G-862 CESIUM MAGNETOMETER

27921-OM REV. C

Operation Manual

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1.0 INTRODUCTION

Congratulations on your purchase, or rental, of one of the finest cesium vapor magnetometers ever produced. This manual will provide you with an understanding of alkali vapor magnetometer technology and will give you instructions for installing the system for airborne, land or marine use. It is not meant to be exhaustive for every case as there are many different situations and applications in which magnetometers can be used. Please contact the factory if you have specific questions relating to your special application.

The Geometrics G-862 magnetometer employs an optically pumped Cesium-vapor atomic magnetic resonance system that functions as the frequency control element in an oscillator circuit. The G-862 contains counter circuitry that internally converts the magnetometer's analog signal into a digital RS−232 output. A description of the G-862 operation is presented in the last chapter.

Figure 1: G-862 Sensor and Sensor driver module

The frequency of the magnetometer electrical oscillator is known as the Larmor frequency and it varies directly with the ambient magnetic field at the sensor. When this frequency is accurately measured it provides a precise measurement of the total magnetic field. The design of the sensor optical package uses a split-beam design which eliminates the need to optimize sensor orientation to obtain precise measurements.

As shown in Figure 1, the G-862 magnetometer consists of two interconnected modules: a sensor module and sensor driver module.

A basic understanding of the physics employed in the G-862, and optically pumped resonance magnetometers in general, is valuable for troubleshooting new installations and for achieving optimum results during field use, but is not essential for either. Such basic information can be found in the Appendix of this manual.

2.0 SYSTEM COMPONENTS

The basic system components of the G-862 consist of the sensor module, a sensor driver module, and an interconnect cable that is permanently attached to the sensor module and detachable from the sensor driver module. These components are identified in Figure 2. The weights, dimensions, and connector's specifications for these components and ancillary system components are listed in the Table 1.

Figure 2: G-862 system components

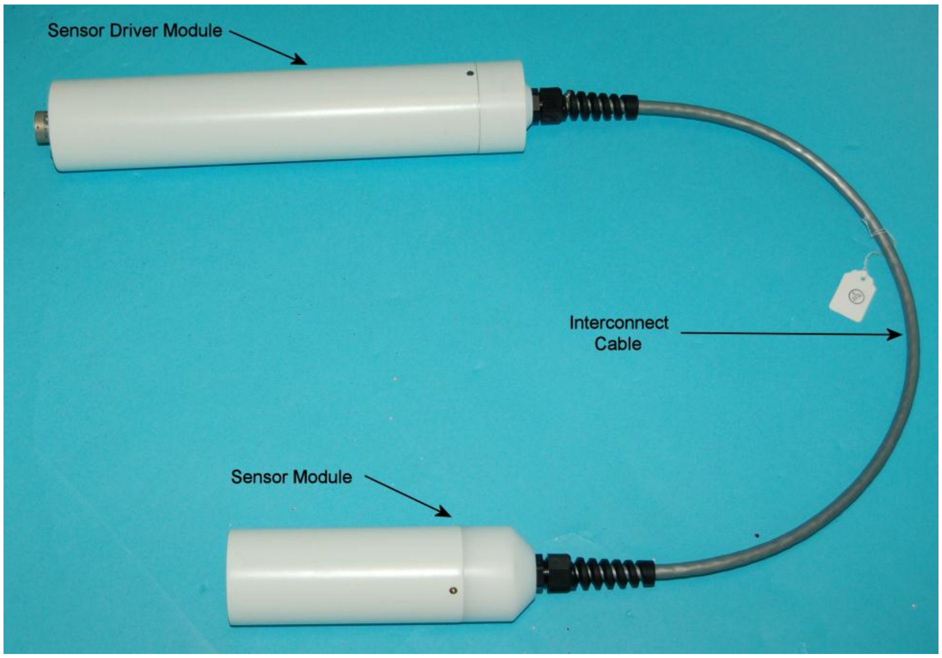


Table 1: G-862 standard component weights and dimensions

Description	*Weight*	*Dimensions*
Cesium sensor package P/N 27516-45, -46, -47	1lb. 8oz.	6-3/4" long x 2-3/4" diameter cylindrical housing with 9, 6, or 3 foot cable
G-862 Sensor driver module P/N 27519-30	2 lbs.	15-1/4" long x 2-3/4" diameter cylindrical housing
Carrying Case P/N 14-403-161	10 lbs.	30-3/4" l x 20-1/5"w x 11-5/8"h

A single multi-conductor cable connected to the Bendix connector on the sensor driver module carries power to and data from the module. This connection is located on the end opposite of the interconnect cable. This coaxial cable may be as long as 50 ft. (15 m) for interconnection with a DC/Data Junction Box (Geometrics P/N 24870-20)

3.0 PERFORMANCE

Geometrics G-862 magnetometer produces a Cesium Larmor frequency output at 3.498572 Hz per nT. 'nT' refers to the magnetic field strength as measured in nanoTesla. 1 nT equals one gamma or 10^{-5} gauss. So, at the earth's surface, in a nominal 50,000 nT field, the Larmor frequency is about 175 kHz. The output of the G-862 sensor electronics is a continuous sine wave at the Larmor frequency. The typical signal amplitude is from 1 to 2 volts peak-to-peak with the sensor in its optimal orientation. This frequency of this signal is counted and reported via RS-232 at a user set rate.

The G-862 is intended for use in airborne, marine, land and base station applications, and operates over the earth's magnetic field range of 20,000 to 100,000 nT. Absolute accuracy depends on the sensor orientation, internal light shift and the accuracy of the external counter's time base. An error due to orientation of the G-862 does not exceed ± 0.25 nT or 0.5 nT peak-to-peak (p-p) throughout the active zones shown in Figure 3. Environmental conditions for proper operation are -35 to +50°C (-31 to +122° F), humidity to 99 percent non-condensing, over an altitude range of 0 to 30,000 feet.

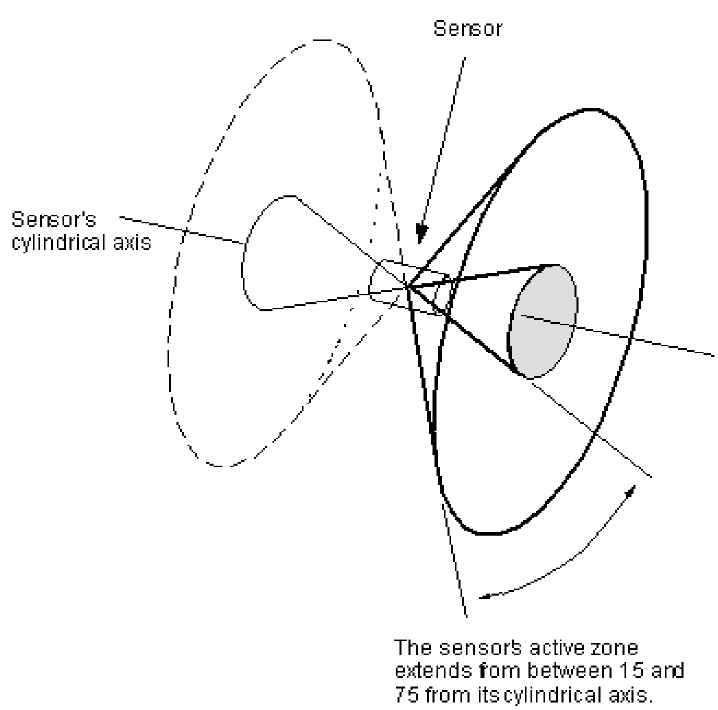
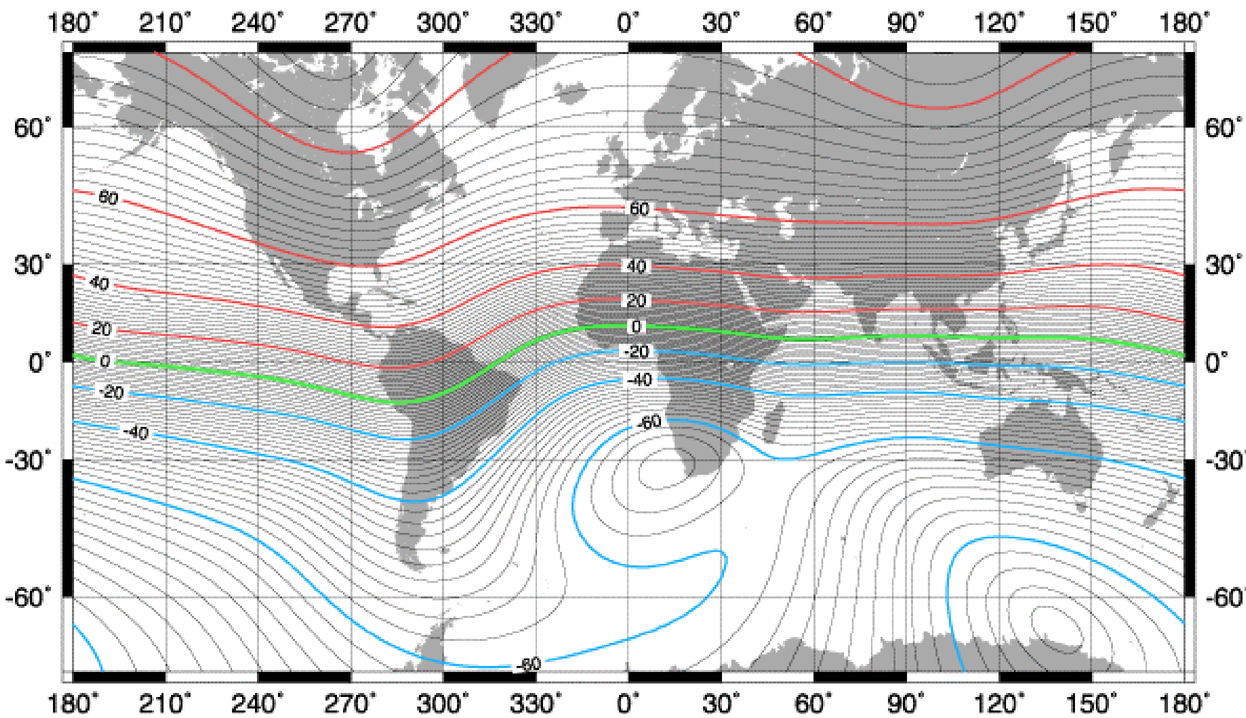


Figure 3: Active zone for the cesium-vapor sensor.

Like all magnetometers, performance of the G-862 is primarily dependent upon the counting circuitry employed and the quality of the installation procedures. Compensation and/or noise reduction techniques must normally be used to minimize the magnetic effect of the platform and its motion. Navigational and positional errors, radiated electromagnetic noise, and heading errors from the vehicle's induced and remnant magnetic fields are typically the major contributors to noise in the survey results.

4.0 INSTALLATION

The particular installation requirements for each system component must be met in order to obtain the best performance from the system. It is important to remember that the sensor driver circuit receives a signal from the sensor whose amplitude is normally one milli-volt as it delivers both heater and lamp oscillator power to the sensor. Anything that increases the cross-talk between the power and signal circuits or introduces noise into the power circuit can degrade the sensor output signal and affect system performance. A Bendix connector terminated multi-conductor cable is used to supply power to and data connections to the matching connector on the G-862 sensor driver module.



