Back-Scatter Cloud Probe with Polarization (BCP-POL)

Operator Manual

DOC-0347, Revision A

2545 Central Avenue
Boulder, CO 80301-5727 USA

2545 CENTRAL AVENUE
BOULDER, COLORADO, USA 80301-5727
TEL: +1 (303) 440-5576
FAX: +1 (303) 440-1965
WWW.DROPLETMEASUREMENT.COM

Trademark Information

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Warranty

The seller warrants that the equipment supplied will be free from defects in material and workmanship for a period of one year from the confirmed date of purchase of the original buyer. Service procedures and repairs are warrantied for 90 days. The equipment owner will pay for shipping to DMT, while DMT covers the return shipping expense.

Consumable components, such as tubing, filters, pump diaphragms, and Nafion humidifiers and dehumidifiers are not covered by this warranty.

Laser Safety Information

CAUTION: The requirement for the BCP-POL to be non-intrusive to aircraft operations (i.e., no external components) dictates the absence of a laser beam-stop mechanism. The laser beam will project unimpeded from the optical window. At distances within 5 meters of the probe, the laser beam is not eye-safe, so precautions must be enforced for operation on the bench or ground.

Benchtop operation: The BCP-POL can be safely operated on the bench if certain precautions are followed. The optical block should be secured on the technician's bench and a beam-stop must be secured in such a position that the direct beam or reflections cannot be seen by the operator or others in the room.

Aircraft operation: Operators should wear protective optical glasses, preventing the 658 nm wavelength from passing. This protects against unlikely events such as a wind-borne scrap of aluminum foil reflecting the beam into the cockpit. For operation on an aircraft, it is the responsibility of the system operator or power distribution system to apply 28 VDC power to the BCP-POL only after airborne. The laser beam diverges quickly, and does become eye-safe after 5 meters, so the instrument can safely be operated while airborne. It is also the operator's or power distribution system's responsibility to deactivate the BCP-POL before landing.

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1.0 Product Description

1.1 Introduction

The Back-Scatter Cloud Probe (BCP-POL) measures cloud particle size distributions, which are then used to derive the total number concentrations, liquid water content (LWC), median volume diameter (MVD), and effective diameter (ED). The BCP-POL's non-intrusive optical housing allows use in a range of ground-based or airborne applications with no contamination from ice crystal shattering or airflow distortions.

Droplet Measurement Technologies (DMT) has implemented state-of-the-art electronics and optics, which offer flexibility to the BCP-POL user in a variety of applications. The non-intrusive optical housing allows use in a range of ground-based or airborne applications. This housing contains the laser module, back-scatter optical components, optical heating circuit, photodetector, and analog signal-conditioning circuit. The analog signal is transmitted to the BCP-POL Electronics Processing Module, where it is digitized and processed. Once digitized, particle pulse height is categorized into a selectable 10, 20, 30 or 40-bin histogram[1]. Analog "housekeeping" parameters are combined with the size information and sent in a serial data stream (RS-422) to the data system.

Figure 1: Back-Scatter Cloud Probe

[1] Users must specify the number of bins when order the BCP-POL. 30 bins is standard.

1.2 BCP-POL Specifications

Measurement Technique:	Single-particle light scattering
Data Parameters:	• Particle optical diameter • Particle number concentration • Liquid water content (LWC) • Effective diameter (ED) • Median volume diameter (MVD) • Temperature • Pressure
Size Range:	To be determined
Number Concentration Range:	0 - 1,000 cm^{-3}
Air Speed Range:	10 - 250 ms^{-1}
Number of Size Bins:	10, 20, 30 or 40 (configured at time of purchase; 30 is standard)
Sampling Frequency:	Selectable, 0.04 sec to 20 sec
Light Collection Angles:	Center-line: 155°, +/- 18.5°
Laser Wavelength:	658 nm
Laser Power:	85mW or less
Data System Interface:	RS-422 serial interface
Additional components:	Electronics box, 1 m connecting cable
Calibration:	Glass beads
Routine Maintenance:	Optics cleaning before every field campaign
Recommended Service:	Annual cleaning and calibration at DMT service facility
Software:	Optional Particle Analysis and Display System (PADS) software
Temp:	-40 to +40 °C. Note: the laser will automatically shut down above +45 °C, preserving laser life-time.
Altitude:	0 - 50,000 feet
Humidity:	0 - 100%
Weight:	1.5kg

1.3

Physical Specifications

Weight:	1.5 kg
Probe Dimensions:	14.7 cm x 13.3 cm x 5.1 cm, with 5.9 cm diameter mounting flange
Electronics Box Dimensions:	21.7 cm x 12 cm x 8.2 cm

1.4 Electrical Specifications

Power Requirements:	28 VDC, 5 A for system and heaters

CAUTION: The requirement for the BCP-POL to be non-intrusive to aircraft operations (i.e., no external components) dictates the absence of a laser beam-stop mechanism. The laser beam will project unimpeded from the optical window. The laser is not eye-safe, so precautions must be enforced for operation on the bench or ground.

