Antenna Aimer

Build this digital compensated compass to help aim your beam toward true headings

While ham-camping recently, my brother Bill (NG4T) and I happened upon the June ARRL VHF QSO Party. We put up a 6 meter Moxon antenna on a painter pole and for several hours identified the contact's grid square, found it on the map, noted the general direction from our square, and then turned the antenna toward the contact's heading to begin a QSO. Afterwards, we realized that all of our headings were made using a fixed dial compass. We then discussed the idea of entering the next contest with a faster and more accurate method of antenna aiming.

Geomagnetism 101 (Figures 1 & 2)
We often hear that a compass points to magnetic north, not true north. Technically, that is not exactly true. The compass actually points in the direction of the horizontal component of the magnetic field where the compass is located, and not to any single point[1]. The angle between the local magnetic field and true north is called magnetic declination and in the continental U.S. the declination varies from approximately 18°W in Maine to 18°E in Washington. An imaginary line starting at the north magnetic pole down through the western end of Lake Superior and extending into the lower tip of Mississippi is known as the agonic line (shown in red). Along this line the declination is zero (i.e. true north and magnetic north are the same). To the left and right are isogonic lines in one degree increments. The green lines indicate magnetic inclination, which is the angle that a magnetic needle makes with level ground at any specific location. Magnetic inclination is 0° at the magnetic equator and 90° at each of the magnetic poles.

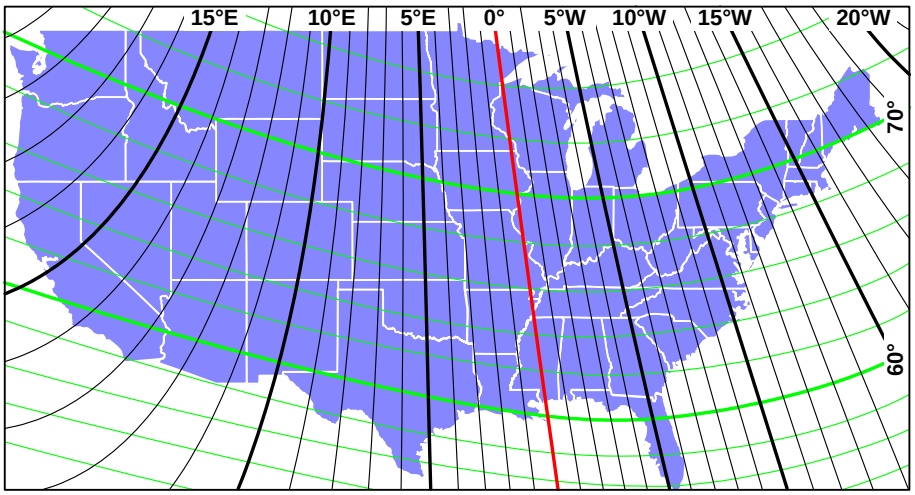

Figure 1

All points along the isogonic lines have constant declination values. East declinations are positive and west declinations are negative. Although the math is simple, the rules can get very confusing[2]. Conversion between true and magnetic bearings can be accomplished with the following equations:

True Bearing = Magnetic Bearing + Magnetic Declination
Magnetic Bearing = True Bearing – Magnetic Declination

For example, to convert a magnetic bearing of 45° to a true bearing:
In Maine (18°W): 45° + (-18°) = 45° - 18° = 27°
In Washington (18°E): 45° + (+18°) = 45° + 18° = 63°.

To convert a true bearing of 45° to a magnetic bearing:
In Maine (18°W): 45° - (-18°) = 45° + 18° = 63°
In Washington (18°E): 45° - (+18°) = 45° - 18° = 27°.

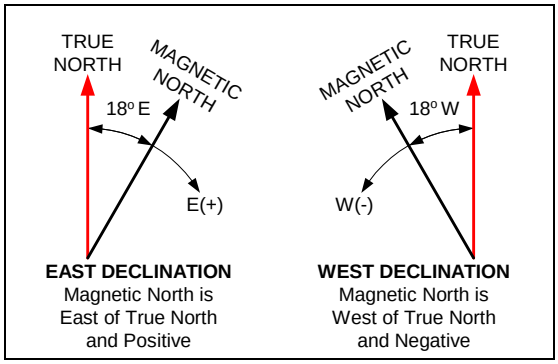

Figure 2

Because the magnetic declination and inclination values change with the movement of the magnetic north pole (25 miles to the NW per year) users should get up-to-date values by using an on-line Magnetic Field Calculator[3]. (Also listed are several URLs for aid in finding latitude & longitude from a zip code or address[3a], latitude & longitude format conversion[3b], and declination/inclination format convertion[3c]).

The declination math can also be done by using a rotating bezel compass or a GPS with true heading capability, but I wanted to simplify and speed up the aiming procedure. While researching this idea I ran across a robotic compass module connected to a microcontroller[4]. By including the magnetic to true heading calculation in the microcontroller's program the resulting display would indicate true headings.

Microcontroller, U1 (Cubloc CB220)
A new type of microcontroller is available that combines Basic programming with PLC (Programmable Logic Controller) ladder logic. Basic is a simple but powerful language that is easy to learn and use even if you're not a programmer. Although not used in this application, ladder logic is used throughout industry for automation and machine control. The Cubloc CB220 microcontroller has 16 I/O ports, 80K flash memory, eight 10-bit A/D

analog inputs, I2C bus (Inter-Integrated Circuit), and three 16-bit PWM analog outputs in a 24 pin DIP that is pin compatible with the Basic Stamp BS2. The power requirement at 5VDC is 40mA. The chip has a built-in 5V regulator that allows it to run from 5.5 to 12VDC power sources. It can also supply 5VDC@100mA to other circuits.

