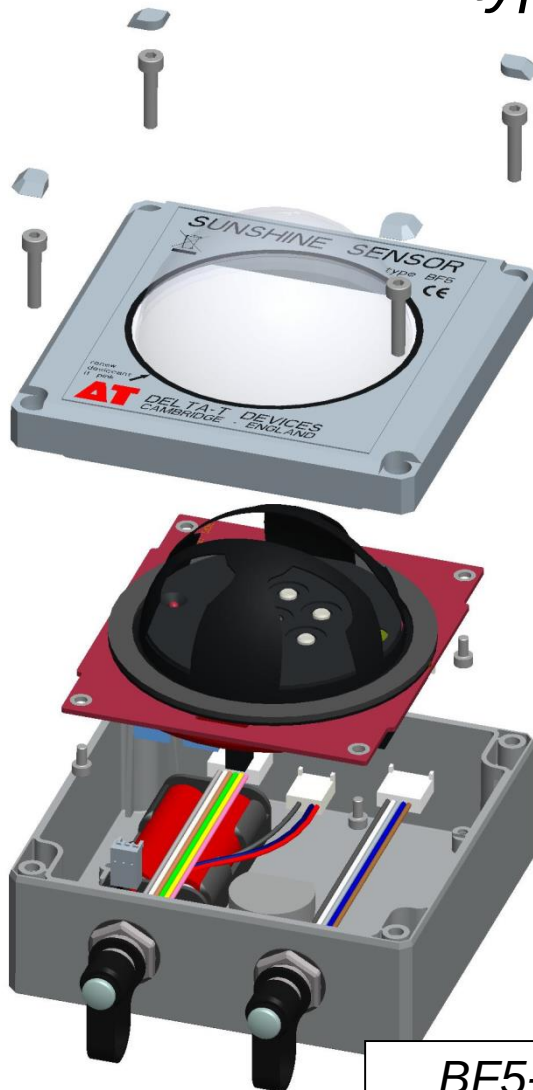

Technical Manual for the

Sunshine Sensor

type ***BF5***



BF5-TM-2.1



Delta-T Devices Ltd

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Warnings

To maintain conformance to CE standards, the equipment must be used as described in this manual.

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This document

Use this Technical Manual to service, calibrate, repair or upgrade the BF5 Sunshine Sensor.
It describes the software electronic functions, with schematics, component layout diagrams and part lists.

BF5 general description

Introduction

The Sunshine Sensor measures Total and Diffuse PAR radiation in the range 400nm – 680nm, and Sunshine presence. These are available as continuously varying analogue outputs suitable for logging with a datalogger (e.g. GP1, DL2), and as instantaneous digital readings.

The BF5 offers these outputs in a choice of units - $\mu\text{mol.m}^{-2}.\text{s}^{-1}$, W.m^{-2} , and lux.

The BF5 shares its main processor PCB with the SPN1, and most of the functions are identical.

Inputs

Photodiodes

A/D readings are obtained from 7 GaAsP photodiodes on the photodiode PCB. These are amplified to give a voltage which is read by the Main PCB A/D converter. A calibration factor is stored for each photodiode.

Temperature

The temperature of the enclosure is measured by a thermister on the photodiode PCB. This controls the current to the heaters. The thermister is positioned to sense the external temperature a little away from the heaters themselves.

RS232

Command characters are received via the RS232 port (9600,N,8,1)

DL-POWER

Presence of an external datalogger is indicated by a voltage of 4V – 15V on the DL-POWER pin. This enables the analogue outputs and causes the BF5 to continuously take readings.

HTR-POWER

A separate supply and ground is provided for the heater power supply, which takes 9V – 15V at up to 1.5A. The actual heater current depends on the external temperature.

Real Time Clock

The BF5 maintains a real time clock, while it is powered up. The clock is reset whenever power is lost.

Analogue Outputs

Whenever the DL-POWER pin is at logic high (anything above about 3V, e.g. via DL2 warm-up relay), measurements are made continuously, and the values of Total, Diffuse, and Sunshine are output on the analogue output pins. All RS232 commands are obeyed.

The DAC output (Total, Diffuse & Sunshine signals) is valid within 110 ms of DL-POWER going high (may be longer if no battery fitted), and is updated every 250ms while DL_POWER remains high. Updates may be slower than this if the BF5 is responding to serial commands as well.

