TELEMARK SAINTECH
Ion Beam
Systems

ION CURRENT DENSITY MONITOR

INSTALLATION AND OPERATION MANUAL

This manual covers the Installation, Operation and Maintenance of the Telemark/Saintech Ion Current Density Monitor.

Telemark/Saintech Ion Beam Systems are protected by US Patent Nos. 6645301, 6734434 and 6849854. Other patents Pending.

July, 2013

www.telemark.com

TABLE OF CONTENTS

WARRANTY

Telemark warrants the company's products to be free of functional defects in material workmanship for a period of twelve (12) months from date of first delivery.

The abovementioned warranty is conditional upon the product being installed and operated in accordance with instructions provided by Telemark.

This warranty is in lieu of all other warranties, expressed or implied and constitutes fulfillment of Telemark's liabilities to the purchaser. Telemark does not warrant the product for use in applications other than that implied by the product specifications.

USER RESPONSIBILITY

The user is responsible for proper operation and ordinary maintenance of the equipment following procedures described in this manual including reference documents. Proper operation includes timely replacement of parts that are missing, broken, or plainly worn. If the user has a reasonable doubt about understanding the use or installation of a component, Telemark or your local representative should be called.

It is vitally important that the user properly install the equipment as described in this manual, with particular attention to the correct grounding methods described.

The Warranty will be void if the equipment is improperly installed and/or grounded.

EXPLANATION OF COMMENTS

Throughout this manual there will be various Cautions, Warnings and Recommendations. These are intended to draw the attention of the operator to potential hazards to personnel and equipment and to provide assistance with the general operation of the system.

WARNING

Warnings are used whenever there is risk of injury to operators or personnel who may be servicing equipment and should ALWAYS be observed.

CAUTION

Cautions are used wherever operational procedures could result in damage to equipment and should be observed.

RECOMMENDATION

Recommendations are provided as suggestions for operational or setup procedures only. A reason for the recommendation will often be provided to assist with decision making

1

SYSTEM OVERVIEW

The Telemark/Saintech Ion Current Density Monitor is designed to measure the ion current flux from ion sources such as the Telemark/Saintech grid-less ion sources, cold-cathode ion sources, anode layer ion sources or Kaufman gridded type ion sources. The system comprises a sensor head that provides a current signal to a monitoring unit. The sensor head is mounted in the vacuum chamber and measures the ion current deposited across the sensor element by positively charged ions entering the sensor head through an aperture pointed in the general direction of the ion source. The monitoring unit, situated outside of the vacuum chamber displays an amplified RMS signal on an LCD digital panel meter. A rear panel mounted subminiature-D type connector provides various output signals. A front panel mounted BNC connector provides a signal suitable for display on an oscilloscope or similar display device.

The Sensor Head

The Sensor Head is specially designed for use in harsh coating environments to maintain constant current monitoring capacity despite the accumulation of dielectric coatings onto the Sensor Element. The sensor head is mounted downstream of the ion source to provide an accurate measure of the ion current density incident on the deposition substrates. A stainless-steel shielded Type-K Thermocouple Cable connects the sensor head to a coaxial electrical feed-through for transmitting the ion current signal.

Monitoring Unit

The Monitoring Unit contains a charged amplifier circuit that converts an input current to an output voltage. Two sensitivity ranges are provided:

20µA / volt : maximum 200 µA

200µA / volt : maximum 2 mA

RMS values of the measured current are displayed on the front of the Monitoring Unit. For more comprehensive analysis of the current characteristics of the ion beam, the BNC connector on the front panel can be coupled to an oscilloscope or other diagnostic instrument. (e.g. LabVIEW environments.)

A 16 character 4 line LCD display shows the relevant data.

The negative Bias Voltage is shown at the top left of the display to an accuracy of 0.1 volts.

