High Reliability CubeSat Software with SPARK/Ada

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Ada and SPARK

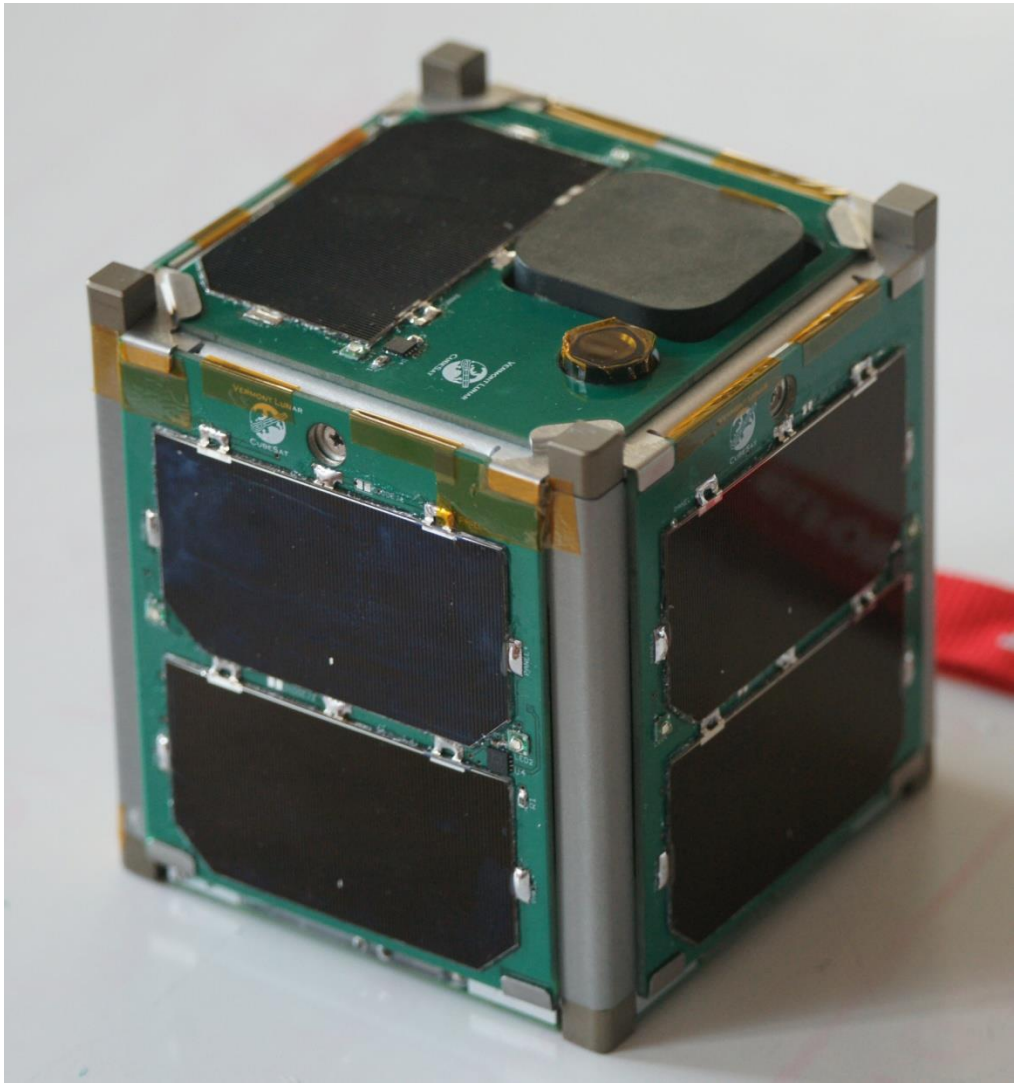
VERMONT TECH

- The Ada language originally issued in 1983 has been revised in 1995, 2005 and 2012

- Although originally developed at the behest of the Defense Department, Ada has taken over the niche for very high integrity software, as SIGAda says: “When the software really has to work”

- As a result, Ada is used in all commercial airline avionics and all air traffic control systems worldwide, as well as high speed trains and nuclear power plants in Europe