When DL-POWER is no longer driven high, all the outputs are set to zero and the DAC powered down within 250 ms.

Two DAC outputs are used for values of Total and Diffuse radiation, with a range of 0V – 2.5V. A digital output indicates sunshine presence. This is a MOSFET transistor open drain output. It will sink up to 0.5A from 15V max when switched on (on = sunshine). This output is protected against excessive external current or voltage.

Analogue Output Resolution

Instantaneous readings	range	resolution @ 12 bits
Total & Diffuse	0 – 2.5V from preamp	0.6 mV
	0 – 2500 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$	0.6 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$
	0 – 1250 W.m^{-2}	0.3 W.m^{-2}
	0 – 250 klux	0.06 klux
Sunshine	0 or 1	1 bit

Note: The typical daily lux range is 0 – 150klux, ie analogue output voltage 0 – 1.5V

Output protection

The analogue and heater connections are designed to stand any misconnection without causing damage to the sensor. In practice this means that any signal connector will take $\pm 15\text{V}$ relative to ground without damage. On early version PCBs, connecting any pair of ground cables to a power supply could potentially cause internal damage.

LED

An LED flashes when readings are taken.

Calculations

Broad concepts

The BF5 Diffuse value has been given a 5% uplift to compensate for a 5% under-reading caused by a combination of diode calibration variations, and differences in diffuse sky sampling areas between diodes.

Lux values are given by a direct conversion from molar values. The factor is calculated from first principles, based on typical Total and Diffuse spectra taken at Winster in a range of conditions..

Energy values require more complex conversion, due to the very different conversion factors for Diffuse radiation in blue sky and grey sky conditions. The measured beam fraction is used as a predictor (though not particularly accurate) of diffuse sky conditions.

Algorithm – all outputs

Let MAX and MIN be the largest and smallest photodiode reading of the seven photodiodes, after being adjusted for any calibration factors (calibration is done in the solar lamp rig against a standard QS as with the BF3)

Then $\text{TOTAL} = \text{MAX} + \text{MIN}$ gives BF5 TOTAL value, in $\mu\text{mol.m}^{-2}.\text{s}^{-1}$
 $\text{DIFFUSE} = 2 * \text{MIN} * 1.05$

IF (DIFFUSE > TOTAL) then DIFFUSE = TOTAL

gives modified BF5 DIFFUSE value, in $\mu\text{mol.m}^{-2}.\text{s}^{-1}$, with sanity check. This modified DIFFUSE value is used in all subsequent calculations.

$$\text{Beam Fraction} = (\text{TOTAL} - \text{DIFFUSE}) / \text{TOTAL}$$

SUNSHINE if $\text{TOTAL}/\text{DIFFUSE} > 1.25$ AND $\text{TOTAL} > 50 \mu\text{mol.m}^{-2}.\text{s}^{-1}$

Molar $\mu\text{mol.m}^{-2}.\text{s}^{-1}$ outputs

The TOTAL and DIFFUSE values are then output via the RS232 and Analogue ports, at $1\text{mV} = 1 \mu\text{mol.m}^{-2}.\text{s}^{-1}$.

Lux outputs

The TOTAL and DIFFUSE values are multiplied by $55.7 \text{ lux} / \mu\text{mol.m}^{-2}.\text{s}^{-1}$ to give lux. These values are output to the RS232 and analogue ports at a sensitivity of $1\text{mV} = 100 \text{ lux}$. This gives an output range of approx 0V to 1.5V for the normal daylight range, with a resolution of 100 lux.

Energy Wm^{-2} outputs

$$\text{Energy TOTAL} = \text{TOTAL} * 0.48$$

$$\text{Energy DIFFUSE} = \text{DIFFUSE} * (0.48 - 0.48 * (\text{Beam Fraction})^4)$$

(Ie Beam fraction to the fourth power)

These values are then output via the RS232 and Analogue ports, at $2\text{mV} = 1 \text{ W.m}^{-2}$.

RS232 commands

Operating modes and Serial commands

The BF5 can be interrogated from any serial port terminal program (eg Windows Hyperterminal, or the Terminal screen in the SunRead software). Set the RS232 settings to 9600 baud, No parity, 8 Data bits, 1 stop bit. In Hyperterminal, also set 'Append line feeds to incoming line ends' in Settings > ASCII setup.