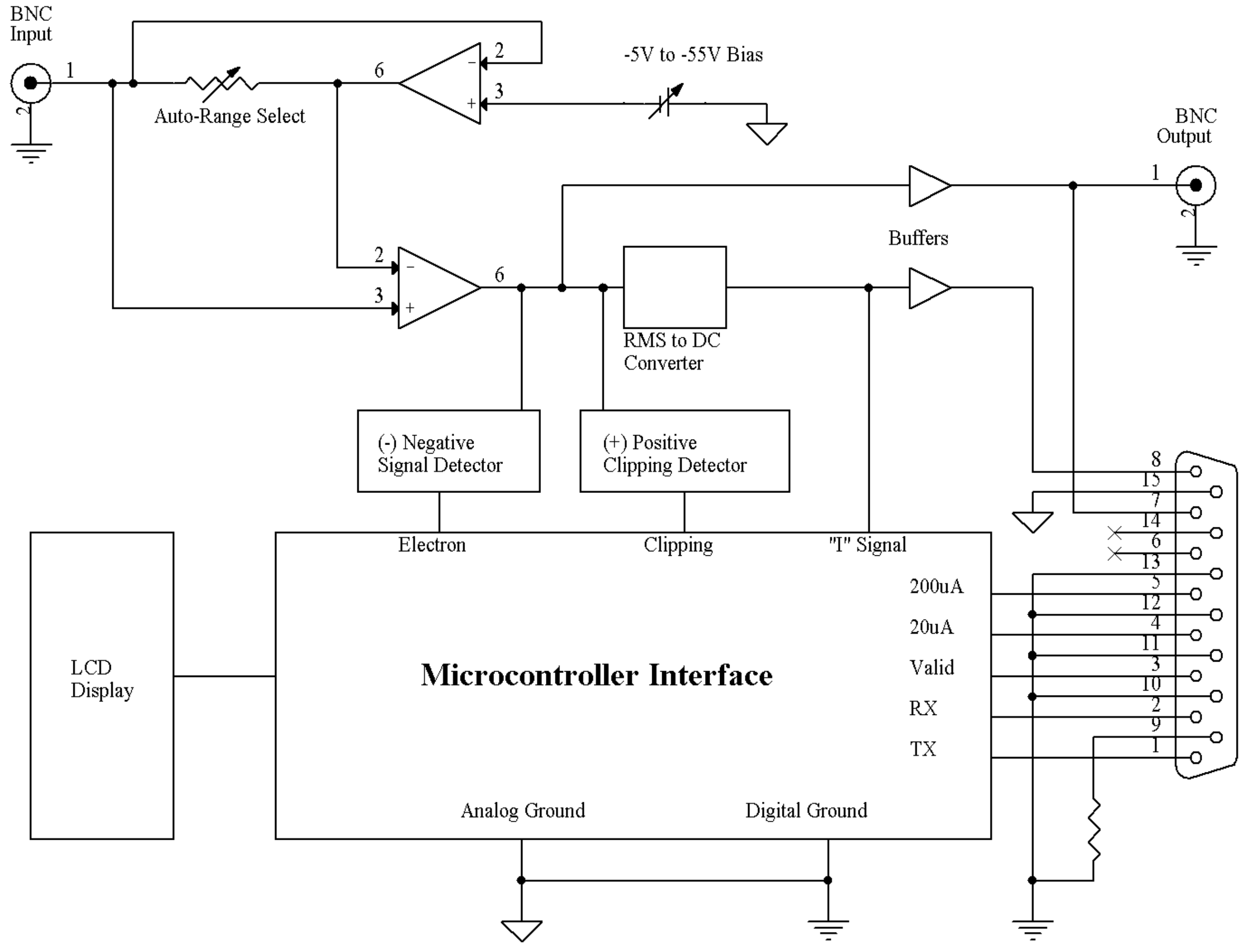
There are two amplifier ranges and the active range is shown on the left of the display as “1” or “2” where, for example, “1” represents the 200 µA range and “2” represents the 2mA range.

A logarithmic bar graph display of the ion current is presented on the bottom of the display.