Our ELaNa IV CubeSat

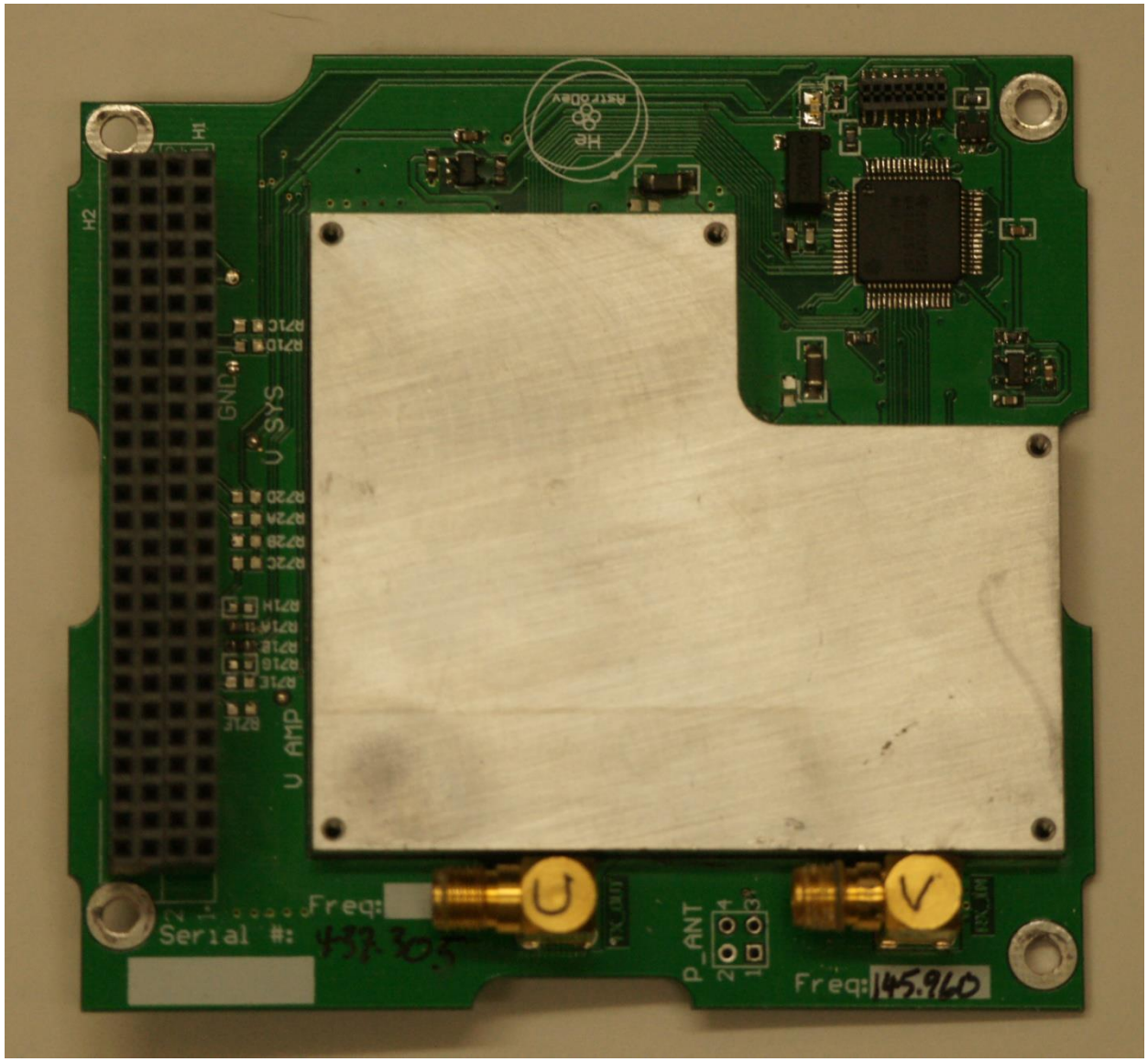


Vermont Lunar CubeSat

Software Controlled Hardware

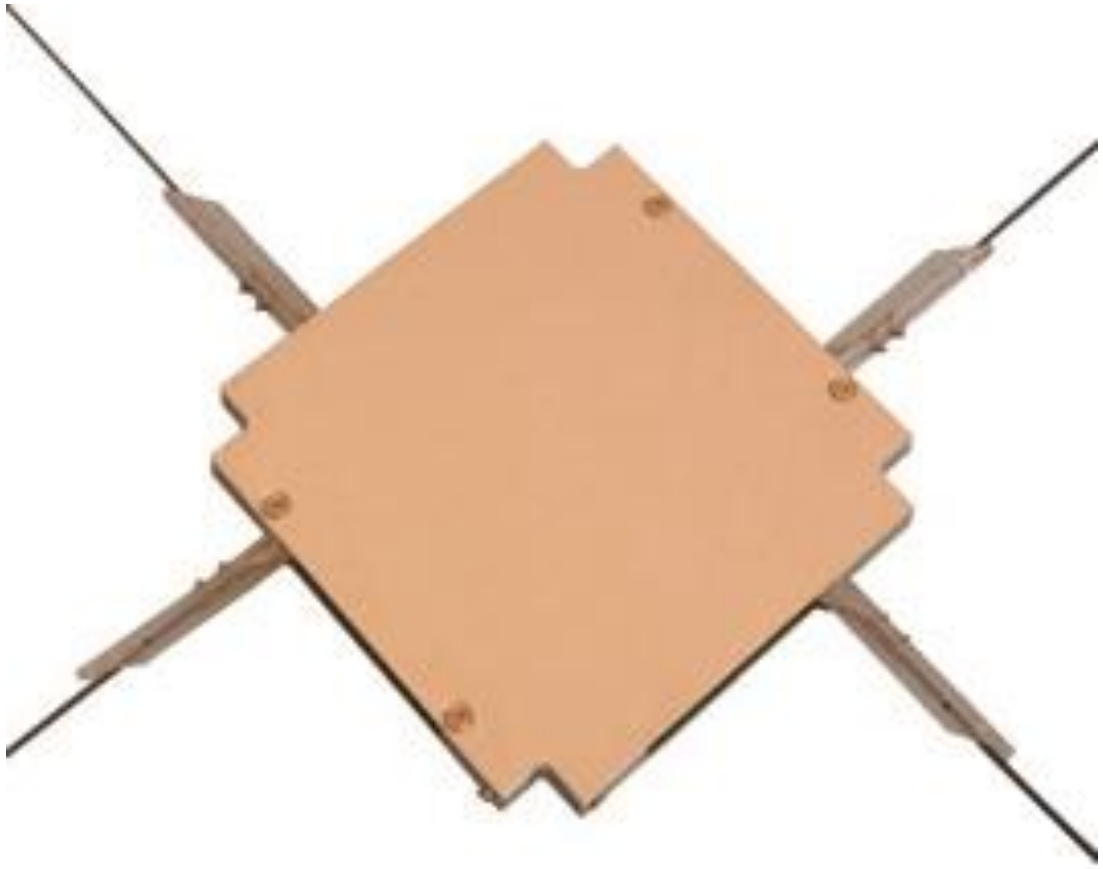