In the following tables, commands TO the sensor via RS232 are in **bold**, responses (also via RS232) are in normal weight. All RS232 input characters are echoed back except for the 'R' command.

For commands with more than one input character, a command is abandoned if the input is not within appropriate range, or 1 minute after a keypress. Unrecognised and aborted commands return '?'.

Sleep mode

Processor is in its lowest power state.

If the sensor is asleep when the DL-POWER pin goes high, then the sensor will wakeup and start to output the analogue values, as described above.

Any RS232 input will wake the sensor up for long enough to respond to the command. The suggested procedure is to send an '**R**', wait for the '»' response, then send the desired command, and wait for the terminating <CR>.

RS232 Input	Response	
R	» (ASCII 175)	For BF3 compatibility
S	tttt.t, dddd.d, s<CR>	Send the current reading, in comma separated ASCII. tttt.t & dddd.d are the Total & Diffuse readings, s is Sunshine presence 0 or 1. A one off reading is taken when the command is received.
I	BF5 v1.0 Nov 13 2008<CR> Units: $\mu\text{mol.m}^{-2}.\text{s}^{-1}$ <CR> 2380mV radio off <CR> 05/67<CR> Ready<CR>	Status information – firmware code version Output units - $\mu\text{mol.m}^{-2}.\text{s}^{-1}$ Battery voltage, radio link status Instrument serial number Logging status
T	TEST:	Enter TEST mode.
Z	2006/01/10 00:09:52	Displays a date and time (reset at power up)
?	I Status Info<CR> S Send data<CR> T TEST: mode<CR> Z Date & Time<CR>	A reminder of the command set
SOP		SOP (ASCII 15) marks a Start of Packet
Any unrecognised character	? »	Any unrecognised character also causes the sensor to recalibrate its internal oscillator.

TEST mode

The sensor is permanently awake, and the analogue outputs are not updated. It will return to Sleep mode after 15 minutes with no keypress. After completion of any command, <CR> and the TEST: prompt will be echoed. Any unrecognised character or incorrectly formatted input will return the sensor to Sleep mode.

This mode is designed for manufacturing and technical support purposes, and is not intended to be accessed by the user or user software. The format of these commands may change without maintaining backwards compatibility.

WARNING – some of these commands can permanently affect the calibration of the instrument

RS232 Input	Response	Action
R	» (ASCII 175)	Returns to Normal mode.
Yyyy/mm/dd	2007/03/14 00:45:39	Set the date
Hhh:mm:ss	2007/03/14 17:47:00	Set the time
Anr	A11 = 0806	Read the value of A/D n. r=0 reads with reference to Vcc, r=1 reads wrt 2.5V. Output is in A/D units 0000 – 4095
Bn	B1 145 38 249 235 231	Read the output of photodiode n. Output is in A/D units, and is updated every 250ms until receipt of another character. Backspace characters used to overwrite the display.
Cnnnn	OK	Calibrates photodiodes to value nnnn.(nnnn is any integer between 0000 and 2500 in $\mu\text{mol.m}^{-2}.\text{s}^{-1}$). Updates values in user calibration area. If nnnn = 0000, then calibrate to average value of the 7 photodiodes.
CLEAR	OK	Resets the user calibration values to unity. Any previous calibration information is lost
DEFAULT	OK	Copies contents of factory calibration area to user calibration area
E	User: 04096 04096 ... Factory: 04096 04096 ...	Displays 7 calibration values (one for each photodiode) held in user and factory default areas. The displayed value should be divided by 4096 to give the actual value.
F	DCO 928 kHz	Reports frequency of main CPU clock
G	DCO 949 kHz	Calibrates frequency of main CPU clock
I	Therm temp 20.40C Chip temp 34.50C Batt 0 mV Ext 5874 mV Vcc 3299 mV 2006/01/10 00:02:43	Reports temperature of PCB thermister and internal CPU temp (can be very inaccurate) Reports battery voltage, external supply, and regulated Vcc. Also reports if DL-POWER or HTR-POWER inputs are active. Reports date & time (reset on power up)