The right hand side of the display shows the numeric representation of the ion current with the appropriate units. (µA/mA)

2

PRINCIPLE OF OPERATION



3

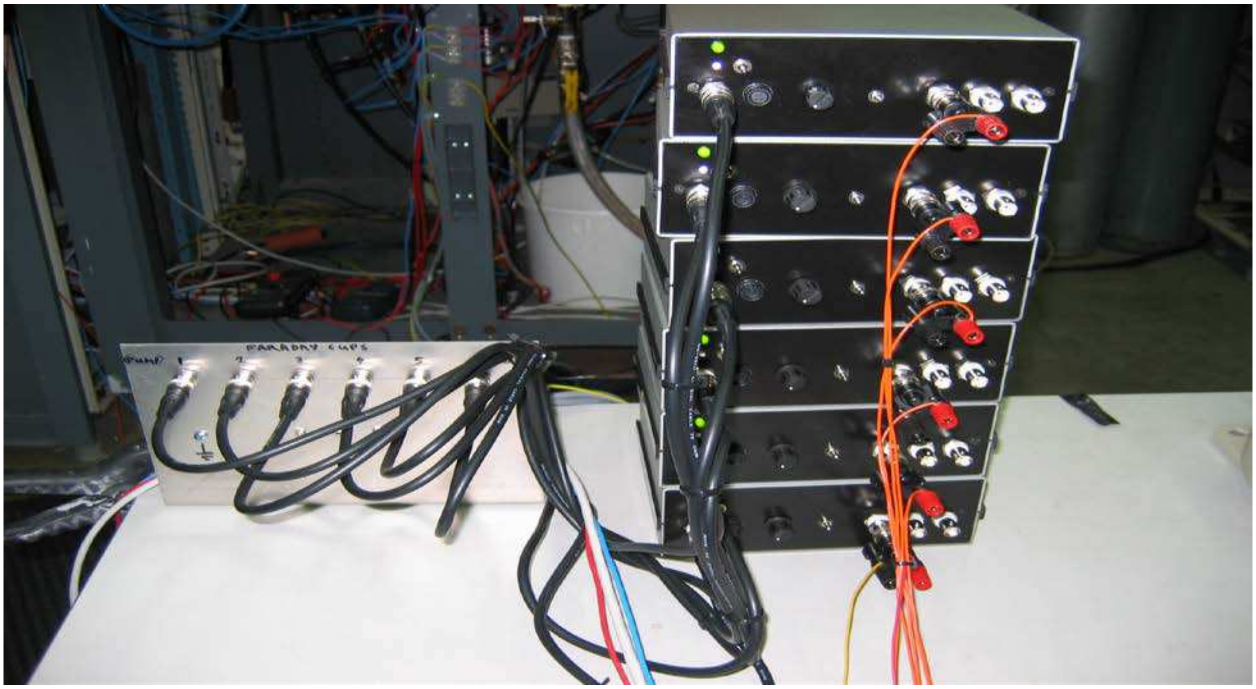
THE DETECTION OF CHARGED PARTICLES

Ion sources are designed to produce a charge neutral beam of energetic ions and electrons that can be directed toward the substrates and sensor. To repel the electrons, a negative bias voltage is applied to the sensor so that only the positive ion current is detected. The bias voltage is adjustable between –5 and –55 Volts (see 'Setting the Bias Voltage', chapter 9). Ions incident at the sensor element cause a current to flow in the signal line which connects to the Monitoring Unit. The signal current is amplified by a charge amplifier which produces a voltage proportional to the input signal current. An RMS to DC converter produces a DC signal proportional to the time varying AC signal. Three outputs of the signal are available. The RMS current is displayed on the front panel LCD display or the RMS signal is output to a rear panel connector for displaying to auxiliary devices or for time logging. Alternatively, where time varying signals are produced in the sensor, the waveform is made available through an alternative BNC connection. The AC signal can best be observed on an oscilloscope.

