Three-phase Axial-field PM Motors for Direct Drive Applications

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And Dan Gray

Galileo's Legacy

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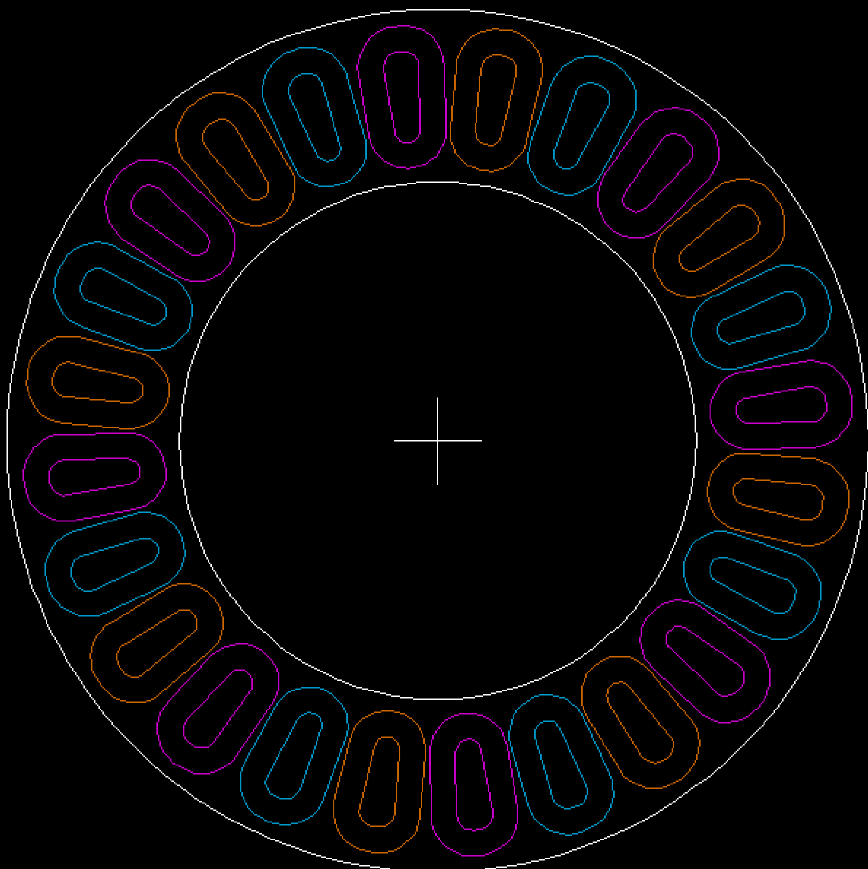
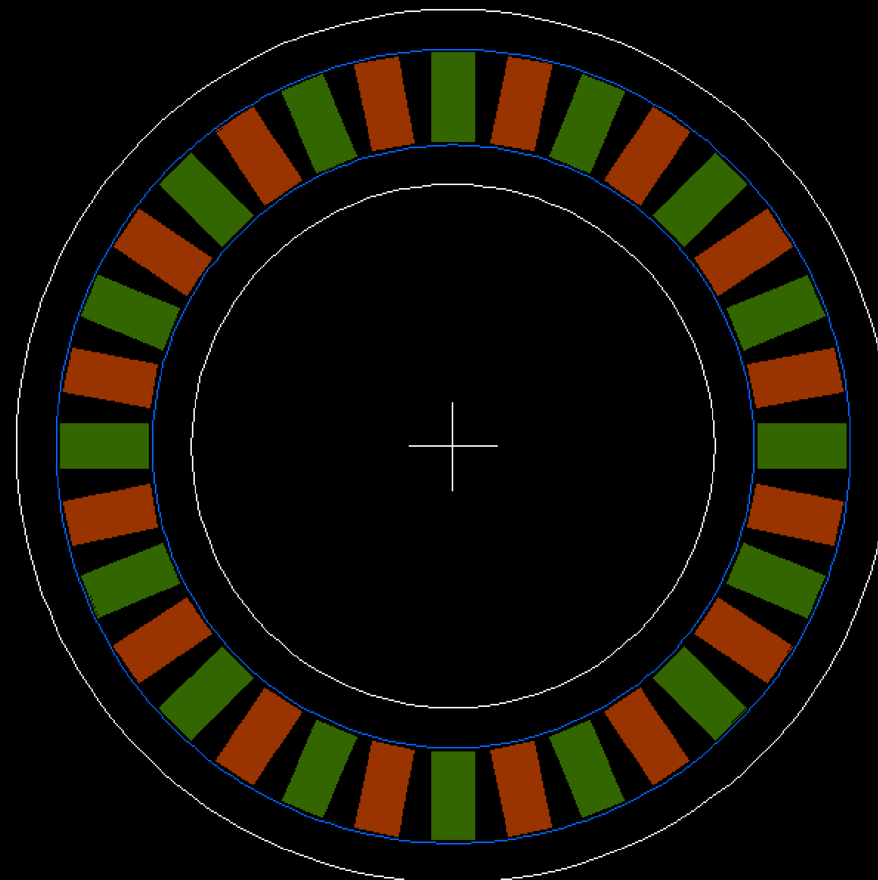
Example of Three-phase PM Motor