Compass Module, M1 (Devantech CMPS03)
This 2-axis compass module was designed for use in robots as an aid to navigation. The module uses two Philips KMZ51 magnetic field sensors, which are sensitive enough to detect the earth's magnetic field. The output from two of them mounted at right angles to each other is used to compute the direction of the horizontal component of the earth's magnetic field. The outputs are pulse width modulation (PWM) or I2C bus, and the power requirement is 5VDC@15mA.

Digital Display Module, DSP1 (Cubloc CSG-4S)
This module features a 4 digit seven-segment LED display with built in I2C bus which greatly simplifies the use of LED displays. The power requirement is 5VDC@5mA per segment. This application will only be using three digits, so the current draw to display 358 (the largest number of segments) is 17 x 5, or 85mA. Set the module's I2C slave address to zero on the rear switch: 1, 3 & 4 = off, 2 = on.

Power Supply
The 9V battery voltage is routed straight to U1 which provides 5V to compass module M1. Reverse polarity protection is provided by D1. A 5V regulator (U2) is used to provide power to the LED display. The regulator's quiescent current adds about 10mA to the total load, so the total battery demand is quite high at 150mA. A fresh 9V alkaline battery can provide this current continuously for about 1½ hours. Although more expensive, a 9V lithium battery (Energizer L522[5]) can supply 120mA continuously for 8 hours before it reaches 5.5 volts. For intermittent duty, either battery should last several hours.

Construction
The circuit is built on perf-board with point-to-point wiring using component leads and small gauge wire. To minimize the amount of metal around the compass module, nylon hardware is used for all standoffs and perf-board mounting (i.e. tap the enclosure perf-board mounting holes with a 4-40NC tap). For the same reason, the compass module is mounted as far away as possible from the battery and other components. A bubble level is mounted on top of the enclosure to ensure that the compass module is level, so make sure that the compass module is mounted parallel to the perf-board. If the mating connector is not used on DSP1, use a minimum of heat when soldering to the pins to prevent them from lifting. The controls are simple: SW1 turns power on and off, SW2 is used to calibrate the compass module, and SW3 switches between magnetic and true headings. SW2 is sized so that the button is recessed below the top of the enclosure to prevent accidental calibrations.

After assuring that the compass module is mounted parallel to the length of the enclosure, place a direction arrow on the top center of the enclosure to help sight the bearing. I cut one out of white plastic and attached it with silicon adhesive.

All of the LED bezel frames I could find took up more space than I wanted, so I elected to mount the plastic lens from inside the enclosure. Using this method means that the display cutout will be visible, so use a Dremel 565 Cutting Kit and a wood frame template to cut a professional looking hole (Figure 6). The plastic lens and bubble level are secured using silicone adhesive.

Programming (Figure 8)
To program the microcontroller, download Cubloc Studio[6] from the manufacturer's website. Install this free software on your PC and practice opening, editing, and saving programs while connected to U1 (CB220). If your PC doesn't have a serial port, use a USB to serial adapter such as the IOGear GUC232A, and set up the communication port in Cubloc Studio to match your port number. When you first connect to the CB220 the software may ask you to do a firmware download from their website. This is a good idea as it will install the latest firmware and bug fixes to the microcontroller. The firmware version used for this project is v2.1.F.

When SW3 is switched to MAGNETIC, the compass module output is displayed. When SW3 is switched to TRUE, the appropriate declination value is simply subtracted from the magnetic reading. Based on whether the declination is positive or negative, math routines then add or subtract 3600 to prevent the true heading from reading greater than 359 or less than zero.

Next, download the *AntennaAimer.zip* file from my website[7]. When you unzip it you will see two files: AntennaAimer.cul and AntennaAimer.cub. When opening a file, you will only see the ".cul" file (".cub" files are not displayed). Look up the desired magnetic declination and direction (E or W), and inclination from the calculator mentioned earlier and jot these down. To customize the program for your declination, follow the instructions in program lines 47-49 and then edit line 50. Save the program and load it into the CB220 by typing Ctrl R. With the PC still connected, the following information will be displayed in the Debug Terminal window each time the program is executed:

- Compass module revision number [register 0, calibration procedure reference]
- Compass module magnetic heading, 0-255 [register 1]
- Compass module magnetic heading, 0-3600 [registers 2 and 3]
- Compass module magnetic heading , 0-360 [(registers 2 and 3)/10]
- Computed true heading, 0-360, [((registers 2 and 3) + declination)/10]
- Switch SW3 position, 0 = magnetic, 1 = true

Unplug the serial cable and the microcontroller is ready to run on its own.

Accuracy and Calibration
Like a compass or GPS, the *Antenna Aimer* must be level to get accurate readings. Similarly, keep the unit away from magnets, motors and large metallic objects to reduce interference. The resolution of the compass module is listed as 0.1°, but due to the possibility of a slight misalignment of the magnetic field sensors (i.e. not exactly 90° to each other), accuracy of the calibration, and local interference the accuracy is listed as $\pm$2°.

The microcontroller program truncates the 4-digit compass module reading to the three most significant digits, so some accuracy is lost here as well. If you find yourself asking how accurately we must aim a beam, there is a very enlightening article[8] on this subject by L.B. Cebik, W4RNL.

Calibration of the CMPS03 compass module only needs to be done once - the calibration data is stored in EEPROM on the compass module's PIC16F872 chip. You do not need to re-calibrate every time the module is powered up or the battery is changed. The module has been factory calibrated to an inclination of 67°, and if your location is close to this you may want to try the compass without re-calibrating[9]. The inclination at my QTH is 65°, so I chose to re-calibrate. You will need a flat level surface free of motors, magnets, and metal and a decent compass to perform the calibration. I found it helpful to place the *Antenna Aimer*, compass and/or GPS on a rotatable board and align them along parallel drawn lines. The compass points can be set in any order, but all four points must be calibrated to magnetic compass points. Use a non-metallic rod to press SW2 and hold it down for one to two seconds at each point.

