A large area avalanche photodiode detector system with USB interface

1. Introduction

When measuring low light levels, a vacuum tube photomultiplier tube or some form of solid-state detector which relies on multiplication (e.g. Avalanche diode, Geiger avalanche diode, silicon photomultiplier) is normally used. Vacuum tube photomultipliers have the advantage that a large photosensitive area is available, in contrast to most solid-state devices, which, in general, allow detection over a small area. Avalanche photodiodes make excellent detectors, and here we describe a detector assembly developed around a large area device, 10 mm diameter. This detector unit is designed to detect low light levels and is based around a detector module, commercially available from AP Technology, (www.advancedphotonix.com) part# 197-70-74-661.

The detector module is supplied as just that, a small box with flying leads, requiring appropriate low voltage dc power supplies. It does include a thermoelectric cooler and the avalanche diode's high voltage bias supply. Here we describe how this module was integrated in a photo-detection subsystem, powered from the mains and controlled either from an internal potentiometer or through a computer interface. The completed unit can operate as a stand-alone, manually adjusted unit and powered from a +5V / 2.5A power supply, providing an analogue output in the range 0 to +1V into a 50 Ω (or greater) load over a typical 10 MHz bandwidth. It can also operate as a USB-controlled device, where the detector gain can be remotely set and where output readings and operating conditions can be monitored. This mode of operation is controlled through a 'C' code software program developed under National Instruments LabWindows CVI.

These notes should be read with reference to the APT module data sheet and data sheets relevant to the other components and sub-assemblies. The unit is contained within a small metal enclosure which incorporates a heatsink to dissipate heat from an integral Peltier heatpump which cools the photodiode. The optical port is in the form of standard 'C' mount with the photosensitive plane set at 12.5 mm from the front face. Two small circuit boards on either side of the APD module contain power supply converters/regulators and USB control circuits respectively. The finished assembly is shown in Figure 1.

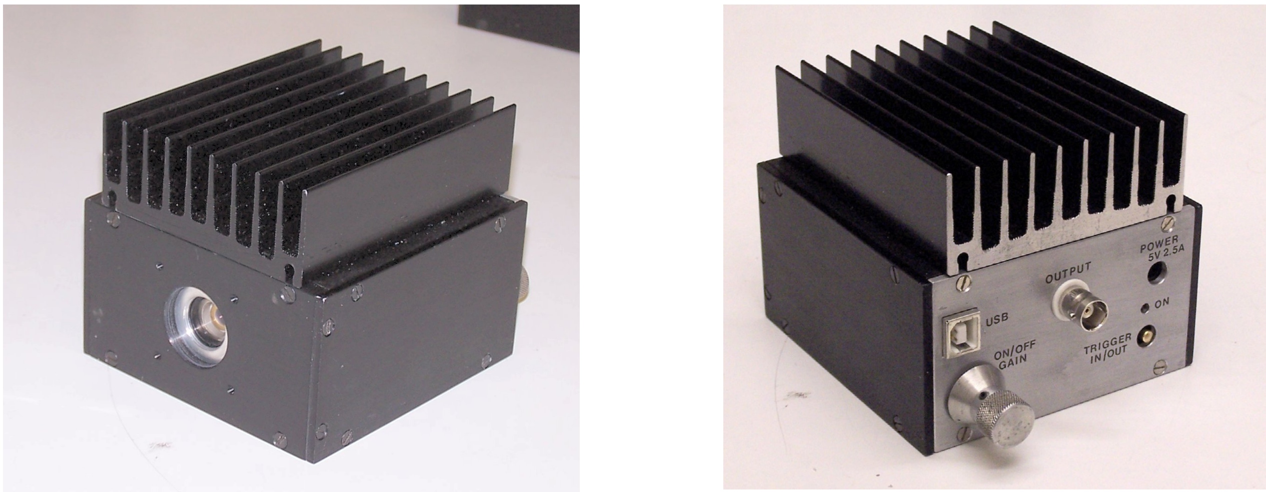


Figure 1: Front and rear views of the avalanche diode detector unit

All electrical connections are made on the rear panel of the unit; this has:

(1) A USB connector (USB 1.0 standard).
(2) A BNC output socket (1V maximum into 50 Ω minimum, +2 V maximum into an open circuit).
(3) An SMB trigger in/out socket (not relevant when operating in manual mode).

(4) A combined on-off switch and manual gain control, active during both manual and software-controlled operating modes.
(5) A DC power input connector (2.5 mm diameter pin).
(6) An indicator light, showing when power to the unit is present, and flashing during software acquisitions.

When the unit is operating without a USB connection, it is assumed that all internal module operating conditions are correctly set, i.e. that the detector temperature is within appropriate limits and that internal adjustments which determine the minimum and maximum gains have been appropriately set. No warnings of error conditions are available in this mode of operation and the trigger in/out connection is not functional. It is important not exceed the 2V maximum output limit of the module as high frequency oscillations could occur if the dynamic range range is exceeded; these can be eliminated only by reducing the output to below 0.5 V or so, either by reducing the input light level, or by reducing the gain, or both.

When the unit is used in conjunction with the USB cable and relevant software driver, internal conditions are monitored and the trigger in/out socket is operational. The software allows three modes of acquisition:

(1) Continuously updated displays of light level and other analogue channels; the trigger i/o socket then provides a TTL logic output which is high during the time that the light signal is acquired;

(2) Software-triggered acquisitions of these analogue measurements activated by a GUI panel pushbutton; the trigger i/o socket then provides a TTL logic output which is high during the time that the light signal is acquired;

(3) Hardware-triggered acquisitions of the analogue measurements; the trigger i/o socket is then a TTL input which initiates conversions following a high-to-low transition.

The circuit diagram of the system is shown in Figure 2. The unit consists of three sub-assemblies: the APD module, a power supply board and a data acquisition / USB board. The power supply board contains a DC-DC converter which converts the external +5V DC input to a +/-15 V output which is further regulated down to +/-12 V as required by the APD module. It also contains a P-channel MOSFET DC input switch which is used as a relay to ‘boost’ the ratings of the module on-off switch, ganged with the ‘gain’ control potentiometer. The latter is placed on the data acquisition board. A second small N-channel MOSFET is used to increase the brightness of the on-off indicator LED when software- and hardware-triggered acquisitions are performed.

