DIY DIGITAL SETTING CIRCLES

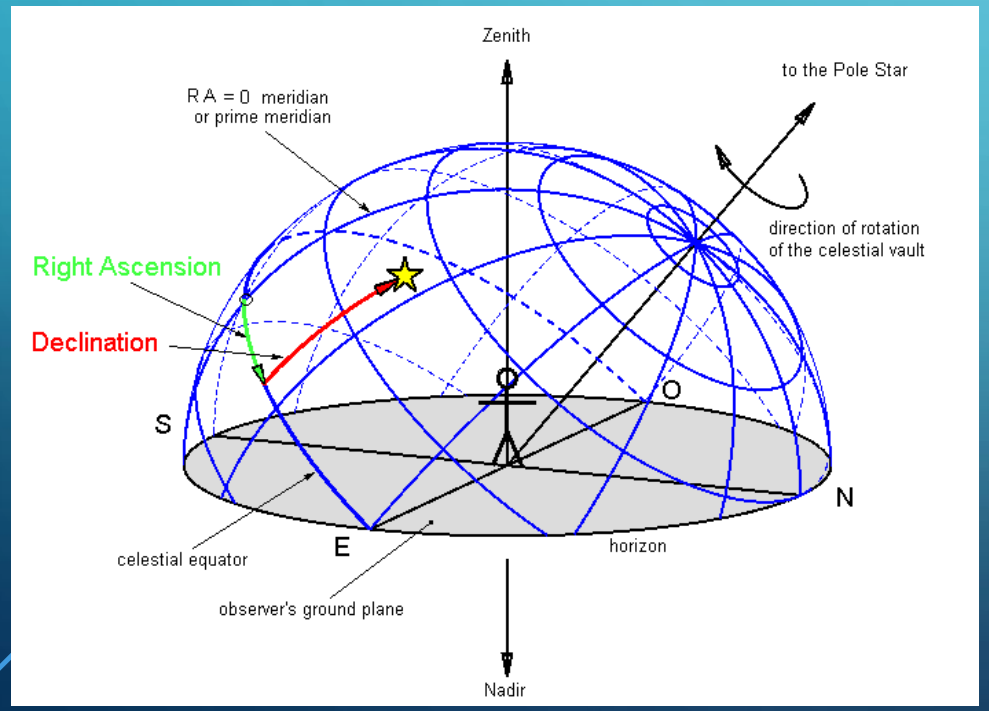
FOR **PUSH-TO** OPERATION OF YOUR TELESCOPES