Clyde Space EPS

Software Controlled Hardware



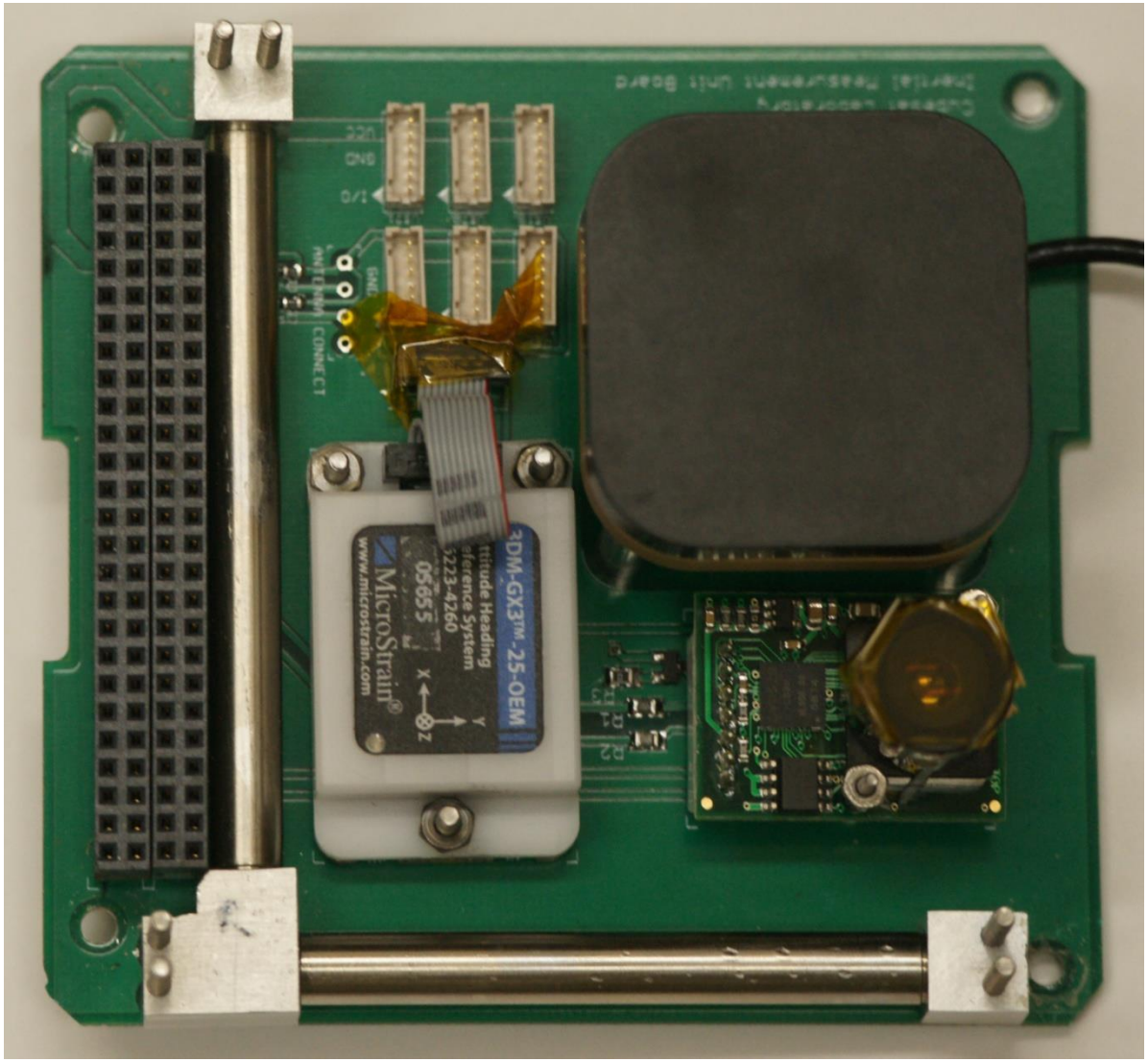
Astrodev Helium-100 transceiver