The heart of the data acquisition board is a USB/PIC module which is used to acquire six analogue inputs and to transmit this to the host PC. One of the channels digitizes the ‘ground’ voltage, and the others are used to (1) convert a reference voltage (4.096 V nominal), (2) the voltage used to set the gain (i.e. HV supply control voltage), (3) a voltage proportional to the voltage provided by the HV supply, (4) a voltage proportional to the detector temperature and (5) an amplified voltage proportional the light input. The latter is slightly offset in a positive direction so as to cater for any small negative offset voltage that may be present at the module output.

The gain-setting voltage, normally in the range of approximately 2.2 V to 4.5 V, is derived from two series-connected potentiometers: the manual ‘gain’ control and a 100 step digital potentiometer (digipot). The output of these variable controls is amplified by x 2.33 to allow the 4.096 V reference voltage to swing to near to +5 V. Preset potentiometer at the top and bottom ends of the potentiometers are used to set the minimum and maximum gain values.

Logic outputs from the USB/PIC modules are used to step through the digipot gain range and to store the ‘power-up’ gain. A logic trigger input/output line is used to interface to external equipment using a bidirectional SMB connector, as described in the timing diagram in previous sections.

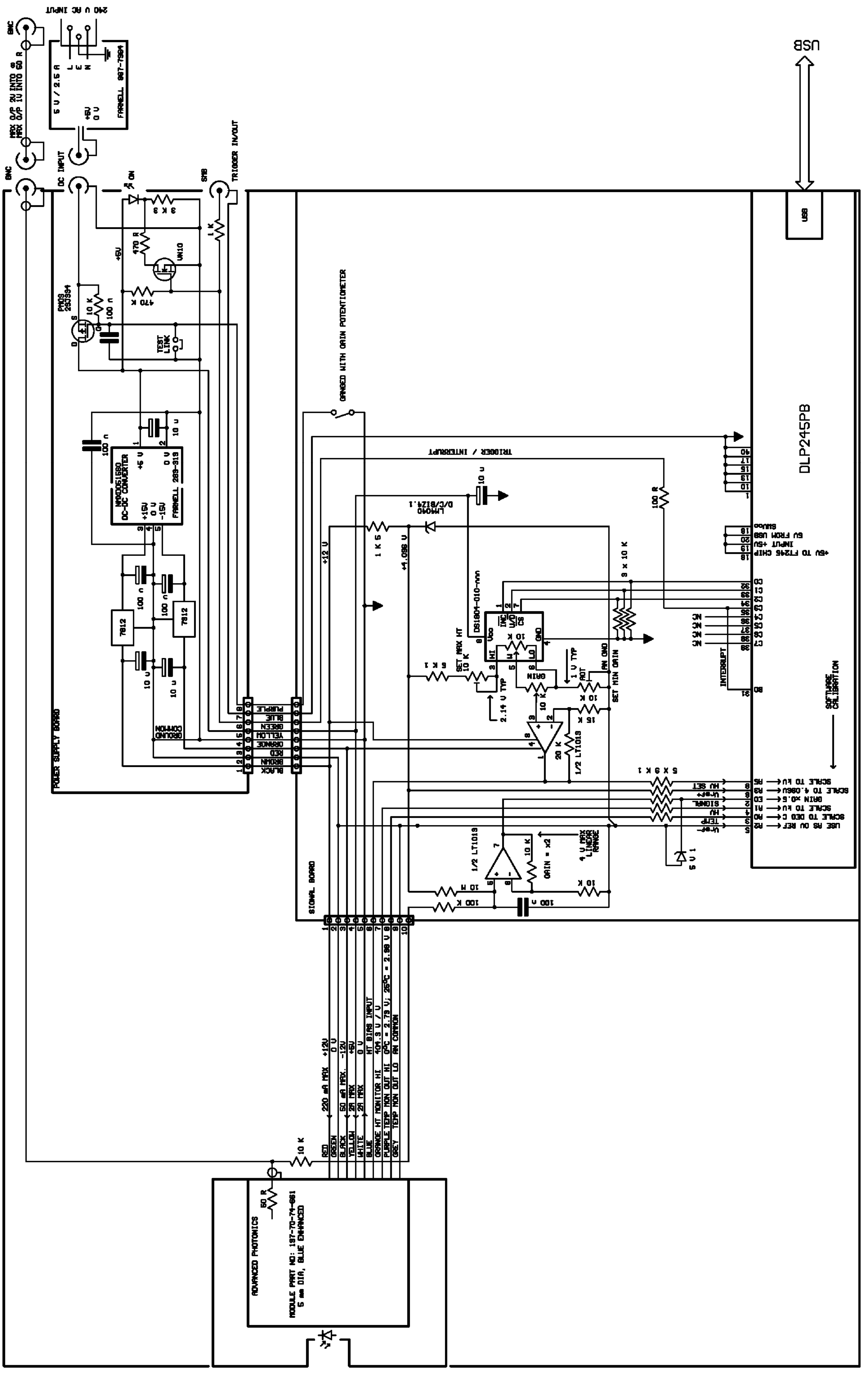


Figure2: Circuit diagram of the APD module.

Data acquisition is performed on six analogue channels: two of these are used to acquire a stable reference voltage (4.096 V) and the ground reference voltage. All other readings are normalized to these values; one channel is dedicated to monitoring the analogue voltage used to set the avalanche diode gain; one is used to monitor the actual gain voltage, one is used to monitor the avalanche diode operating temperature and the last is used to monitor the output signal, i.e. voltage proportional to input light intensity.

These voltages are digitized, and other control functions performed, within a PIC microcontroller, interfaced to a USB transceiver; both of these are contained within a custom module, FTDI DLP245PB. These six sets of readings are acquired over a 20 ms period through sequential digitization of the six channels repetitively every 320 µs: some 62 readings per channel (10 bit nominal resolution) result in six values of near-16 bit resolution being passed to the host PC. High level software delays set the acquisition rate to ~5 Hz. The details of the acquisition timing are shown in Figure 3. A 20 ms sampling period is chosen so as to minimize the 'noise' introduced by 50 Hz (and multiples thereof) optical and electrical signals.