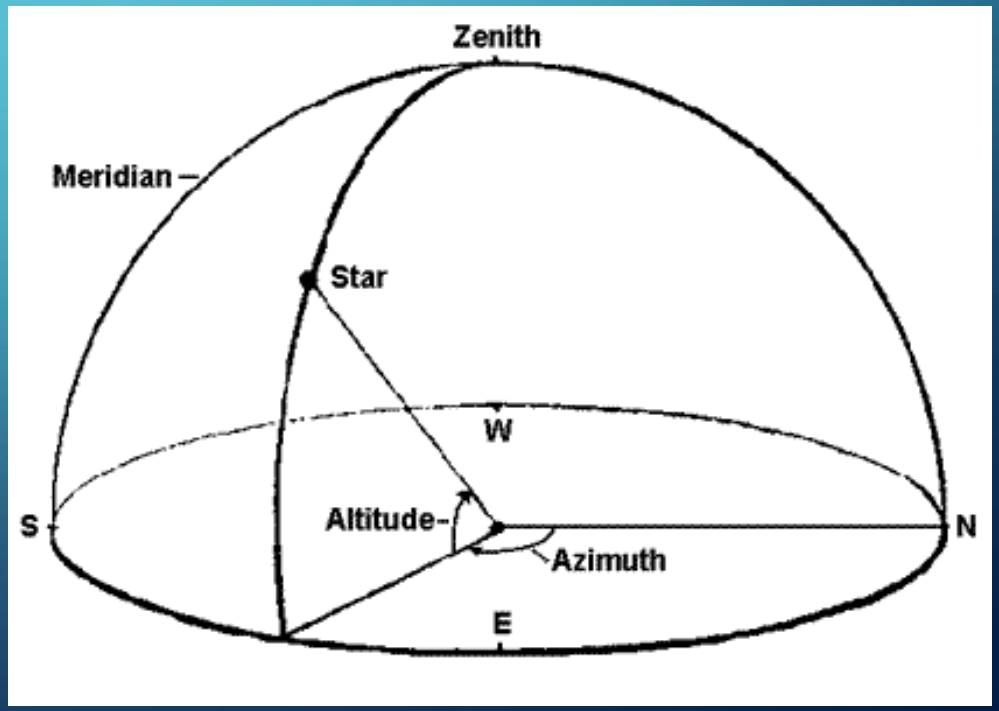
ROBERT HORTON

DECEMBER 7, 2020

FIRST: COORDINATES IN THE SKY

- Celestial objects are typically located by their Right Ascension (RA) and Declination (Dec)
  - Similar to locating a position on Earth with Longitude and Latitude
  - Right Ascension is measured in Hours:Minutes:Seconds because it is tied to the daily rotation of the Earth
  - Declination is measured in Degrees away from the Celestial Equator, + for North, - for South
- Positions of celestial objects, from your location on Earth, can also be represented by Altitude and Azimuth
  - Altitude (aka Elevation) is the number of degrees the object appears above your local horizon
  - Azimuth is the clockwise (Eastward) number of degrees from True North





- The positions of the stars are dictated by your location on Earth and the current date and time
- Over time, the stars appear to rotate around the North Celestial Pole due to Earth's rotation
- So, the primary adjustment to either coordinate system is to account for the passage of time

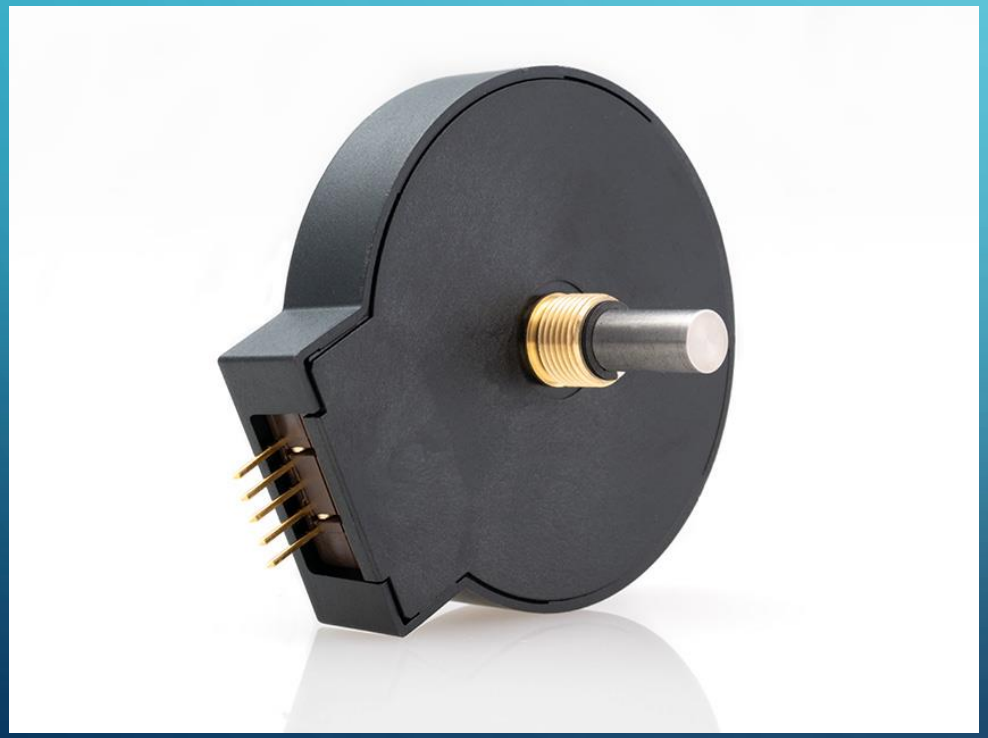
https://photographingspace.com/how-to-maintain-star-colour-in-your-star-trail-images/

WHAT ARE SETTING CIRCLES ?

