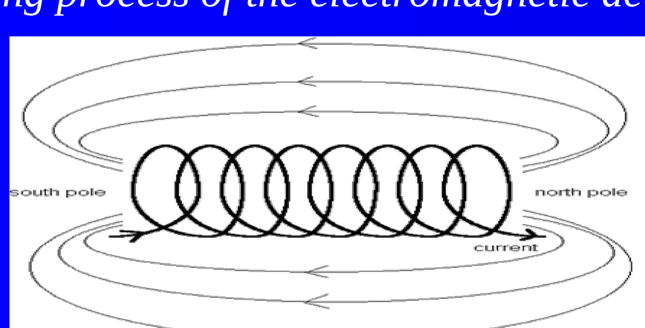
- Suspends from a thin torsion hinge
- Rotates 90° out of the plane of the array
- Magnetic actuation causes all shutters to rotate open at once
- Applied voltage to the wall further attracts the shutter to latch it into place
- Light shields cover slits in silicon nitride

What is NIRSpec?

- "Near Infra-Red Spectrograph"
- Observes spectra between 0.6 to 5 μm wavelength
- Able to obtain spectra from over 100 objects simultaneously [1]

Magnet Background

The current magnet design to actuate the microshutters consists of a mechanical arm which holds a magnet. This arm sweeps the span of the array opening shutters row by row. The design has many complications. Its complexity hampers its reliability. A proposal for a simpler, more effective design was implemented and is undergoing testing. By applying current through coiled wires, a magnetic field can be generated. My contribution to the JWST team consists of working on the set-up, design, and testing process of the electromagnetic actuation concept.

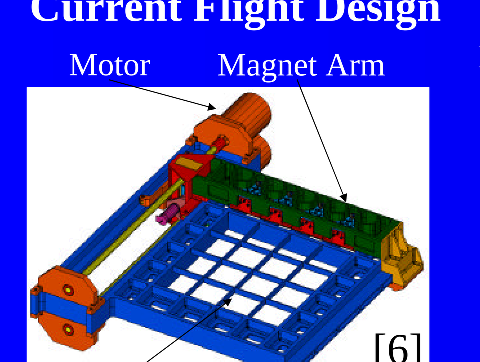


Simple diagram of an electromagnet

Field lines are uniform and parallel in the center of the magnet

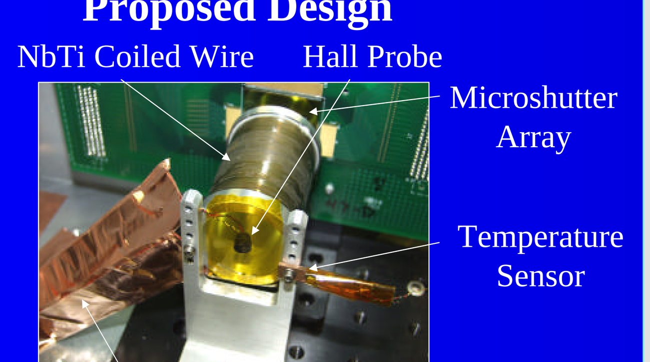
[4] [5]

Current Flight Design



Array sits under structural supports

Proposed Design



Copper Tape-thermal protection

Mobile Arm Design		Electromagnetic Design	
Moving Components		No Moving Parts	
Many Mechanisms		No Mechanisms	
Highly Complex Design		Simple Design	
Row-by-Row Actuation		Simultaneous Actuation	
Low Power		High Power	

Advantages	
Disadvantages	

Super-conducting Magnet Characteristics:

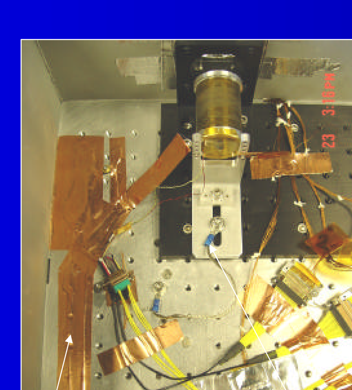
- Niobium Titanium (NbTi) wire
- N = 4000 turns
- Operates below 7 K
- ~33.0 mm inner diameter
- ~40.5 mm outer diameter
- ~47.5 mm length

Electromagnetic Actuation

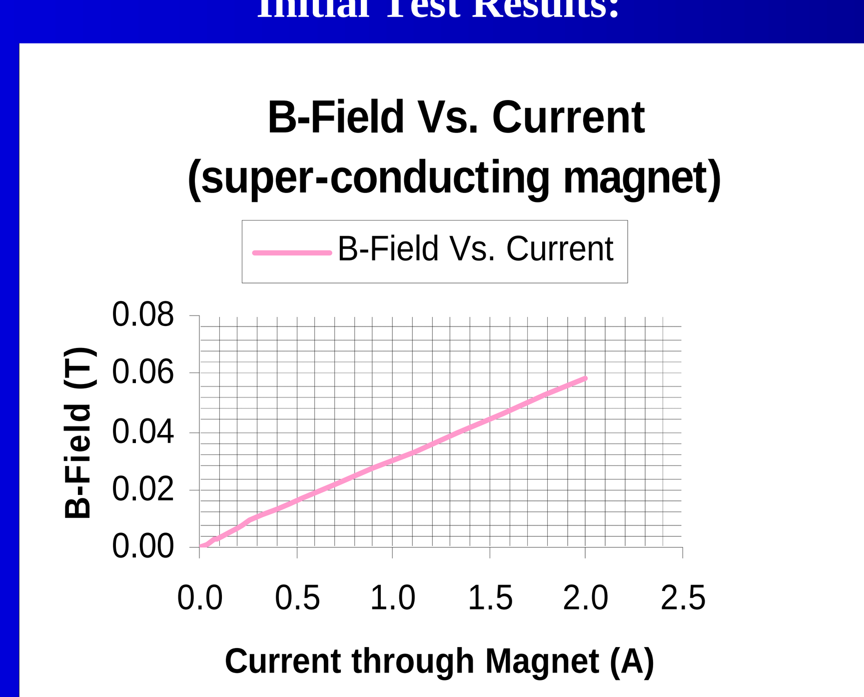
The first test failed to actuate any shutters. The magnet never reached a super-conductive state. Adjustments were made to stabilize the temperature of the magnet below 7K.