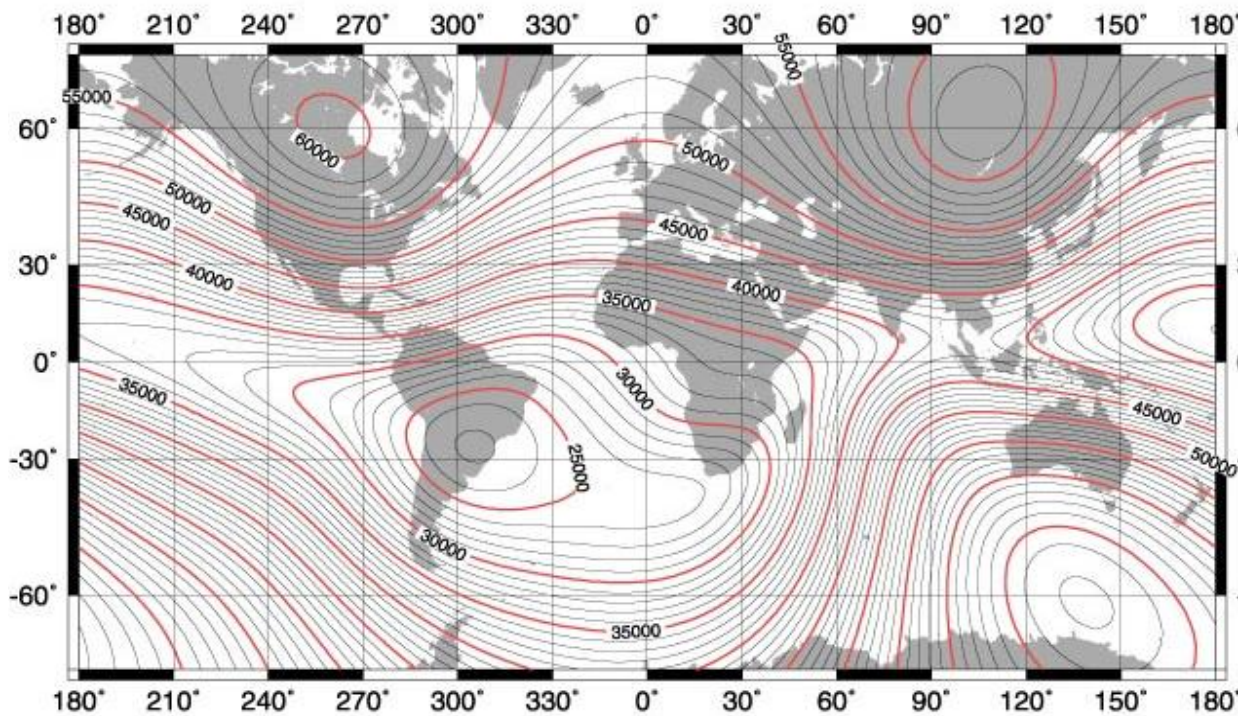
Epoch 2000, 2º contour interval.

Figure 4: Surface inclination of the earth's magnetic field.

4.1 Sensor orientation

Magnetic fields are vector fields. At any point they are defined by their magnitude and direction. If the G-862 sensor is going to accurately measure the local magnetic field magnitude, it must be properly oriented relative to the local magnetic field direction.

The sensor head must be oriented so that the local field impinges at an angle of from 30º to 60º to the cylindrical axis of the sensor, for all platform attitudes. Alignments that produce a field/axis angle less than 15º place the magnetic field within the sensor's "polar dead zone". Similarly, alignments that produce a field/axis angle greater than 75º place the magnetic field within the sensor's "equatorial dead zone". The sensor will not produce



Epoch 2000, 1000 nT contour interval.

Figure 5: Magnetic field intensity at the Earth's surface.

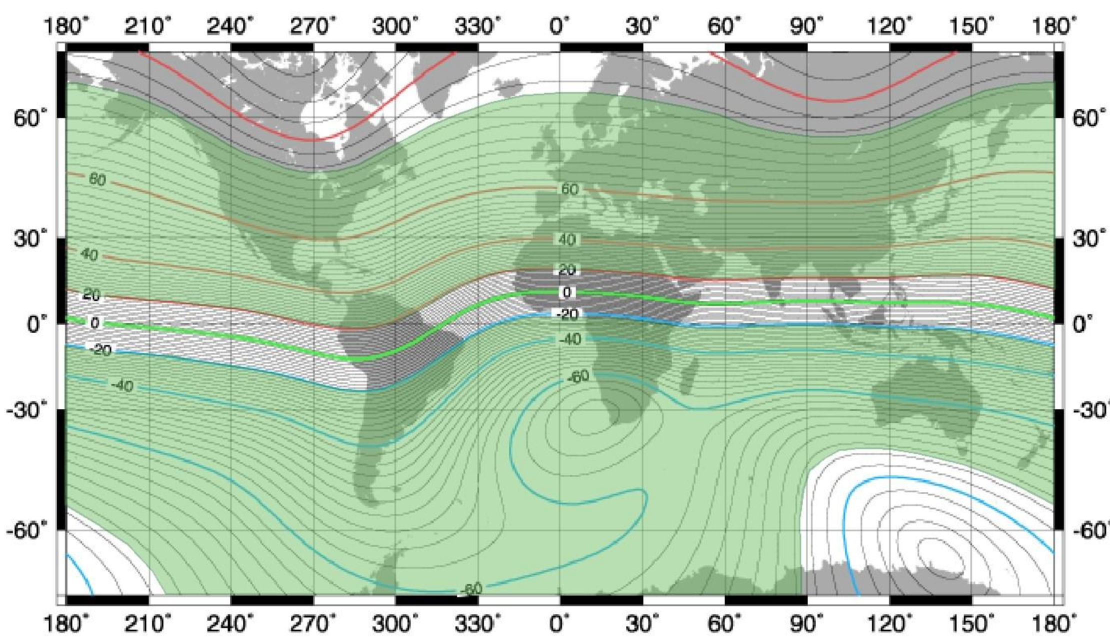
usable data when the angle between the earth's field and the cylindrical axis falls within one of these two zones.

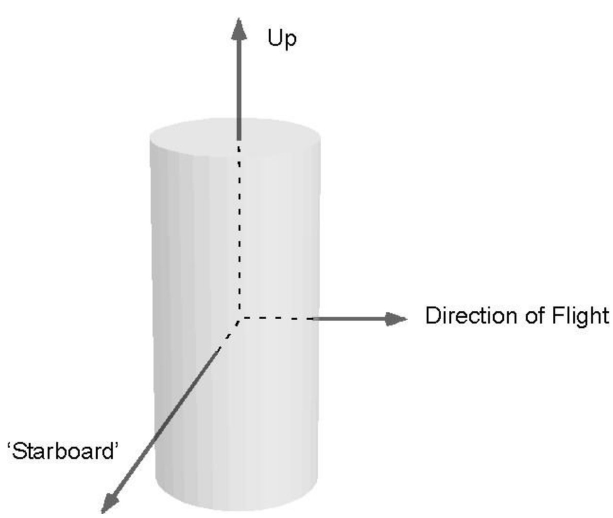
Unless the sensor is quite near very magnetic objects, the local magnetic field will be almost entirely due to the earth's magnetic field. So, in latitudes where the inclination of the earth's field vector is 45º, vertical orientation of the sensor's axis will allow operation in all practical flight attitudes. In equatorial regions it may be necessary to orient the sensor horizontally and at an angle to the flight path. In Polar Regions the sensor may be mounted with its major axis tilted east or west to obtain the desired angle.

The maps in Figures 4 and 5 may be used to determine the inclination and total intensity of the Earth's magnetic field in the intended area of survey. This inclination information should be used to adjust the sensor orientation for the best performance in the survey area. The intensity information may be used as a check of the system operation.

In regards to sensor orientation, the Earth’s surface can be divided into three zones based upon magnetic field inclination: mid-latitude, equatorial, and polar. Within each of these zones there is a particular sensor orientation that will yield adequate signal strength over the entire zone. These regions and the corresponding sensor orientations recommended for each region are shown in Figures 6 through 9.

Figure 6: Mid-latitude zone.

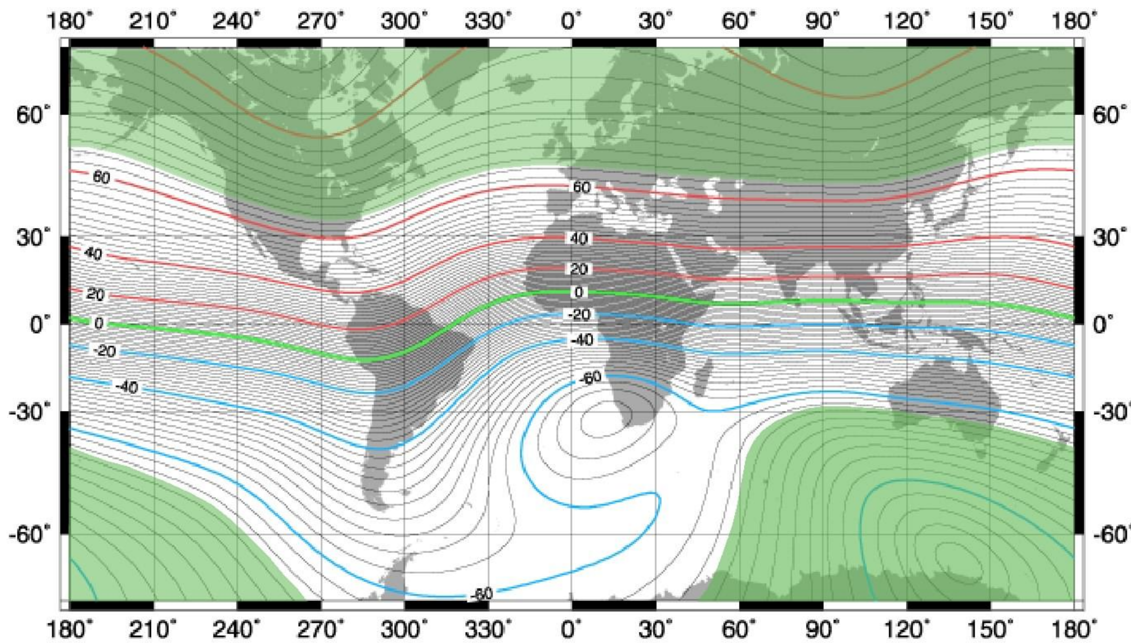


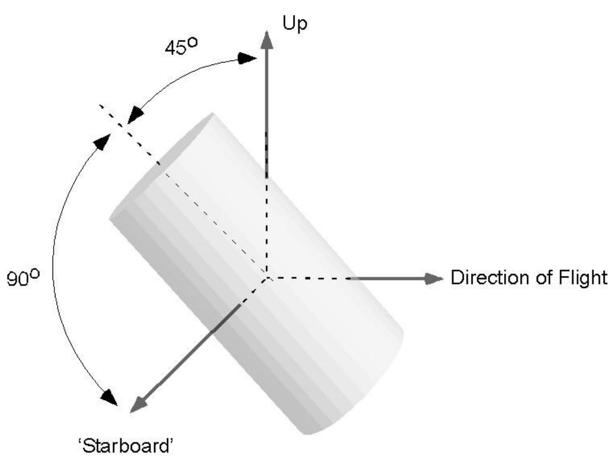


The diagram to the left shows the recommended sensor orientation for operation in mid latitudes. This zone is shown as the shaded regions above and includes those areas where the absolute inclination of the Earth’s magnetic field is greater or equal to 20º and less than or equal to 75º. There are no restrictions on the direction of travel when using this sensor orientation.

Note that the orientation zones show in Figures 6 through 9 overlap one another by 10º of magnetic inclination. In these regions of overlap either of the recommend orientations may be used. Also, note that in the equatorial region there are two different recommended sensor orientations. In this region the magnetic field is nearly horizontal and there will be some restrictions on the direction of flight. Choosing one of the two recommended orientations will allow you to choose flight directions most suitable for your survey area.