The Detection of Charged Particles during PVD Processes

The Telemark/Saintech Ion Current Density Monitor operates on the same principal of a Faraday cup. A Faraday cup measures the flux of charged particles as they enter the cup. As the charged particles impinge the electrically conducting surfaces of the sensor element they are neutralized thus inducing an electric current.

An array of ICDMs can be used to determine the ion flux distribution. This photo shows six of the first generation Monitoring Units used in the Saintech Development Laboratory for ion flux distribution measurements.



4

INSTALLATION

The complete Ion Current Density Monitor package includes the following items:

* Sensor Head w/ Sensor Element
* Monitoring Unit
* Power cable (IEC connector)
* High temperature, stainless-steel shielded, Type-K Thermocouple cable (vacuum side)
* BNC connecting cable 1.5m (~5ft.)
* Coaxial BNC 1” (Bolt type) vacuum feed-through (Other options available.)

Mounting the Sensor Head

A mounting bracket with a 5mm stud is provided to attach the sensor head to a support bracket inside the chamber. The support bracket would be made by the installer to suit the particular requirements of the installation. It is recommended that the support be made from stainless steel. If aluminum is used, care should be taken to ensure that the body of the sensor head is properly grounded due to the high surface resistance of the native oxides of aluminum.

Electrical connections

1. Install the coax electrical feed-through.
2. Connect the non-threaded side of the shielded cable assembly to the vacuum side of the coax connector. (Note that the connector just pushes onto the feed-through.)
3. Install the mounting bracket onto the support bracket within the vacuum chamber.
4. Mount the sensor head end (threaded) of the shielded cable assembly onto the mounting bracket within the vacuum chamber. Tighten the set screw on the mounting bracket to hold the cable end in place.
5. Install the sensor head to the shielded cable assembly. Gently push the sensor onto the mounting bracket and then turn the sensor to engage the screw which retains the sensor in place.
6. Make sure the sensor head is aligned with the aperture facing towards the ion source. (If not loosen the mounting bracket setscrew and nut, re-align the sensor head, and re-tighten.
7. Using a continuity tester, do the following:

a) Test that there is continuity (virtually no resistance) from the inner sensor element to the connection at the atmospheric side of the feed-through;

b) Test that there is continuity between the body of the sensor head and chamber ground;

c) Test that there is NO continuity (high resistance) between the inner detector element and chamber ground.

NOTE : Typically, the body of the sensor head will be earthed by connection through the mounting bracket. However, if this is not the case, ensure a suitable connection of the sensor head body to chamber ground has been established.

RECOMMENDATION

To provide the most accurate indication of the *substrate* ion current density, the detector head should be mounted at approximately the same distance from the ion source as the substrates. In a typical coating set-up, the detector head will be most conveniently mounted adjacent to a quartz crystal deposition monitor or similar. Do not mount the front face of the detector behind the alignment of the work plate.

Connecting the Monitoring Unit

1. (a) Connect the BNC cable (supplied) to the BNC feed-through.

   (b) Check to ensure that the ground connection of the BNC feed-through is connected to chamber ground.