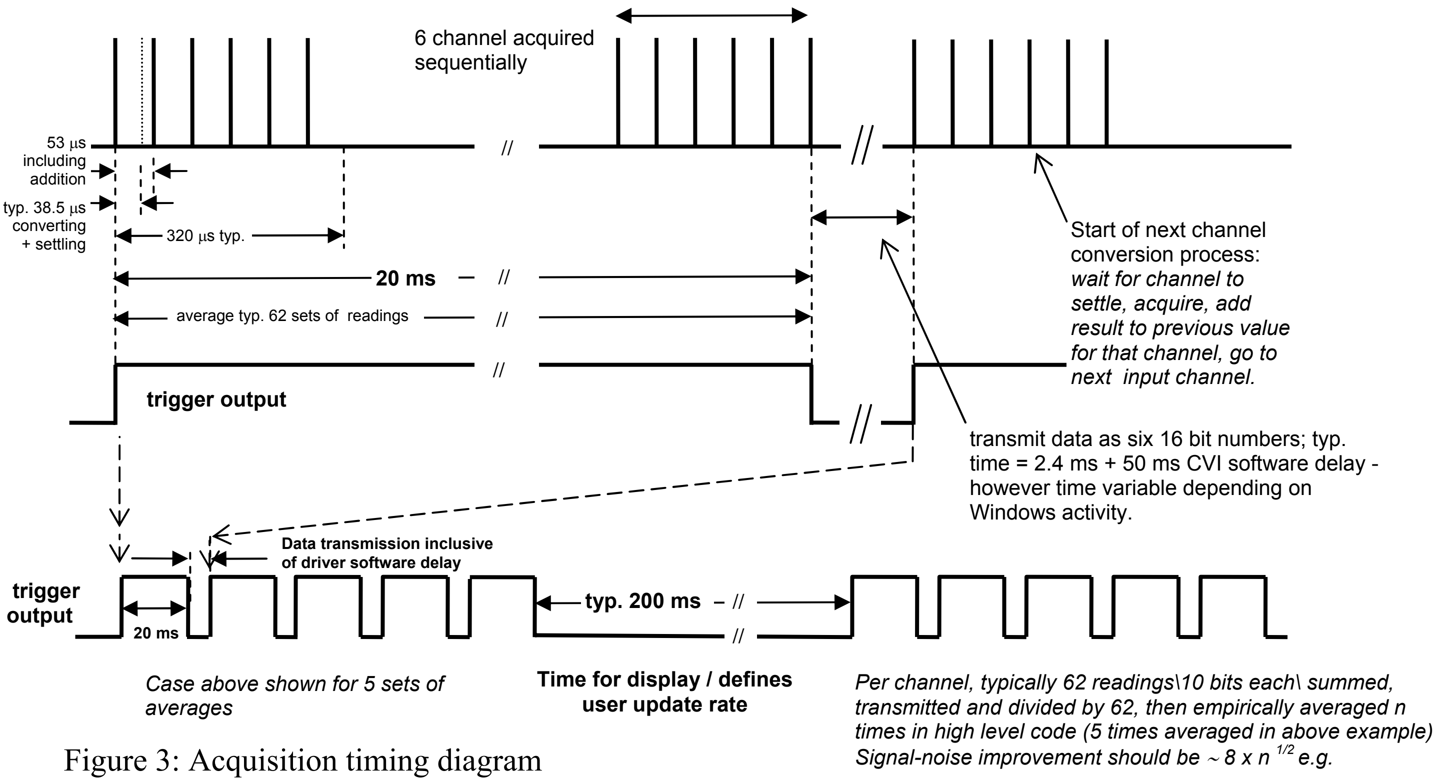


Figure 3: Acquisition timing diagram

The gain of the avalanche diode is determined by an analogue voltage within the range of 0-5 V with a scaling factor of around 404 V/V, i.e. a voltage of 2.5 V results in a detector bias voltage of 1.01 kV. This control voltage is derived from a 100 step 'digipot' which drives the manual gain control potentiometer. The full control range of the digipot is thus obtained with the potentiometer set to maximum and *vice-versa*. At power up, the digipot is set to maximum, while at software start-up the digipot is set to mid-scale.

2. Software

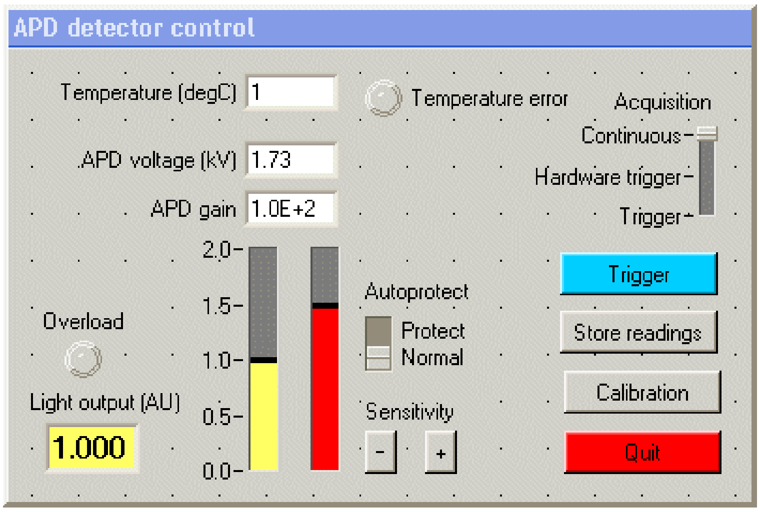
The software is arranged to operate on two GUI's: a main user panel and a calibration factor panel. The latter is password-protected and values preset in that panel should not normally require adjustment. These are sown in Figure 4. The operation is (hopefully) intuitive and the following features are provided: main panel

The main panel has:

- A display of ‘light’ output signal, scaled such that 2.000 V = maximum module output;
- A display of currently-set HT voltage;
- A display of APD gain, calculated from detector data sheet, derived from measured HT voltage;
- A display of APD operating temperature in deg C;
- A warning light which comes on if the APD temperature is outside normal limits;
- A warning light which comes on if the detector output exceeds 2 V;
- A 3-position ‘mode’ control selecting: Continuous, Hardware trigger or Software trigger;
- A software trigger pushbutton control;
- A pushbutton to open the ‘calibration’ GUI;
- A two-position switch for normal or automatic protection control (APC) operation. In normal mode, gain can be adjusted manually; in the APC mode, if the light output reading is greater than a preset APC trip level (set in the calibration GUI), the APD gain is progressively reduced until the reading is some 5% less than the APC trip level. Note that this protected mode of operation only reduces the gain and does not increase it, i.e. it does not function like an automatic gain control arrangement;
- Avalanche photodiode gain setting through up/down controls;
- A bargraph–type display of gain setting, i.e. position of the digipot;
- ‘Store readings’ button: when activated, this stores the current date, time, gain, bias voltage and light output values in a file in ‘.csv’ format. File naming is through a standard file dialogue box and options are provided to either append to the existing file or to start a new file;
- A ‘Quit’ button