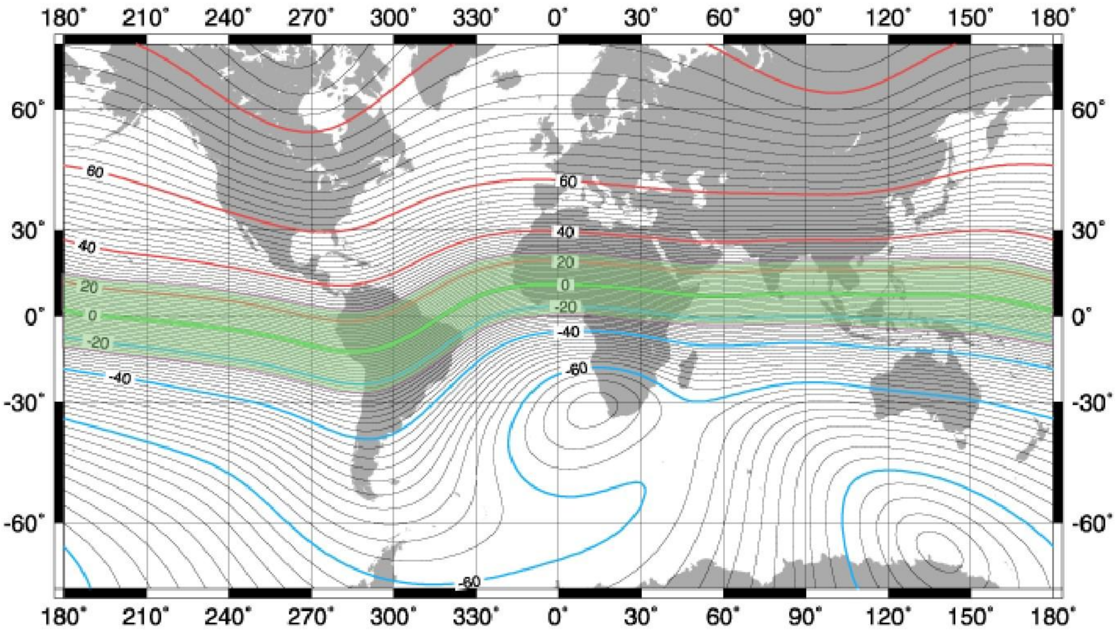
Figure 7: Polar latitude zones.

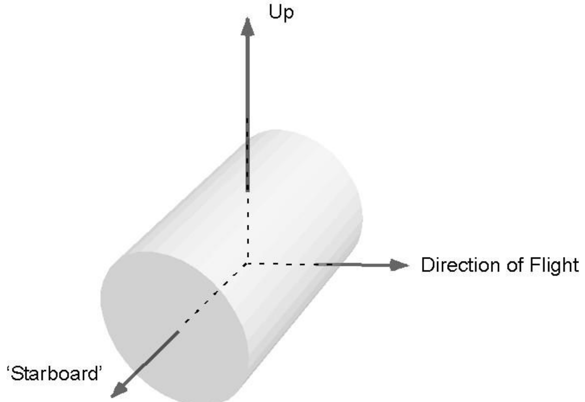


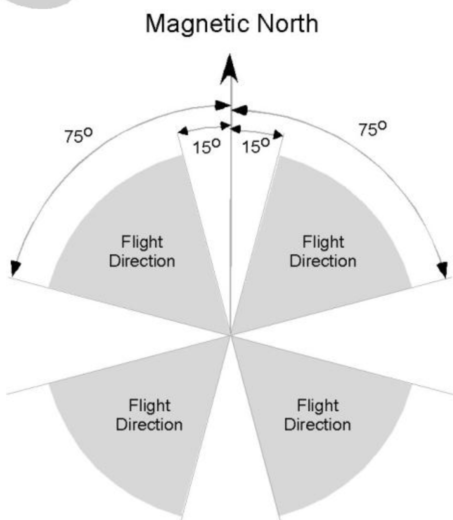


The diagram to the left shows the recommended sensor orientation for operation in polar latitudes. This zone is shown as the shaded regions above and includes those areas where the absolute inclination of the Earth's magnetic field is greater or equal to 65º. There are no restrictions on the direction of travel when using this sensor orientation.

Figure 8: Equatorial latitude zone - 1.



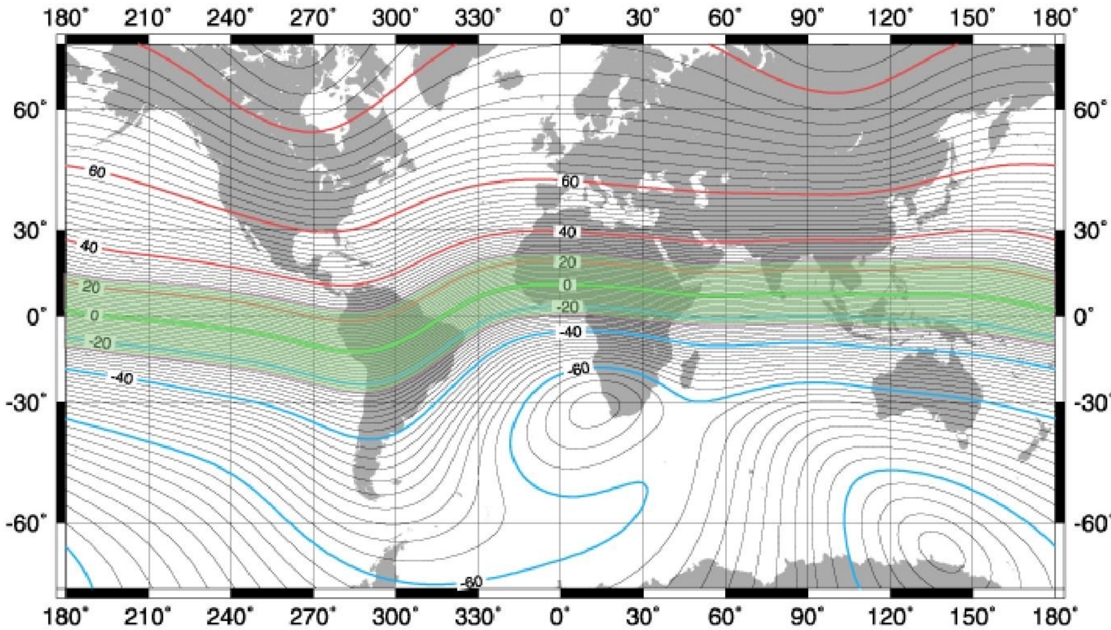


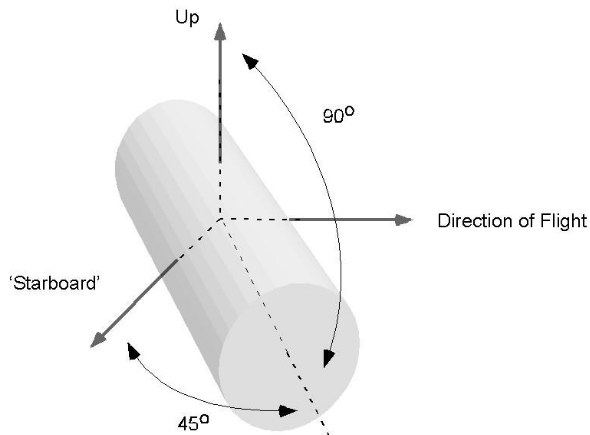


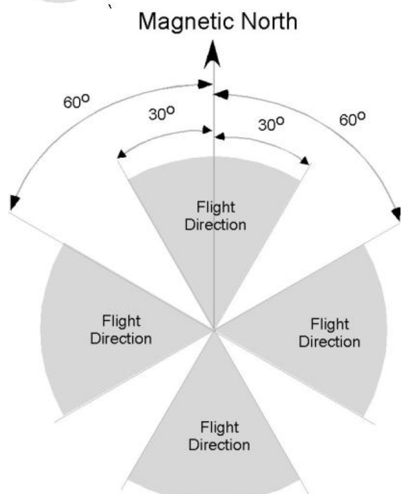
The diagram to the left shows the recommended sensor orientation for operation in equatorial latitudes. This zone is shown as the shaded region above and includes those areas where the absolute inclination of the Earth's magnetic field is less than or equal to 25º.

There are restrictions on the direction of flight when using this sensor orientation in this region. The bottom diagram to the left shows the flight directions where the sensor will produce good signal strength. These flight directions are 60º wide and are centered on 45º, 135º, 225º, and 315º.

Figure 9: Equatorial latitude zone - 2.







The top diagram to the left shows an alternative sensor orientation for operation in equatorial latitudes. This zone is the same as that shown in Figure 8 except that the sensor is rotated about its equator by 45º allowing N-S, E-W survey lines. It includes those areas where the absolute inclination of the Earth's magnetic field is less than or equal to 25º.

As with the sensor orientation shown in Figure 8, there are restrictions on the direction of travel when using this sensor orientation in this region. The bottom diagram to the left shows the flight directions where the sensor will produce adequate signal strength. These flight directions are 60^0 *wide and are centered on the cardinal magnetic field directions* 0^0, 90^0, 180^0, *and* 270^0

In addition to the diagrams provided here, the program CsAz may be used to calculate the sensor's output for a particular orientation for the magnetic field attitude in your survey area. This is a DOS program and is provided on the Magnetometer Support CD supplied with your magnetometer.

4.2 Sensor attachment

An acceptable mount for the G-862 sensor will provide a stable, nonmagnetic attachment to the vehicle, provide vibration dampening and allow the sensor's orientation to be adjusted with minimal effort. One example of such a mounting solution is the sensor mount available from Geometrics (P/N 27530-04). A similar structure is shown in Figure 10 below and is designed for attachment inside of a towed bird, a wing pod, or inside a tail mounted stinger or any circular enclosure with an inside diameter of 7 inches.

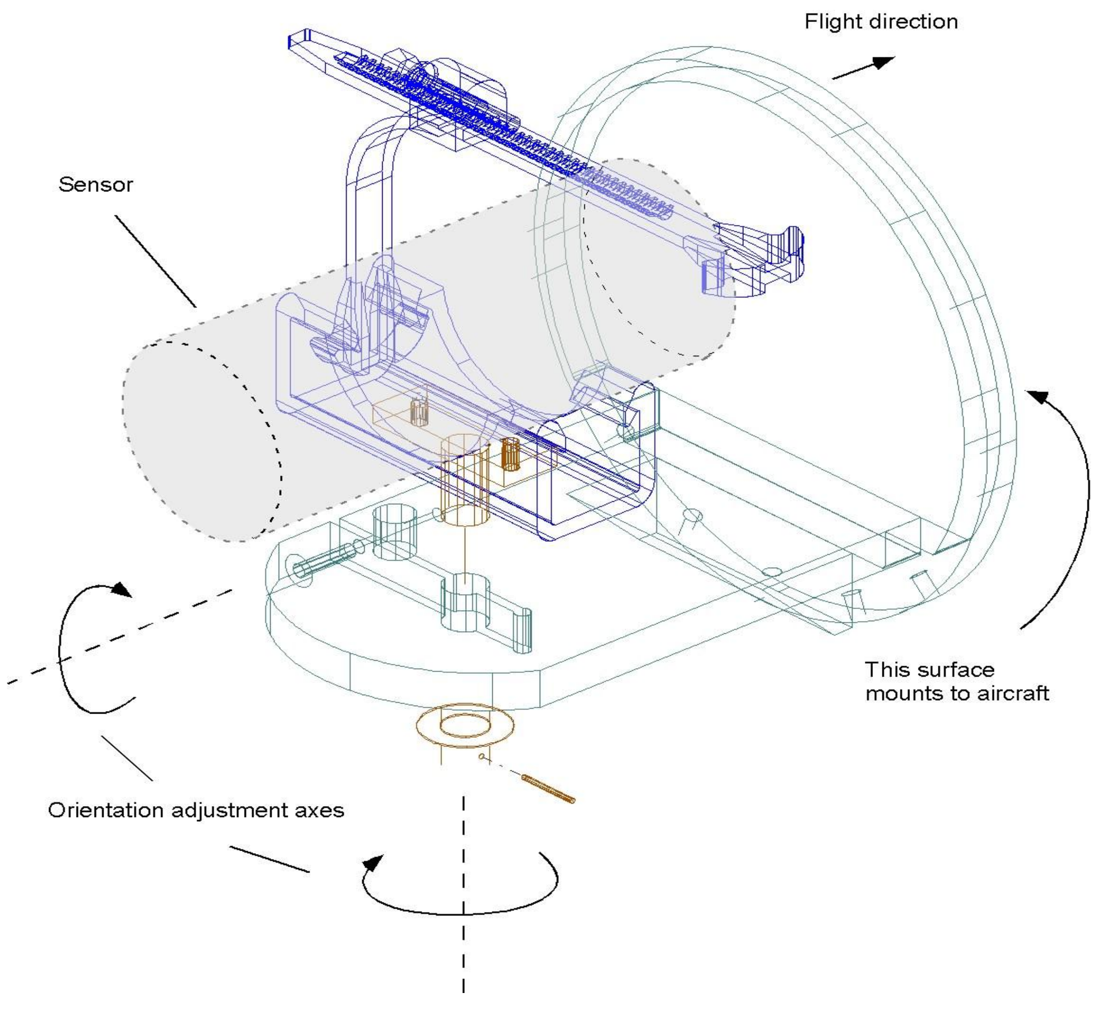


Figure 9: Sensor mount that provides for two axes of adjustment.

