

# **IMPULSE™ 2-2**

## **pulsed power module**

## **operation manual**

Models:

SF-IMPULSE2GX-SH-SE

SF-IMPULSE2GX-DH-SE

SF-IMPULSE2KX-SH-SE

SF-IMPULSE2KX-DH-SE

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# Safety Warnings

**READ ALL SAFETY WARNINGS AND INSTRUCTIONS BEFORE USING**

Please read all instructions and warnings contained in this manual before installing or operating this equipment.

Users shall observe all safety protocols at their facility. All personnel who work with or who are exposed to this equipment must take precautions to protect themselves from serious or possibly fatal bodily injury.

Starfire Industries LLC provides information on its products and associated hazards, but it assumes no responsibility for the after-sale operation of equipment or the safety practices of the owner or user.

**WARNING: HIGH VOLTAGE**

Hazardous and potentially lethal voltages may be present when this equipment is in use. The system shall be set up and operated only by qualified personnel who are thoroughly familiar with the equipment.

**WARNING: NEVER DISCONNECT CABLES WHEN HIGH-VOLTAGES ARE PRESENT**

Power off any high voltage inputs and the IMPULSE™ unit before disconnecting high voltage inputs or outputs.

Disconnect all sources of input power before handling or moving this unit or any equipment connected to it.

**WARNING: UNIT MUST BE PROPERLY GROUNDED**

Ensure an appropriate grounding strap (multiconductor braided 6 AWG or better) is connected to the IMPULSE™ ground terminal and secured to the facility equipment common ground.

**WARNING: DO NOT ATTEMPT TO OPERATE IF UNIT IS DAMAGED OR DISASSEMBLED****WARNING: DO NOT ATTEMPT TO SERVICE OR REPAIR**

There are no user-serviceable parts inside of the IMPULSE™. Attempting to service or repair the unit may result in the unit being in an unsafe state. Contact reseller or Starfire Industries for any service or repair.

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# Important Setup and Use Information



**CAUTION: REGARDLESS OF THE OPERATING MODE SELECTED, THE USER MUST ENSURE THE INPUT POWER SUPPLY IS SET UP SUCH THAT IT WILL NOT EXCEED THE OPERATIONAL LIMITS OF THE IMPULSE™: (-1000V, 4A, 2kW)**



**CAUTION: OPERATE DC CHARGING SUPPLY IN VOLTAGE CONTROL MODE**

**IMPORTANT:** Use a voltage-controlled DC power supply set to constant voltage mode. Disable any high-voltage strike pulse or plasma initiation features to avoid damage to the IMPULSE™.

Some DC power supplies have power or current control modes. Power control mode or current control mode must not be used when operating the IMPULSE™ or unstable operation and damage to the unit may occur.

Setting a current limit of at most 4 amps is recommended to avoid over-current condition while starting or operating the IMPULSE™, but the DC power supply should be operated in a constant-voltage mode. Similarly, a power limit of 2kW can be set, but the DC power supply should be operated in a constant-voltage mode.



**CAUTION: ENSURE ADEQUATE AIRFLOW AROUND UNIT WHILE IN OPERATION**

Avoid blocking air flow on the top and sides of the unit to maintain adequate airflow. The IMPULSE™ units are rated for 2kW operation over a range of voltages and repetition rates/duty factors provided they have access to sufficient ventilation. It is good practice to leave space around the 2U rack for airflow.



**CAUTION: ENSURE ADEQUATE GROUNDING TO PROTECT UNIT WHILE IN OPERATION**

The ground terminal lug located on the rear panel must be connected to the common ground point for the facility equipment during IMPULSE™ installation. Use an appropriate grounding strap (multiconductor braided 6 AWG or better) .

**IMPORTANT:** The user should connect the N-type cable from the IMPULSE™ directly to the sputter gun. For example, a Kurt J. Lesker TORUS sputter gun will have a corresponding N-type connector with the center pin connected directly to the cathode and the outer conductor connected to the in-vacuum anode which is typically tied to the rest of the vacuum system and, therefore, grounded.