The separate ‘calibration panel’ may be called up from the main panel and has:

- A push-button to store the current up-down control setting into digi-pot memory; this setting would then be used at subsequent power-up without software use;
- Controls to set the trip level at which automatic protection control (APC) takes over;
- A control to set the temperature calibration factor;
- A control to set HT voltage calibration factor, typically 404 V output / 1 V input;
- A control to set the temperature tolerance before the error indicator is activated;
- Display of current ‘HT set’ control voltage;
- A control to apply a small zero offset to the displayed output. The internal A/D converters cannot handle a negative input, so a small offset is applied by the hardware circuits: this offset and that of the module are nulled out by this control, which clearly can also compensate for dark current variations within the detector.
- A control to calibrate the signal amplitude, i.e. the GUI-displayed reading, used such that it matches the analogue output voltage available at the BNC connector.
- Two controls to define the non-linear calibration relationship between the applied detector bias/HT voltage and the gain of module: Scaling exponent and HT exponent.
- Display of reference + voltage (ref hi, nominally 4.096 V);
- Display of reference - voltage (ref lo, nominally 0 V);



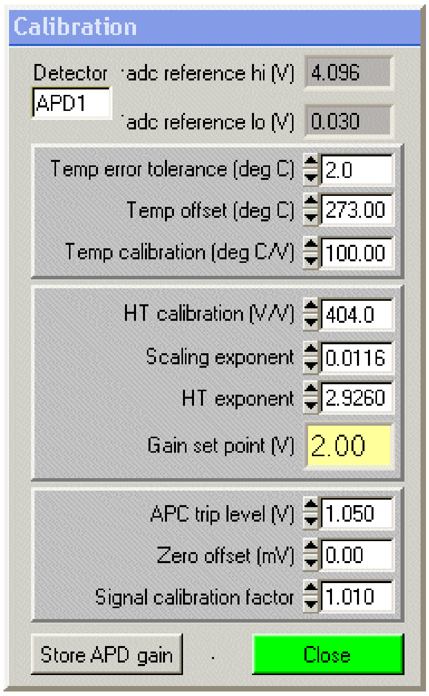


Figure 4: The graphical user interfaces

3. Performance

The performance of the APD detector module is described in detail in the device's data sheet and the reader is encouraged to examine that carefully. Figure 5 shows plots of meased gain vs. applied bais to the avalanche diode. Typical results of response time and noise performance are shown in Figures 6 and 7.

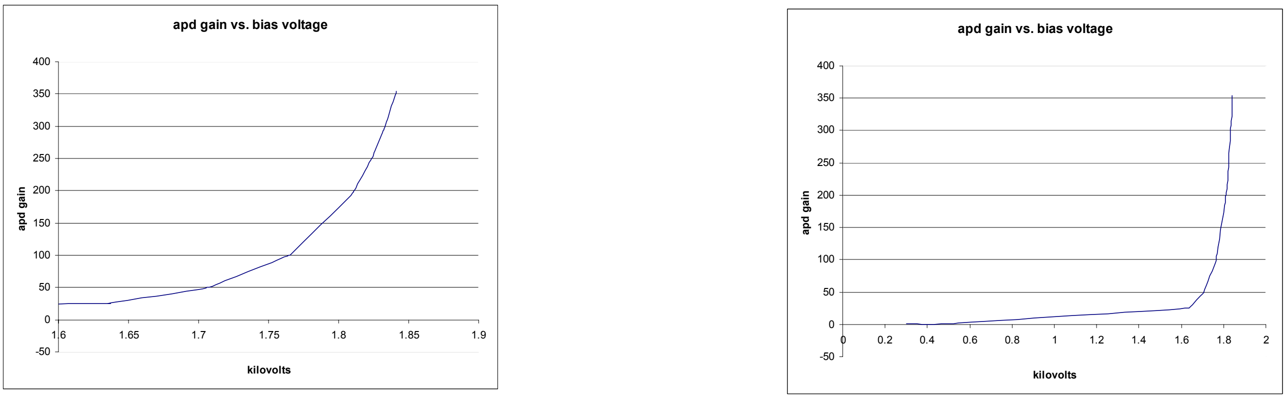


Figure 5: Measured variation of gain as a function of applied bias voltage.

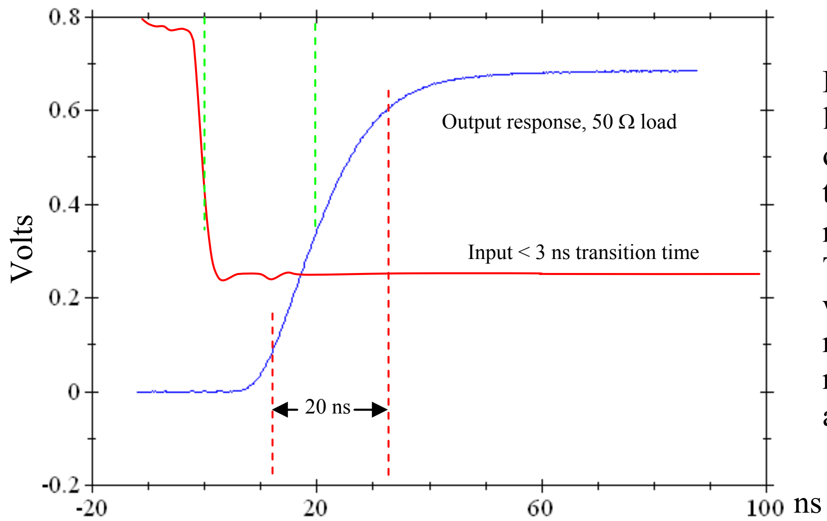
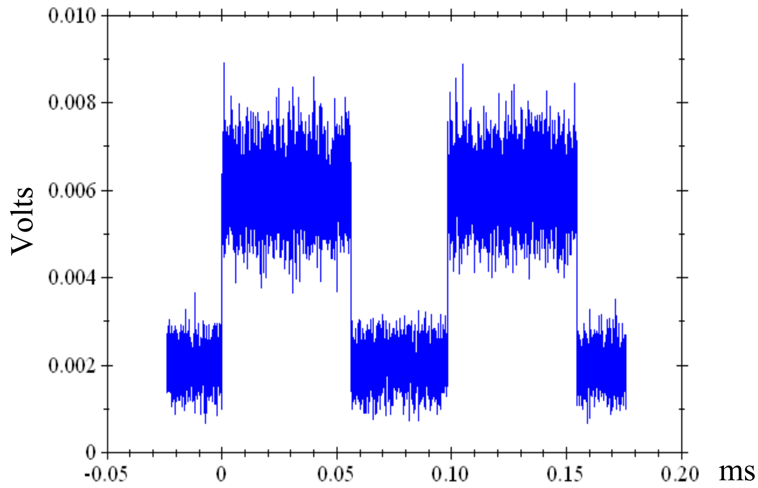