4.3 Environmental Considerations

Optically pumped magnetometers are more sensitive to magnetic field variation than are proton and fluxgate types. To realize the full performance of the cesium-vapor technology, special precautions must be taken during planning and execution of the installation.

Vibration

The G-862 is often installed on aircraft and this environment presents particular challenges. Intense vibration of system circuitry can induce micro-phonic noise and shorten the life of system components. For performance and safety considerations the sensor, sensor driver, and system cabling are normally hard mounted to the aircraft or are hard mounted in components that are themselves firmly attached to the aircraft in structures such as stinger and wingtip pods. Some attachment points may be prone to intense vibration and we recommend the use of good quality shock mounts that are designed to isolate the G-862 components from as much of the intense vibration as possible. Special care should be taken in securing or routing the cable so that it does not encounter hard or sharp objects that could damage the cable. Those components used to mount the G-862 sensor or any or any objects near this sensor should be non-magnetic in order to minimize the system heading error.

Electronic/electromagnetic

Sources of performance problems may arise in two areas: external electromagnetic noise and errors introduced from platform motion. Electrostatic and electromagnetic signals from aircraft systems, including other sensor instrumentation, can significantly lower the signal to noise ratio of the magnetometer. An example is the "hash" created by sparking brushes in certain aircraft generators. This can be seen as a rapidly changing field value causing excessive scatter in the readings. The permanent, induced and eddy-current magnetic effects of the airplane can cause significant errors that are dependent on attitude, motion and heading in the earth's magnetic field. The use of a device such as the RMS Instruments' Automatic Aeromagnetic Digital Compensator, Geometrics software program MagComp or fixed aero-magnetic compensation techniques will help reduce these types of errors (See Geometrics technical report TR-15). Variations in electrical currents in aircraft systems will also cause shifts, bias or increased heading error in the readings. Consult with Geometrics about the compensation and noise reduction processes before installation if you are unfamiliar with the procedures used to minimize noise and platform errors.

Temperature

The G-862 is designed to operate over an ambient temperature range of -35 to +50°C. In an enclosed region it may be necessary to provide adequate cooling by free flowing air. If the sensor and electronics are in an unconfined region, convection cooling is generally adequate. The cesium lamp only needs to dissipate 3 to 4 watts of heat and when operating in cold regions providing some insulation or baffling will help reduce the sensor's power consumption.

The G-862 requires a minimum warm up period of 15 minutes. In cold regions the warm up period will be longer and, to avoid delay, we recommend that the sensor power be left on overnight when ambient temperatures are expected to fall below -10°C.

5.0 TROUBLESHOOTING

Operation of the G-862 is relatively simple and when trouble arises it is usually easy to recognize and correct. Table 2 is a troubleshooting guide provided to help in quickly locating the probable cause of the most common system problems.

Table 2: Troubleshooting

Symptom	Probable Causes	Corrective Actions
Long warm-up time.	Low voltage.	Increase voltage (minimum 24 VDC at the electronics) or repair the Coax cable.
	Low ambient temperature.	Insulate sensor housing.
	Low heater setting.	Adjust heater to 34.5 K-ohms: contact factory for details.
	Defective internal sensor or electronic components.	Return sensor and electronics to Geometrics for repair.
Noisy magnetic field readings.	Local field is noisy.	Locate and eliminate source of noise or relocate sensor.
	Sensor not oriented correctly.	Refer to Sensor Orientation section of this manual, or use MagPick IGRF and CsAz software to model magnetic field and sensor behavior, and correct orientation if necessary.
	Heater setting incorrect.	Adjust heater to 34.5 K-ohms: contact factory for details.
	Signal amplitude too low with correct orientation.	Adjust signal amplitude or return sensor and electronics to Geometrics for repair.

Symptom	Probable Causes	Corrective Actions
	Sensor cable or connector worn or damaged.	Replace sensor cable and connector assembly.
Sensor cable kinked or cut.	Handling or mechanical problem.	Change handling or mechanical mount. Then replace sensor cable and connector.
Excessive current consumption.	Damaged multi conductor cable. Defective sensor or electronics.	Replace multi conductor cable. Return sensor and electronics to Geometrics for repair.

Preventing a problem is almost always less costly than correcting the problem. We recommend checking the follow items as part of any new installation or whenever an existing installation is altered. It is also recommended that these items are checked periodically as part of a scheduled platform or system safety check.

1. Power check
    a. Minimum 24 Volts DC at electronics bottle. 28VDC recommended
    b. Maximum 35 Volts DC at electronics bottle
    c. Starting current 1 Ampere at 28 Volts
    d. Running current 0.3 to 0.6 Ampere at 28 Volts depending upon ambient temperature
2. Connector checks
    a. Dirt or corrosion
    b. Bent pins
    c. Back-shell tight
3. Cable jacket check
    a. Kinks
    b. Abrasions
    c. Cuts
4. Sensor orientation
    a. Use CsAz to model sensor behavior
    b. Adjust sensor orientation and observe dead zones
    c. Return sensor to correct orientation for the survey area
5. Field readings
    a. Reasonably close to CsAz model estimate
    b. Sample to sample noise less than 0.1 nT @ 10 Hz when not moving
6. Larmor amplitude check and adjustment (Authorized Repair Facility only)
    a. Potentiometer on sensor-driver board adjusted for 2.0 Volts Peak to Peak at 50,000 nT after 20 minute warm up
7. Heater check and adjustment (Authorized Repair Facility only)

6.0 G-862 MAGNETOMETER

Geometrics CM-221 counter board transforms the instrument's analog output signal into RS-232 digital data. The CM-221 counter module is an integrated circuit that converts the cesium Larmor signal (70 kHz to 350 kHz) into a numeric value indicating the magnetic field strength in nanotesla (20,000 nT to 100,000 nT). In addition there are 2 external 12 bit A/D channels and 6 internal A/D channels that can be digitized and appended to the output data. This can be useful, for instance, in digitizing an analog altimeter signal and incorporating it into the magnetometer data stream. A Julian clock string can be enabled and added to the output data stream as well. Finally there is an External Event pin that can be used for external trigger.

Table 3: G-862 standard component weights and dimensions

Description	Weight	Dimensions
Cesium sensor package P/N 27516-45	1lb. 8oz.	2'3/8"x5-1/2" cylindrical housing with 109 in. cable. Termination: Burndy 0119 G6JF12-88 PNE
Electronics W/counter P/N 27519-30	2lb. 5oz.	12-5/8" including connectors. 11-5/8" long x 2-1/2" cylindrical housing
Carrying Case P/N 27615-01	10 lbs.	18l" l x 9.5" w x 15" h
Digital signal/power cable P/N 27611-02	2lb, 2oz.	25' multi-conductor: Belden # 8418. Termination: SP06A14-19S-SR and SP06A14-19P-SR
Power/data junction box P/N 24870-20	9oz.	L 4-3/4", W 3-1/4", H 3-1/4"
Serial data cable P/N 60-230-237	5oz.	6' DB9
Optional AC/DC Power Supply P/N 24810-02	2lbs. (typical)	Input: 100V-240V @ 50-60 Hz; output 30V, 1.9A 7" x 4" x 2.5" (typical) with 4' output cord.

The G-862 is shipped with a 25 ft. external signal/power interface cable, a power/data junction box, and an RS-232 data cable. The signal/power interface cable attaches to a mating connector on the sensor driver module. These components are used to connect the magnetometer to the user's 30VDC power source and logging computer. The signal/power cable also carries analog signal but the junction box does not break these channels out to its DB9 connector. If the user wishes to observe or record analog signal they may use the interface cable for this purpose. To do so we recommend that electrical connection is made using a mating connector (e.g. Amphenol SP02A-14-19S) although the connectors used on the interface cable are of the solder type and they may be removed and reused to suit the application. Table 4 describes the pin-out of the 19 pin connector on the G-862 magnetometer. The interface cable is wired straight through, pin-to-pin**.**

Table 4: G-862 interface cable pin-out

Circuit description of the external signal/power interface cable Connector type SP02A-14 -19P

Pin #	Function	Description
A	30V power	Magnetometer power; 24 – 32VDC
B	GND	Power ground
C	TxD	From logging computer, connects to RxD of G-862
D	Rxd	To logging computer, connects to TxD of G-862
E	COMMON	RS-232 Ground
F	RESET	Contact closure to GND
G	EVENT	External Trigger Input
H	CHANNEL 1 +	Analog channel #1 – differential input, 5v full scale, 2KΩ input impedance.
J	CHANNEL 1 -	
K	CHANNEL 2 +	Analog channel #2 – differential input, 5v full scale, 2KΩ input impedance
L	CHANNEL 2 -	
M	CHANNEL 3 +	Analog channel #3 – differential input, 5v full scale, 2KΩ input impedance
N	CHANNEL 3 -	
P	CHANNEL 4 +	Analog channel #4 – single ended ±2.048v full scale, >10KΩ input impedance
R	CHANNEL 4 -	
S	CHANNEL 5 +	Analog channel #4 – single ended ±2.048v full scale, >10KΩ input impedance
T	CHANNEL 5 -	
U	Ext GND	External Input Ground use for EVENT and RESET lines
V	Boost Enable	Wire to Pin A to enable Boost Power Supply.

Note: 1) All analog channels have 12 bit resolution ± 1%; 2) Differential channels 1, 2 and 3 may be able accept other full-scale voltages if original order called for custom input specification - consult the factory if you suspect that your system has non-standard input ranges; 3) If the single ended channels 4 or 5 are used, the signal source must be operated from a power source that is isolated from power ground.

6.1 CM-221 Output Format

The output data format of the G-862 is programmable. For example each of the A/D channels can be added or removed from the output data stream by sending the appropriate commands to the CM-221. There are several other commands that are discussed in detail below.

Figure 12 shows the standard single counter configuration. Commands from the PC are sent out the computer RS-232 transmit pin (TxD) to the counter. Magnetometer and other data are read on the computer receive pin (RxD).

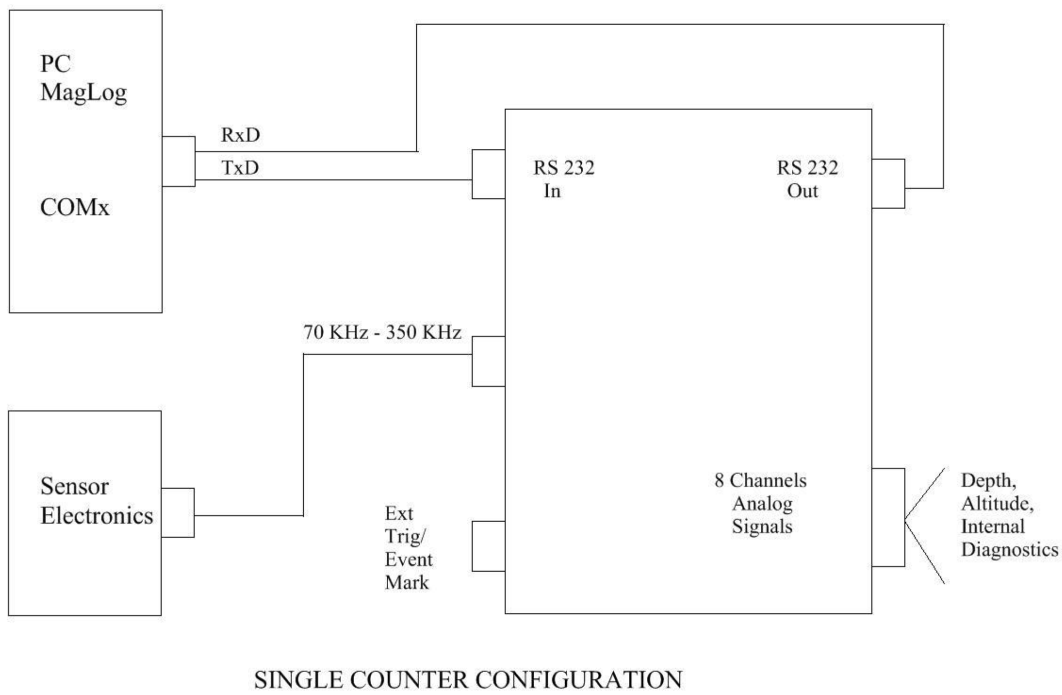


Figure 10: Schematic of CM-221, magnetometer, and computer connections

Upon power on the counter module defaults to the following setup:

- Baud rate: 9600 baud, 8 data bits, no parity, 1 stop bit
- Cycle rate: 10 Hz
- Analog channels: Channel 0 (Larmor signal level) enabled, channels 1-5 disabled
- Julian Clock: Disabled
- Output Format: ASCII

The default output data stream contains all printable ASCII characters with each sample terminated with a carriage return/line feed sequence. Table 5 illustrates an example of this format.