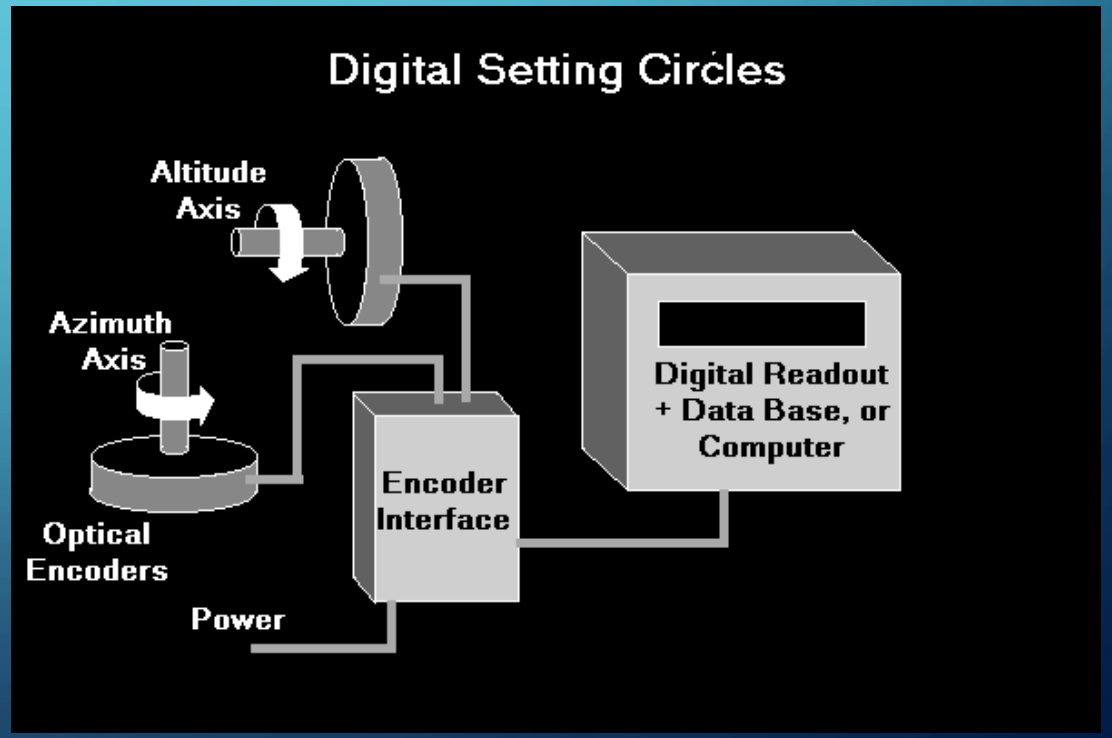
- The next step after “Star Hopping” to aid in finding celestial objects
- Analog Setting Circles are placed on each axis of a telescope mount
  - Right Ascension axis divided into 24 hours (360 degrees for Azimuth axis)
  - Declination axis divided into +/- 90 degrees (also Altitude axis)
  - These circles can be turned to “Set” them to the telescope’s current sky position
  - Once “Set” you can find new objects by moving the scope to their catalog positions
  - R.A. circles are typically driven by the clock drive to maintain their sky position over time

WHAT ARE DIGITAL SETTING CIRCLES (DSC) ?

- Mount an optical shaft Encoder on each axis in place of the analog setting circles
  - Divides the rotation of the axis into some number of “ticks” or “pulses”
  - Count the “ticks” to tell how far the axis has turned
  - Example: 10,000 tick Encoder divides a full 360 rotation into 2.16 arc minute increments
- A Computer converts and displays the Encoder values to RA/Dec (or Alt/Azi)



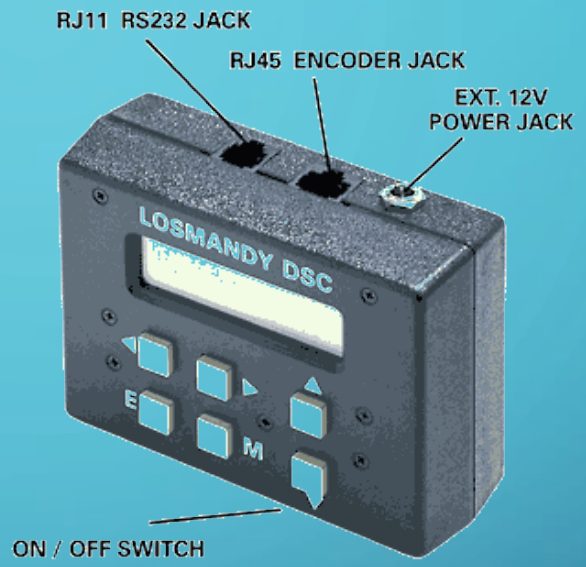
https://www.usdigital.com/products/encoders/incremental/shaft/S2