1. Set the compass module flat, pointing North (0°). Press SW2 and release.
2. Set the compass module flat, pointing East (90°). Press SW2 and release.
3. Set the compass module flat, pointing South (180°). Press SW2 and release.
4. Set the compass module flat, pointing West (270°). Press SW2 and release.

When complete, the display should agree with the magnetic compass when SW3 is switched to MAGNETIC mode. In TRUE mode, the display should reflect your declination by adding this positive or negative value to the magnetic reading. In either mode, ensure that the display goes from 0 to 359 as the device is rotated 360°.

"Heading" Out

Armed with new hardware and software, Bill and I participated in the 2007 ARRL September VHF QSO Party. A Grid Square program[10] by WB5KIA (Figure 3) was used to get headings from our portable QTH. Using this handy program, we entered the contact's 4-digit grid square and automatically got a true heading from our campsite to the center of his/her grid. (When available, a contact's 6-digit grid square further increased our aiming accuracy.) This heading was then relayed to the antenna turner equipped with the *Antenna Aimer*. Compared to our previous effort this contest progressed much more efficiently and allowed us to quickly zero in on desired headings. It worked especially well for our multi-element 2m and 70cm Yagi's whose higher gain and narrower beamwidth required additional aiming precision.

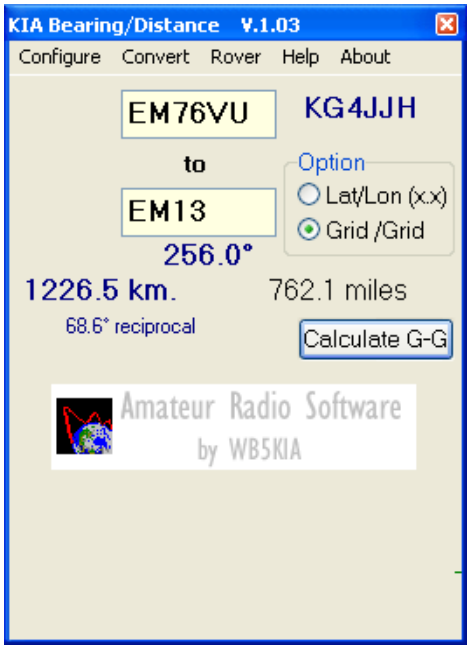

Figure 3

Summary

For me, this project was a great introduction to the world of microcontrollers. The parts count is low and the programming is fairly easy to understand, so both beginners and experts should have plenty of fun. Additionally, I now have a much better understanding of the relationship between magnetic and true north.

Possible enhancements to this project include the use of an LCD display[11] to reduce power consumption and display more data; the use of a 3-axis compass module[12] for automatic tilt correction; and mounting the unit (with no display) on a rotator mounted beam with a corded or Bluetooth link[13] to the shack. This method would provide an independent measure of azimuth and eliminate any nonlinearity in the rotator's position indicator.

So, don't get caught aiming your antenna with a compass and ignoring the declination. This is especially true for northeast and northwest coast amateurs where the declination is the highest. Declination error is calculated as 100 feet per degree per mile, so an amateur in Seattle WA trying for a 4000 mile DX contact could be off target by as much as 17.5°, or 1326 miles[14].

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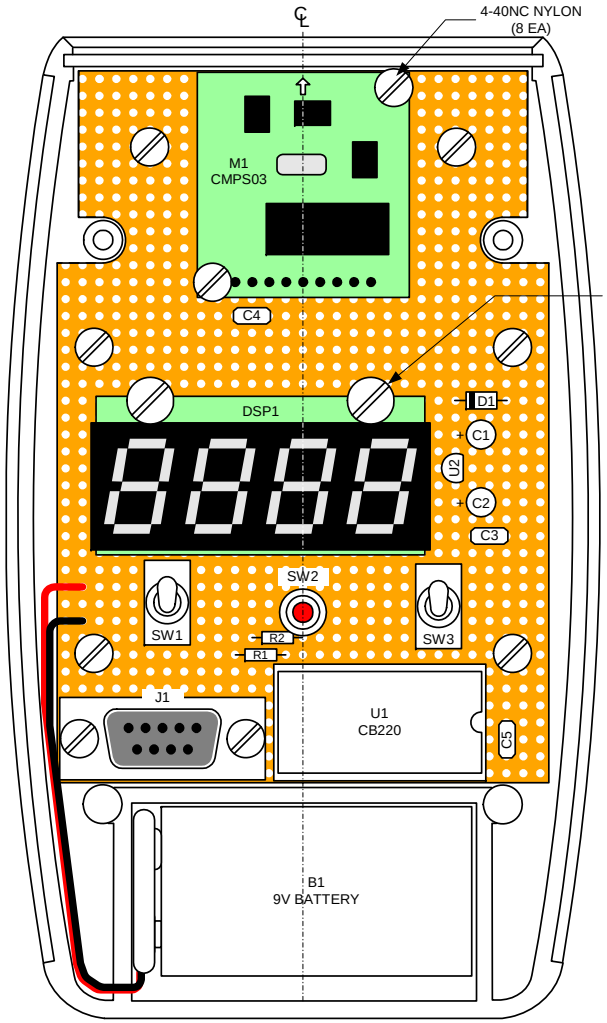
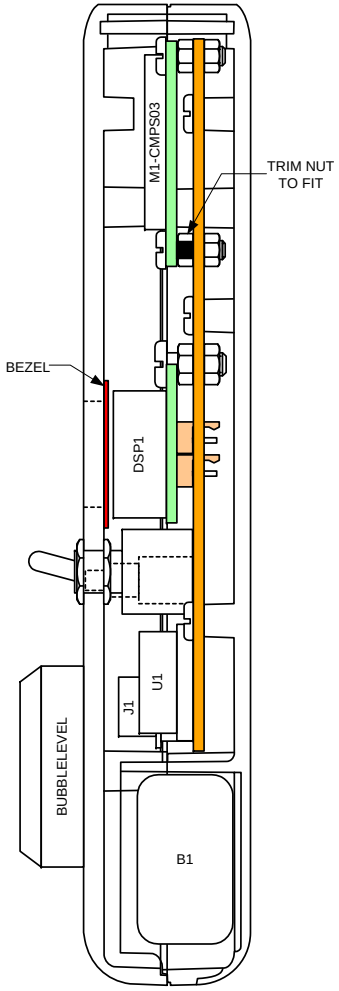
www.kg4jjh.com