JSET	Therm temp 37.20C Chip temp 61.90C6 ppm Temp Offset: -24.70C Xtal Offset: 5 ppm	Requires stable temp, and 1PPS input on DL-POWER. Reports chip temp offset, using thermister as reference, and calibrates crystal. J<CR> just reports calibration values.
Nc,nnnnn	OK	Sets user calibration factor for individual photodiode 'c' to 'nnnnn'. 04096 represents unity
Onnnn,nnnn		Sets DAC0 (Total output) and DAC1 (Diffuse output) to nnnn (0 – 4095, 2.5V full scale)
Pn.nx	<CR> or =X<CR>	If x is 0 or 1, sets CPU pin Pn.n to x If x is '=', reads value of pin Pn.n
Q	0 214 186 206 246 263 ...	Reports 8 raw A/D readings from photodiode channel 0 (ground) and 7 photodiodes.
S	266.7, 217.2, 0 (1 195 170 187 226 242 163 154)	Reports calculated Total, Diffuse & Sun outputs, and the raw photodiode readings used to generate them.
Tn.nn	<CR>ratio 1.25	Reports sunshine threshold ratio (always 1.25 for BF5) T<CR> just reports ratio.
WRITE	OK <CR>	Copies contents of user calibration area to factory calibration area.
Xnccc<CR> X<CR>	string 0 A100 0: A100 1: 09-Mar-07 2: 7300-934 3: 8400-234 4: 5: 6: 7:	The sensor records 8 text strings of up to 16 characters each. Xnccc<CR> sets string 'n' to 'ccc' X<CR> reports all 8 strings. String 1 is serial number String 2 is calibration date String 3 & 4 are Main & Photodiode PCB serial numbers Others as yet unused
?	Yyyy/mm/dd Date Hhh:mm:ss Time An0, An1 read ADCn Vcc/Vref Bn read PD Cnnnn Calibrate CLEAR Set cal to 1 DEFAULT Restore default cal E cal values F Get DCO Freq G Set DCO to 1MHz I Status Info JSET Cal Xtal Nc,nnnn set cal c to nnnnn Onnnn,nnnn set DACs Pn.nx read/set pin x is 01=	A reminder of the TEST: command set.

	Q Scan PDs R Reset to normal S Send data Tn.nn Sunshine ratio Un Set units WRITE user cal to default XncccCR Write ccc to string Xn	
--	---	--

Packet mode

Packet mode is used for downloading new firmware to the sensor. It allows for full CRC checking of data packets to minimise the likelihood of any firmware corruption.

Packet description – command and response

Packets sent to and from the sensor have the following structure:

Byte	Name	Value	Description
1	SOP	0FH	Start of Packet Marker
2	Cmd	Command	One of the defined command codes
3	AddLo	Address	Low byte of the address
4	AddHi	Address	High byte of the address
5	Len	length	Number of bytes of data in the packet
6	Data	Data	Up to 16 bytes of data
6 + len	CRC Lo	CRC	Low byte of CRC value
7 + len	CRC Hi	CRC	High byte of CRC value

The data length can be any size. However, the BF5 Receive buffer is only 32 bytes long, so in practice complete packets should be shorter than this to prevent overflow. Response packets may be longer.

The CRC is used to detect corrupt data packets. The polynomial used is $x^0 + x^2 + x^{15} + x^{16}$ (CRC-16). On receipt, the complete message will CRC to zero if there are no errors.

The sensor will always respond with a correctly formed packet to confirm that the command has succeeded.

Poorly formed packets or packets containing unrecognised commands will be discarded.

Command GetVersion

Returns the sensor firmware version string

Cmd	Address	Length	Data
0	Ignore	0	None

Response

Cmd	Address	Length	Data
0	0000H	String length	Version string eg 'SPN1 v1.03 Mar 13 2007'

Command Erase

Erases the memory block containing address. These are normally 512 bytes long, apart from the two information memory blocks at 1000H to 10FFH which are only 128 bytes each.

Cmd	Address	Length	Data
1	An address within the block	0	None

Response

Cmd	Address	Length	Data
1	Address	0	None

Command Write

Writes a block of data to memory (which should have been cleared first), starting at Address. The data is written then read back in the response data block to confirm that it has actually been written.