Figure 6: Step response into a matched load; this remains unchanged when operating into an open circuit load, but the output voltage doubles, i.e. the module's source impedance is 50 Ω. The response does not vary appreciably with gain setting. Source and detection risetimes are <<5 ns, so the 20 ns risetime seen is due to module's internal amplifier.

Figure 7: Typical noise performance of the APD module mid-band. The unit's shot noise can be clearly seen above the 1 mV rms Johnson noise. Detection bandwidth = 20 MHz



5. Components

Apart from the usual resistors and capacitors, the active devices, controls and connectors are listed below:

AP Technology		197-70-74-661 blue-enhanced APD module £ 965	
FTDI USB interface		DLP245PB	£ 47.20
Farnell	867-7964	3A-161DB-05 15W 5V/2.5A PSU	£ 12.27
Farnell	283-319	NMXD0515SO DC/DC CONVERTER,	£ 28.24
Farnell	948-6100	LM4040DIZ-4.1	£ 0.53
Farnell	670-870	DS1804-10	£ 2.70
Farnell	958-9740	LT1013CPG4	£ 1.45
Farnell	108-7091	L7812ACV	£ 0.40
Farnell	975-6256	L7912CV	£ 0.45
Farnell	327-2084	2SJ334 PMOS FET	£ 3.51
Farnell	359-9218	'on' LED MV50640..	£ 0.094
Farnell	855-7250	148.SSG56S103SP 10 K switched pot.	£ 7.45
Farnell	320-365	ELMA 020-3520; 14.5 mm control knob ¼"	£ 1.25
Farnell	320-778	ELMA 044-3120; 14.5 mm control knob skirt	£ 0.52
Farnell	320-845	ELMA 040-3020; 14.5 mm control knob cap	£ 0.21
Farnell	583-522	BNC output socket, insulated	£ 1.66
Farnell	224-959	DC power input socket / 2.1 mm	£ 0.443
Farnell	738-906	Heatsink HS MARSTON 47DN-01000-A-200	£ 9.91
Rapid	16-1508	r/a SMB input socket	£ 2.05
Total			**~£ 1090**

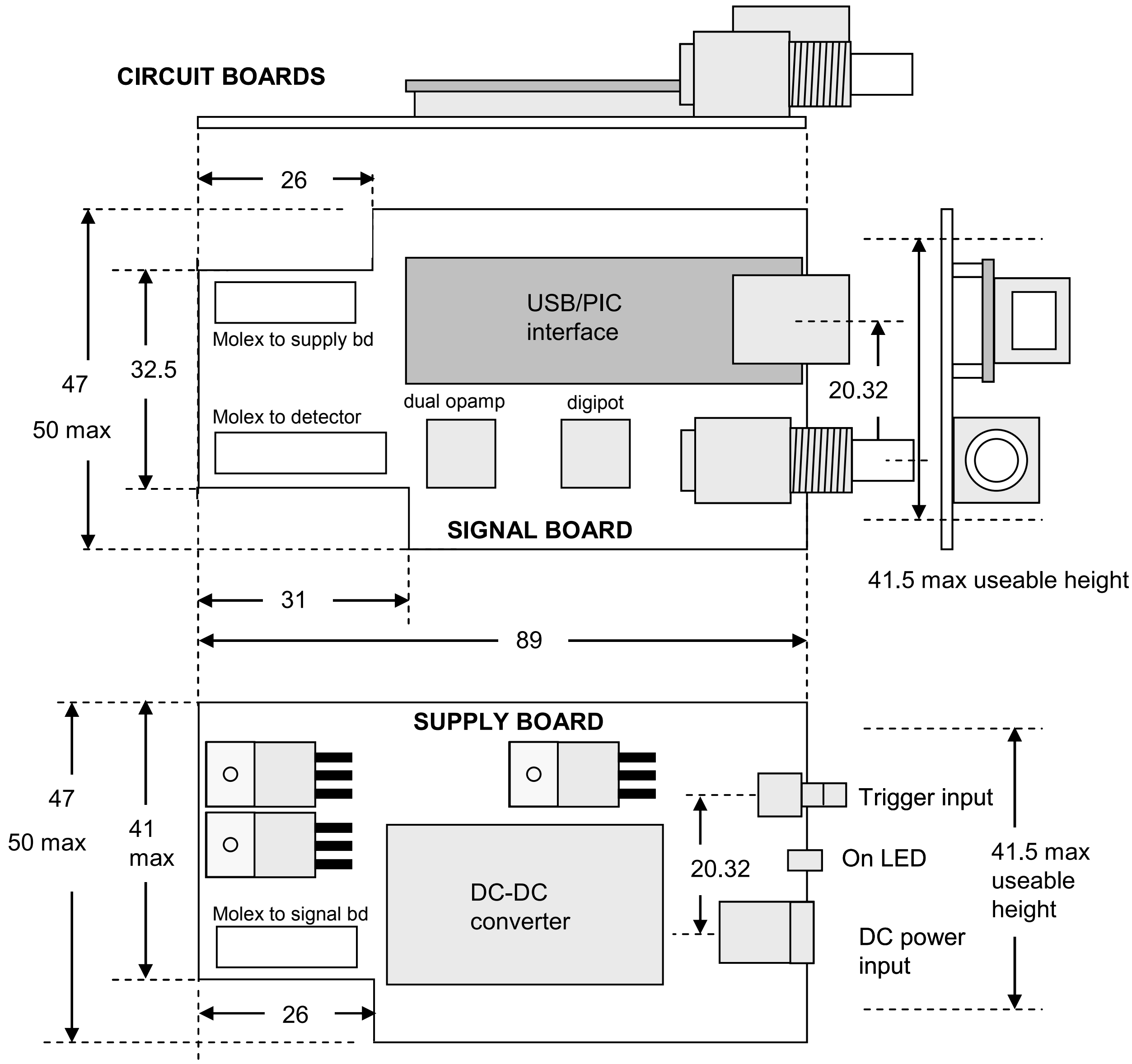
This device was designed partially to evaluate the high field photodiodes and has been found useful when performing kinetic absorption spectrophotometery studies. It's performance is quite respectable, though more modern solid-state devices, such as silicon photonultipliers are poised to provide improved performance and potentially provide much increased active areas. Nevertheless, this approach may be of interest where a highly linear detector is required.