Notes

1. *What is declination?* The Compass Store; http://www.thecompassstore.com/whatisdec.html
2. *The Doctor is On-Line,* July 2002; http://www.arrl.org/members-only/qst/doctor/comments.html?qid=135&nextq=Q4
3. *Magnetic Field Calculator*, National Geophysical Data Center; http://www.ngdc.noaa.gov/seg/geomag/jsp/IGRFWMM.jsp
    a. *Map Coordinates Finder for Street Address, City, State, or Zip*; http://www.batchgeocode.com/lookup/
    b. *Latitude & Longitude Format Converter* http://www.geology.enr.state.nc.us/gis/latlon.html
    c. *Convert Degree, Minutes, & Seconds to Decimal*; http://id.mind.net/~zona/mmts/trigonometryRealms/degMinSec/degMinSec.htm
4. *Digital Compass using Devantech CMPS03; http://zedomax.com/blog/zedomax-diy-hack-lets-make-a-digital-compass/*
5. Energizer L522 Product Data Sheet; http://data.energizer.com/PDFs/l522.pdf
6. Cubloc Studio; http://www.comfiletech.com/
7. http://www.kg4jjh.com/aimer.html/, click on "Source Code (AA.ZIP)"
8. *How Accurately Must We Aim a Beam*, L.B. Cebik, W4RNL; http://cebik.com/trans/bwaim.html
9. *Calibrating the CMPS01, CMPS03 Robot Compass Modules; http://www.robot-electronics.co.uk/htm/cmps_cal.shtml*
10. Grid Square Program, Stephen Gradijan, WB5KIA; http://www.qsl.net/wb5kia/
11. LCD Module, Cubloc; http://www.comfiletech.com/index.asp?PageAction=VIEWCATS&Category=9
12. Magneto Sensors; http://www.sparkfun.com/commerce/categories.php?cPath=23_83
13. Bluetooth Wire Module, Cubloc ACODE300; http://www.comfiletech.com/index.asp?PageAction=VIEWCATS&Category=24
14. Error = ((100 feet x 17.5° x 4000 miles)/5280 feet/mile) = 1325.7 miles