http://www.bogan.ca/astro/telescopes/digtcrcl.html

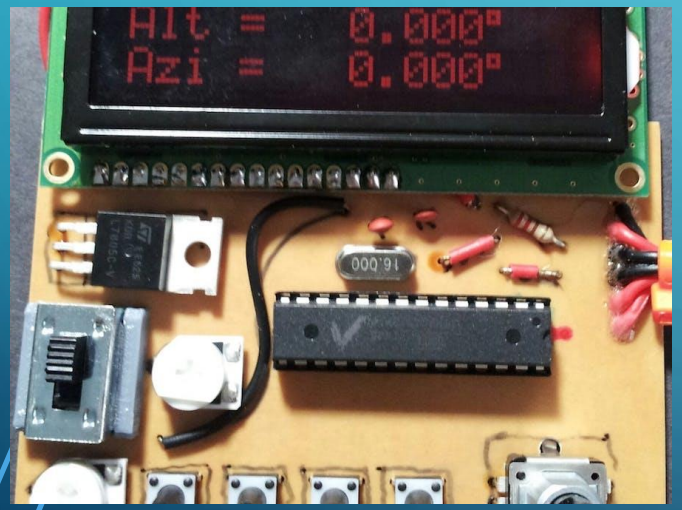
MANY COMMERCIAL DSC UNITS

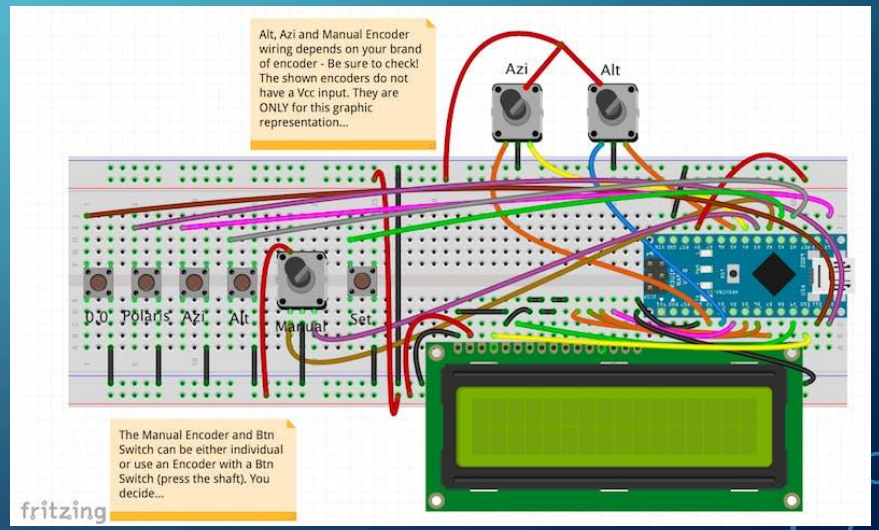
- AstroSystems SkyCommander
- Celestron Advanced Astro Master
- Lumicon Sky Vector II
- Astro Devices Nexus DSC
- Losmandy DSC
- Argo Navis
- Meade Magellan I
- TScope DSC



WHY YET ANOTHER DSC ? (YA-DSC)

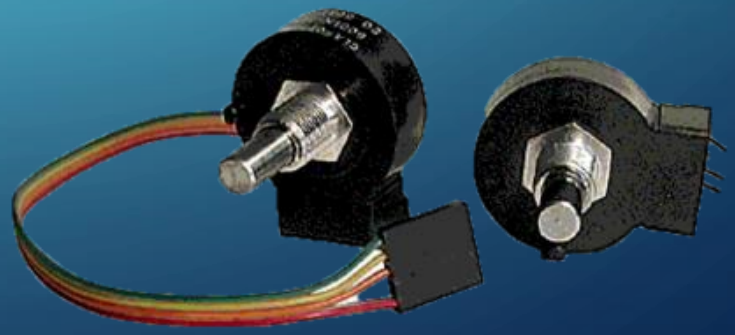
- Many DSCs are no longer manufactured – GoTo systems are king now
- The Used market is still relatively pricey ($500)
- Older computer technology can show performance issues with high tick count encoders
- It's a chance to learn more about Astronomical Computing
- VAS's 14-Irene is already set up to accept the attachment of the Encoders
- Avoids the complexity, baggage, and setup needs of a full laptop computer system
- Because COVID-19 has given me even more time to mess around in retirement !