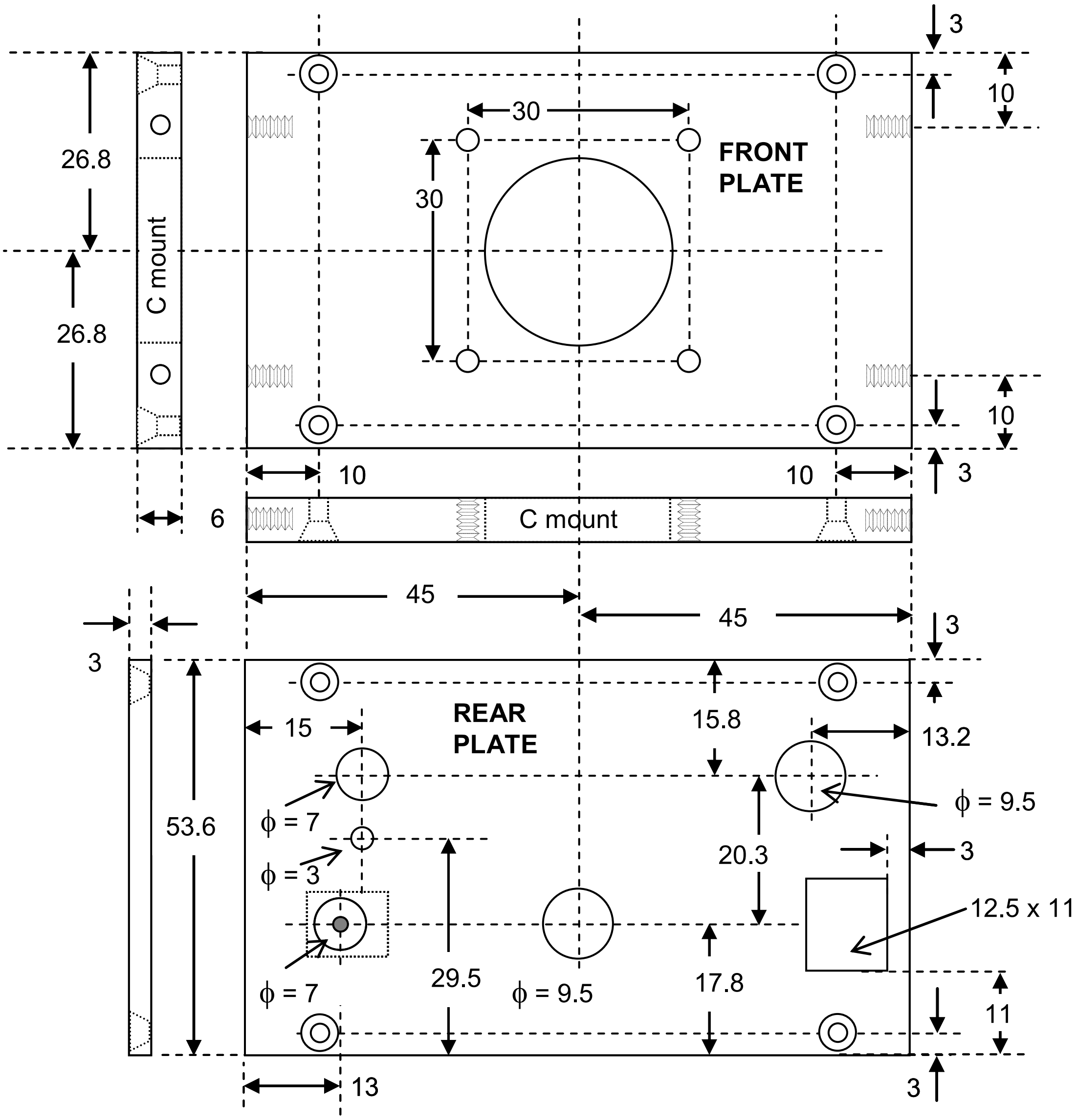
The device was constructed in January 2006 at the Gray Institute, when the Institute was based in Northwood, Middlesex. The note was written by B. Vojnovic and RG Newman, who also performed the construction and developed the software. The note was updated in June 2011.

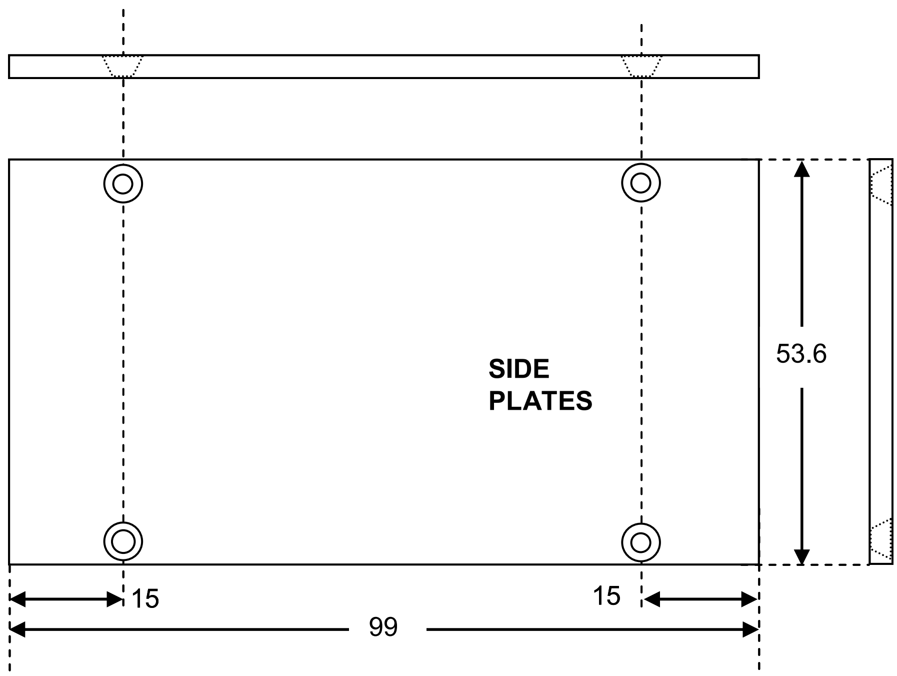
We acknowledge the financial support of Cancer Research UK, the MRC and EPSRC.