ANTENNA AIMER
TOP REMOVED



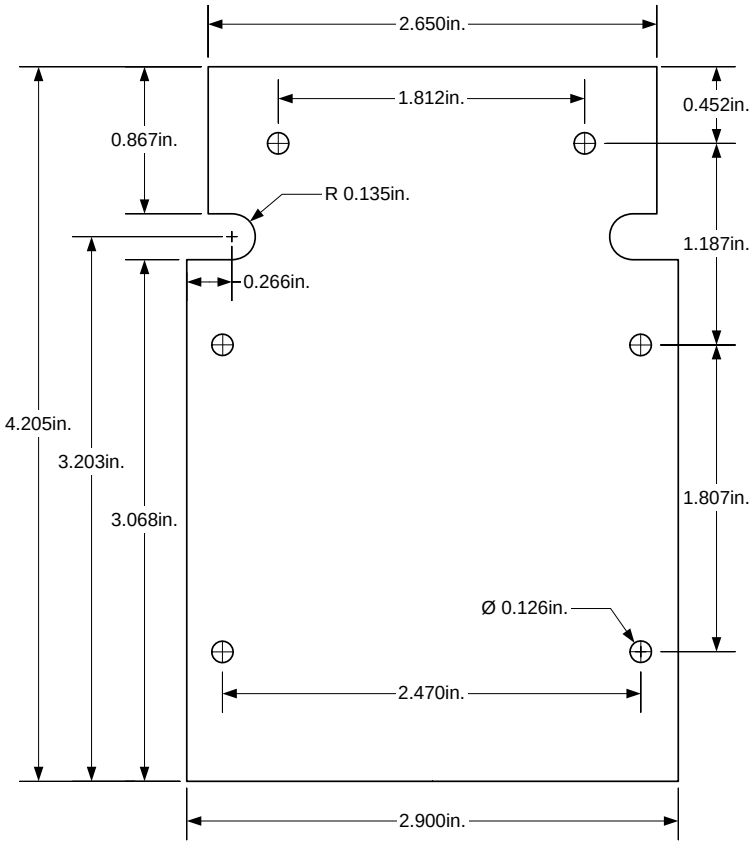
ANTENNA AIMER
CUTAWAY SIDE VIEW

ANTENNA AIMER
ASSEMBLY

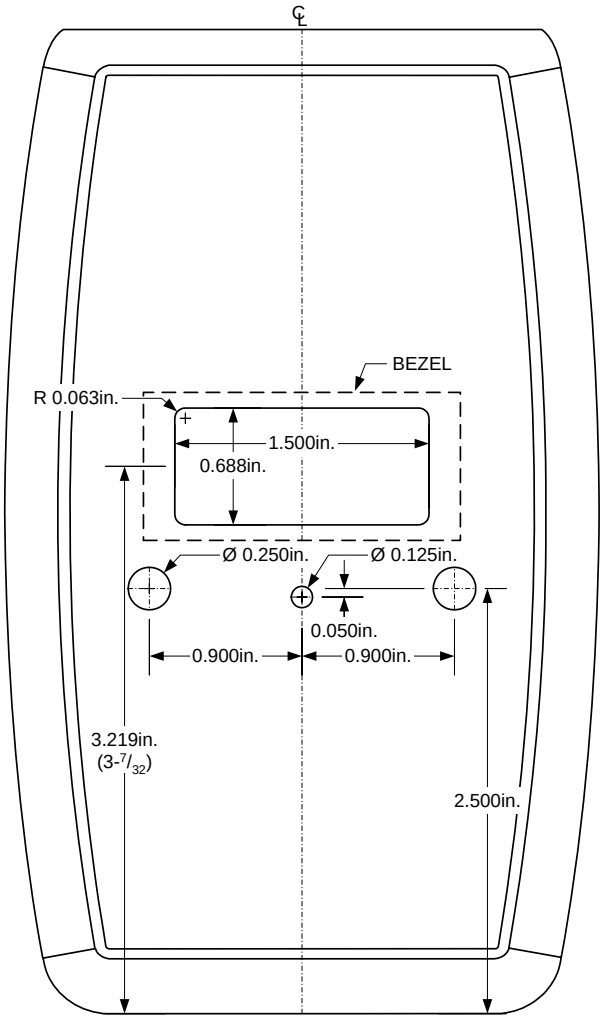
NOTES
1. MOUNT COMPASS MODULE USING NYLON HARDWARE TO REDUCE MAGNETIC INTERFERENCE.
2. FOR BEST ACCURACY, COMPASS MODULE SHOULD BE MOUNTED PARALLEL TO TOP OF CASE (I.E., LEVEL WHEN BUBBLE IS LEVEL).
3. MOUNT LED DISPLAY SO THAT THE THIRD DIGIT IS CENTERED ON THE PERF BOARD.
4. CUT ENCLOSURE DISPLAY HOLE WITH DREMEL TOOL AND TEMPLATE.

DESIGN: KG4JJH	08/20/07	KG4JJH
TESTED: KG4JJH	09/10/07	ANTENNA AIMER ASSEMBLY & LAYOUT
		SCALE: 1:1 / SHEET 1 OF 3 / REV. 0

Figure 4



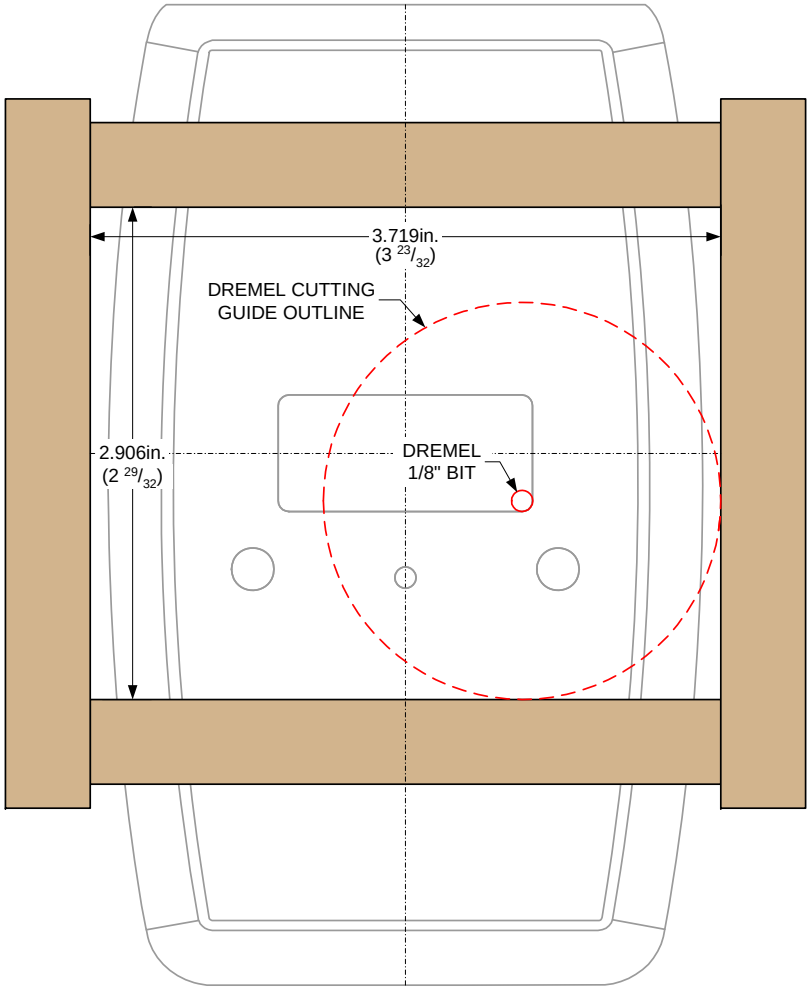
PERF BOARD



ENCLOSURE
CUTOUTS

DESIGN: KG4JJH	08/20/07	KG4JJH
TESTED: KG4JJH	09/10/07	ANTENNA AIMER DETAILS
		SCALE: 1:1 / SHEET 2 OF 3 / REV. 0

Figure 5



BEZEL CUTOUT TEMPLATE
MATERIAL: 3/8" THICK MDF

NOTES
1. FASTEN TEMPLATE TOGETHER WITH GLUE.
2. CLAMP ENCLOSURE TOP TO TABLE & TEMPLATE TO ENCLOSURE TOP.
3. MAKE A TRIAL CUT IN CENTER OF CUTOUT TO DETERMINE BEST DREMEL CUTTING SPEED.