1.5 Summary of BCP-POL Electronic and Software Features

- Classification of particle optical diameter in histogram form.
- Size distributions accumulated in the probe, with serial transmission to any standard computer communications port (RS-422).
- Monitoring of multiple variables, e.g. total particles, average transit time, over-range particles, and various probe health indicators. See section **Error! Reference source not found.** for conversion equations for analog-to-digital channels.
- User-programmable sample rates and bin thresholds.
- Zero dead-time losses.
- Dynamic threshold feature (see section 3.0**Error! Reference source not found.**)

2.0 Theory of Operation

Particles passing through the laser beam scatter light in all directions, but only light within a cone subtending angles between 136.5° and 173.5° is collected and directed onto a slit that defines a region within the laser beam where particles are measured and counted. Light passing through the slit continues through a polarizing beam splitter. The P polarized component is directed to one photo-detector and the S polarized component to the other photo-detector (see Figure 2). The photo-detector converts the photons scattered by each particle into an electrical pulse. These electrical pulses are then transmitted to a signal processor, which amplifies and digitizes them.

A spherical particle will scatter predominantly P polarized light—i.e., light with the same plane of polarization as the incident light. Non-spherical or crystalline particles will scatter less P polarized light and more S polarized light, which is light with a plane of polarization perpendicular to the incident light polarization. The P polarization signal is used to generate a size distribution that relates number concentration to each particle's optical diameter. This data is accumulated at programmable time intervals and stored along with information that monitors the data quality and health of the system.