Table 5: Example of CM-221 default output data stream.

Character #	Description
1	An ASCII '$' (marks first character of data stream)
2	An ASCII '1' or a blank (depending on whether Mag reading is above or below 99999.999nT).
3-7	5 digits of Mag data
8	An ASCII decimal point ['.']
9-11	3 more digits of Mag data
12	An ASCII comma [',']
13-16	4 digits of A/D channel 0 (9999 full scale, 0 to +5 volts in). This channel is internal and contains the signal level of the magnetometer.
17	An ASCII carriage return
18	An ASCII line feed

If the data were captured to a file and then copied to a line printer the printout would look something like this:

```
$ 99778.131,3749
$ 99890.376,3687
$ 99955.517,3545
$ 99998.293,3472
$100078.835,3329
$100032.071,3381
$ 99979.159,3498
$ 86778.508,3514
$ 78778.216,3645
$ 69978.347,3797
```

Counter modules can be daisy chained to form multiple sensor arrays as shown in Figure 13. Note that the output data from counter 0 goes into the input port of counter 1, and so on. This allows each counter module to append its output data onto the end of the data stream coming from the previous counter(s). As each counter receives data characters from previous counters they get echoed to the next. An exception to this is the carriage return/line feed sequence. Here, the carriage return is replaced by a comma and the line feed is ignored. Thus one long concatenated string from all counters is output from/through the last counter, and is terminated by a carriage return/line feed sequence by the last counter only. Note that only the first counter outputs a preamble character (the default character is '$').

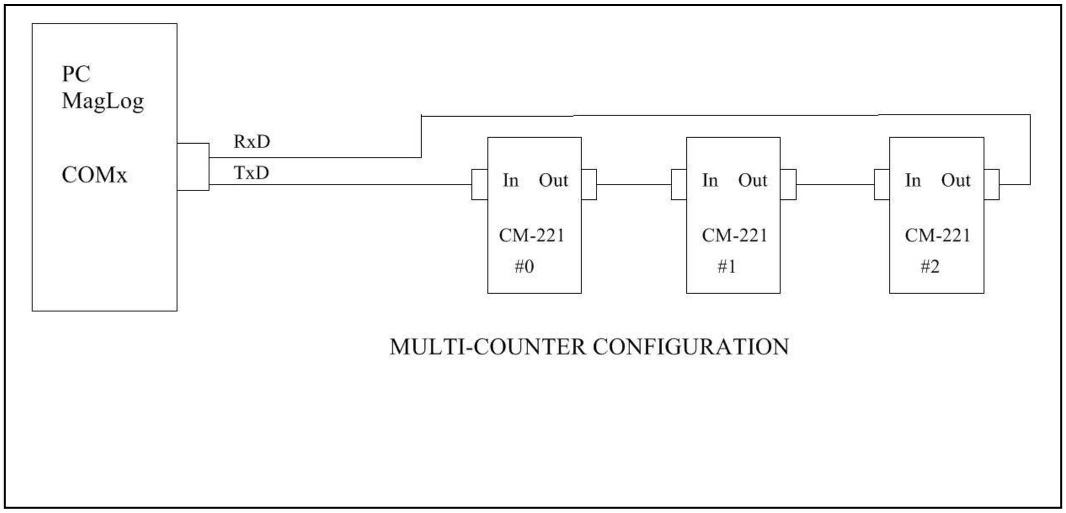


Figure 11: Schematic diagram of daisy-chained CM-221 counter modules.

6.2 Commands

Commands are sent into the input port of the first counter. Note that commands are the only characters that enter the first counter. A command string is stored in an incoming buffer until terminated by a carriage return. The command will then be executed at the end of the current sample, immediately after the last 'data' byte has been sent out the output port. Then the command will be echoed to the next counter (or back to the logging computer if it is the last/only counter in the chain).

Subsequent counter modules in multiple counter arrays differentiate between output data and commands by assuming that all characters between the data preamble character ('$' is the default) and the next line feed are data bytes from the previous counter(s). Commands only arrive at subsequent counters after the data transmission is complete. Each command is identified by the first character, followed by some number of operand characters and a carriage return.

Only one command can be sent at a time. After each command, you must wait for the command echo before sending another.

All commands are terminated with a carriage return. A line feed may be sent as well, but it will be ignored by each counter module. However, at the end of every output data string there will be a carriage return and a line feed sent. This method insures that the final counter will have a carriage return/line feed sequence so that if the file is printed it will look correct on paper. By using the carriage return as the command terminator and stripping input line feeds insures that dumb terminals (and dumb terminal emulation software) can be used to control the counter output. (Dumb terminals do not normally transmit line feeds when <Enter> is pressed).

Here are the current list of commands and the format of each:

Command	Format:		Description:
Set Cycle time	Byte	1: 'C'	Set time in 0.01 sec increments
		2: x	MS digit of number ('0'-'9')
		3: x	3S digit of number
		4: x	2S digit of number
		5: x	LS digit of number
		x: x	5 MS optional char ('0' or '5')
		6/7: CR	carriage return

[Note: the 5 MS char is optional. It was added to allow setting the cycle time to more precision after the initial software release]

Set A/D ch's	Byte	1: 'A'	Enable/disable A/D channels
		2: x	'0' = turn off channel; '1' = turn on
		3: x	select channel # ('0'-'5')
		4: x	MS digit of counter # ('0' or '1')
		5: x	LS digit of counter # ('0' - '9')
		6: CR	carriage return

[Note: characters 4 and 5 can be omitted. If this is done the command will default to counter 0.]

Change Baud Rate	Byte	1: 'B'	Baud rate change command
		2: x	MS char (1,0,0,0,0,0,0)
		3: x	S char (9,9,4,2,1,0,0)
		4: x	3S char (2,6,8,4,2,6,3)
		5: x	2S char (0,0,0,0,0,0,0)
		6: x	LS char (0,0,0,0,0,0,0)
		7: CR	carriage return
Output Format	Byte	1: 'O'	select output format
		2: x	format select:
			'A'= ASCII (default)
			'E'= excess 3
			'P'= packed BCD
			'S'= Sandia G-822A fmt
		x: x	'0' = Sandia single Mag
			'1' = Sandia dual Mag
		3: CR	carriage return

[Note: the '0' and '1' 3rd characters are valid only when selecting the Sandia format. This format was developed for an earlier logging software program and is now obsolete. Excess3 is used for high speed multi-sensor array data transmissions.]

Julian Clock Format:	Byte	1: 'O'	select output format
		2: J	format select:
		3: x	Day field: '1'= on ; '0' = off
		4: x	Hour field: '1'= on ; '0' = off
		5: x	Min field: '1'= on ; '0' = off
		6: x	Sec field: '1'= on ; '0' = off
		7: x	10mS field: '1'= on ; '0' = off
		8: x	MSB of counter # ('0' or '1')
		9: x	LSB of counter # ('0' thru '9')
		10: CR	carriage return

[Note: characters 8 and 9 can be omitted. If this is done the command will default to counter 0.]

Julian Time Enable:	Byte	1: 'J'	Enable/Disable Julian time output
		2: x	'0' = turn off; '1' = turn on
		3: x	MS digit of which counter ('0','1')
		4: x	LS digit of counter # ('0' - '9')
		5: CR	carriage return

[Note: characters 3 and 4 can be omitted. If this is done the command will affect all counters in the chain.]

Set Julian Day:	Byte	1: 'D'	Set the Julian day number
		2: x	MS digit of number ('0'-'3')
		3: x	2S digit of number ('0'-'9')
		4: x	LS digit of number ('0'-'9')
		5: CR	carriage return

Set Hour:	Byte	1: 'H'	Set the hour
		2: x	MS digit of number ('0'-'2')
		3: x	LS digit of number ('0'-'9')
		4: CR	carriage return

Set Minute:	Byte	1: 'M'	Set the minute
		2: x	MS digit of number ('0'-'5')
		3: x	LS digit of number ('0'-'9')
		4: CR	carriage return

Set Second:	Byte	1: 'S'	Set the second
		2: x	MS digit of number ('0'-'5')
		3: x	LS digit of number ('0'-'9')
		4: CR	carriage return
Find counters:	Byte	1: 'F'	Find and assign counter numbers
		2: '0'	assign first counter as # 0 (MSB)
		3: '0'	LSB
		4: CR	carriage return
Set Preamble	Byte	1: 'P'	Set the preamble char ('$')
		2: x	The desired character
		3: CR	carriage return
Jump to debug	Byte	1: 'X'	first char of 'XBUG' string
		2: 'B'	2'cnd char
		3: 'U'	3'rd char
		4: 'G'	4'rth char
		5: CR	carriage return
Error echo	Byte	1: 'E'	Syntax err - echo 'ERR' + counter #
		2: 'R'	2'cnd char
		3: 'R'	3'rd char
		4: x	MS digit of counter number ('0'-'1')
		5: x	LS digit of counter number ('0'-'9)
		6: ':'	colon delimits error message cmd

[Note: xxx: bad command string is echoed in the following characters, followed by a ... x: CR carriage return]

Reset	Byte	1: 'R'	Reset the microprocessor
		2: 'E'	2'cnd char
		3: 'S'	3'rd char
		4: 'E'	4'th char
		5: 'T'	5'th char
		6: CR	carriage return
Interrogate Setup:	Byte	1: 'I'	Interrogate command
		2: x	item select: 'A'= Analog output fields selected 'J'= Julian Clock fields selected 'V'= software version number.
		3: x	MS digit of counter number ('0'-'1')

		4: x	LS digit of counter number ('0'-'9)
		5: CR	carriage return

[Note: Characters 3 and 4 are optional. If they are omitted the command will return the output from counter 0. The addressed counter will insert characters into the command string just before the carriage return before echoing to subsequent counters. See detailed command description for format and definition of these added characters.]

Enable Trigger	Byte	1: 'T'	Trigger Command
		2: 1	Cycle and output on Trigger Input
		3: CR	carriage return

Disable Trigger	Byte	1: 'T'	Set the preamble char ('$')
		2: 0	Cycle and output on internal timing
		3: CR	carriage return

[Note: External triggers are input to the CM-221 counter via the External Event Pin of the counter board (JP1 pin 4) which is also wired to pin G of the 19 pin Bendix connector on the G-862 electronics module. The external event input is compatible with both TTL and RS232 signal levels. A logic low is defined as any input level in the range of +0.8 volts to -25 volts. Logic high is defined as any input level in the range of +2.0 volts to +25 volts. A trigger occurs on an input transition from low to high. The external trigger input has no internal pull up and floats near ground. The input impedance is 3000 ohms or higher. The external trigger input is edge triggered. Therefore the external trigger signal must have sharp edges. If a mechanical switch is used as a trigger input it must be properly debounced to prevent multiple triggers. The trigger pulse must be greater than 2 microseconds in width. When not in external trigger mode any external triggers received are ignored.]

6.3 Detailed command descriptions:

Cycle Time Set

Cycle time is set by transmitting the number of 0.01 second increments needed to make the desired output rate. The default rate is 10 hertz (C0010). To set the output rate to 1.2 seconds the command string would be "C0120".