24 coils arranged in three phases



Stator

32 magnets on soft steel annulus



Rotor

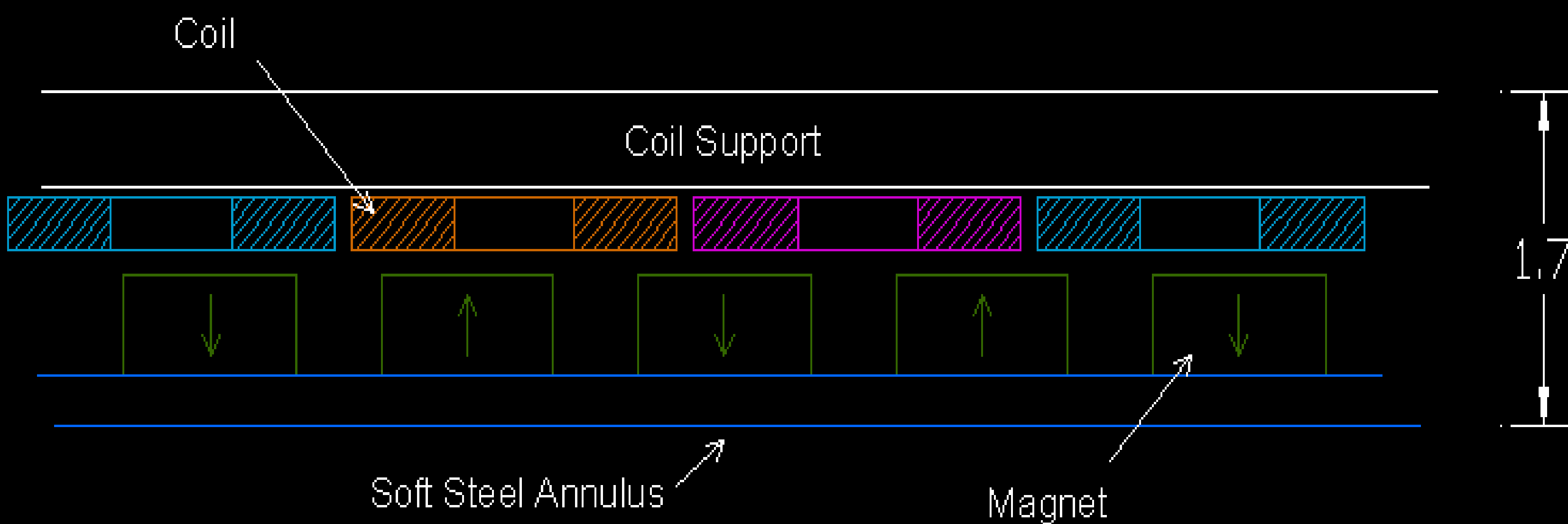
Why use a Direct Drive Motor?

- Zero Backlash
- Zero or near zero Periodic error (depends on encoder)
- Extremely fast response to disturbances: wind, mechanical binding, etc...
- No slippage (roller drive systems)
- Fast slew rates (think Gamma Ray Burst follow-up)
- Better tracking
- Better pointing
- No aligning worm gears
- No lapping of worm gears
- No mechanical resistance of gears