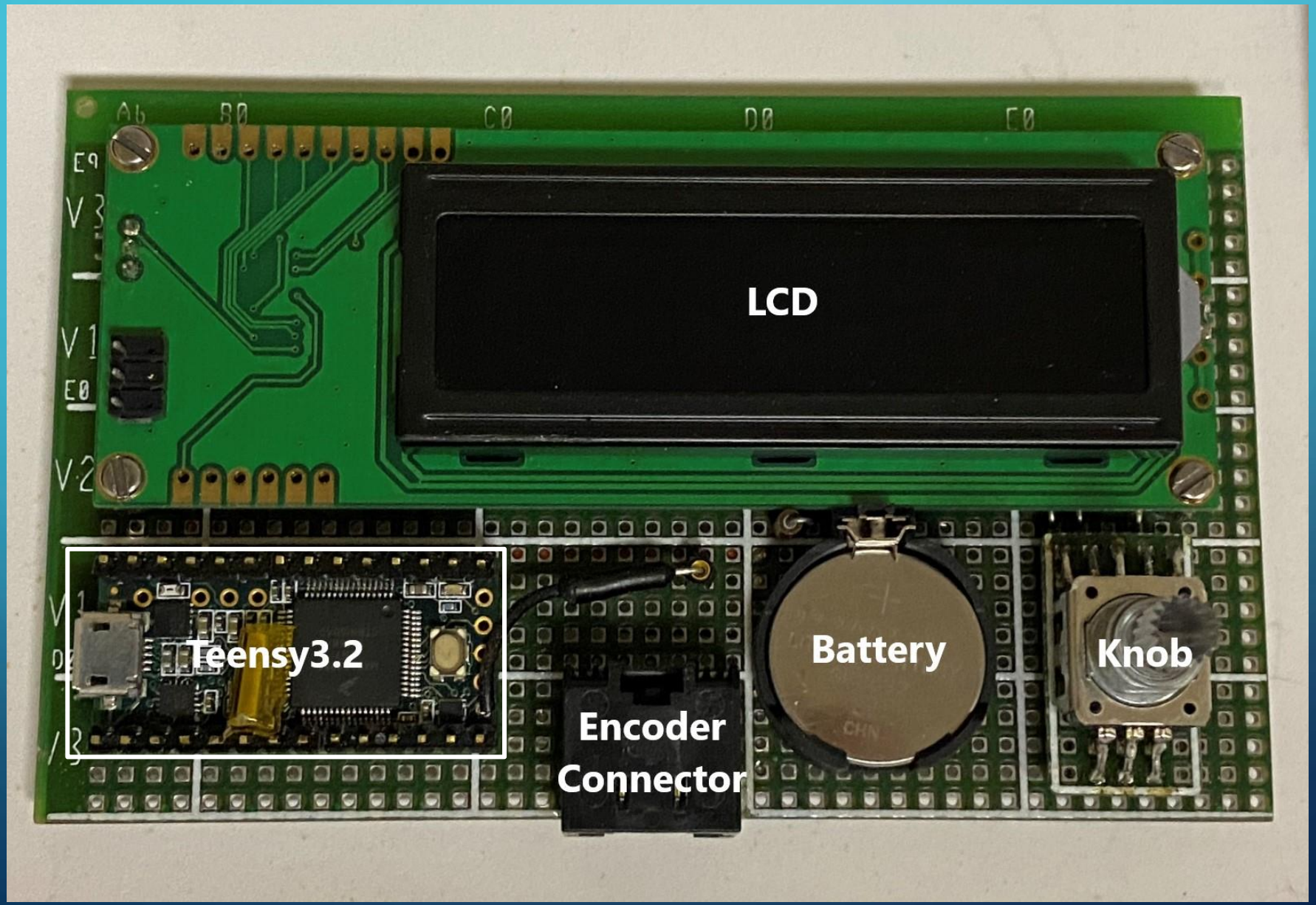


THE HARDWARE…

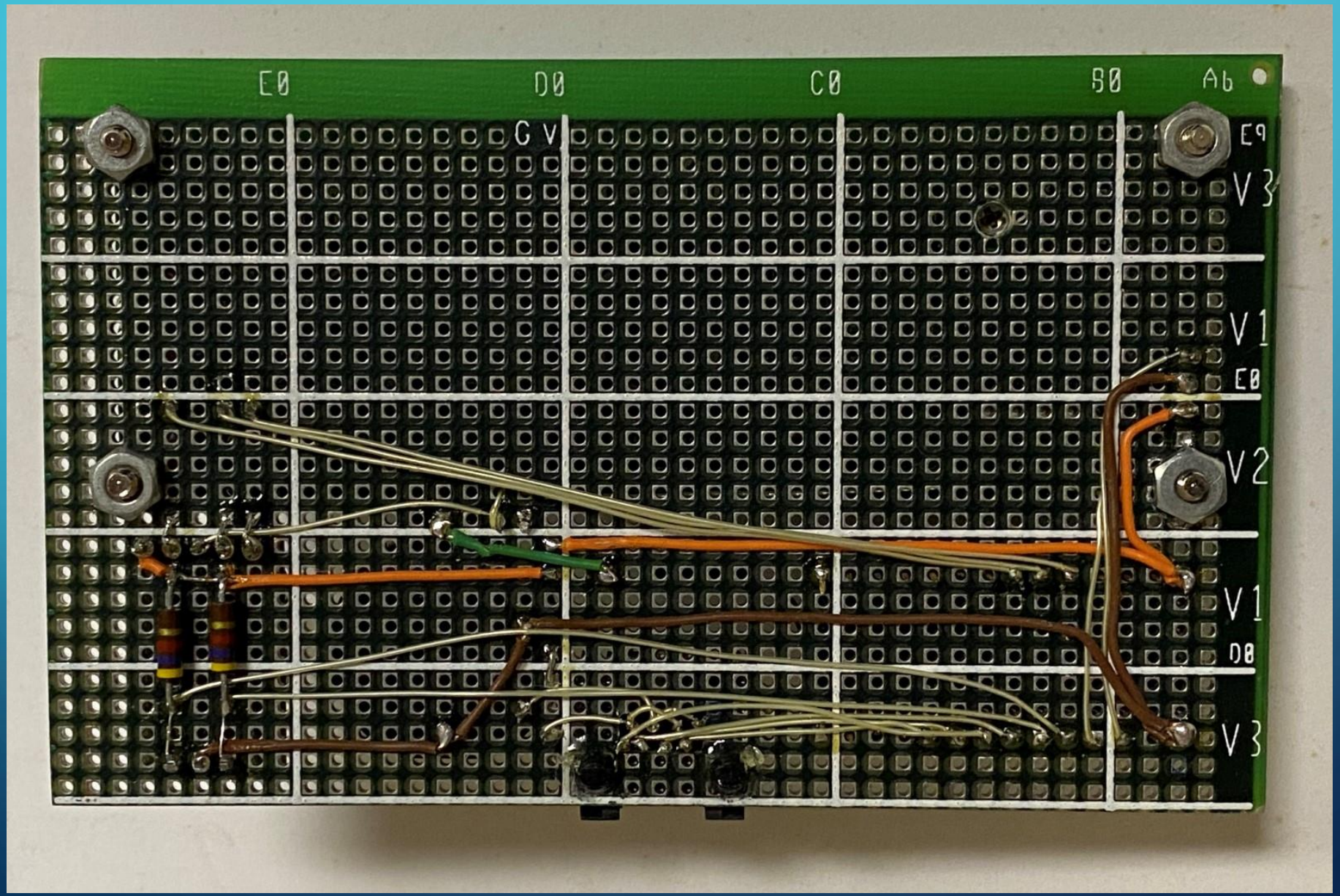
- Teensy 3.2 Microcomputer $19.80
  - Introduced in 2014
  - 32-bit ARM Cortex-M4 running at 74MHz
  - 256KB Flash, 64KB RAM, 2KB EEPROM
  - 34 Digital I/O (3.3 Volt, 5 Volt tolerant)
  - 21 Analog Inputs, 1 Analog Output, 12-bits
  - Real Time Clock, 12 Timers
  - USB, SPI, Serial, I2C, CAN, I2S Communication
  - Arduino compatible IDE (C, C++)
  - www.pjrc.com
- 2 Line by 20 Character Serial LCD Display $14.95
- 24 tick Rotary Encoder Knob (+RGB LED) $4.50
- CR2032 Battery + Holder (for RTC) $1.50
- Misc. Components, Sockets & Connectors $1.00
  - www.sparkfun.com www.adafruit.com
- Optical Shaft Encoders (10000 tick) $83 each
  - www.usdigital.com