After the initial software release another character was added to allow the cycle time to be set to 5 ms resolution. To maintain compatibility with older versions this character is optional. For an example on using this extra precision, the command "C00125" would set the cycle time to 8 hertz (125 ms).

A/D channel select/enable

Three pieces of information are needed to select and turn on/off an A/D channel: The counter #, the channel number, and a flag indicating whether to enable or disable that channel. The enable/disable flag is sent first (after the 'A' command identifier). A '0' character will turn off the channel, a '1' turns it on. The next character specifies the channel number (0-7), followed by 2 characters indicating the counter number (00-19). If the counter number is not sent then it defaults to counter 0.

Baud Rate Change

The baud rate can be commanded to change by giving a 'B' command character followed by 5 more number characters specifying the desired baud rate. Valid baud rate commands are: 'B19200', 'B09600', 'B04800', 'B02400', 'B01200', 'B00600', and 'B00300'. This command will not execute until the entire command has finished echoing out to the next counter/logging device. This allows the command to propagate through all counters and be implemented before output data arrives at a different rate.

Output Format Select

The default (ASCII) output format is described in detail at the beginning of this document. This is the easiest format to view and import into various processing utilities. It is also very inefficient in terms of disk storage space and time required to transmit each cycle. There are three other output formats that can be used as well:

Packed BCD

Packed BCD format throws away all commas, decimals, spaces, and the magnetometer most significant byte ('1' if more than 100,000 nT, or a blank is less than 100,000nT). The Preamble character is left alone. In addition all numeral characters (ASCII codes 30 hex through 39 hex) have the upper nibble (always a 3) discarded and two lower nibbles combined to form one byte. Finally, the carriage return, line feed sequence is replaced with a single terminating character '*' (2A hex).

It is very difficult to show what these files would look like if displayed on a computer screen since each type of computer would display these binary characters differently. Many of these binary characters would be interpreted as screen commands which might ring the bell or clear the screen. Therefore it is necessary to convert ASCII printouts to hexadecimal numbers to show the Packed BCD format.

An ASCII counter output of:

'$ 54369.127,1234,5678,0000' (plus carriage return line feed)

converted to hexadecimal numbers would be:

24 20 35 34 33 36 39 2E 31 32 37 2C 31 32 33 34
2C 35 36 37 38 2C 30 30 30 30 0D 0A

['$'= 24, ' '= 20, '.'= 2E, ','= 2C, CR/LF = 0D 0A,
'0'-'9'= 3x (where x = number 0-9)]

Using the above definition the same data in packed BCD output format would be:

```
 24 54 36 91 27 12 34 56 78 00 00 2A
  \   \       \   \   \   \___Terminating character ('*')
  \   \       \   \   \__analog channel #3 ('0000')
   \   \       \   \__analog channel #2 ('5678')
   \   \       \__analog channel #1 ('1234')
    \   \__Mag reading ('54369.127')
    \__Preamble Character ('$')
```

Note how easy it is to see the numbers if viewing a hex dump of the data. Remember though that it must be translated to printable characters before copying the raw data to printers or a CRT screen.

Commands that are echoed through the counter chain are received and sent as unmodified ASCII strings. Thus all commands will appear in the binary data set after the next '*' data terminating character and will be terminated itself by a carriage return line feed sequence. Binary transmission then resumes with the next sample.

Excess 3 format

Excess three format is very similar to packed BCD. In fact the only difference is that each byte has 33 hex added to it after converting to Packed BCD. The reason for adding 33 hex to each packed BCD number is to avoid some difficult pitfalls with Packed BCD:

Packed BCD is a very common format but has potential problems that can arise. ASCII digits are combined to form bytes with hexadecimal values in the control character range (less than 20 hex) which must be handled very carefully by the logging program. Examples of these characters include the Cntl-S and Cntl-Q software handshake controls (11 hex and 13 hex), the bell character (Cntl-G, 07 hex), and the ASCII null (Cntl-shift-@, 00H). Most terminal emulation programs can be configured to handle these characters as data instead of commands, but this is not the way the typical default configuration is set up. Note that MagLog and MagLogLite Logging software from Geometrics are designed to receive and decode the Excess 3 data transmission. This is typically used for multiple sensor array systems such as MTADS employed for UXO or archaeological surveys.

Packed BCD eliminates this by shifting all numbers up by 33 hex. This moves all possible output values out of the control character range. It also makes them printable to a screen or printer without bells, beeps, screen clears, form feeds, etc. However they will still look like gibberish without translation.

Sandia/Super-Counter format

This is a printable ASCII format that mimics the output from a one or two channel G-862 magnetometer. Its output is limited to one counter module, with the Mag and signal level values as the only data being sent out. The Mag reading is preceded with an 'A' followed by 10 characters of ASCII Mag data. The G-862 format sometimes has a second Mag reading following the first which is preceded with an ASCII 'B'. If selected the CM-221 counter places the signal level in the first 4 significant characters of the second Mag data slot. The sample is terminated by a carriage return line feed sequence.

The purpose of this format is to allow customer with existing G-862 Sandia logging software to be able to use the CM-221 without upgrading to new logging software. Note that Geometrics no longer supports the Sandia logging software.

The single channel Sandia format is selected with the command string "OS" or "OS0". The dual channel output is selected by the command string "OS1".

***Example output*:**

This is the ASCII output example from earlier, but with 3 A/D channels:

- -

```
 $ 99778.131,3749,0004,0005
 $ 99890.376,3687,0003,0007
 $ 99955.517,3545,0003,0006
 $ 99998.293,3472,0005,0006
 $100078.835,3329,0004,0005
 $100032.071,3381,0006,0006
 $ 99979.159,3498,0003,0007
 $ 86778.508,3514,0004,0007
 $ 78778.216,3645,0004,0004
 $ 69978.347,3797,0003,0005
```

The same data displayed in hexadecimal:

- - - - - - - - - - - - - - - - - - - -

```
24 20 39 39 37 37 38 2E 31 33 31 2C 33 37 34 39
2C 30 30 30 34 2C 30 30 30 35 0D 0A 24 20 39 39
38 39 30 2E 33 37 36 2C 33 36 38 37 2C 30 30 30
33 2C 30 30 30 37 0D 0A 24 20 39 39 39 35 35 2E
35 31 37 2C 33 35 34 35 2C 30 30 30 33 2C 30 30
30 36 0D 0A 24 20 39 39 39 39 38 2E 32 39 33 2C
33 34 37 32 2C 30 30 30 35 2C 30 30 30 36 0D 0A
24 31 30 30 30 37 38 2E 38 33 35 2C 33 33 32 39
2C 30 30 30 34 2C 30 30 30 35 0D 0A 24 31 30 30
30 33 32 2E 30 37 31 2C 33 33 38 31 2C 30 30 30
36 2C 30 30 30 36 0D 0A 24 20 39 39 39 37 39 2E
31 35 39 2C 33 34 39 38 2C 30 30 30 33 2C 30 30
30 37 0D 0A 24 20 38 36 37 37 38 2E 35 30 38 2C
33 35 31 34 2C 30 30 30 34 2C 30 30 30 37 0D 0A
24 20 37 38 37 37 38 2E 32 31 36 2C 33 36 34 35
2C 30 30 30 34 2C 30 30 30 34 0D 0A 24 20 36 39
39 37 38 2E 33 34 37 2C 33 37 39 37 2C 30 30 30
33 2C 30 30 30 35 0D 0A
```

The same data in Packed BCD format:

- - - - - - - - - - - - - - - - - -

```
24 99 77 81 31 37 49 00 04 00 05 2A 24 99 89 03
76 36 87 00 03 00 07 2A 24 99 95 55 17 35 45 00
03 00 06 2A 24 99 99 82 93 34 72 00 05 00 06 2A
24 00 07 88 35 33 29 00 04 00 05 2A 24 00 03 20
```

```
71 33 81 00 06 00 06 2A 24 99 97 91 59 34 98 00
03 00 07 2A 24 86 77 85 08 35 14 00 04 00 07 2A
24 78 77 82 16 36 45 00 04 00 04 2A 24 69 97 83
47 37 97 00 03 00 05 2A
```

The same data in Excess 3 format:
- - - - - - - - - - - - - - - - -

```
57 CC AA B4 64 6A 7C 33 37 33 38 5D 57 CC BC 36
A9 69 BA 33 36 33 3A 5D 57 CC C8 88 4A 68 78 33
36 33 39 5D 57 CC CC B5 C6 67 A5 33 38 33 39 5A
57 33 3A BB 68 66 5C 33 37 33 38 5D 57 33 36 53
A4 66 B4 33 39 33 39 5D 57 CC CA C4 8C 67 CB 33
36 33 3A 5D 57 B9 AA B8 3B 68 47 33 37 33 3A 5A
57 AB AA B5 49 69 78 33 37 33 37 5D 57 9C CA B6
7A 6A CA 33 36 33 38 5D
```

The same data displayed in dual channel Sandia/G-862 ASCII format:
- -

```
A9977813100B3749000000
A9989037600B3687000000
A9995551700B3545000000
A9999829300B3472000000
A0007883500B3329000000
A0003207100B3381000000
A9997915900B3498000000
A8677850800B3514000000
A7877821600B3645000000
A6997834700B3797000000
```

(Note how the most significant '1' is truncated for readings greater than 100,000 nT).

The same data in single channel Sandia format (ASCII):

```
A9977813100
A9989037600
A9995551700
A9999829300
A0007883500
A0003207100
A9997915900
A8677850800
A7877821600
A6997834700
```

Julian Time Set

The Set Time commands (D,H,M,S) will initialize the time in all counter modules. If a particular counter has all Julian clock fields enabled the output string will have the following inserted after the last A/D channel and before the CR/LF:

,DxxxHxxMxxSxx_xx

The x's would be ASCII characters (0-9) as required. The time registers are not incremented until enabled with the 'J1xx' command, so they can be set up then synchronized by sending the enable command at the correct time.

In Packed BCD and excess format the letters D,H,M,S, and _ are stripped and the data encoded as per the Mag data above. The Day info is put into 2 bytes with the most significant nibble of the most significant byte set to zero.

Julian Time Enable

This command starts/stops the Julian clock. To start the clock on counter 0 the command would be "J100". "1" turns on the clock, while the "00" selects counter 0. To turn off the clock update on counter 2 the command would be "J002".

If the counter number information is omitted the command will affect all counters in the chain. Thus the command "J0" will turn off the update for every counter.

Note that the "Jxxx" command only affects whether the clock increments with time. It has no effect on whether or which of the clock fields are output. The "OJxxxxxyy" commands select which field is output.

Julian Output format

There are five clock output fields that can be turned on or off. These are the Julian Day, Hour, Minutes, Seconds, and Fractional seconds (to .01 seconds). These are selected with the "OJxxxxxyy" command. Each of the five x's corresponds to an output field, and can either be a '0' or a '1'. '1' turns the field on, '0' turns the field off. The yy characters are the counter number. Following is a diagram showing which character corresponds which each display field:

```
command:  "OJ0111103"
           \\\\\\\__Counter number LSB
           \\\\\\__Counter number MSB
            \\\\\__10 ms field
            \\\\__Seconds field
             \\\__Minutes field
             \\__Hours field
              \__Days field
```

In this example counter three would have all clock fields output except the Julian Day.

The counter number characters are optional. If not present the command would affect only counter 0 in the chain.

Find Counters

This command is used to figure out how many counters there are in the daisy chain. An 'F00' is sent to the first counter which assigns it as counter 0. Before the command is echoed to the next counter the command is modified to 'F01'. The next counter modifies it to 'F02', and so on until the logging PC gets the command echo of 'Fxx' where xx is the number of counters in the chain.

Continuous data output can be inhibited by sending the command 'F01' to the first counter. In this mode there is no first counter (#00) which normally starts data transmission. Data output can be resumed by sending a new 'F00' command.

Set Preamble character

By default the first character of each data stream is a '$'. If another character is desired the 'Px' command is used to change it to the character sent following the 'P'. All characters are allowed except: control characters, digits (0-9), spaces, commas, decimal points, and the termination char ('*').

Echo Error command

This is not really a command but a message. If a command string is incorrectly sent or garbled the counter receiving it will change it to 'ERRxx' before echoing it to the next counter. 'xx' specifies the counter number where the syntax error first occurred. This error message is interpreted as a command by subsequent counters which echoes the string unchanged.