DESIGN: KG4JJH	08/20/07	KG4JJH
TESTED: KG4JJH	09/10/07	ANTENNA AIMER BEZEL TEMPLATE
		SCALE: 1:1 / SHEET 3 OF 3 / REV. 0

Figure 6

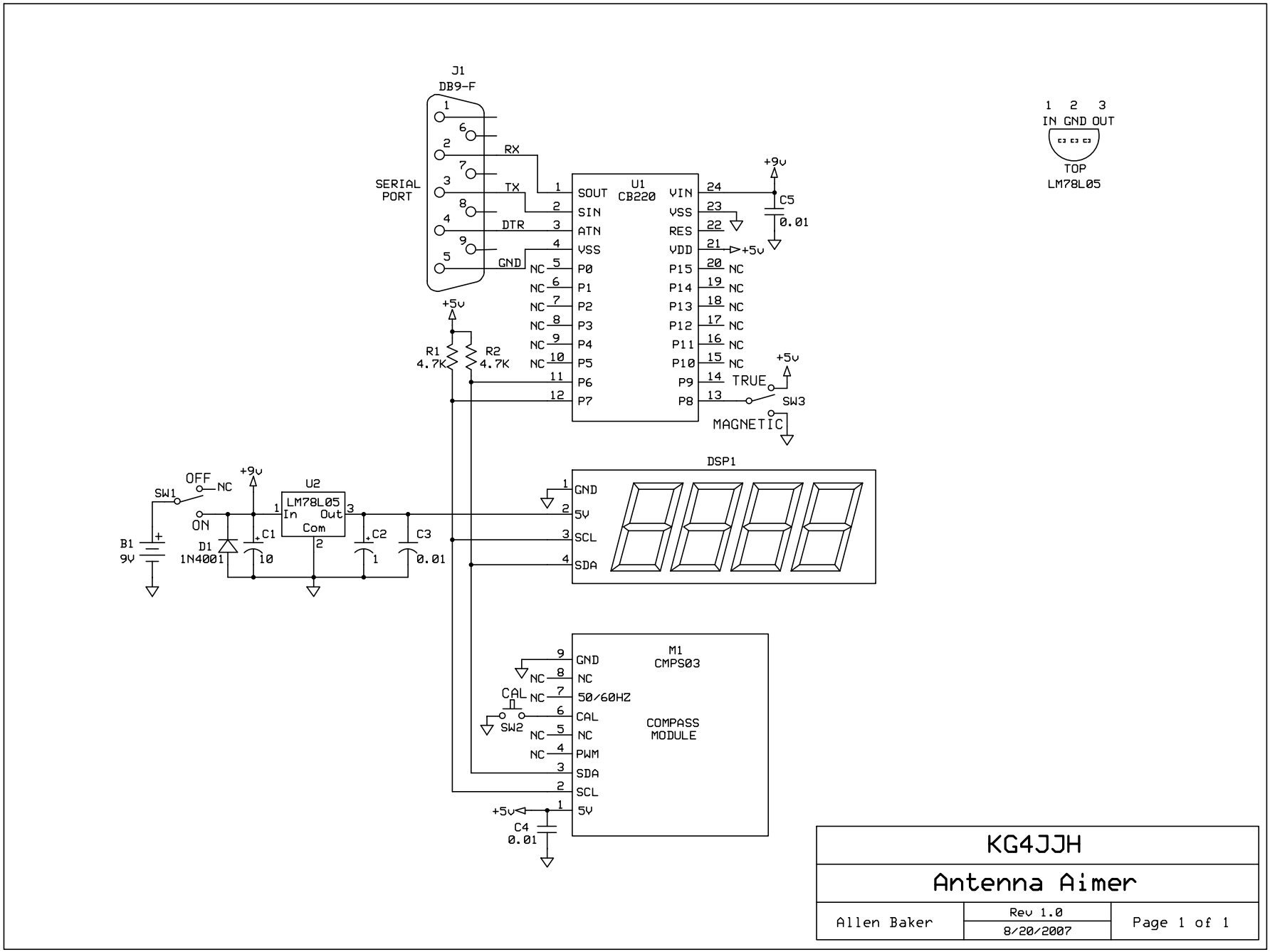

J1
DB9-F
SERIAL PORT
RX
TX
DTR
GND
U1
CB220
SOUT
SIN
ATN
VSS
NC P0
NC P1
NC P2
NC P3
NC P4
NC P5
P6
P7
VIN
VSS
RES
VDD
P15 NC
P14 NC
P13 NC
P12 NC
P11 NC
P10 NC
P9
P8
+9v
C5
0.01
+5v
R1 4.7K
R2 4.7K
TRUE
SW3
MAGNETIC
1 2 3
IN GND OUT
TOP
LM78L05
DSP1
GND
5V
SCL
SDA
SW1
OFF
ON
NC
U2
LM78L05
In Out
Com
B1
9V
D1
1N4001
C1
10
C2
1
C3
0.01
M1
CMPS03
COMPASS MODULE
CAL
SW2
50/60HZ
PWM
C4
0.01
KG4JJH
Antenna Aimer
Allen Baker
Rev 1.0
8/20/2007
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Figure 7