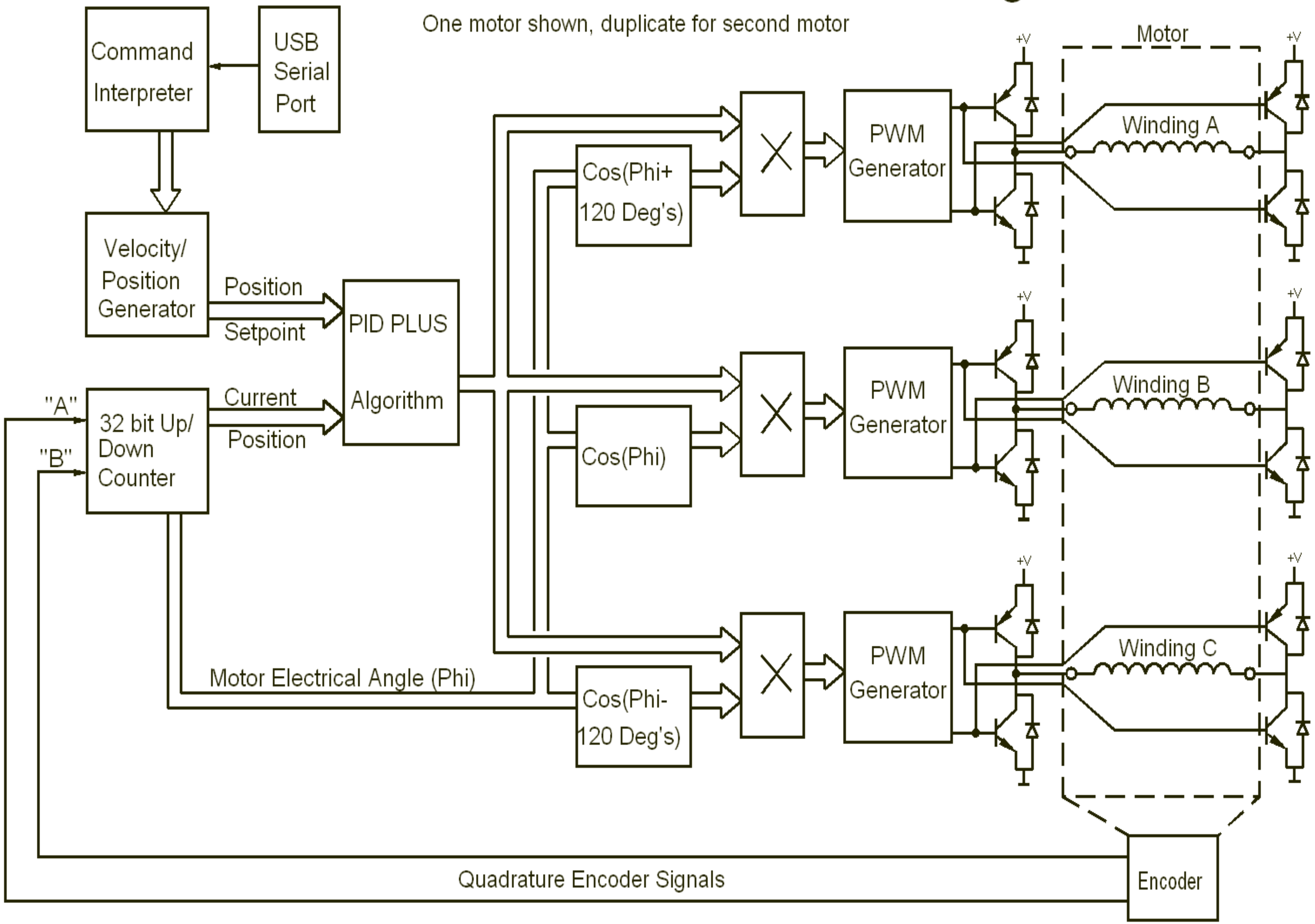
Why not to use a Direct Drive Motor?

- Cost (we're helping that problem)
- You need a high resolution encoder which may be expensive (we're solving that problem too)
- Magnets can be dangerous

Motor Cross-section (How it works)



Direct Drive Motor Controller Block Diagram



Design Considerations

- The motor is designed with 3N coils and 4N magnets
  - Example: 6 coils and 8 magnets, 18 coils and 24 magnets, etc.
- Magnets alternate polarity
- Coils are wired in three phases. All coils have the same polarity
- Backing the magnets with ~1/4" thick soft steel ring increases the flux by about a factor of two
- Coil thickness should be about the same as the thickness of the magnets
- Backing the coils with a soft steel ring increases the flux by about 25% and can supply preload for a bearing
  - Be careful! The forces are tremendous for large motors.