Interrogate Setup command

This command allows the operator or logging software to identify which analog channels and Julian clock fields are being outputted via the serial port. This information is used to verify output fields with their hardware channels, and to allow automated calculation of data field position within each sample being sent out. In addition the software revision number can be interrogated.

The first character 'I' designates the interrogate command; the second letter designates which item to interrogate. 'A' specifies interrogating the analog channels, 'J' specifies the Julian clock, and 'V' specifies the software revision number.

The next two characters specify the counter number '00' through '19'. If the counter number is omitted, counter 0 will respond.

The addressed counter will insert a response into the command string before sending echoing it out the serial port to the display terminal or subsequent counter modules. Subsequent counter modules will ignore these extra response characters and pass them unmodified down the chain. The response format for each of the three interrogate items are detailed in the examples below:

Analog channels

The command "IA01" will command counter number one to output characters indicating which of the six analog channels have been selected for output. Counter 1 will modify the command string to "IA01:abcdef" where the letters a-f are either an ASCII '0' (channel off) or '1' (channel on) corresponding to channels 0-5 respectively. If analog channel 0,3, and 4 were selected on counter 1 the echoed command string would be "AI01:100110" followed with a carriage return line feed.

Julian Clock:

The command "IJ" will command counter 0 to output which Julian clock fields have been selected for output (note that the two digit counter number was not specified, so counter 0 responds by default). Counter 0 will modify the command string to "IJ:abcde" where the letters a-e would be replaced with an ASCII '0' (field off) or '1' (field on). The five output fields are:

a: Julian day
b: Hour
c: Minute
d: Second
e: Fractional Seconds (to 10 milliseconds)

If counter 0 had all clock fields selected for output except the Julian Day it would modify the command string to "IJ:01111" followed with a carriage return line feed.

Software Version Number

The command "IV02" will command counter 2 to send its two character software version number. Counter 2 would change the command string to "IV02:xx" where xx is the version number of the software. If Counter 2 was software version "A4" then the echoed command string would be "IV02:A4" followed by a carriage return line feed.

Reset command

If the command 'RESET' is sent to the counter a power up reset will occur initializing all parameters to default. The reset sequence will not start until the reset command has finished echoing out the RS-232 port to the next counter/logging device. This allows each device down the chain to reset in sequence.

Jump to debug

If the command string 'XBUG' is received the counter will do a one way jump to factory debug mode where a rudimentary operating system allows probing of registers, ports and memory for debugging purposes. It will only function properly with a single counter module (no daisy chained counters).

6.4 Power-up Initialization

By default all counters will wake up thinking that they are counter #0 and begin to output data at the default 10 hertz rate. This data will appear as commands to any subsequent counters and will cause a brief period of chaos until each counter figures out where they stand in the daisy chain. Thus there will be some garbled transmissions to the logging PC upon power-up or reset.

7.0 ACCESSORY SOFTWARE

7.1 Terminal Emulation Software - Tera Term

Tera Term is a program that supports RS 232 communications between a Windows PC and any connected device such as the G-862. This software is provided through LogMeTT.com, and can be downloaded through the LogMeTT web page:

http://logmett.com/index.php?/products/teraterm.html

This software is provided at no charge. Please make sure you adhere to the Tera Term License terms and conditions when you download and use this software.

Tera Term defaults to 9600 Baud, 1 Start Bit, 8 Data Bits, and No Parity upon startup.

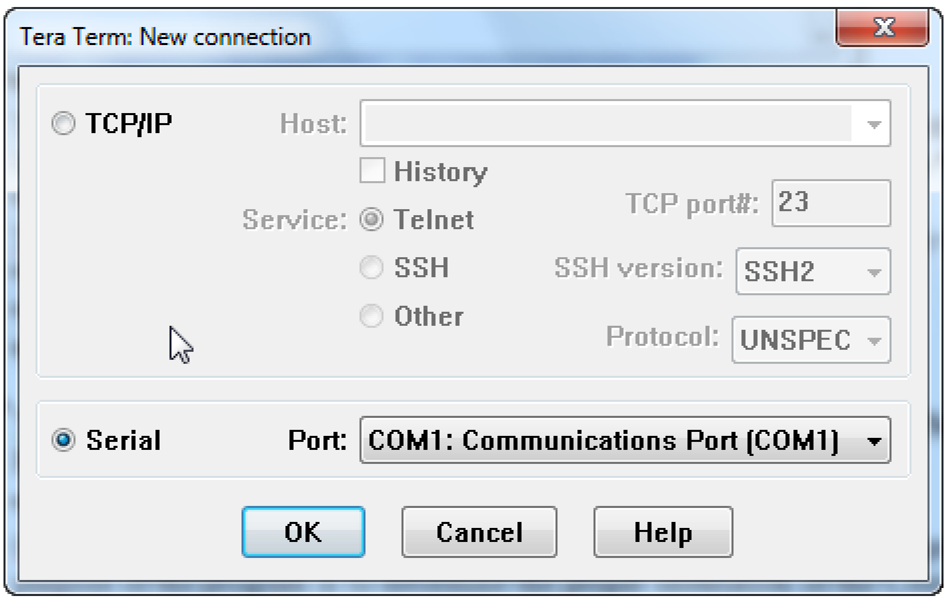


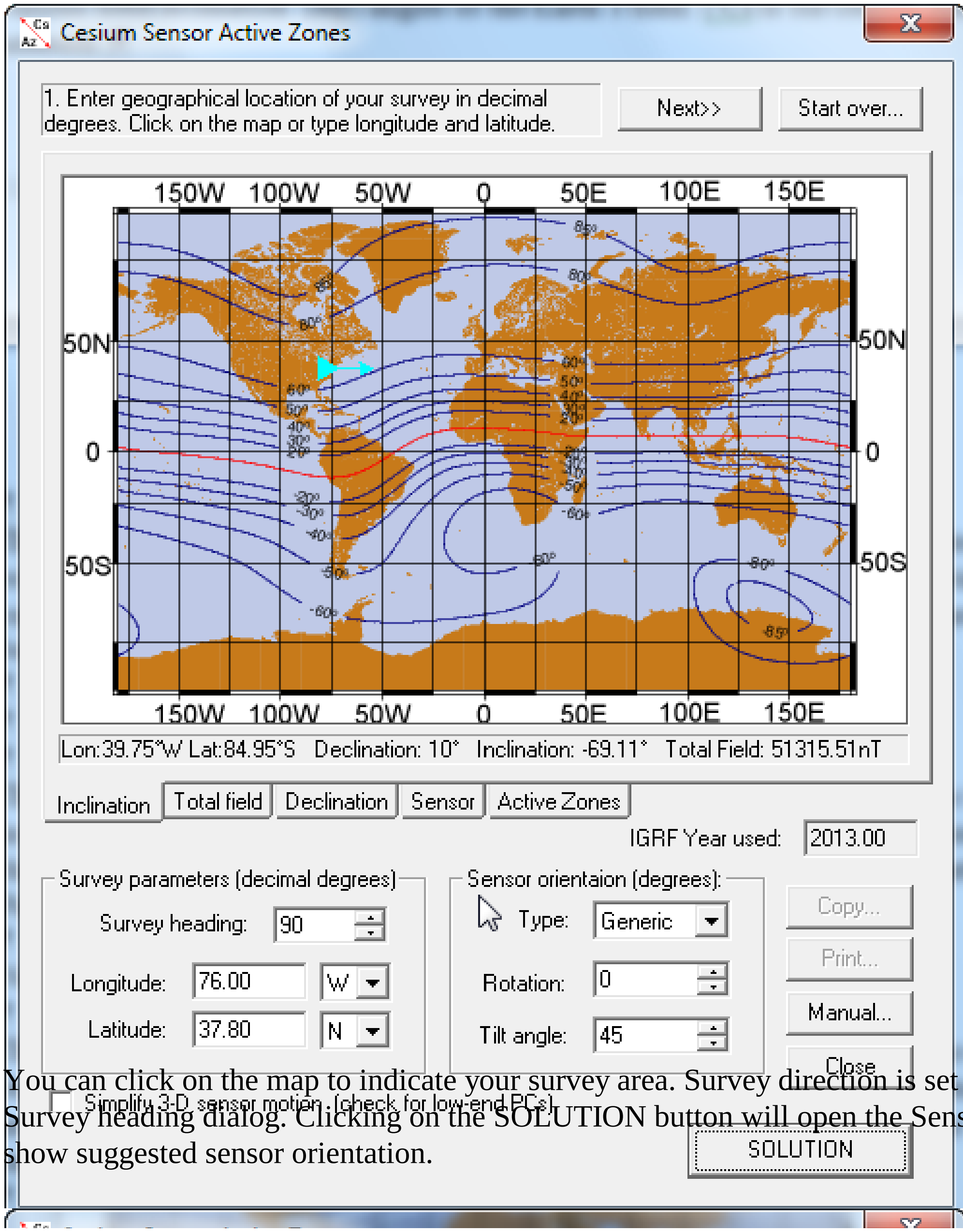
Figure 12: Tera Term Initial Screen

Click on the Serial radio button and select the Com Port from the Port: drop down list before clicking OK to start a terminal emulation session through RS-232 to the G-862.

7.2 Cesium Sensor Azimuth Program - CsAz

CsAz is a Windows program written by Geometrics for users of Cesium magnetometers. The purpose of the program is to determine the proper orientation of the Cesium sensor at various field inclination (dip) angles of the Earth's field. (Cs is for cesium and Az is for azimuth.)

The program is easy to operate. Begin by clicking on the CsAz icon on the desktop. You will see a map of the world at the top of the window including an arrow showing the current selected position and survey direction, and some fields for user input at the bottom of the window.



You can click on the map to indicate your survey area. Survey direction is set in the Survey heading dialog. Clicking on the SOLUTION button will open the Sensor tab to show suggested sensor orientation.