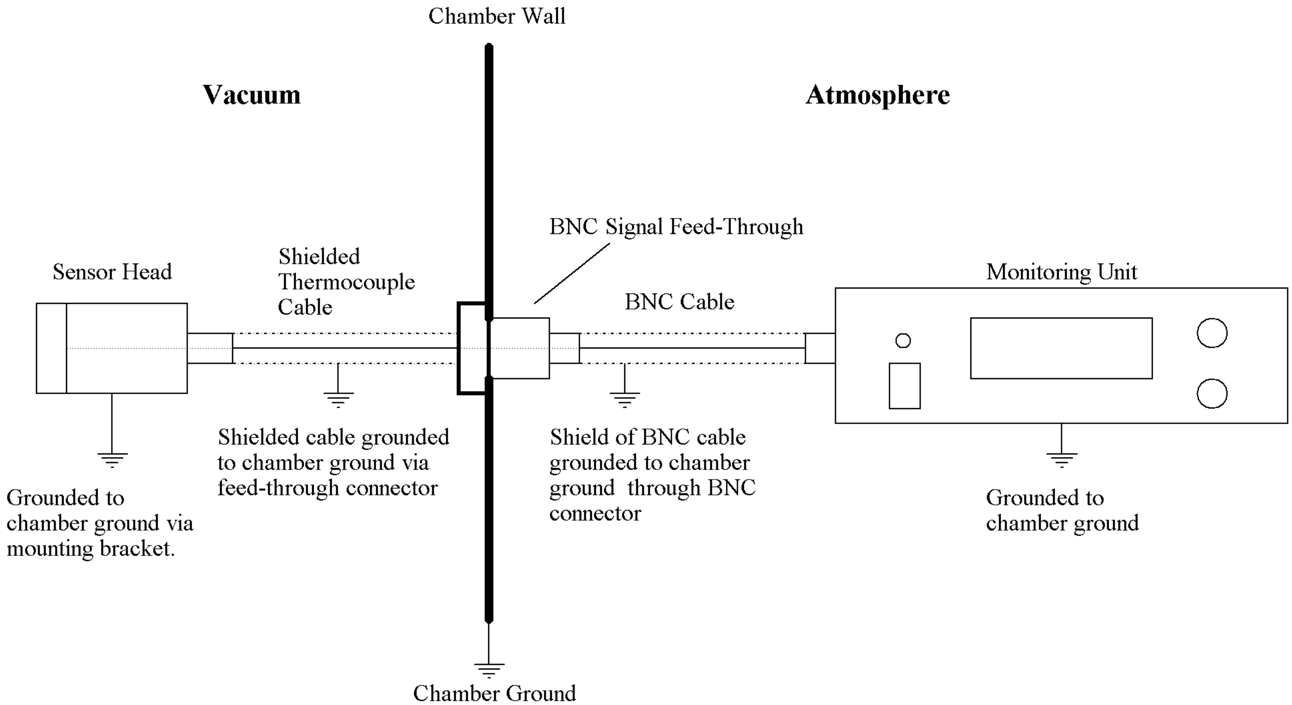
2. Connect the BNC connection of the co-axial cable to the CURRENT SIGNAL IN connection on the rear panel of the Monitoring Unit (see picture below).

3. Connect the IEC power cable to the socket at the rear of the Monitoring Unit (see picture below).

4. Turn the power on.

Your **Telemark/Saintech Ion Current Density Monitor** is now ready for use. See CURRENT MONITORING in the next chapter for operating instructions.

When complete, the installation should be represented as follows :



5

CURRENT MONITORING

1. Turn the Monitoring Unit on using the POWER switch on the front panel.
2. Initially, set the bias voltage to approximately -35 Volts (see SETTING THE BIAS VOLTAGE section later in this manual).
3. Establish the ion beam as appropriate
4. Observe the Digital Meter reading. Depending on the magnitude of the ion current, the ICM will auto-select the correct range. The selected range will be displayed on the left-hand side of the LCD display. The actual ion current will be displayed in digital form on the right-hand side of the LCD display

The Aperture area is 1 cm^2 allowing the meter reading to be interpreted as a <u>current per cm^2</u>.

6

CONNECTING THE AMPLIFIER MODULE TO AN OSCILLOSCOPE

Detailed analysis of the operation of the ion beam can be performed by connecting the Amplifier output to an oscilloscope or similar diagnostic equipment. See USING THE CURRENT MONITOR WITH A TELEMARK/SAINTECH ION SOURCE for diagnostic examples.

A BNC is provided on the front panel for connecting the output AC signal to a diagnostic instrument for display.

For time-varying signals as is typically seen with the Telemark/Saintech Ion Beam Systems, valuable information can be obtained to assist with the optimization of the ion beam operation.

Connecting the ICDM to a Telemark/Saintech Ion Beam System

If you have purchased one of the range of Series III Telemark/Saintech Ion Beam Systems, full instructions will be included with the ion beam system for connecting the rear-panel mounted Output Interface of the ICM to the rear panel of the ion beam system.