Cmd	Address	Length	Data
2	A Start Address within the block	length	Data bytes to write,

Response

Cmd	Address	Length	Data
2	Start Address	length	Data bytes read back from memory

Command Read

Reads 16 bytes of memory starting at Address.

Cmd	Address	Length	Data
3	Start Address	0	None

Response

Cmd	Address	Length	Data
3	Start Address	16	16 bytes read from memory

Command Copy

Copies a block of data from Source Address to Destination Address. Destination block will be cleared before it is written. Make sure you don't write over a block boundary. The destination address and the size of the block to copy are given in four bytes of data.

If the destination block is the top block in memory FE00H, which contains the interrupt vector table, then the processor is reset after the copy, and no response will be returned.

Cmd	Address	Length	Data
4	Source Address	4	DestLo, DestHi, SizeLo, SizeHi

Response

Cmd	Address	Length	Data
4	Start Address	0	None

Command Reset

Resets the processor, as if from a power up.

Cmd	Address	Length	Data
6	0000H	0	None

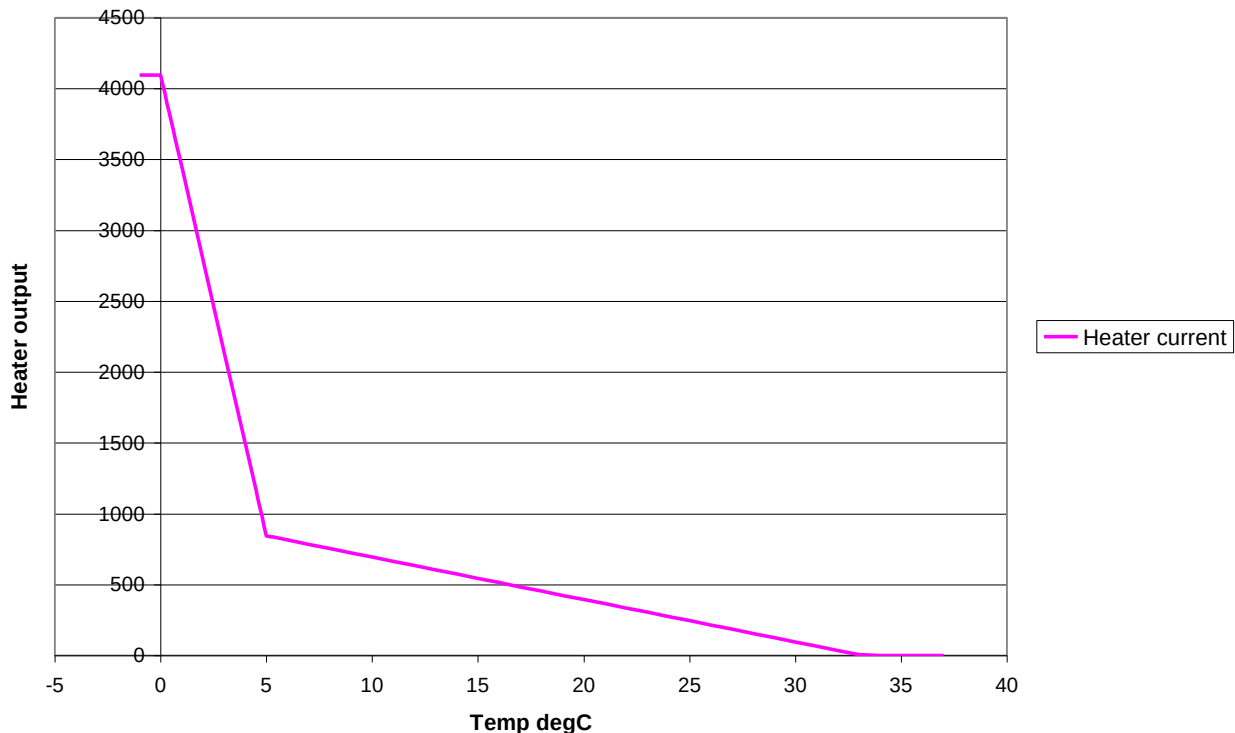
Response

None

Heater

The heater is active whenever power is applied to the heater connectors. The amount of current drawn is varied smoothly depending on external temperature, which is measured by a thermister on the photo PCB in contact with the outer part of the enclosure top. The heater is controlled by a 8Hz 12 bit PWM switch, controlled according to the graph below.