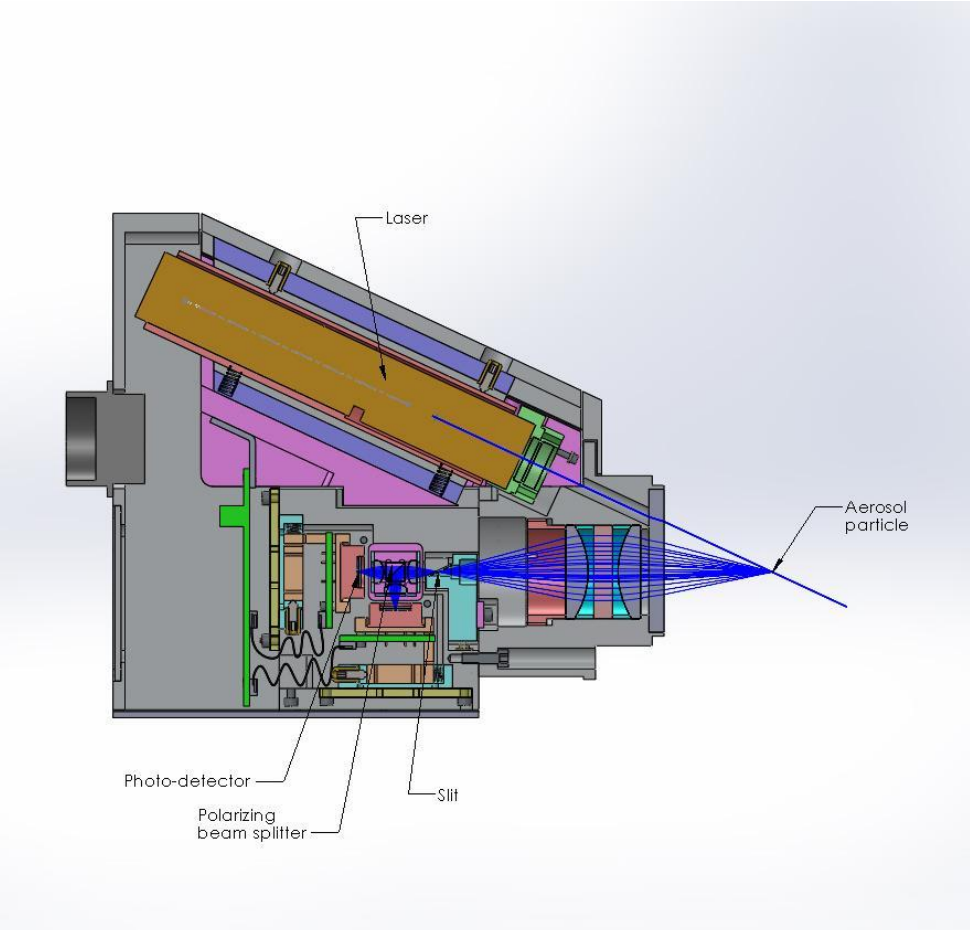

Figure 2: Back-Scatter Cloud Probe Optical Path

3.0 Dynamic Threshold Feature

The BCP-POL's dynamic threshold feature automatically adjusts the instrument's S and P polarization signals to account for drifts due to temperature changes.

The dynamic threshold feature works as follows. The instrument's S and P Detector voltages are digitized with a 12-bit ADC, which yields a value between 0 and 4095. A histogram is created of all counts between 0 and 512. (Signals above 512 are assumed to be responses to particles, and thus not relevant to establishing the baseline.) The system then identifies the narrowest band that contains at least 75% of counts in the histogram. This band, referred to as the "noise band," is the system's attempt to identify a range for baseline noise when no particles are present.

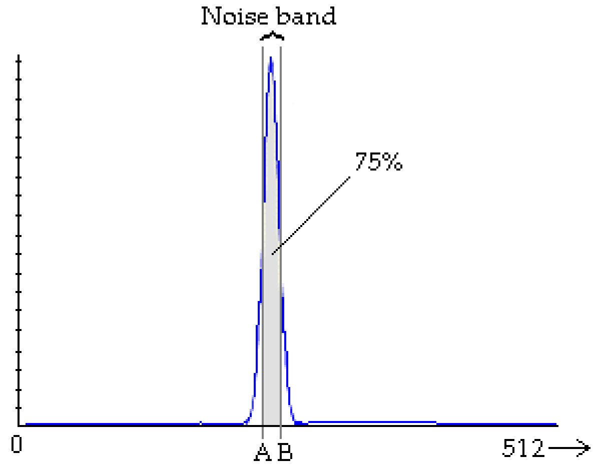

Figure 3: Identifying a Noise Band

If the noise band exceeds 20 counts (i.e., the width is too wide), or if no noise band was identified, the previous noise band is used. These qualifications are imposed in order to distinguish the noise from actual particle events. The instrument then uses the noise band to adjust the sizer baseline and identify particles. The noise band updates at a rate of 10 Hz.

There are four BCP-POL output channels related to dynamic thresholding. For the S Detector signal, **S Noise Bandwidth** is the width of the noise band—that is, [B – A] in Figure 4. **S Baseline Threshold** is the upper boundary of the noise band, i.e. B in Figure 4. Both of these channels are given in digital counts. **P Noise Bandwidth** and **P Baseline Threshold** are the corresponding channels for the P detector.

4.0 Bench-top Testing

4.1 Bench-top test and Calibration Confirmation

CAUTION: The BCP-POL can be safely operated on the bench if certain precautions are followed. The requirement for the BCP-POL to be non-intrusive to aircraft operations (i.e., no external components) dictates that there not be a laser beam-stop mechanism. The laser beam will project unimpeded from the optical window. The laser is not eye-safe, so precautions must be enforced for operation on the bench or ground. The optical block should be secured on the technician's bench and a beam-stop must be secured in such a position that the direct beam or reflections cannot be seen by the operator or others in the room. Operators should wear protective optical glasses, preventing the 658 nm wavelength from passing. In addition, the operator should be trained in safe handling of class IIIB lasers. The work space should be isolated from other people who are not also wearing such protective glasses and are not similarly trained.

Operation can be verified by using a can of "Freeze Mist," commonly available at electronic supply stores. Direct the mist through the laser beam at a point directly above the collection optics, about 4-5 cm from the sapphire window. Calibration with precision glass beads is performed at DMT's facility, as the company maintains a bead-dispenser fixture to ensure correct placement of particles in the beam.

Standard BCP-POL serial communication is configured for RS-422.

The BCP-POL will communicate with the PADS software package supplied with the BCP-POL. Review the PADS manual for details.