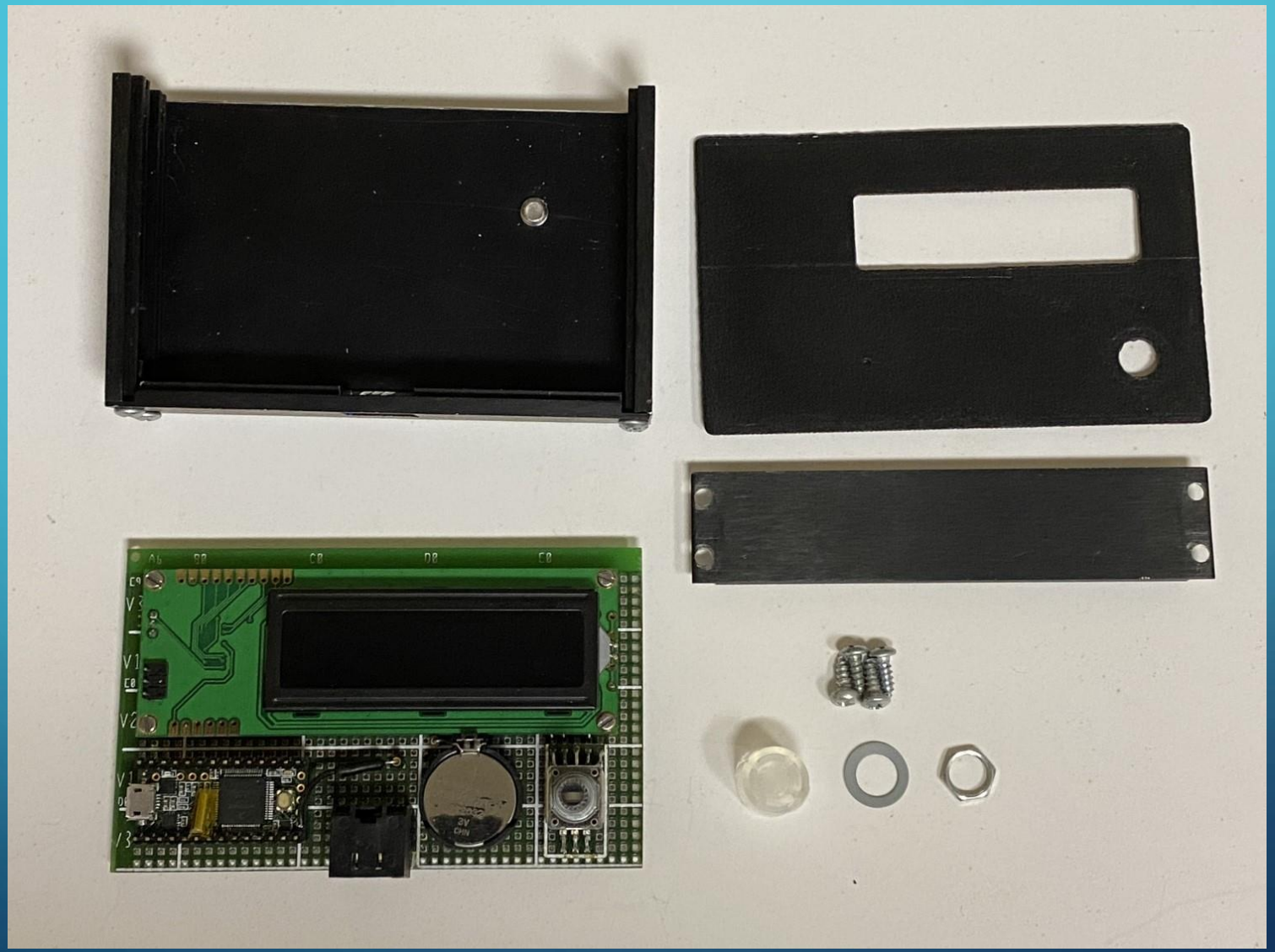
THE HARDWARE…



THE HARDWARE…



THE HARDWARE…



14-IRENE ADDITIONS…

14-IRENE ADDITIONS…

THE SOFTWARE….

- Sky & Telescope's Astronomical Computing column (1980s-1990s)
  - Programs to perform various astronomy related tasks, written in Basic
  - "Where is it in the Sky", June 1984
  - "A Computer Assault on Kepler's Equation", August 1985
  - "A New Concept in Computer-Aided Telescopes", (Taki) February 1989
- Practical Astronomy with your Calculator, Peter Duffett-Smith (1982)
- Celestial Basic, Eric Burgess (1982)
- Microcomputers in Astronomy, Russell M. Genet (1983)
- Astronomy with your Personal Computer, Peter Duffett-Smith (1985)
- The Internet (Google, GitHub)
  - Palm DSC, David Ek's DSC, etc…
- Arduino Libraries
  - Encoder, TimeLib, EEPROM, Ephemeris

EXAMPLE CALCULATION FLOW

- Given: Latitude, Longitude, Calendar Date, Local Time and Time Zone
  - Calculate Julian Date from the Calendar Date (S&T August 1991)
  - Calculate Greenwich Mean Sidereal Time (GMST) from Julian Date (S&T June 1984)
  - Calculate Local Sidereal Time (LST) from GMST and Longitude

- Given: Object Coordinates – Right Ascension (RA) and Declination (DEC)
  - Calculate Local Hour Angle (LHA) from LST and RA
  - Using Spherical Trigonometry, Calculate Altitude (ALT) and Azimuth (AZI) from LHA, DEC and LAT
  - Display Current Telescope ALT & AZI and Object's ALT & AZI
  - Push the Telescope until the two coordinates match

TeensyDSC - menu.ino | Arduino 1.8.12

File Edit Sketch Tools Help

TeensyDSC | SimpleDSC | debug.h | debug | kep.h | kep | menu.h | menu | objects.h | objects | taki.h | taki

```
67 void displayDateTime(void)
68 {
69   while (!digitalRead(buttonPin)) {
70     gotoLCD(0);
71     Serial1.printf("   %04d/%02d/%02d   ", year(), month(), day());
72     gotoLCD(16);
73     Serial1.printf("    %02d:%02d:%02d    ", hour(), minute(), second());
74     delay(100);
75   }
76   while (digitalRead(buttonPin));
77 }
78
79 void displaySidereal(void)
80 {
81   long J;
82   double F;
83   double GMST, LST;
84   double hrs, mins, secs;
85
86   while (!digitalRead(buttonPin)) {
87     double dhms = day()+(hour()-EEdata.tzOffset)/24.0+minute()/1440.0+second()/86400.0;
88     calendarToJulian(year(), month(), dhms, &J, &F);
89     julianToGMST( J, F, &GMST);
90     mins = modf(GMST, &hrs) * 60.0;
91     secs = modf(mins, &mins) * 60.0;
92     gotoLCD(0);  Serial1.printf("GMST: %02d:%02d:%02d  ", int(hrs), int(mins), int(secs));
93     LST = GMST + EEdata.longitude/15.0;
94     if (LST<0.0) LST += 24.0;
95     mins = modf(LST, &hrs) * 60.0;
96     secs = modf(mins, &mins) * 60.0;
97     gotoLCD(16); Serial1.printf("LST:  %02d:%02d:%02d  ", int(hrs), int(mins), int(secs));
98     delay(100);
99   }
100  while (digitalRead(buttonPin));
101 }
```