Heater current



This is designed to provide a gentle heat to disperse dew at higher temperatures, and a smooth transition to maximum heating near freezing to remove frost, while minimizing any thermal shock, which can affect the reading accuracy.

Internal data storage

The MSP430F169 microprocessor contains several different blocks of memory. There is 2kB of RAM (addresses 0200H to 09FFH) which is used for working memory. There are then two 128 byte segments of flash information memory (addresses 1000H to 10FFH). These are used to store the instrument calibration values, sunshine ratio settings, and string values used to store serial numbers, calibration date etc. Finally, there is 60kB of flash program memory in 512 byte segments (addresses 1100H to FFFFH), of which the top segment contains the interrupt vector table. All of this memory is in-system programmable, which makes firmware upgrades over the serial port a possibility. The BF5 firmware sits near the top of program memory, which leaves the lower program memory space available for logging data storage or the bootloader software.

There is also position for a 512k or 1024k SPI EEPROM on the pcb, which will expand logging memory substantially.

SunRead Software

The SunRead software supplied with the BF5 is very similar to BF3Read as provided with the BF3, and is fully compatible with the BF3 as well as the SPN1. It communicates via RS232 and gives an instant screen display of the BF5 reading values and serial number. The software also provides a basic logging capability, recording the readings to file on the connected PC.

It also provides a terminal screen, which enables use of all the serial commands, and may be useful for technical support and debugging. This is enabled by adding '/e' to the command line.

SPN1 Programmer software

This software allows upgrading of the SPN1 or BF5 firmware over a serial connection. It does this by downloading a bootloader program to the bottom of program memory. When this has all been downloaded correctly, the interrupt vector segment is overwritten and the processor then restarts running the bootloader program. This contains a basic set of packet commands, and can then download the new firmware back to its position at the top of program memory. This process is usually reliable, but could be compromised by either a power failure at the time when the interrupt segment is being overwritten, or downloading an inappropriate or corrupt firmware file. In this case, the instrument would probably have to be returned to Delta-T for reprogramming.

The software also allows the sunshine threshold to be adjusted (SPN1 only), and the instrument calibration to be adjusted by a fixed amount. Changing the instrument calibration this way only affects the 'User' calibration settings, and the original factory calibration can always be restored if necessary.

Calibration process

For the BF5 to perform correctly, each of the 7 photodiodes must be matched to each other, and also have an appropriate sensitivity to incoming radiation. This is done by storing 7 individual calibration factors for the 7 sensors.

The BF5 is calibrated with its shadowmask removed, by placing it under a light source, and comparing it with a reference sensor. The light source provides a constant intensity bright light, approximating the solar spectrum, with a very good spatial uniformity. This ensures that the 7 sensors are accurately calibrated. The BF5 is then fully built, and given a final check in the lamp rig against a reference. The reference sensors are calibrated periodically by the manufacturer

It is not really practical for users to do a full recalibration without dismantling the instrument, and without specialist light sources, and we do not recommend this. However, if the BF5 is consistently reading out by a constant factor against a good reference, and otherwise appears accurate, then it is possible to adjust the overall sensitivity using the SPN1Programmer software.

Circuit Operation

Overview

The BF5 contains two circuit boards, which are connected together as a sandwich structure. The photodiode PCB supports the 7 photodiodes, bezel and diffusers, and also contains the amplifier and multiplexer to switch these signals into the main A/D converter on the main PCB.

The main PCB contains the MSP430 processor, and all the associated power supply circuitry, output conversion and protection circuits, and connectors.

Photodiode PCB

All power is supplied via J1 from the main PCB. This also carries a signal to drive the LED. The thermister TH1 is used to sense the external temperature of the enclosure away from the heaters.

The Vcc rail is only powered up when readings are taken. R2 and C4 ensure that the 74HC164 shift register is properly reset at power up. The WAND_CLK and WAND_START lines clock a single pulse to each output in turn, switching on the 8 channels via the 4066 CMOS switch. Channel 0 is a zero channel, which is used to remove any offset voltages measured. Channels 1 to 7 switch the 7 photodiodes.