Motor Optimization

- Motor windings are optimized for peak torque when the resistance of the windings equals the maximum voltage divided by the maximum current.
- Under this condition, the peak torque is proportional to
  - The radius of the motor
  - The average strength of the magnetic field
  - The square root of the volume of the copper in the magnetic field
  - The maximum current through the windings
- So, to optimize a motor
  - Use NdFeB magnets
  - Get as much magnet volume in the motor as possible
  - Use soft steel to back the magnets to increase the flux
  - Select the wire diameter and the number of turns to optimize the resistance of the windings

Example Direct Drive Motor

- 3-phase
- 230 turns per coil
- 6 coils per phase, 18 coils in all
- 22 AWG wire
- 11 ohms per phase, series connected
- 12 N-m/amp per phase
- 24 N-m maximum, 24 V system
- Easily drives 0.7-meter telescope
- Motor material cost ~ $200

Rotor Construction

Magnets

Soft Steel Annulus

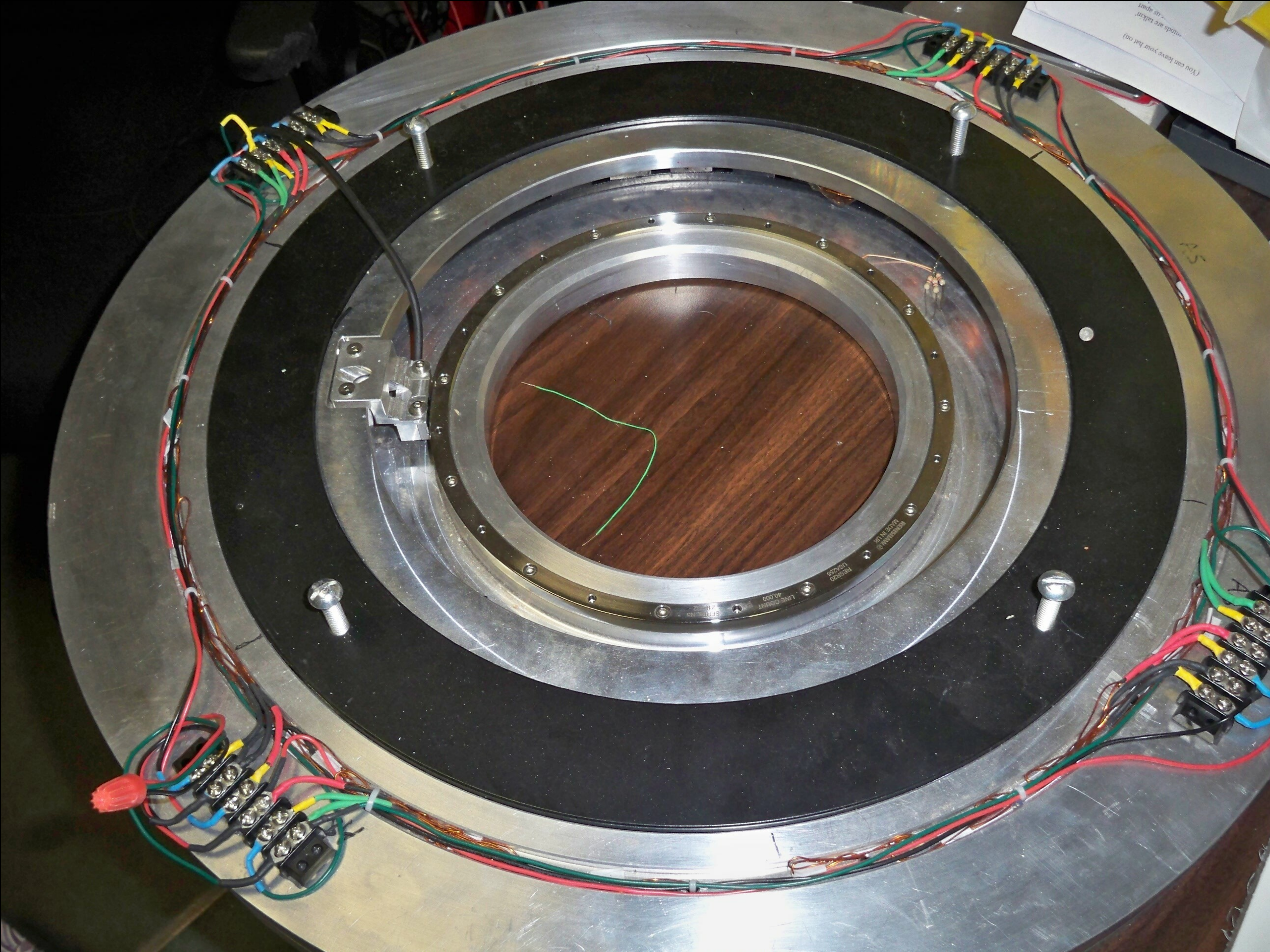
Aluminum Housing

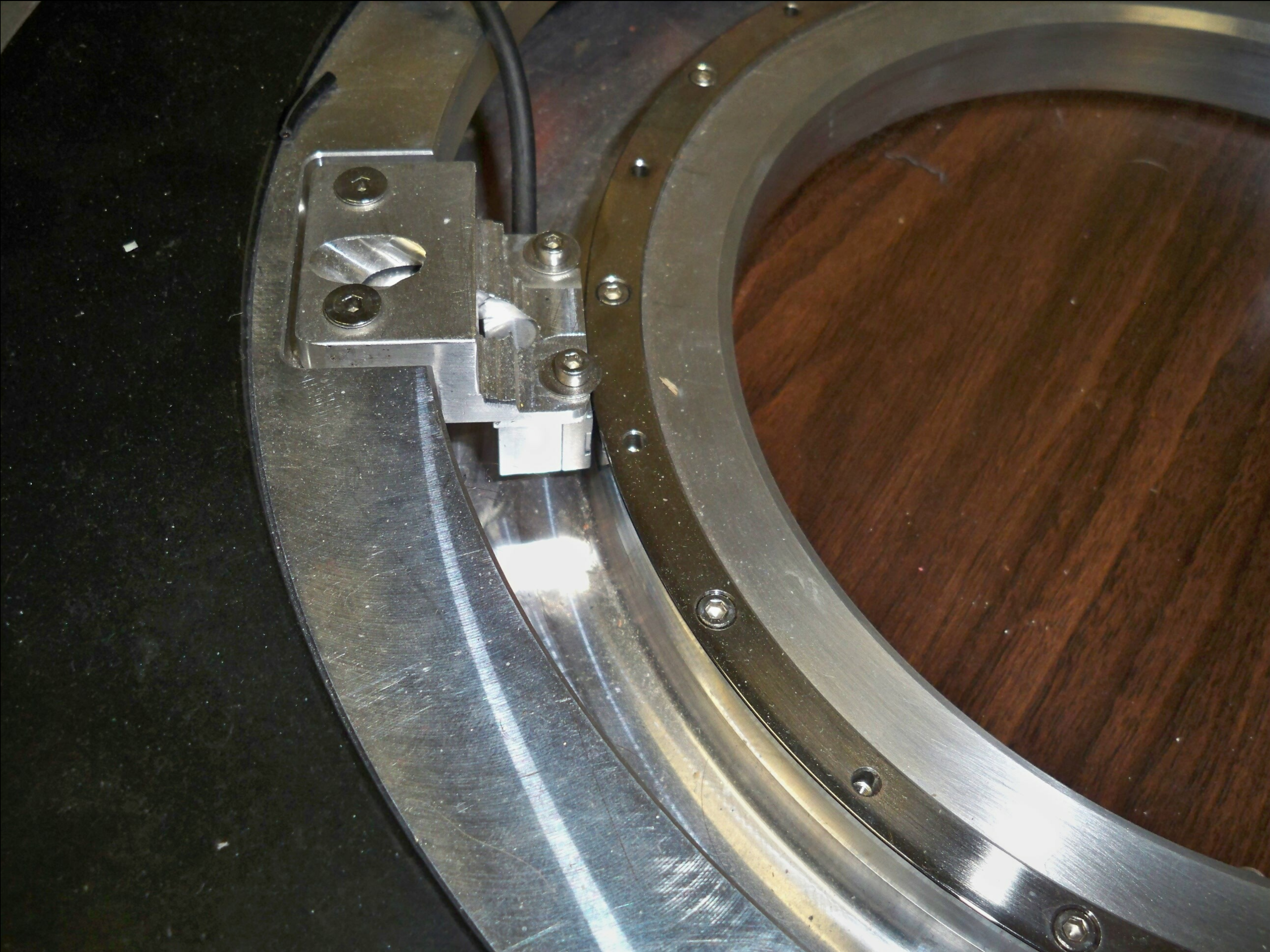
Encoder Mounting Area

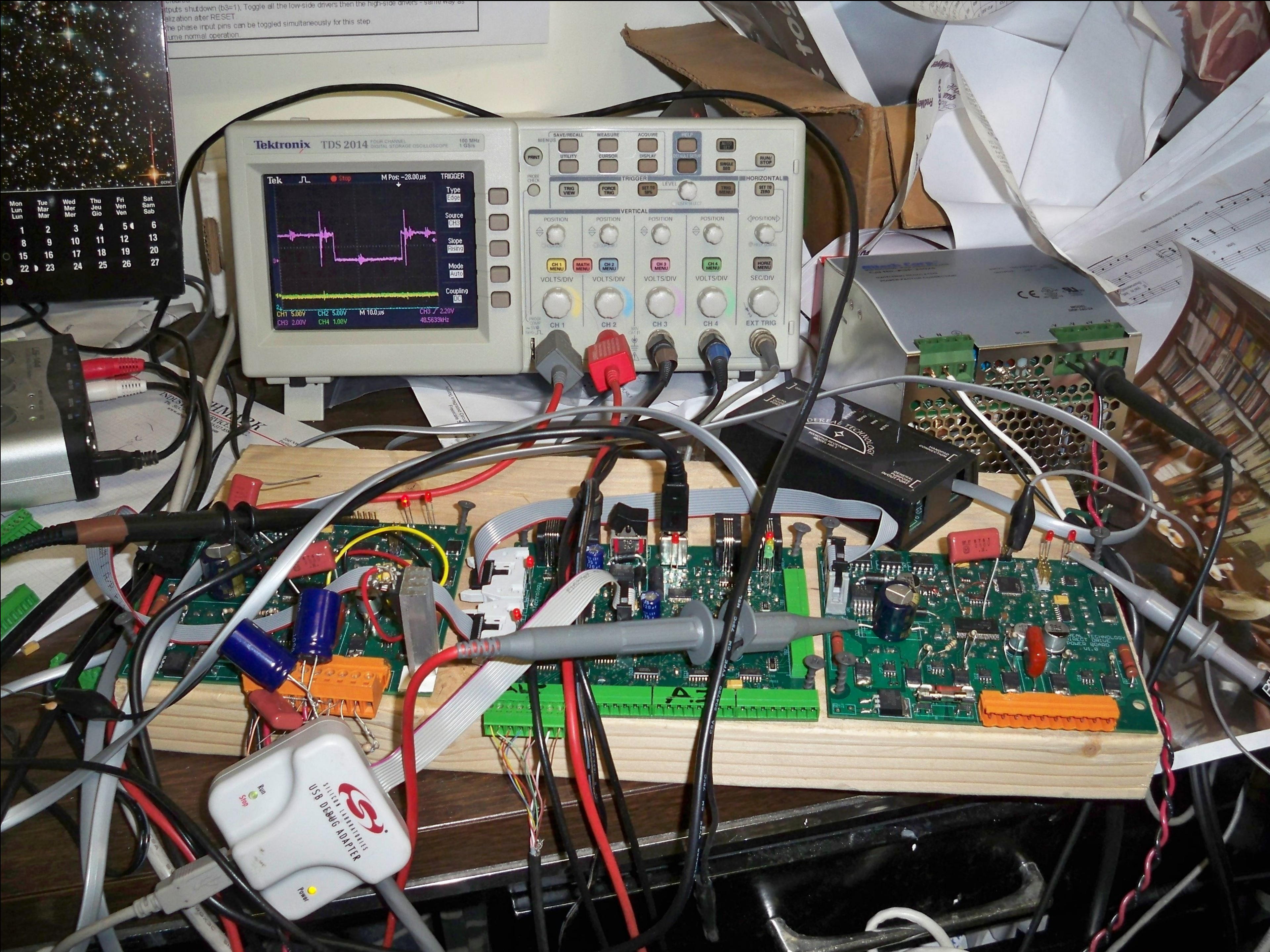
Bearing Race and balls

Stator Construction

Bearing Race






Tektronix TDS 2014
Tek
M Pos: -28.00µs
TRIGGER
Type
Edge
Source