Antenna Aimer KG4JJH						
Part #	**Description**	**Mouser Part #**	**Qty**	**Source**	**Price**	**Ext**
U1	IC, Microcontroller, Cubloc CB220, 24 pin DIP	-	1	www.cubloc.com	$34.00	$34.00
U2	Voltage Regulator, 5V@100mA, 78L05	512-LM78L05ACZ		www.mouser.com	$0.27	$0.27
M1	Compass Module, Devantech CMPS03, 9 pin SIP	-	1	www.snailinstruments.com/eng/robotics/	$46.50	$46.50
DSP1	Display, 4 Digit, I2C Bus, Cubloc CSG-4S	-	1	www.cubloc.com	$19.00	$19.00
SW1, SW2	Switch, Toggle, SPDT	108-1MS1T2B3M2QE-EVX	2	www.mouser.com	$1.90	$3.80
SW3	Switch, Pushbutton, SPST	10PA018	1	www.mouser.com	$1.24	$1.24
J1	Connector, DB9, Female	152-5309	1	www.mouser.com	$3.08	$3.08
-	Enclosure, Plastic, 5.8" x 3.5" x 0.98"	546-1553DBKBAT	1	www.mouser.com	$10.56	$10.56
R1, R2	Resistor, Metal Film, 1/4W, 1%, 4.7K	271-4.7K-RC	2	www.mouser.com	$0.09	$0.18
C1	Capacitor, Electrolytic, 10uF, 25V	140-XRL25V10-RC	1	www.mouser.com	$0.09	$0.09
C2	Capacitor, Electrolytic, 1uF, 25V	140-XRL25V1-RC	1	www.mouser.com	$0.09	$0.09
C3, C4, C5	Capacitor, Ceramic, 0.01uF	581-SR215C103J	3	www.mouser.com	$0.36	$1.08
D1	Diode, 1N4001	512-1N4001	1	www.mouser.com	$0.05	$0.05
-	Machine Screw and Nuts, Nylon, 4-40 x 1/2"	-	8	www.mcmaster.com	$0.20	$1.60
-	Machine Screw and Nuts, Nylon, 6-32 x 1/2"	-	2	www.mcmaster.com	$0.25	$0.50
-	IC Socket, 24 pin DIP (0.6" wide)	575-393624	1	www.mouser.com	$2.20	$2.20
-	Bezel Lens, Red, 1.87" x 0.87", #PRD180LPR-ND	-	1	www.digikey.com	$1.53	$1.53
-	Bubble Level, Starrett Bull's-Eye Circular Level	-	1	www.homedepot.com	$2.90	$2.90
					Total	$128.67