7

MAINTENANCE

Apart from occasional cleaning of the sensor collector, there should be no need for maintenance of the head.

The picture above shows main parts of the Sensor Head. Included is the stainless steel shielded Type-K Thermocouple cable assembly and mounting bracket.

Removing the Sensor Head from the Vacuum Chamber

1. Disconnect the signal line at the vacuum feed-through. The coax connector can be pulled from the vacuum side of the feed-through. Do not apply force to the coax cable when removing the connector.

2. Remove the sensor head from the shielded cable assembly connected to the mounting bracket. The sensor head is screwed onto the cable assembly. It should not be necessary to remove the cable assembly to clean the sensor head.

Cleaning

The sensor collector and the sensor head body should be periodically cleaned to remove coating deposits.

1. With the sensor head removed as instructed above, unscrew the sensor aperture.

2. Remove the ring insulator and sensor collector element.

CAUTION

The ring insulator is made of ceramic and is therefore fragile. Take care not to drop it on hard surfaces

3. Brush the collector and inner surfaces of the body with a light abrasive pad, e.g. Scotch Brite.

DO NOT GLASS BEAD. The sensor collector element is coated with Titanium Nitride (TiN). Although TiN is a very hard coating, it will be permanently damaged by abrasive bead blasting.

RECOMMENDATION

It is not essential (also not recommended) to remove the complete sensor head from the vacuum chamber for cleaning when only routine cleaning of the collector element is all that is required

Reassembly

1. Insert the sensor element into the body so that the mesh engages the metal contact screw.

2. Locate the ring insulator in the sensor body aperture cover.

3. Screw the sensor body aperture cover against the sensor body. Tighten to light finger pressure only – **do not over-tighten as it will deform the collector**

Checking the Signal Line contact

1. Using a standard continuity tester, make contact with one probe to the sensor (mesh) and the other probe to the center contact of the BNC connector on the air side of the feed-through.

2. Check also for no continuity between the sensor and ground.

8

TROUBLE SHOOTING

Problem	Likely or possible cause
No ion current detected	1. Detector body not correctly earthed 2. No continuity for current wire 3. Check for proper bias voltage
Unstable current readings	Detector may require cleaning

9

SETTING THE BIAS VOLTAGE

In order to prevent charging of dielectric surfaces in the vacuum chamber, ion beams for ion assisted deposition must be charge neutral. Charge neutrality is achieved by additional electrons from the ion source filament, hollow cathode electron source, or from an additional neutralizer.

In order to measure the positive ion current, the electrons must be removed from the beam prior to reaching the sensor. The monitoring unit is equipped to provide a negative voltage bias to the sensor. The bias voltage control is located on the front panel. The bias voltage is adjustable between -5 and –55 V. Figures 3a to 3e on the next page show the evolution of an ion current signal from a Telemark/Saintech ST55 Ion Source (operating a time-varying AC anode voltage) with changing bias voltage.

At zero bias (Figure 3(a)), a negatively extending sinusoidal half wave corresponds to the heating current waveform that drives the cathode filament emission. That is, without any bias, the main component of the signal is due to electrons. Seen superimposed on the left hand waveform is an additional signal which we will see is due to the positive ion signal.

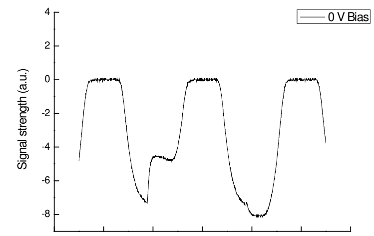


Figure 3a

With just –5 Volts applied to the detector (3b), the strongly negative signal has been neutralized but the signal due to the positive ions is barely discernible.

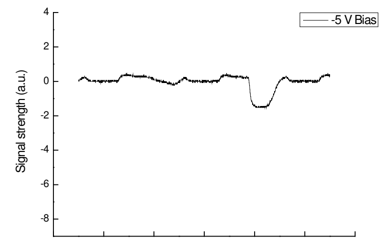


Figure 3b

At –25V (3c), the shape of the right hand waveform in particular, has continued to evolve as more electrons are repelled.