Software Controlled Hardware



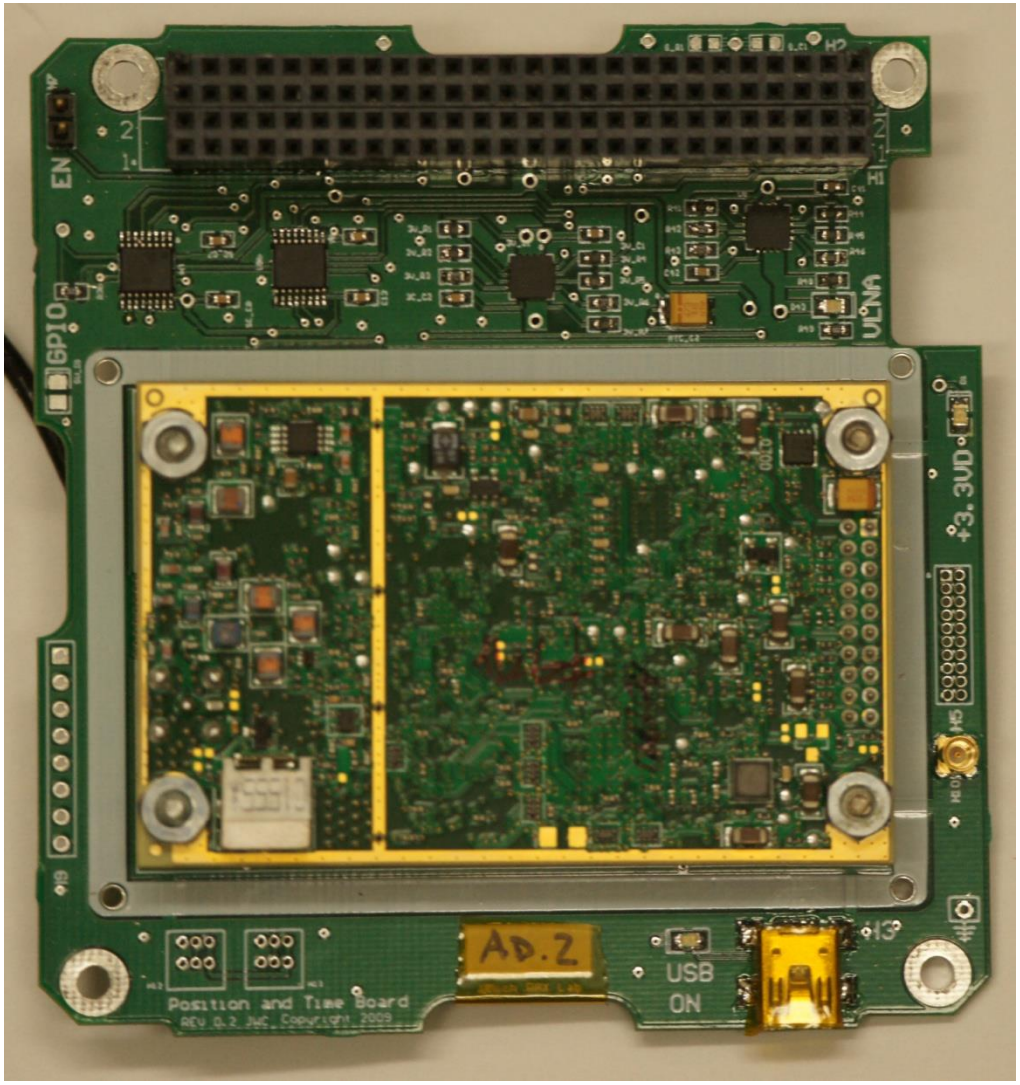
ISIS AntS crossed dipole antenna

Software Controlled Hardware

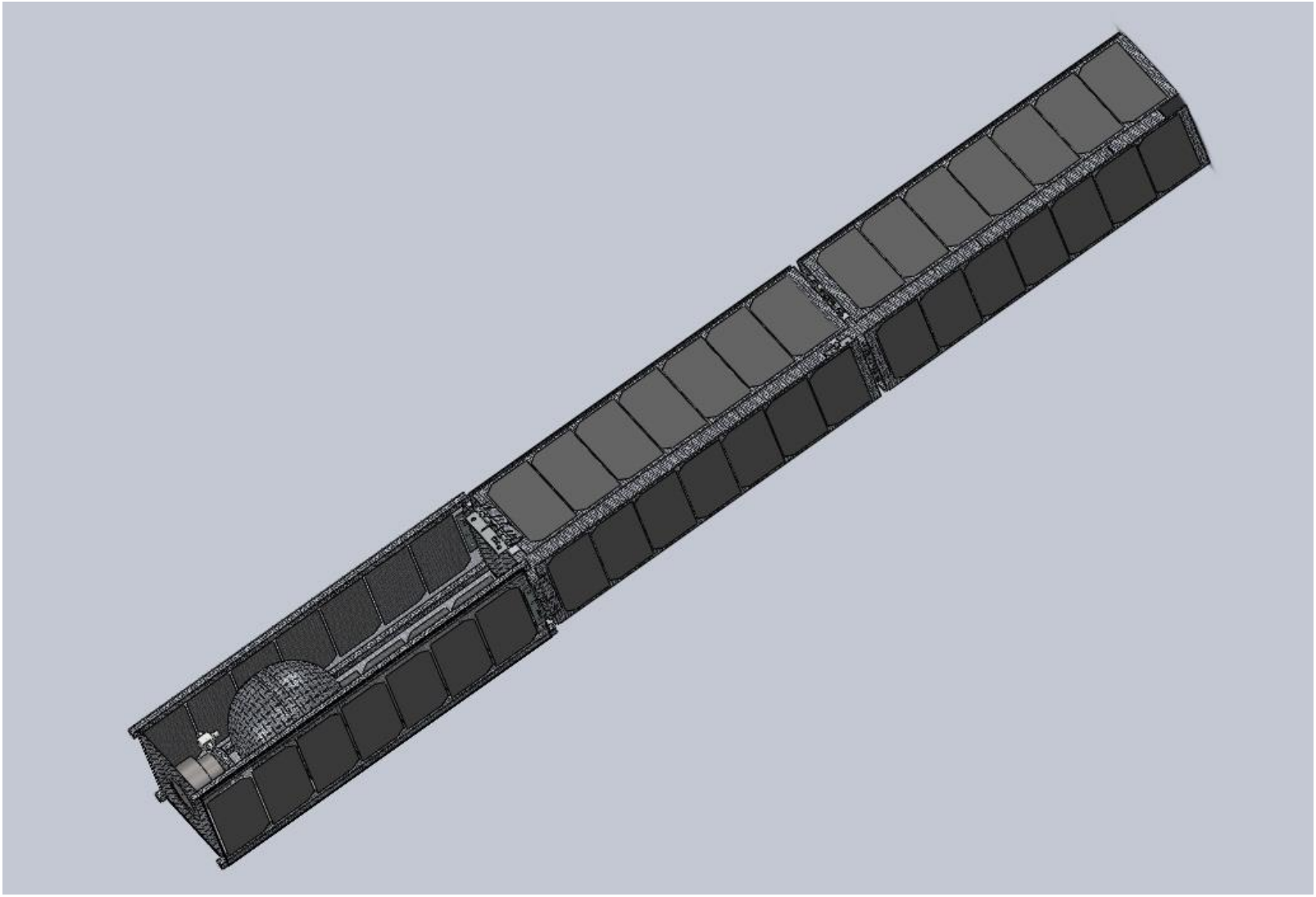


IMU, GPS patch, camera & hysteresis board

NovAtel OEMV-1 GPS Board Mounted on University of Michigan Position and Time Board