CH3
Slope
Rising
Mode
Auto
Coupling
DC
CH1 5.00V
CH2 5.00V
M 10.0µs
CH3 2.00V
CH4 1.00V
48.5633kHz
SAVE/RECALL
MEASURE
ACQUIRE
HELP
UTILITY
CURSOR
DISPLAY
PRINT
RUN/STOP
TRIGGER
LEVEL
HORIZONTAL
VERTICAL
POSITION
VOLTS/DIV
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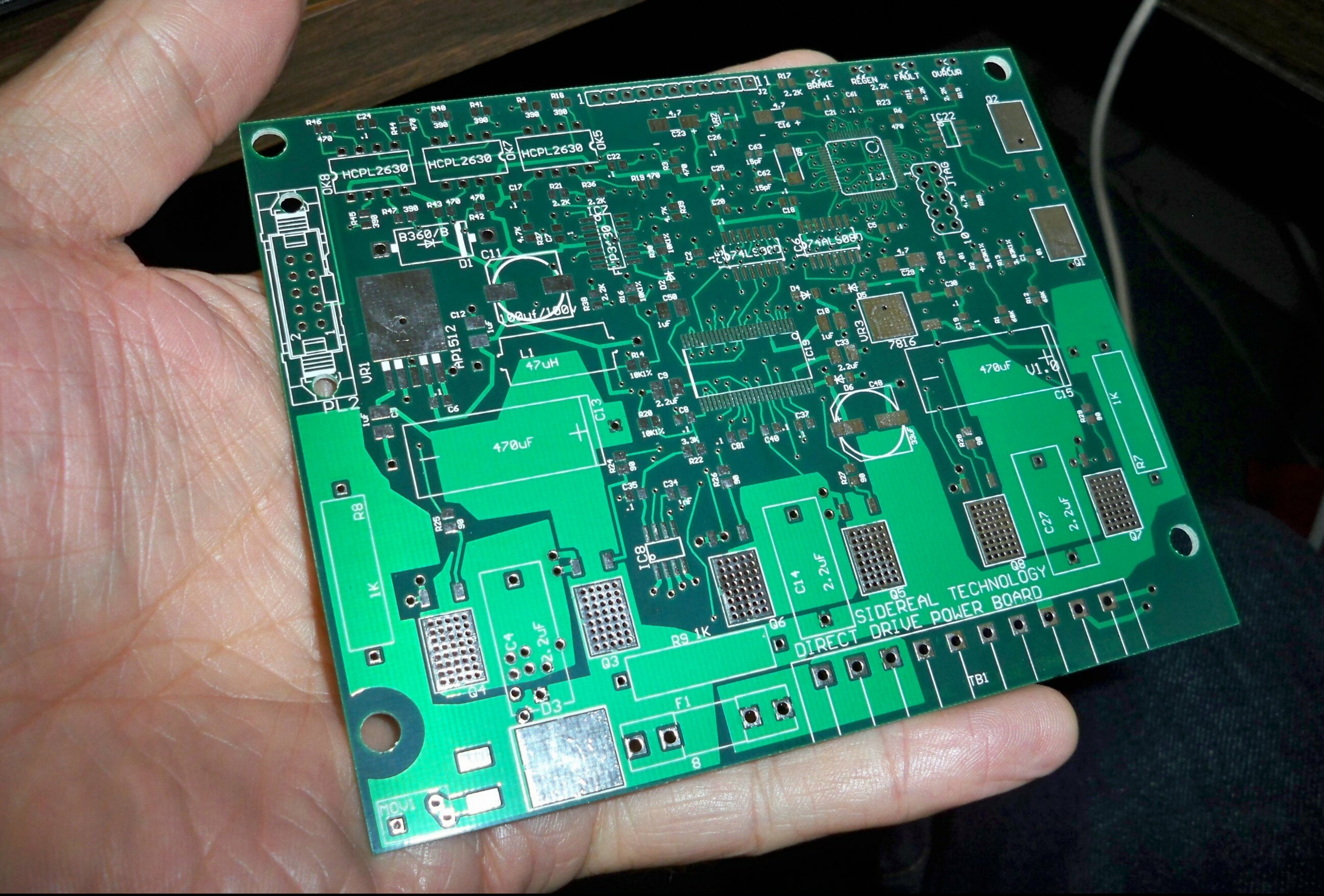
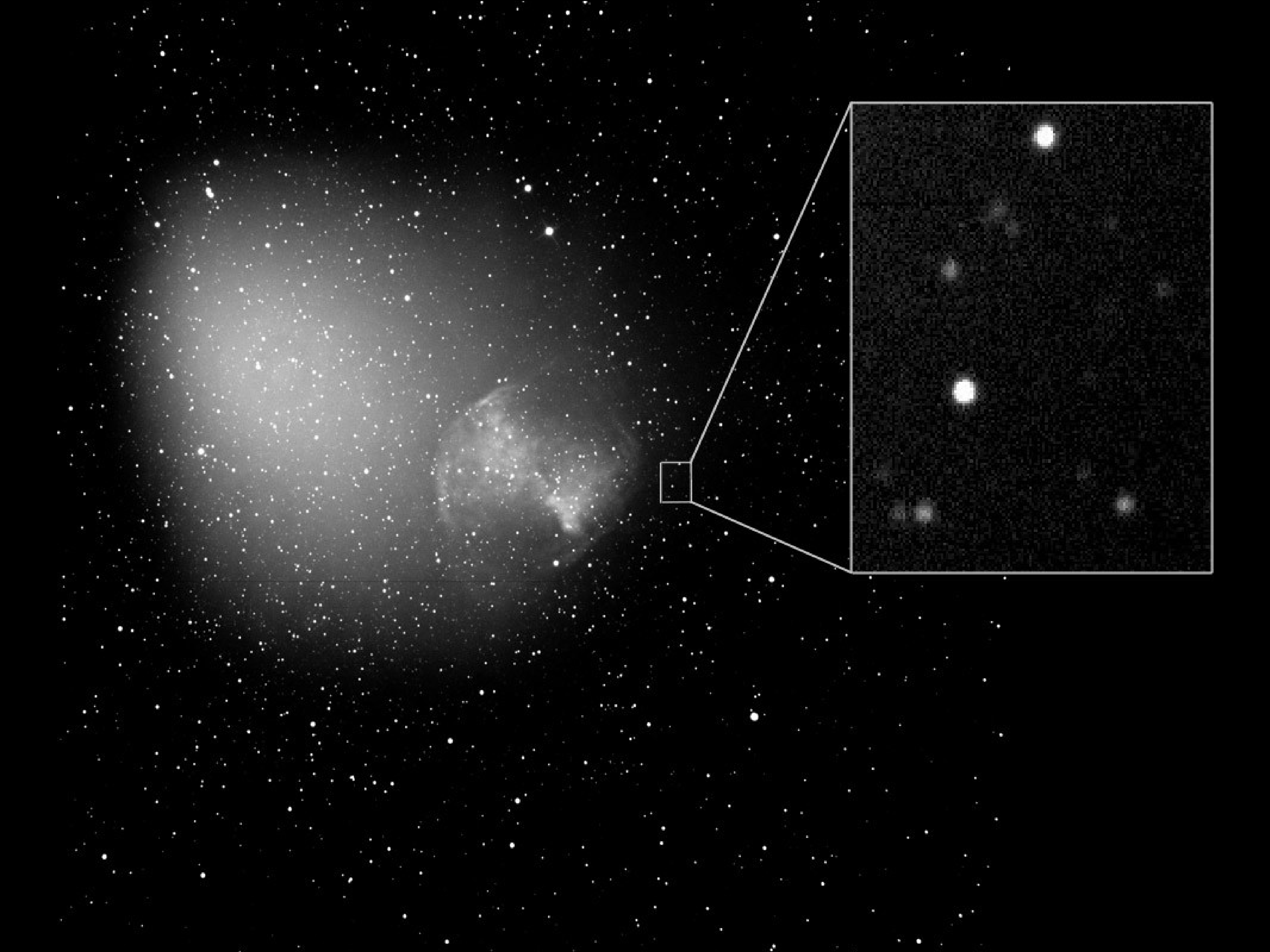
CH 1
CH 2
CH 3
CH 4
EXT TRIG
USB DEBUG ADAPTER
Run
Stop
Power