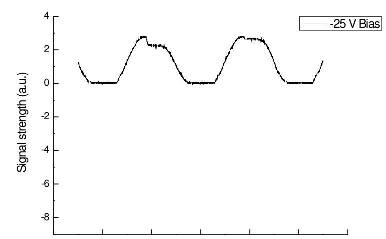
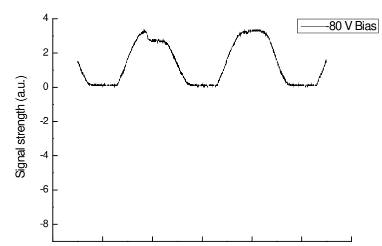


Figure 3c

From –25V to –80V (3d), the shape of the signal remains largely unaltered, indicating that the signal is entirely due to the positive ions in the ion beam. However, there is an approximate 25% increase in the peak signal strength when increasing the bias from –25V to –80V, indicating that the bias is starting to attract additional ions from the ion beam that would not normally impinge on the entrance aperture.



The Ion Current Monitor has a bias voltage range of between -5 to –55 volts. **For typical operating conditions, a bias of approximately 35V is sufficient.**

10

ION CURRENT MONITOR ELECTRONICS SPECIFICATIONS

Operating ambient temp. range	0 – 35° C
Bias Voltage	Adj. between -5VDC and -55VDC
Input capacitance max.	Typ. 1000 pF, allows for 10 meters of coax. @ 100pF/meter
Output signal: AC output	+/- 10V full scale (Output load > 2kΩ) 0 to +10V represents positive ion current. Negative volts represents electron current. 0 to approx. 16kHz (-3db) bandwidth.
Output signal: RMS output	0 to +10V full-scale (Output load > 2kΩ) 0 to full-scale response time typ. 1.5 secs. Full scale to 0 response time typ. 2.5 secs.
Input ranges	0 - 200μA full-scale (20μA/volt output) 0 - 2mA full-scale (200μA/volt output)
Accuracy: AC output	+/- 1% of full-scale
Accuracy: RMS output	+/- 3.2% DC Input, +/- 5.2% AC Input
Accuracy: RS232 Digital Output	+/- 5.2% of full-scale

Sensor Head Specifications – Vacuum

Operating temp. range	maximum 350 degrees C

Range change conditions:

1. RMS signal > 115% of full scale – change to next higher range
2. RMS signal < 5% of full scale – change to next lower range
3. AC input signal clipping (> 245% of full scale) for one second AND RMS signal > 55% of full scale – change to next higher range

11

REAR PANEL I/O INTERFACE CONNECTOR

DB15F Pin connections

Pin 1. RS232 TX output	--------	Reference is pin 9 ONLY	
Pin 2. RS232 RX input	--------	Reference is pin 9 ONLY	
Pin 3. Digital VALID output			
Pin 4. Not Connected			
Pin 5. Digital 200µA output		Range indicators	All Open Collector
Pin 6. Digital 20µA output			active low.
Pin 7. AC output	--------	Reference is Pin 15	
Pin 8. RMS DC output	--------	Reference is Pin 15	
Pin 9. RS232 Ground reference			
Pin 10. Digital Ground			
Pin 11. Digital Ground			
Pin 12. Digital Ground			
Pin 13. Digital Ground			
Pin 14. Not Connected			
Pin 15. Analogue Ground Reference			

The digital outputs are buffered using a ULN2003A open collector driver IC, each collector is in series with 3.3 ohms. Pin 9 of this device is connected to the cathode of a 5 watt 33V zener diode. This design provides protection for the driver IC due to high voltage fly-back from long connection wires (induction) when the outputs switch off.

It is important not to connect any voltage higher than 30 volts to any output pin. This may result in excessive currents being drawn and excessive power dissipated in the driver IC, 3.3 ohm protection resistors and 33V protection zener diode.