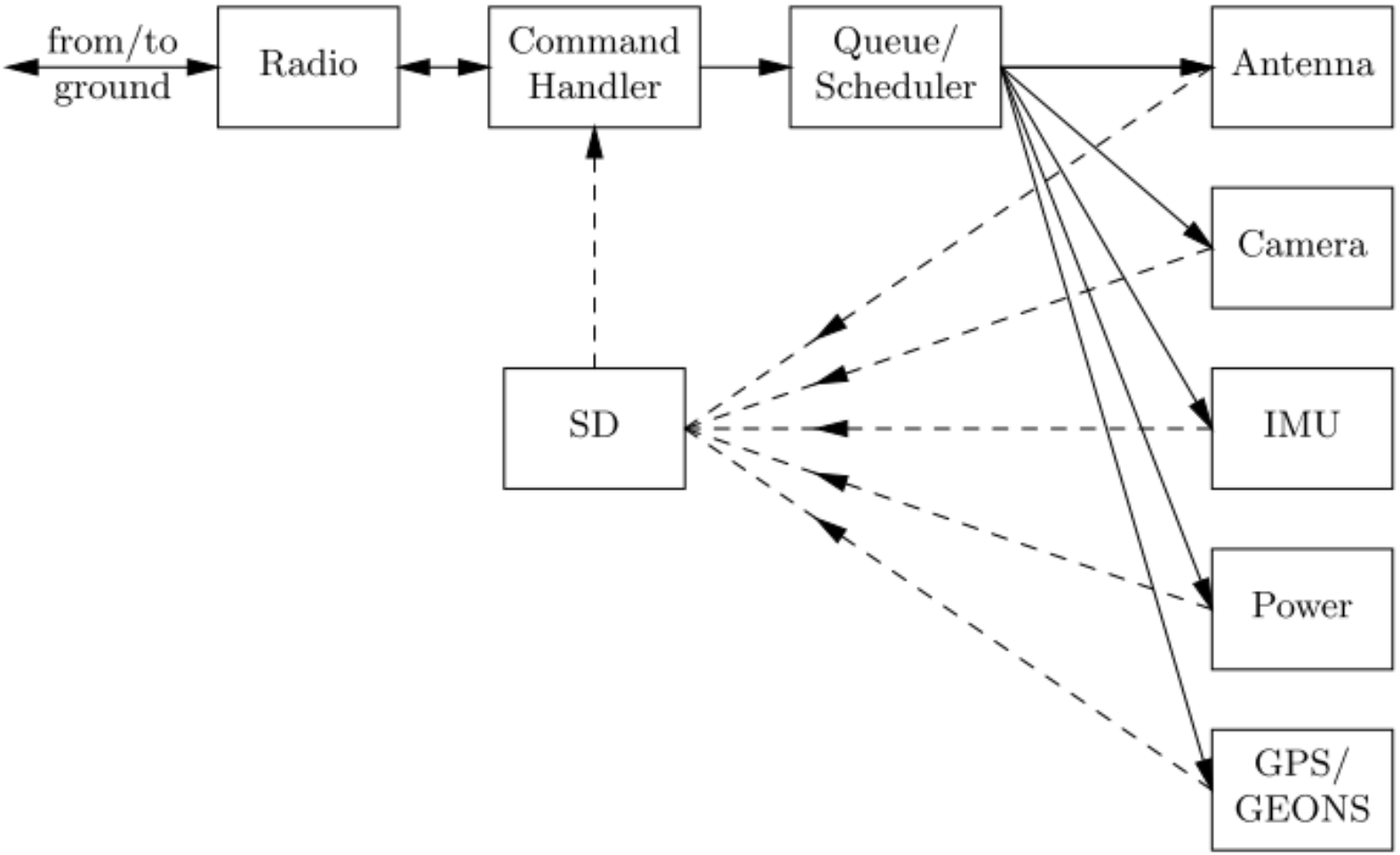


Follow on CubeSat

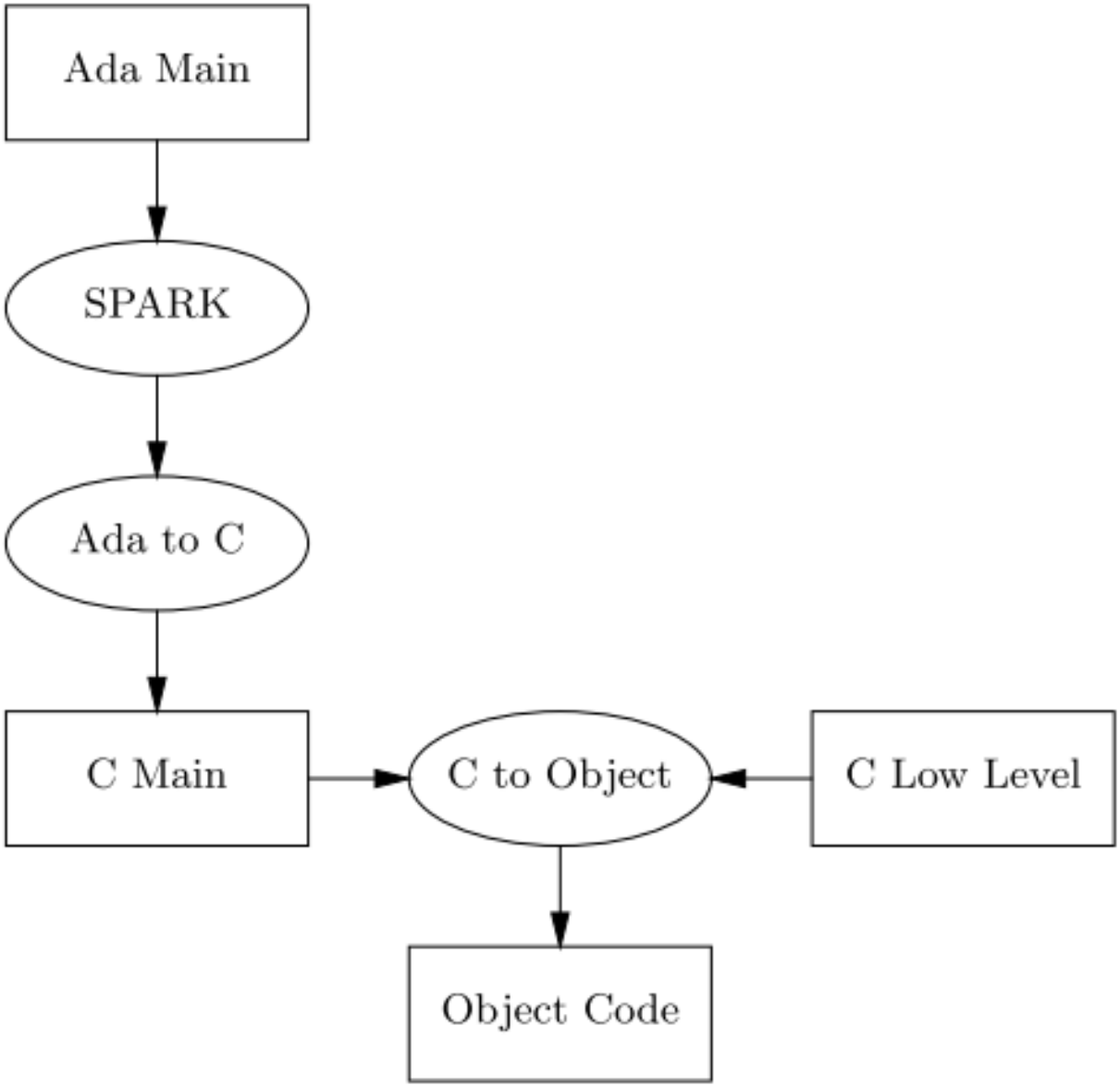


Triple CubeSat Ion Drive Lunar or Interplanetary with fold outs

Control Program Architecture



Software Tool Chain



Subsystems Used in ELaNa IV CubeSat

Subsystem	*Interfacing*
Antenna	I^2C
Radio	RS-232
Camera	SPI
EPS (Power Supply)	I^2C
Inertial Measurement Unit (IMU)	RS-232
GPS & GEONS	SPI