SIDEREAL TECHNOLOGY
DIRECT DRIVE POWER BOARD
HCPL2630
HCPL2630
HCPL2630
BRAKE
REGEN
FAULT
OVRCUR
JTAG
B360/B
100uF/100V
AP1512
47uH
470uF
470uF
7816
V1.0
2.2uF
1K
TB1
MOV1



Controller Features

- Takes position inputs from encoders
- Takes commands from serial port
  - Command set is open source and documentation is available
- Generates desired position with various constraints in several modes of operation
- Generates high-current PWM outputs for
  - 2 three-phase motors
  - Or 2 brushless DC motors

Software Features

- Has been 4 years of development, with many hours of testing by many people
- Can be controlled by ASCOM or LX200 protocol
- Is robust, and proven by hundreds of users
- Software has practically any feature that you can imagine

Software Features

- Telescope modeling called PointXP by Dave Rowe is built in to the software
- Scripting can be done using any ASCOM software
- Built in scripting is available
- Track any non-sidereal object
- Open Source is coming

Summary

- A direct drive motor has been integrated with an on-axis, high-resolution encoder in a self-contained azimuth turntable
- The three-phase motor is driven by a new SiTech controller
- Sub-arcsecond positioning has been achieved
- The azimuth turntable is being integrated into the experimental Cal Poly 18" Newtonian
- Software is sophisticated, proven by hundreds of users
- Motors, controllers, and newly designed encoders will be available within about 6 months. Prototypes at SAS and RTMC this year.

GUIDER
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POWER
USB
RS232
HAND
PAD
SLEW
PAN
GUIDE
COM
DATA
SIDEREAL TECHNOLOGY
SERVO CONTROLLER II
ALT / DEC
INPUTS
AZM / R.A.
ALT / DEC
MOTORS
AZM / R.A.
+ LIMIT
- LIMIT
HOME
P SYNC
AN IN
GND
+ 5V
+ LIMIT
- LIMIT
HOME
P SYNC
AN IN
GND
+ 5V
M.E. A
M.E. B
S.E. A
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STATUS