The analogue outputs are fully short-circuit protected. The buffer amplifiers are powered from current limited supplies.

DB15 Pin 1 is the ion current monitor RS232 transmit data pin, this connects to the external equipment RX data pin.

DB15 Pin 2 is the ion current monitor RS232 receive data pin, this connects to the external equipment TX data pin.

DB15 Pin 9 is the ground reference for pins 1 and 2. This pin has a 22 ohm resistor connected to the internal digital ground plane to reduce RF noise. If you must screen the cable, only connect one end of the screen to a Digital Ground pin(10…13). NEVER connect both ends!

RS232 output is updated every 200mS. There is no update for 1.5 seconds if the ion current monitor is changing range. It is recommended to use a minimum 2 second timeout delay.

RS232 connection requirements:

19k2 baud rate

8 data bits

No parity

1 stop bit

No flow control

RS232 transmit data format

Carriage-return:	0x0d	Two carriage-returns indicate start of update,	
Carriage-return:	0x0d	Not included in CRC calculation.	
Status character:	0x30	0011 | 0000	Ok, value is valid.
	0x41	0100 | 0001	Input clipping, value not valid.
	0x42	0100 | 0010	Input electrons, value not valid.
	0x44	0100 | 0100	-63V internal supply low, value not valid.
	0x48	0100 | 1000	Bad EEPROM check byte, value is still valid.

The low order four bits are ORed to indicate multiple errors.

Only one character is sent.

Comma:	0x2c	
Absolute value (Amps)		
Most significant figure:	0x30…0x31	“0” or “1”
Decimal point:	0x2e	
2nd most significant figure:	0x30…0x39	Decimal digit
3rd most significant figure:	0x30…0x39	Decimal digit
Least significant figure:	0x30…0x39	Decimal digit
ASCII “E”:	0x45	
ASCII “-“:	0x2d	
Exponent:	0x32…0x34	“2”, “3” or “4”
Comma:	0x2c	

Seven ASCII character value in one of the following formats:

“ddd.duA”	0 <= I <= 230.0uA	Range1
“##ddduA”	I <= 999uA	Range1/2
“dd.ddmA”	I >= 1mA	Range2

Where ‘#’ means a space character (0x20)
And ‘d’ is an ASCII digit character (0x30…0x39)
Leading zero digits are suppressed and replaced with space characters (0x20)

Comma:	0x2c	
Tens digit:	0x30…0x39	Decimal digit or 0x20 if ‘0’.
Ones digit:	0x30…0x39	Decimal digit
Decimal point:	0x2e	
Tenths digit:	0x30…0x39	Decimal digit
Comma:	0x2c	Included in CRC calculation.
High nibble:	0x41…0x50	((CRC & 0xf0) >> 4) + 0x41
Low nibble:	0x41…0x50	((CRC & 0x0f) >> 0) + 0x41

The CRC is transmitted as two ASCII nibble characters, high nibble followed by low. Adding a binary (0x00…0x0f) to ASCII “A” (0x41) generates a contiguous ASCII upper case letter group; this does not involve determining digits or letters. This is primarily intended for machine-machine communication where efficiency is more desirable than human readability, but is still readable.

The Cyclic Redundancy Check byte (CRC) is calculated as follows.

Initialize variable CRC = 0xC1

For each 'byte' transmitted; excluding the two ASCII CRC nibble characters or the two initial carriage-return characters, but including commas and decimal points:

(Exclusive OR) bit wise, CRC with 'byte' and save result back in CRC.

Rotate CRC one bit to the right. I.e. bit0->bit7, bit7->6 … bit1->0, All at once.

To switch correction factors, send two escape characters (0x1b) in succession then the command character ASCII 'F" (0x46) followed by either ASCII '0' or 'A', where '0' is for DC correction, 'A' is for 50/60Hz correction. You have five seconds to send all characters, otherwise command input is terminated and search for a new header character (0x1b) begins. There is no CRC or check byte attached.