The BCP-POL heater circuits are temperature controlled and can be activated on the ground. The optics block heater and the electronic heaters are set for 20ºC.

5.0 Aircraft Operation

For operation on an aircraft, it is the responsibility of the system operator or power distribution system to apply 28 VDC power to the BCP-POL only after airborne. The laser beam diverges quickly, and does become eye-safe after just several meters, so the instrument can safely be operated while airborne. It is also the operator's or power distribution system's responsibility to deactivate the BCP-POL before landing. DMT is not liable for misuse of the BCP-POL.

The Optics Cap (MP-3413), shown on the left in Figure 4, is mounted to the inside of the aircraft skin. The BCP-POL Optics Block is then attached to the Optics Cap and secured via 4 post and nylon lock-nuts. The posts have M-4 threads. If the aircraft needs to be flown while the BCP-POL Optics Block is away for maintenance, the Blanking Cap can be installed to allow the aircraft to remain pressure-tight. The blanking cap, (MP-2363-A), is on the right in Figure 4.

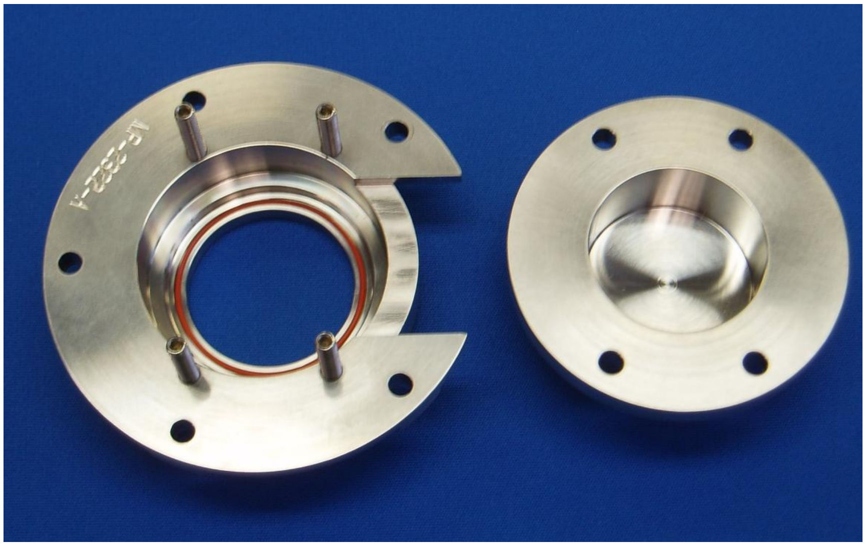

Figure 4: BCP-POL Optics Cap (left) and Blanking Cap (right)

6.0 Particle Analysis and Display System (PADS)

DMT's Particle Analysis and Display Software (PADS, shown in **Error! Reference source not found.**) can be purchased with the BCP-POL, allowing any computer with an available serial port to act as the data logger. The PADS program needs Windows 2000, Windows 7 or Windows XP for successful operation (see the PADS manual for operating instructions). *The BCP-POL does not work with DMT's older PACS software*.

PADS allows the user to do the following tasks, among others:

- Start data recording and sampling
- View a size histogram of particles measured by the BCP-POL
- View particle volume and number concentrations, as well as Liquid Water Content (LWC), Median Volume Diameter (MVD) and Effective Diameter (ED)
- Monitor instrument operational parameters like optic block temperature, electronic box temperature, and the baseline monitor voltage

7.0 Routine Maintenance

The Back-Scatter Cloud Probe is environmentally sealed and is water resistant, ***but not waterproof***.

The optical path is protected with a fused silica window. It can be seen through the water trough port. Water residue can cause contamination on the windows and this contamination will distort or attenuate the amount of scattered light collected from a particular particle.

To clean the sapphire window, follow accepted optical cleaning techniques:

- Use white vinegar on a Q-tip to remove water spots on the exposed sapphire window, then use alcohol or acetone for final cleaning procedures. Use the Q-tip for only one swipe of the window. Do not clean with a continued circular motion as that may cause scratches on the window.
- If the aircraft is "de-iced" before takeoff, the chemical residue may end up on the sapphire window and prevent correct operation during the flight. The window will need to be protected or cleaned before operation will be restored.

8.0 Communications between the PC and BCP-POL Firmware

Any computer capable of communications over an RS-422 port should be capable of communicating with the BCP-POL. The port parameters for communications should be set to the Baud rate specified in PADS, 8 data bits, and one stop bit with no parity checking. Since binary data are sent across the interface it is possible that some systems will react to the non-ASCII characters that are sent as control characters. It is recommended that all communications with the BCP-POL electronics be programmed at a low level to avoid this problem.