Adjustments between First Two Tests:

- Heat-strapped wire connectors to cold plate with copper wire (see pictures below)
- Added Indium underneath heat sinks
  - Indium: malleable and metallic –excellent thermal conductor
- Secured all wires to cold plate with copper tape
- Added spring washers under magnet mounting screws to maintain preload
  - Higher pressure between the magnet and its bracket creates a better thermal interface

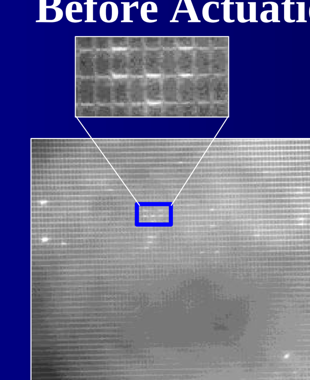


Initial Test Results:

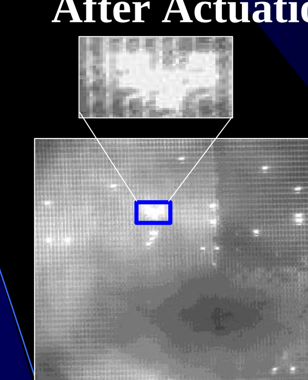


NOTE: 0.2 T is needed to open most or all of the microshutters
B-Field is measured with a Hall Probe

Before Actuation:



After Actuation:



Improvements for Set-up in Next Test Set-up:

- Optimize cryogenic harness
  - Replace manganin wire with copper wire (from helium tank to cold plate) and stainless steel (from the room to nitrogen tank and connecting to helium tank)
    - Copper: good thermal conductor because of its low resistance which causes heat to dissipate easily -offers direct contact from helium tank to cold plate on which the equipment sits [7]
    - Stainless Steel: more durable than manganin and is a poor thermal conductor with high resistivity-its use between tanks causes liquid helium (4K) to ***not*** boil off due to liquid nitrogen temperature (77K)
- Use 8000 turn or higher NbTi magnet
  - # of turns is directly proportional to the B-field
  - With more turns, a smaller amount of current is needed to produce the same B-Field

$$B = m_o n I$$
$$m_o = \text{permeability of free space}$$
$$n = \frac{N}{L} = \text{\# of turns per unit length}$$
$$I = \text{current}$$

NOTE: This equation is a simplified version of the actual calculation of the B-field for our magnet. The equation only considers the field in the middle of a long solenoid.

- Apply copper cladding over NbTi wire
  - Copper will keep the magnet from heating when secured to a cold (4K) base
- Insert a more thermally insulated window on dewar wall to prevent heating from lamp used to illuminate the shutter array during testing

References

[1] <http://www.stsci.edu/jwst/>
[2] <http://ngst.gsfc.nasa.gov/htm>
[3] A. S. Kutyrev, S. H. Moseley "Programmable 2D Addressable Cryogenic Aperture Masks"
[4] Tipler, P.A. (1999) Physics for Scientists and Engineers. 4th ed. Vol. 2 New York, New York
[5]<http://www.physics.gla.ac.uk/~kskeldon/PubSci/exhibits/E2/>
[6] S. H. Moseley (Feb. 2003) "Microshutter Array (MSA) Technical Status Report"
[7] <http://www.tpub.com/neets/book4/11e.htm>

Work in Progress

- Repeat the original test with a higher quality and more powerful NbTi electromagnet
- Observe smaller array sections with a high magnification/ high resolution digital camera
- Adjust the magnet's characteristics (# of turns, wire gage, diameter, length, etc) to create a B-field that opens all shutters (~0.2 T)
- Analyze the angle at which the shutters open
- Design a copper electromagnet to operate at room temperature for the Microshutter Fabrication Team who will attempt to actuate entire array at once
- Begin the Flight Design of magnet that must operate at 30 K (non-super-conductive)
- Utilize ANSYS to simulate the theoretical outcome of the magnet and compare with experimental data

Acknowledgments

- Illinois Space Grant Consortium
- Ernest Buchanan, Code 680
- Dr. Todd King, Code 541
- Dr. Alexander Kutyrev, Code 685
- James Loughlin, Code 542
- David Rapchun, Code 685
- Scott Schwinger, Code 544
- Dr. Peter Shirron, Code 552
- George Voellmer, Code 543