The photodiodes have a current source output, which is amplified up by a high gain op-amp with chopper stabilized autozeroing inputs to minimise input offsets. This has a virtual-earth input current to voltage converter. The output from this first amplifier is in the range 0V to -1.25V, which is inverted and amplified up again by the second op-amp to give 0V – 2.5V to the A/D input, smoothed by R10 & C9.

Main PCB – Power supply

The BF5 can take its power from several sources:

1. 3V battery. This drives a regulated switched capacitor charge pump, IC4 to give a regulated 3.3V with only a few uA of quiescent current. When the /Snooze signal is taken high, the regulation and output current improve, at the expense of quiescent current, so the cpu only switches this when taking readings. IC6B provides a buffered battery voltage signal to the cpu.
2. Any external voltage, either from the heater supply, DL-POWER input or RS232 DTR line. These are diode-ored together, and regulated down to 3.3V by IC1, an LP2951. This is chosen because it has a wide input voltage capability, even though its quiescent current is higher. This is not a particular problem as the sensor will not be powered up but inactive when any of these power sources are available. The external voltage is buffered by IC6A before measurement by the cpu. All of these inputs can be sensed by the cpu via the DL-ON, HTR-ON and Ext-Power signals. All the external inputs are protected from reverse connection by diodes, and will stand up to 30V otherwise.

The two power sources are gated by IC3, which switches the external power through to the main Vcc rail for preference.

IC2 provides a regulated 1.8V from the Vneg processor pin, and this is inverted by a switched capacitor inverter IC5 to give -1.8V for the photodiode board op-amps.

The heater circuit (HTR-POWER to HTR-GND) is kept isolated from the rest of the sensor circuitry. The two grounds are connected by an inductor to give the same DC voltage, but cut down any higher frequency noise. The heater itself is switched with a power FET TR1, with a 8Hz PWM signal from the cpu, which varies with external temperature. The circuit is protected from overcurrent and reverse protection by D1 and F1 resettable fuse.

Main PCB – CPU and output circuitry

CPU and clock

The MSP430 has two clock sources, a low current 32kHz watch crystal XT1, and an internal digitally controlled oscillator, which runs at about 1MHz. This can start up very quickly, and provides most of the clock sources. The DCO can be calibrated to the XT1 oscillator if necessary, but in general this is only required if RS232 characters are received incorrectly.

The MSP430 maintains a real-time clock, driven by the 32kHz crystal. This is calibrated for accuracy against a 1PPS signal from GPS or similar, on the DL_POWER input, which improves the overall clock drift significantly

Voltage reference.

IC8 provides an accurate 2.5V reference for the 6 A/D input channels, and the two DAC outputs. These are used for measuring the photodiode values, and also the various battery voltages and external temperature. The external temperature can be measured by a thermister, either on the photodiode PCB, mounted on the main PCB, or connected via J9 pins 1&2. The two DAC channels provide the Total and Diffuse outputs directly.

Output protection

The Total and Diffuse outputs are protected against applied negative voltages by diodes to ground, and resettable fuses. IC10 and TR3 act as an 'active zener', giving minimal currents below 2.5V (the normal output range), but with a very sharp turnon if an applied voltage exceeds about 3.2V, again causing the resettable fuses to go high impedance. TZ4 & TZ5 provide additional protection against fast transients. The SUN output is protected by resettable fuse F5 and a 24V transzorb.

Serial i/o

IC9 provides the level conversion for the two serial ports. Only serial0 is normally used. The serial chip has a low current listening mode, so is only powered up (by RS232-ON) when the cpu needs to transmit RS232 messages.

Serial lines are protected by transzorbs, if the high voltage 'E' versions of the serial driver are not used.

SDI-12

Circuitry is provided, (though not normally fitted) for SDI-12 connection, using Serial1 inputs to the cpu. 12V power input comes via the CTS line, and is regulated down to 5V by IC12. The logic gates IC13 & IC14 provide the level shifting and 5V driver to the SDI-12 line. These have been selected for the ability to deal with mixed 3.3V/5V signals.

Test & Expansion connectors

All the external signals, and several extra cpu lines are taken to J8. The heater power and battery inputs are brought out on spare pins on the JTAG connector J4. These are used during PCB board testing, and can also be used in the future for add-on boards if required.

Memory expansion

There is space on the PCB for an additional serial memory chip IC11, to enable use as a self-contained logger if required.

Cables