The host computer initiates all communications with the firmware electronics. There are several commands that the firmware responds to, which are listed in the table below. Each command is preceded by an ESC character ("1B").The command number (e.g., "01") follows.

1B01	Initialize
1B02	get normal data, no PbP and no Raw PbP[2]
1B03	get normal data and PbP data
1B04	get normal data and PbP data and Raw PbP data
1B05	get firmware version

The firmware only responds with data after it has received a request for data, so all of the timing for data acquisition needs to be performed in the host processor. To increase the data rate from the probe, the host only needs to increase the rate at which it makes

[2] For descriptions of PbP (particle-by-particle) and raw PbP data, see sections 8.3.2 and 8.3.3.

requests for data. After filing a data request, the firmware clears all of its summation and starts taking a new set of data.

8.1 SETUP DATA ACQUISITION PARAMETERS COMMAND

The table below shows the format of the packet PADS sends to the firmware to set up the data acquisition parameters. These parameters will remain until power is cycled or a new setup data acquisition parameters command is sent.

Start Byte	Length in Bytes	Parameter Name
0	2	ESC and command number (1B01)
2	2	ADC Lower Thresh
4	2	# of PbP packets
6	2	Channel Count
8	2	# of bytes of raw data per channel
10	2	Spare
12	2	Spare
14	80	Thresholds (40 bins)
94	2	Checksum

For command number 01 (setup data acquisition parameters) the probe responds with two ACK characters (ASCII character 6).

8.2 SEND DATA (POLL REQUEST) COMMAND

PADS sends the firmware one of the following commands to get data:

1B02 get normal data, no PbP and no Raw PbP
1B03 get normal data and PbP data
1B04 get normal data and PbP data and Raw PbP data

8.3 Response to SEND DATA COMMAND

After the BCP-POL receives a Send Data request, it responds with the data packet below. Note that the data in italics is only sent if it was requested. PbP data is sent in the event of a 03 or 04 command, while raw data is only sent with an 04 command. The total length of this packet depends on the number of PBP particles recorded.

The first 16 channels in the data packet are analog-to-digital signals that must be converted by the data system (e.g., PADS) into meaningful numbers. The data arrive in hex format. PADS or another data system must then use a scaling algorithm specified within the program to yield valid results. See Table 2 for scaling equations.

Start Byte	# of Bytes	Name
0	2	HK 1
2	2	HK 2
4	2	HK 3
6	2	HK 4
8	2	HK 5 / P APD Voltage (V)
10	2	HK 6 / P APD Temp (C)
12	2	HK 7 / +5V Monitor
14	2	HK 8 / Board Temp (C)
16	2	HK 9 / S APD Voltage (V)
18	2	HK 10 / S APD Temp (C)
20	2	HK 11
22	2	HK 12
24	2	HK 13
26	2	HK 14
28	2	HK 15
30	2	HK 16
32	4	unused
36	2	unused
38	2	S Noise Bandwidth
40	2	S Baseline Threshold
42	2	P Noise Bandwidth
44	2	P Baseline Threshold
46	4	Oversize Reject
50	120	Histogram/Bin Data (4 bytes per bin, 30 bins)
170	6	Timer response header
176	*	*PbP Data (12 bytes per PBP particle)*
*	*2080*	*Raw Data*
*	2	CheckSum

* These numbers depend on the amount of PbP data sent.

Table 1: Data Packet BCP-POL sends to Host Computer in Response to Send Data Command

8.3.1 Definitions of the *Send Data* Response Parameters

Table 2 provides definition for the channels in the BCP-POL data packet. For housekeeping channels, shaded in gray, the appropriate conversion equation is also provided. This conversion equation allows the user to calculate meaningful values (i.e., values in volts or degrees Celsius) from the original analog reading, *x*.