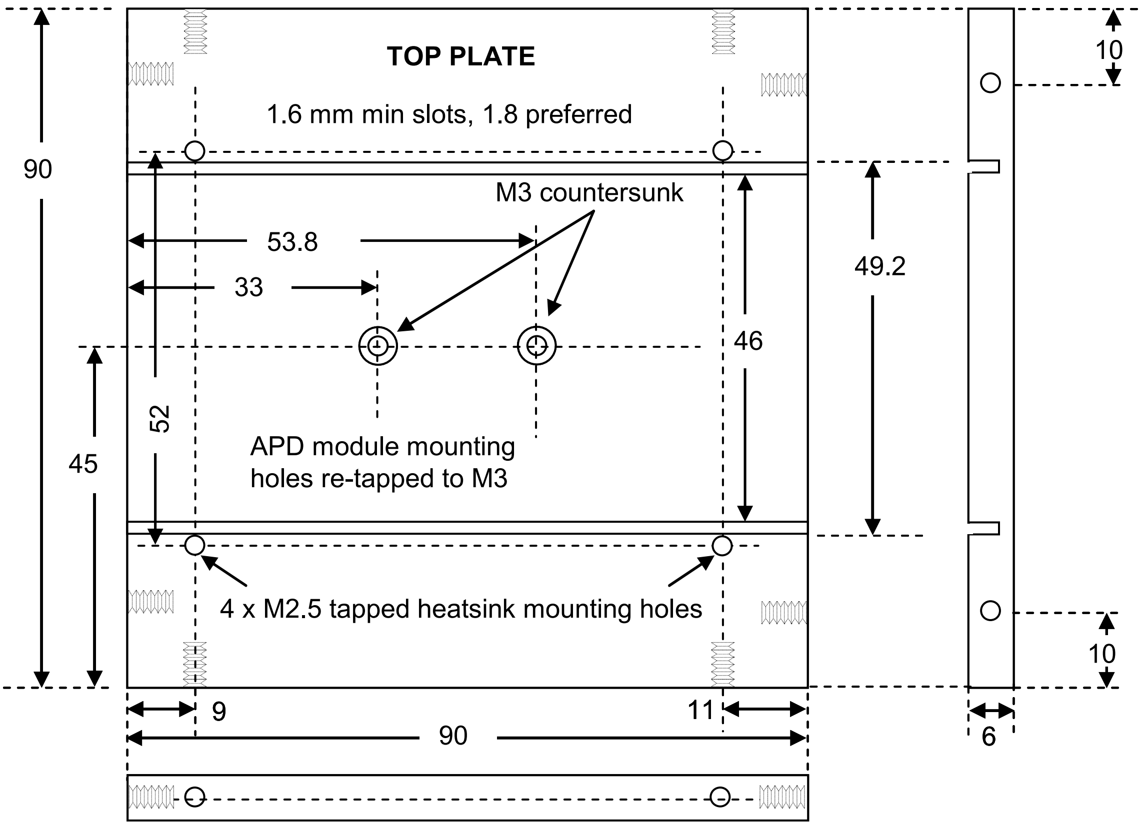
Appendix 1

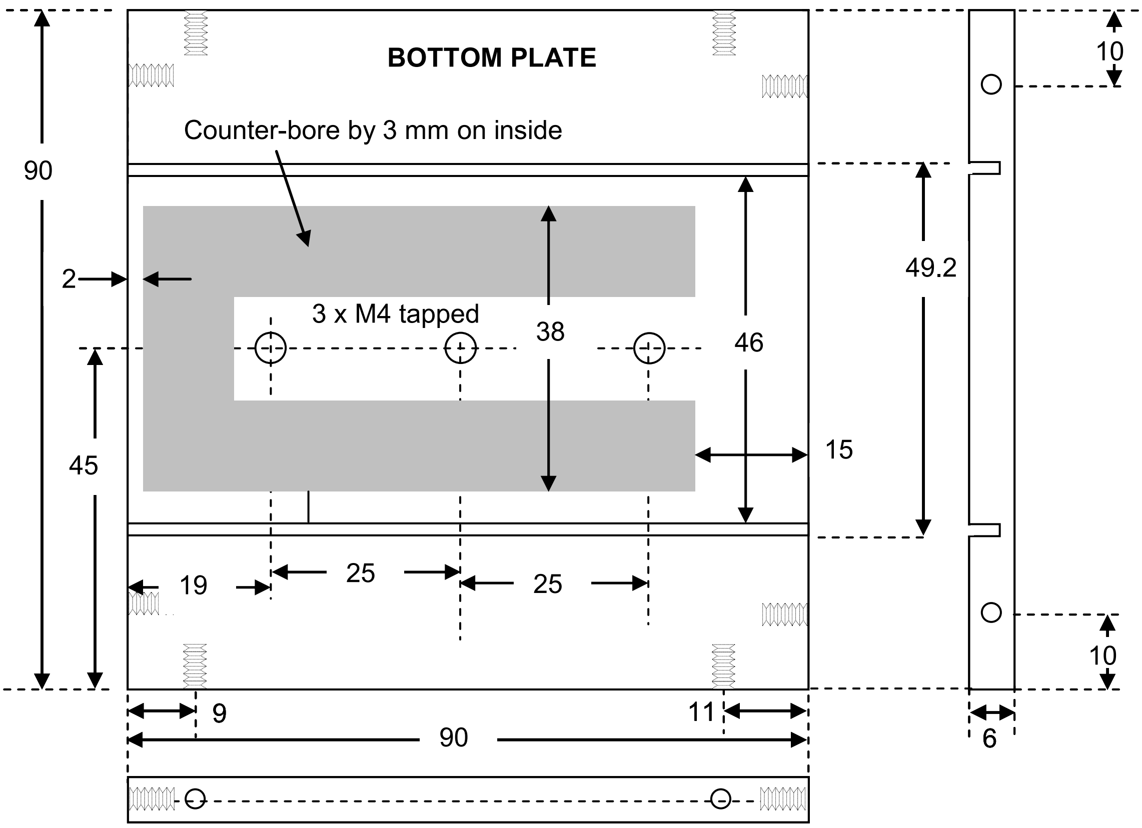
Simplified drawings of the component parts and the overall assembly of the device. Circuit boards slide into the top and bottom slots and are held by the rear panel.