Table 1

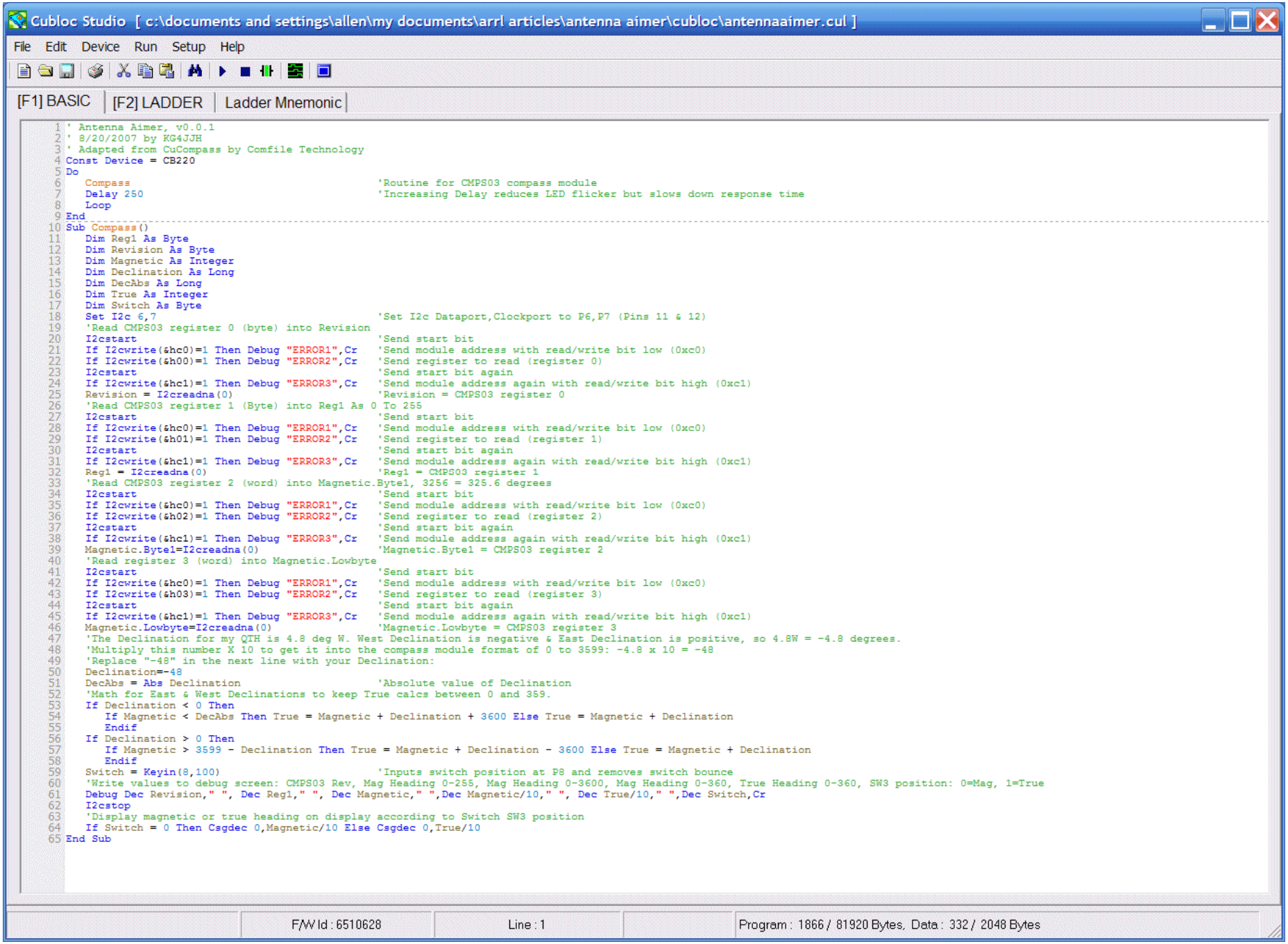
Cubloc Studio [c:\documents and settings\allen\my documents\arrl articles\antenna aimer\cubloc\antennaaimer.cul]
File Edit Device Run Setup Help
[F1] BASIC
[F2] LADDER
Ladder Mnemonic
' Antenna Aimer, v0.0.1
' 8/20/2007 by KG4JJH
' Adapted from CuCompass by Comfile Technology
Const Device = CB220
Do
Compass 'Routine for CMPS03 compass module
Delay 250 'Increasing Delay reduces LED flicker but slows down response time
Loop
End
Sub Compass()
Dim Reg1 As Byte
Dim Revision As Byte
Dim Magnetic As Integer
Dim Declination As Long
Dim DecAbs As Long
Dim True As Integer
Dim Switch As Byte
Set I2c 6,7 'Set I2c Dataport,Clockport to P6,P7 (Pins 11 & 12)
'Read CMPS03 register 0 (byte) into Revision
I2cstart 'Send start bit
If I2cwrite(&hc0)=1 Then Debug "ERROR1",Cr 'Send module address with read/write bit low (0xc0)
If I2cwrite(&h00)=1 Then Debug "ERROR2",Cr 'Send register to read (register 0)
I2cstart 'Send start bit again
If I2cwrite(&hc1)=1 Then Debug "ERROR3",Cr 'Send module address again with read/write bit high (0xc1)
Revision = I2creadna(0) 'Revision = CMPS03 register 0
'Read CMPS03 register 1 (Byte) into Reg1 As 0 To 255
I2cstart 'Send start bit
If I2cwrite(&hc0)=1 Then Debug "ERROR1",Cr 'Send module address with read/write bit low (0xc0)
If I2cwrite(&h01)=1 Then Debug "ERROR2",Cr 'Send register to read (register 1)
I2cstart 'Send start bit again
If I2cwrite(&hc1)=1 Then Debug "ERROR3",Cr 'Send module address again with read/write bit high (0xc1)
Reg1 = I2creadna(0) 'Reg1 = CMPS03 register 1
'Read CMPS03 register 2 (word) into Magnetic.Byte1, 3256 = 325.6 degrees
I2cstart 'Send start bit
If I2cwrite(&hc0)=1 Then Debug "ERROR1",Cr 'Send module address with read/write bit low (0xc0)
If I2cwrite(&h02)=1 Then Debug "ERROR2",Cr 'Send register to read (register 2)
I2cstart 'Send start bit again
If I2cwrite(&hc1)=1 Then Debug "ERROR3",Cr 'Send module address again with read/write bit high (0xc1)
Magnetic.Byte1=I2creadna(0) 'Magnetic.Byte1 = CMPS03 register 2
'Read register 3 (word) into Magnetic.Lowbyte
I2cstart 'Send start bit
If I2cwrite(&hc0)=1 Then Debug "ERROR1",Cr 'Send module address with read/write bit low (0xc0)
If I2cwrite(&h03)=1 Then Debug "ERROR2",Cr 'Send register to read (register 3)
I2cstart 'Send start bit again
If I2cwrite(&hc1)=1 Then Debug "ERROR3",Cr 'Send module address again with read/write bit high (0xc1)
Magnetic.Lowbyte=I2creadna(0) 'Magnetic.Lowbyte = CMPS03 register 3
'The Declination for my QTH is 4.8 deg W. West Declination is negative & East Declination is positive, so 4.8W = -4.8 degrees.
'Multiply this number X 10 to get it into the compass module format of 0 to 3599: -4.8 x 10 = -48
'Replace "-48" in the next line with your Declination:
Declination=-48
DecAbs = Abs Declination 'Absolute value of Declination
'Math for East & West Declinations to keep True calcs between 0 and 359.
If Declination < 0 Then
If Magnetic < DecAbs Then True = Magnetic + Declination + 3600 Else True = Magnetic + Declination
Endif
If Declination > 0 Then
If Magnetic > 3599 - Declination Then True = Magnetic + Declination - 3600 Else True = Magnetic + Declination
Endif
Switch = Keyin(8,100) 'Inputs switch position at P8 and removes switch bounce
'Write values to debug screen: CMPS03 Rev, Mag Heading 0-255, Mag Heading 0-3600, Mag Heading 0-360, True Heading 0-360, SW3 position: 0=Mag, 1=True
Debug Dec Revision," ", Dec Reg1," ", Dec Magnetic," ",Dec Magnetic/10," ", Dec True/10," ",Dec Switch,Cr
I2cstop
'Display magnetic or true heading on display according to Switch SW3 position
If Switch = 0 Then Csgdec 0,Magnetic/10 Else Csgdec 0,True/10
End Sub
F/W Id : 6510628
Line : 1
Program : 1866 / 81920 Bytes, Data : 332 / 2048 Bytes

Figure 8