Simple One-Handed Knob Control… Twist & Press

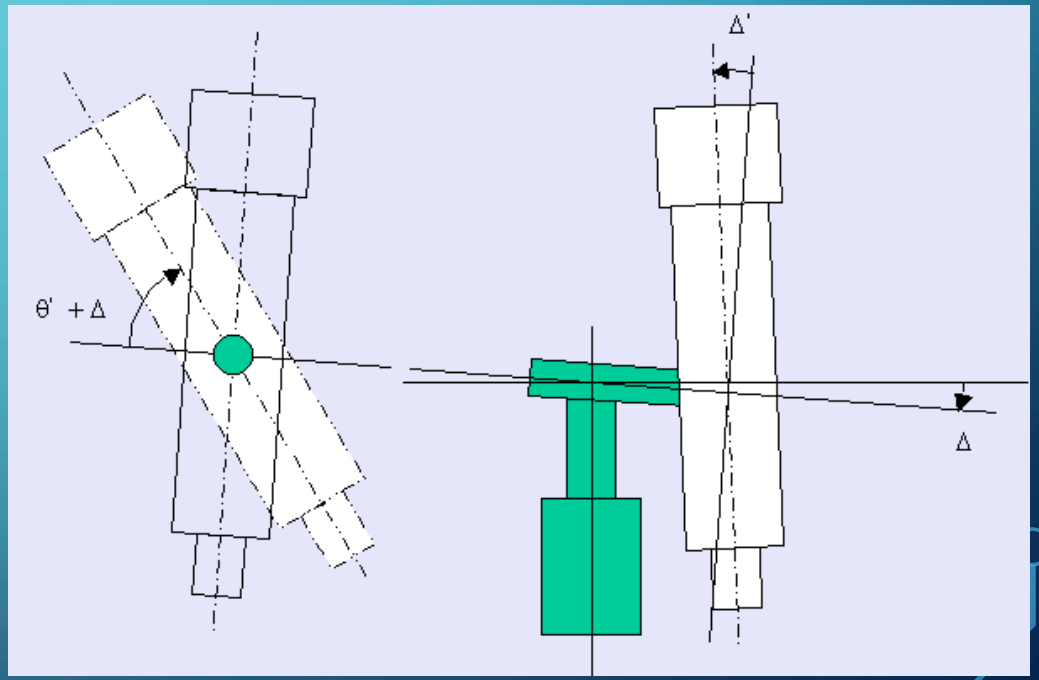
- Main Menu
  - Bright Stars (39)
  - Planets (7)
  - Messier Catalog (109)
  - Caldwell Catalog (108)
  - Double Stars (108)
  - Target RA & Dec
  - Show Date & Time
  - Show Sidereal
  - Show RA & Dec
  - Show Alt & Azi (***)
  - Goto Setup Menu

*** Coordinates sent on USB Serial to Computer/Laptop for use with Planetarium programs like Stellarium

- Setup Menu
  - Align to Star #1
  - Align to Star #2
  - Set Date & Time
  - Set Time Zone
  - Set Location (Latitude/Longitude)
  - Encoder Resolution/Direction
  - Init to NCP
  - Tracking Mount
  - LCD Brightness
  - Mount Error Z1
  - Mount Error Z2
  - Mount Error Z3
  - Goto Main Menu

CORRECTIONS AND ADJUSTMENTS

- Precession: 50.29” per year (S&T October 1991)
- Atmospheric Refraction: ~34’ of altitude at the horizon (S&T July 1986)
- Others…
  - Annual Aberration: 20”
  - Nutation: 17”
  - Solar/Stellar Parallax: <10”
- Telescope & Mount Mechanical Corrections
  - Polar or Azimuth Axis Misalignment
  - Non-Perpendicular Axes
  - Collimation Errors
  - Tube & Mount Flexure
  - Gearing Errors (Backlash & Periodic)
  - Field Rotation: (S&T September 1992)



SOME MORE LINKS…

- Positions in the Sky
- Sidereal Time Calculator
- Project Pluto: Astronomy C/C++ Source Code
- Taki: Equations for Pointing a Telescope
- Arduino-DSC (Github)
- Teensy-DSC (Github)
- ESP-DSC (Github)
- The Ek's Files: Build your own Digital Setting Circles
- Gigi: gDSC : Bluetooth Ek DSC

DEMO TIME…