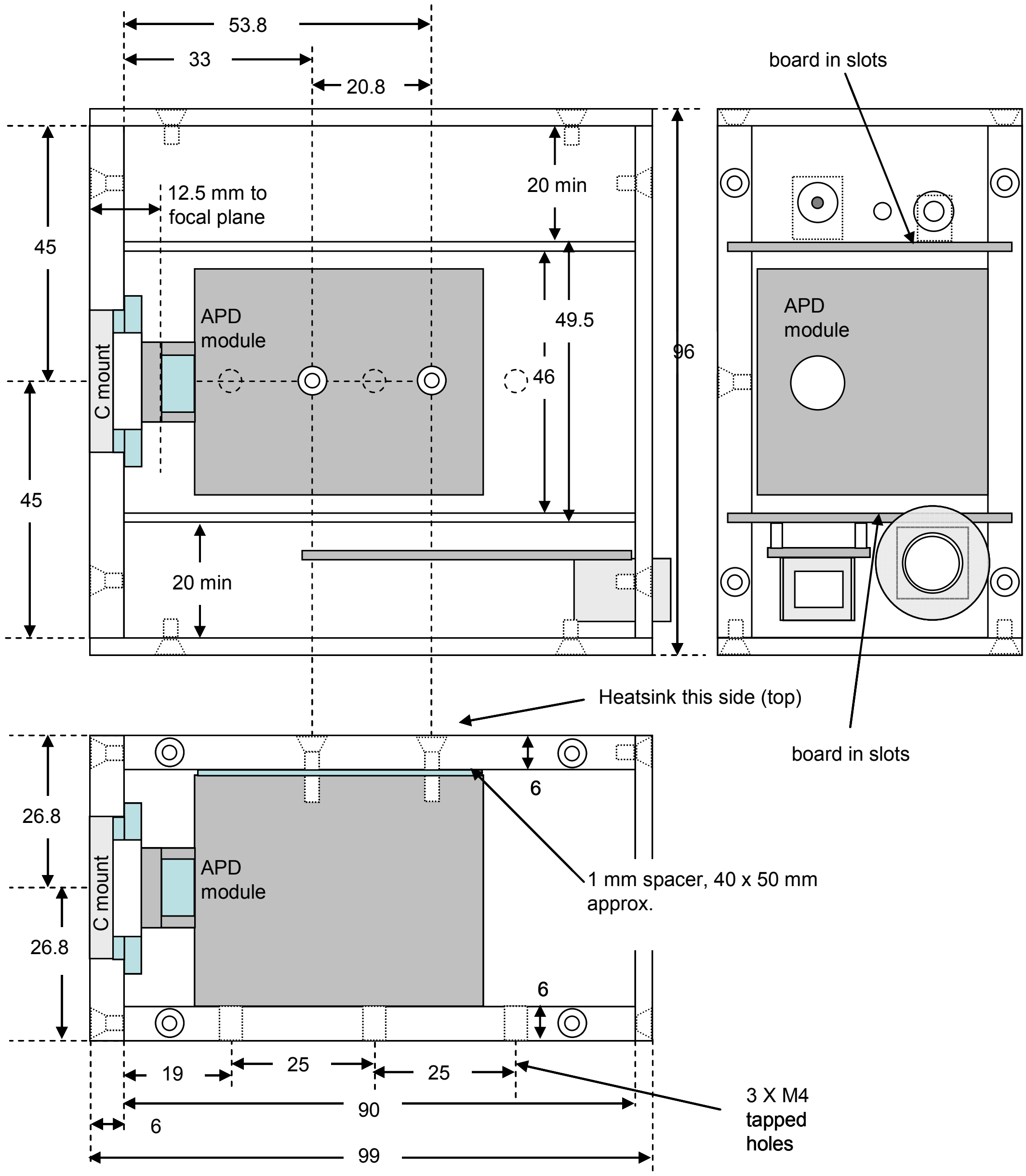



FRONT PLATE
C mount
C mount
26.8
26.8
30
30
10
10
3
3
10
10
6
45
45
3
3
REAR PLATE
53.6
15
15.8
13.2
ϕ = 9.5
ϕ = 7
ϕ = 3
20.3
3
12.5 x 11
ϕ = 7
29.5
ϕ = 9.5
17.8
11
13
3

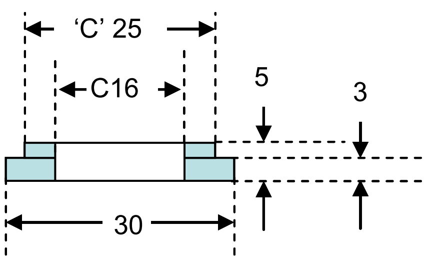

SIDE PLATES
53.6
15
15
99


TOP PLATE
1.6 mm min slots, 1.8 preferred
M3 countersunk
53.8
33
90
52
45
46
49.2
10
APD module mounting
holes re-tapped to M3
4 x M2.5 tapped heatsink mounting holes
9
11
90
6

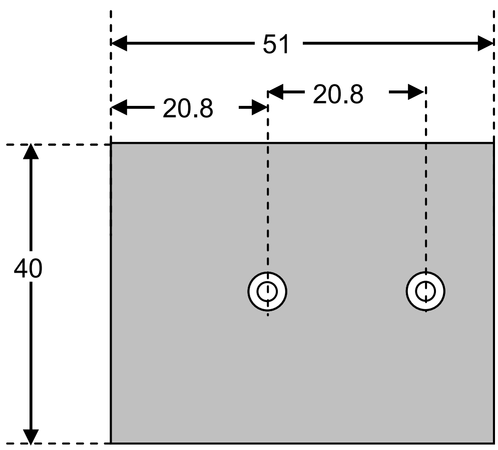

BOTTOM PLATE
Counter-bore by 3 mm on inside
90
2
3 x M4 tapped
38
46
49.2
10
45
15
19
25
25
9
11
90
6



OVERALL ASSEMBLY



LIGHT SHIELD



SPACER PLATE 1 mm thick