Figure 13: CsAz Inclination Tab

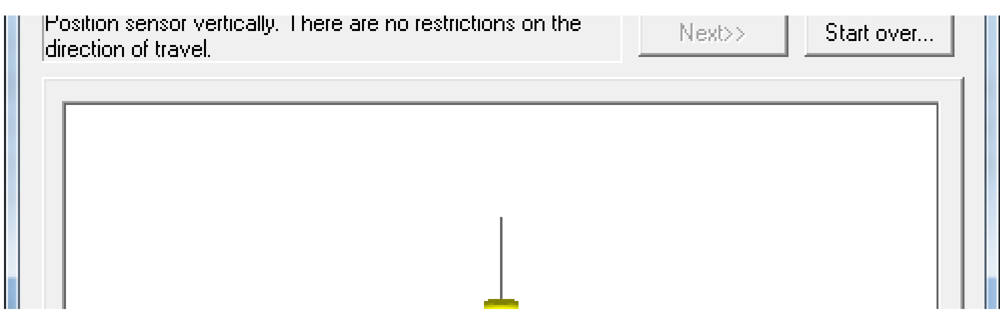
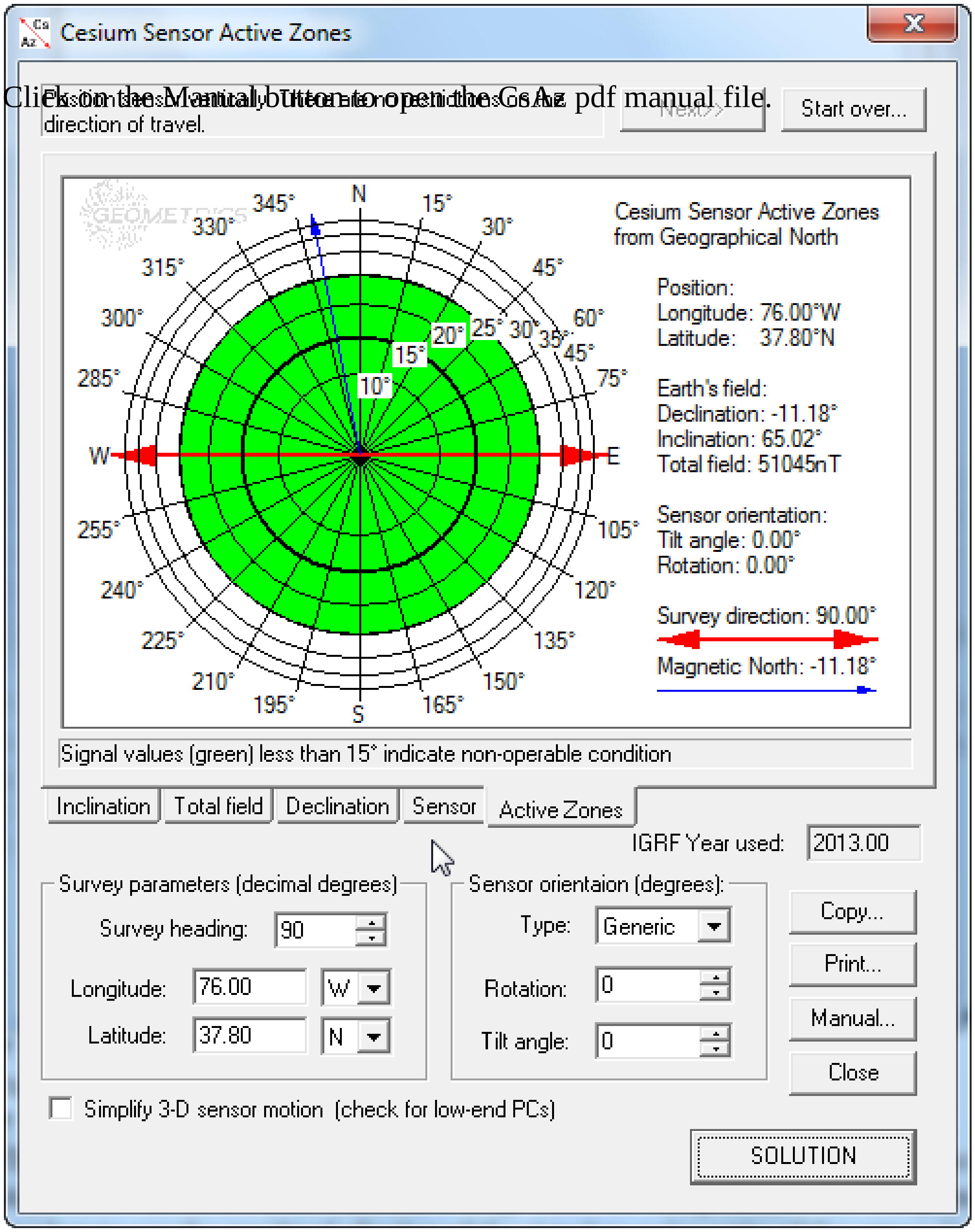


Figure 14: CsAz Sensor Tab

Next click on the Active Zones tab to see detailed information.



Click on the Manual button to open the CsAz pdf manual file.

Figure 15: CsAz Active Zones Tab

APPENDIX A1. MODEL G-862 SPECIFICATIONS

OPERATING PRINCIPLE:	Self-oscillating split-beam Cesium Vapor (non-radioactive)
OPERATING RANGE:	20,000 to 100,000 nT
OPERATING ZONES:	The earth′s field vector should be at an angle greater than 6º from the sensor′s equator and greater than 6º away from the sensor′s long axis. Automatic hemisphere switching.
SENSITIVITY	< 0.004 nT/√Hz rms. Typically 0.02 nT P-P at a 0.1 second sample rate (90% of all readings falling within the P-P envelope) using CM-221 Mini-Counter
HEADING ERROR:	< 0.15 nT over entire 360º polar and equatorial spins.
ABSOLUTE ACCURACY:	Better than 3 nT throughout range
OUTPUT:	Cycle of Larmor frequency = 3.498572 Hz/nT, RS-232 data at 9600 baud, concatenated data streams from up to 6 sensors
MECHANICAL:	
SENSOR:	2.375” (60.32 mm) dia., 6.25” (158.75 mm) long, 12 oz. (339g) without cable, 24 oz. (680 g) with cable
SENSOR ELECTRONICS:	2.5” (63.5 mm) dia., 11” (279.4 mm) long, 29oz 822g)
CABLES:	
Sensor to sensor driver / counter:	109” (2.77 m) standard. Cable length can be increased by 43” (1.10 m) for a total length of 152” (3.87 m).
Sensor driver to external counter:	33’ (10 m) standard. Cable length can be increased up to 164’ (50 m)
Sensor driver / counter to Power/data junction	25’ (7.6 m) standard. Cable length can be increased up to 200’ (61 m)
OPERATING TEMPERATURE:	-30ºF to +122ºF (-35ºC to +50ºC)
STORAGE TEMPERATURE:	-48ºF to +158ºF (-45ºC to +70ºC)
ALTITUDE:	Up to 30,000 ft. (9,000 m)
WATER TIGHT:	Sealed for up to 2 ft. (0.9 m) water depth
POWER:	24 to 32 VDC, 0.75 amp at turn-on and 0.5 amp thereafter
ACCESSORIES:	
Standard:	Power/RS-232 multi-conductor cable (electronics to power/data junction box with 9 pin RS-232 connector and power lugs), lengths to be specified, operation manual and carrying case
Optional:	Birds, Stingers, Wingtips, Avionics, GPS receivers

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE

APPENDIX A2. CESIUM-VAPOR SENSOR THEORY

Note: The following section is provided for information purposes only. Understanding this theoretical discussion is not required for proper operation of the magnetometer.

For purposes of this discussion, the ambient magnetic field or earth's magnetic field is called H_0. A separate magnetic field generated by an AC signal applied to a coil inside the sensor is called H1. This coil is shown cross-section along with the other sensor components in Figure A11.

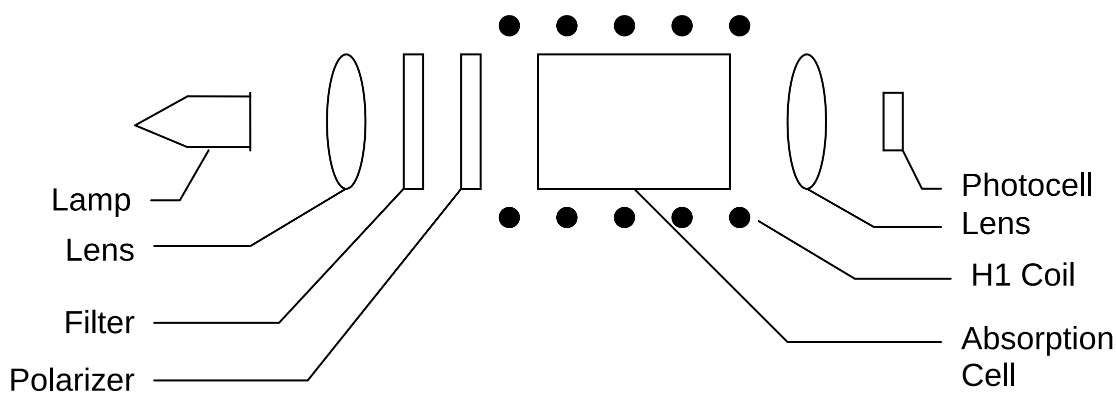


Figure A11: G-862 cesium-vapor cell

To initiate operation of the sensor, the lamp oscillator's RF power increases until the lamp strikes (plasma ignites and fluoresces). The lamp oscillator then reduces its power to produce the regulated amount of light. The heater warms the absorption cell until a Cesium vapor is formed. A lens bends the light from the lamp to parallel rays. The lamp produces many spectral lines but only one line in the infrared region is employed. All of the other light is blocked by a high grade optical filter.

The infrared line of interest is then passed through a split-circular polarizer. On one side of the polarizer the transmitted light has an electrostatic vector that advances with a right-handed rotation. For conceptual purposes, it can be said that all of the photons in this light have the same right-hand spin direction. The light transmitted through the other side of the split-circular polarizer produces light in which the vector advances with a left-handed rotation, therefore having the opposite spin. Both circular polarized light beams pass through the absorption cell. Because there is a buffer gas in the cell, the single cell can be considered as two separate cells, each having the opposite sense polarized light passed through it. Both light beams exit the cell and pass to a second lens. This lens focuses the light onto an infrared photo detector.

Because Cesium is an alkali metal, the outer most electron shell (orbit) has only one electron. It is the presence of this single electron that makes the Cesium atom well-suited for optical pumping and therefore magnetometry.

The Cesium atom has a **net magnetic dipole moment**. This net dipole moment, termed **F**, is the sum of the **nuclear dipole moment**, called **I**, and the **electron's angular momentum**, called **J**. In a Cesium atom:

I = 7/2
J = 1/2

and thus **F** can have two values depending on whether the electron's angular momentum adds to or subtracts from the nuclear dipole moment. Therefore, **F** can have the value of **3** or **4**. These values are called the hyperfine energy levels of the ground state of Cesium.

Normally the net dipole moments are randomly distributed about the direction (vector sum of the 3 axial components) of the ambient magnetic field (H_0). Any **misalignment** between the net atomic dipole moment and the ambient field vector causes the Cesium atom to be at a higher energy level than if the vectors were aligned. These small differences are called **Zeeman splitting** of the base energy level.

The laws of quantum electrodynamics limit the inhabitable atomic magnetic dipole orientations and therefore the atomic excitation energy to several discrete levels: 9 levels for the **F=4** state and 7 levels for the **F=3** state. *It is this variation in electron energy level state that is measured to compute the ambient magnetic field strength.*

When a photon of the infrared light strikes a Cesium atom in the absorption cell, it may be captured and drive the atom from its present energy level to a higher energy level. To be absorbed the photon must not only have the exact energy of the Cesium band gap (therefore the narrow IR line) but must also have the correct spin orientation for that atom.

There is a high probability that the atom will immediately decay back to the initial energy level but its original orientation to the ambient field is lost and it assumes a random orientation. An atom that returns to the base level aligned such that it can absorb another photon will be driven back to the higher state. Alternately, if the atom returns to the base level with an orientation that does not allow it to absorb an incoming photon, then it will remain at that level and in that orientation. Atoms will be repeatedly driven to the higher state until they happen to fall into the orientation that cannot absorb a photon. Consequently, the circularly polarized light will depopulate either the aligned or inverse aligned energy states depending on the orientation (spin) of light polarization. Remember that one side of the cell is right-hand polarized and the other left-hand polarized to minimize sensor rotational light shifts and subsequent heading errors.

Once most of the Cesium atoms have absorbed photons and are in a state that does not allow them to absorb another photon, the light absorption of the cell is greatly reduced, i.e., more light hits the photo detector. If an oscillating electromagnetic field of the correct radio frequency is introduced into the cell, the atoms will be driven back (depopulating the energy level) into an orientation that will allow them to absorb photons again. This frequency is called the Larmor frequency and is exactly proportional to the energy difference caused by the Zeeman splitting mentioned previously. This energy splitting is in turn directly proportional to the ambient magnetic field strength. The relationship between frequency and energy is given by:

$$E = f\hbar$$

Where:

E is the Zeeman energy difference

f is the frequency of the Larmor

$\hbar$ is Planck's constant

In Cesium this Larmor frequency is exactly 3.498572 times the ambient field measured in nano-teslas (gammas). In the G-862 this radio frequency field is generated by a coil, called the H1 coil that is wound around the tube holding the optical components. When the R.F. field is present the total light passing through the cell is reduced because atoms are in an energy state in which they can again absorb the infrared light.

There is a small variation in the atomic light absorption at the frequency of the applied H1 depopulation signal. This variation in light intensity appears on the photo-detector as a small AC signal (micro-volts). If this AC signal is amplified and shifted to the correct phase, it can be fed back to the H1 coil to produce a self-sustaining oscillation. In practice simply connecting the 90° phase shifted and amplified signal to the H1 coil will cause the oscillation to spontaneously start. Reversing the direction of the earth field vector (H_0) through the sensor requires the drive to the H1 coil to be inverted to obtain oscillation. (See Automatic Hemisphere Switching, section 2.4.3).

APPENDIX A3. G-862 GENERAL BLOCK DIAGRAM OF SYSTEM COMPONENTS