Channel	***Definition***	***Conversion Equation***
Housekeeping [1-16]	An array which holds the most recent Analog-to-Digital conversion values for the 16 analog house-keeping channels.	Varies
P APD Voltage (V)	The voltage at the P-Detector's avalanche photodiode. This voltage will be between 100V and 200V and should stay stable ±2V.	$0.06105x$
P APD Temp (C)	The temperature at the P-Detector's avalanche photodiode. This temperature should be approximately 25 ºC and stay stable ±3 ºC.	$72.815 - 0.048325x + (1.4967 * 10^{-5})x^2 – (2.2627 * 10^{-9})x^3 + (1.2632 * 10\text{-}^{13})x^4$
+5V Monitor (V)	The power 5V reference for the control system, which should be 5V +/- 0.3V.	$0.002442x$
Board Temp (C)	The temperature of the digital board. This temperature will generally be higher than ambient temperature, since the board is enclosed in the instrument.	$158.029 - 0.0519x$
S APD Voltage (V)	The voltage at the S-Detector's avalanche photodiode. This voltage will be between 100V and 200V and should stay stable ±2V.	$0.06105x$
S APD Temp (C)	The temperature at the S-Detector's avalanche photodiode. This temperature should be approximately 25 ºC and stay stable ±3 ºC.	$72.815 - 0.048325x + (1.4967 * 10^{-5})x^2 – (2.2627 * 10^{-9})x^3 + (1.2632 * 10\text{-}^{13})x^4$
S Noise Bandwidth	The width of the S detector's noise band in digital counts. See section 3.0 for more information.	
S Baseline Threshold	The upper boundary of the S detector's noise band in digital counts. See section 3.0 for more information.	
P Noise Bandwidth	The width of the P detector's noise band in digital counts. See section 3.0 for more information.	
P Baseline Threshold	The upper boundary of the P detector's noise band in digital counts. See section 3.0 for more information.	
Oversize Reject	A counter for how many times that the Analog to Digital Converter was at its maximum digitized count (4096). These particles are not processed into the calculated parameters and only reported as "over-range particles".	

Bin Counts	An array which holds the digital thresholds for the different peak size channels which are defined in the Setup command.
Checksum	The 16-bit sum of the characters in the packet.

Table 2: Definitions and Conversion Equations for Channels in the BCP-POL Data Packet

8.3.2 PBP Data

Fourteen bytes of PBP data are sent for each PBP particle. These bytes break down as follows, with each datum taking up two bytes:

- S arrival time in one-microsecond resolution
- S peak (0 to 4095)
- P peak (0 to 4095)
- S transit time (full width of half max)
- P transit time (full width of half max)
- S peak address (0 to 511)
- P peak address (0 to 511)

8.3.3 Raw Data

The BCP-POL electronics capture one raw waveform of S and P during each sampling period. The sample resolution is 25 nanoseconds, and each sample is 12 bits (0 – 4095 counts). The S and P samples are concatenated to give 24 bits, or 3 bytes. There are 512 samples of interweaved S and P samples sent to PADS. The total sample size is thus 512 * 3 = 1536 bytes.

The two waveforms can be displayed in PADS. See Figure 5. The ideal waveform will look like a Gaussian curve.

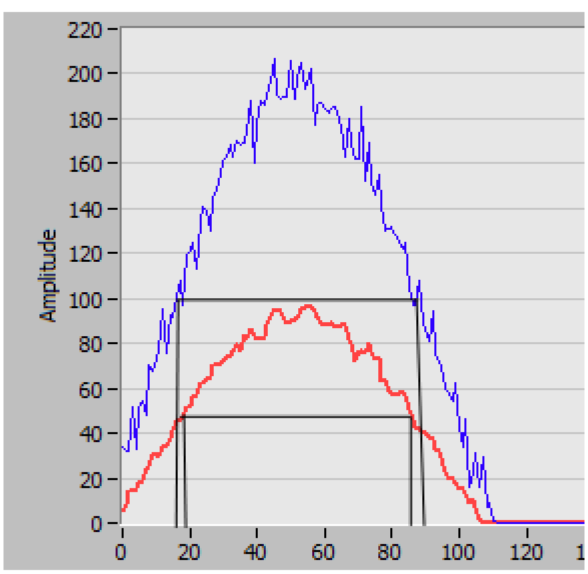

Figure 5: Example Raw Data Plot of the S Polarization (top) and P Polarization (bottom)

9.0 BCP-POL Part Numbers

- The BCP-POL optics block, electronics module, interconnecting cable and power-in/signal-out cable have been assigned an assembly P/N 000214D010000-01.
- The Optics Cap is P/N MP-3413.
- The Blanking Cap is P/N MP-2363-A.

Appendix A: Revisions to Manual

Rev. Date	Rev No.	Summary	Section
11-5-12	A	Updated BCP to reflect polarization component	Throughout