Student Participation

Time	*Students*	*Notes*
Summer 2011	2	Design and implementation of radio and interfacing subsystems
AY 2011-2012	0	Small enhancements
Summer 2012	1	Completed implementation of most subsystems
AY 2011-2012	4	File transfer, integration, camera, radio, IMU, navigation program

Control Software

- Control Software written in SPARK/Ada using Adacore's GNAT Programming Studio & GNAT Pro compiler
- Praxis' SPARK Toolset used to prove the correctness of the code
- Sofcheck's AdaMagic compiles it to produce ANSI C intermediate code
- C code compiled to object code
- Software runs on CubeSat Kit MSP430 CPU

SPARK/Ada Example

```
procedure Matrix_2 (J : in Natural)
   --# global in out Upper_Matrix; in In_Matrix, Diagonal;
   --# derives Upper_Matrix from Upper_Matrix, J, In_Matrix, Diagonal;
   --# pre J >= Diagonal'First and J < Diagonal'Last and
   --#     Upper_Matrix'First(1) = Upper_Matrix'First(2) and
   --#     Upper_Matrix'Last (1) = Upper_Matrix'Last (2) and
   --#     Diagonal'First        = Upper_Matrix'First(1) and
   --#     Diagonal'Last         = Upper_Matrix'Last (1);
   is
   begin
     Upper_Matrix (J, J) := 1.0;
     for I in reverse Natural range Diagonal'First .. J - 1 loop
       Upper_Matrix (I, J) := 0.0;
       for K in Natural range J + 1 .. Diagonal'Last loop
         Upper_Matrix (I, J) := Upper_Matrix (I, J) +
                                (Diagonal (K) * (Upper_Matrix (I, K) * Upper_Matrix (J, K)));
       end loop;
       Upper_Matrix (I, J) := (In_Matrix (I, J) - Upper_Matrix (I, J)) / Diagonal (J);
     end loop;
   end Matrix_2;
```

SPARK/Ada Example

VERMONT TECH

```
procedure Get_From_Radio(Ch : out Character; Rx_Success : out Boolean)
  --# global in out USCI_A1.State, Utility.Hardware; in Utility.Timer_Done;
  --# derives      USCI_A1.State    from USCI_A1.State &
  --#              Ch               from USCI_A1.State &
  --#              Rx_Success       from USCI_A1.State &
  --#              Utility.Hardware from Utility.Hardware &
  --#              null             from Utility.Timer_Done;
  is
    Finished : Boolean;
  begin
    Utility.Start_B(Utility.Millisecond_Count_Type(20));

    loop
      Finished := Utility.Get_Timer_Finished;
      exit when Finished;
    end loop;

    if USCI_A1.Get_Rx_Buffer_Used > 0 then
      USCI_A1.Eat_Char(Ch);
      Rx_Success := True;
    else
      Ch := ' ';
      Rx_Success := False;
    end if;
  end Get_From_Radio;
```

Navigation Components

- Converting the NASA Goddard GEONS navigation system to SPARK/Ada yields about 1% of the error rate of C software
- This process has already found a number of errors in the NASA GEONS software
- The GEONS software runs on the GPS board ARM processor
- Celestial navigation camera
- Novatel GPS on University of Michigan Position and Time Board
- Passive magnetic attitude control
- Inertial measurement unit (3 axis magnetometer, gyro and accelerometer)

NASA Launch Opportunity

- NASA's 2010 CubeSat Launch Initiative
- Our project was in the first group selected for launch
- Our single-unit CubeSat will be launched as part of NASA's ELaNa IV on an Air Force Minotaur 1 flight in September 2013 to a 500 km altitude, 40.5^{o} inclination orbit
- It will test the Lunar navigation system in Low Earth Orbit
- Follow our project at www.cubesatlab.org

NASA Launch Opportunity
Minotaur 1 – Wallops Island

First two stages are Minuteman II first two stages, third and fourth stages are Pegasus second and third stages

Acknowledgements

- NASA Vermont Space Grant Consortium
- NASA
- Vermont Technical College
- AdaCore, Inc. (GNAT Pro)
- Altran Praxis (SPARK)
- SofCheck (AdaMagic)
- Applied Graphics, Inc. (STK)
- LED Dynamics (PV boards)
- Microstrain (IMU)

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