**IMPORTANT:** Minimize cable lengths between the IMPULSE™ and the magnetron sputtering gun. A length of less than 6' is considered appropriate for low-loss coaxial cabling.

**CAUTION: DO NOT ENERGIZE OR ENABLE OUTPUT OF ANY CONNECTED DC POWER SUPPLIES WHILE THE IMPULSE™ IS OFF**

Never energize or enable output of any connected power supplies while the IMPULSE™ is powered off. Turn off or disable connected power supplies before turning off the IMPULSE™. The IMPULSE™ contains switches on the high-voltage input lines as a safety measure to prevent accidental shock when the IMPULSE™ is not powered. Prolonged power input to this safety circuit can damage it, preventing it from functioning. In addition, when the IMPULSE™ is energized with high-voltage present on the input, large electrical transients can result that may damage the IMPULSE™, or other connected equipment.

**SET CURRENT THRESHOLD APPROPRIATELY TO OPTIMIZE ARC DETECTION AND OVER-CURRENT SET POINTS FOR TARGET CONDITIONING**

A user-selectable current threshold setting is available in the IMPULSE™ system control. Once the instantaneous current exceeds this threshold level, the IMPULSE™ will terminate the current pulse and will not fire again until the next scheduled pulse. This scenario can occur during an arc event when the instantaneous current rises rapidly in a run-away event. This scenario can also occur during a normal HiPIMS pulse when the current threshold is set too low (a spurious arc-detection). These two scenarios are difficult to distinguish without viewing the target to observe arcs. If the target is not observable, a trial-and-error approach may be needed to determine the cause of the pulse interruption. Start by lowering the DC power supply voltage. If arcing is occurring, decreasing the DC power supply input voltage will often stop the arcing. If a discharge cannot be maintained with reduced DC power supply input voltage, then the arc-detection current threshold on the IMPULSE™ can be increased. Once a reliable discharge condition is found as a starting point, DC power supply voltage and IMPULSE™ arc-detect current threshold settings can be increased as needed to reach the desired operating mode. Use of an oscilloscope to view the current and voltage waveforms on the output monitoring lines is encouraged.

As a starting point, the arc-detect threshold should be set to roughly 120-150% of the peak pulse current in a typical HiPIMS discharge pulse. This allows for drift in discharge conditions over time while minimizing the current levels reached during arc events. This setting can be raised, or lowered, as needed to allow changes in operating parameters. To minimize the damage caused to a sputter target during an arc, which will also minimize the arc-rate of the target, the arc-detect threshold should be set as low as possible without causing spurious arc detection.



## Warranty and Return Policy

Please refer to reseller's warranty policy documentation regarding return policy guidelines and procedures.

# Product Overview

## Front Panel

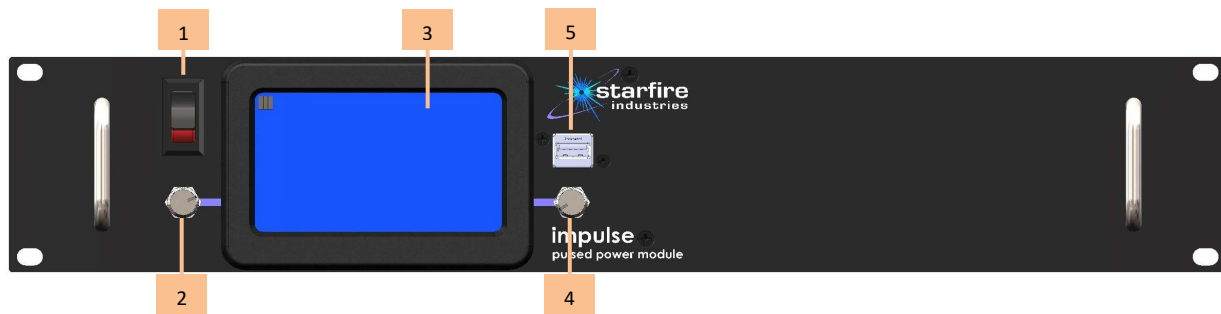


Figure 1. Front view of single unit (models SF-IMPULSE2GX-SH-SE or SF-IMPULSE2KX-SH-SE)

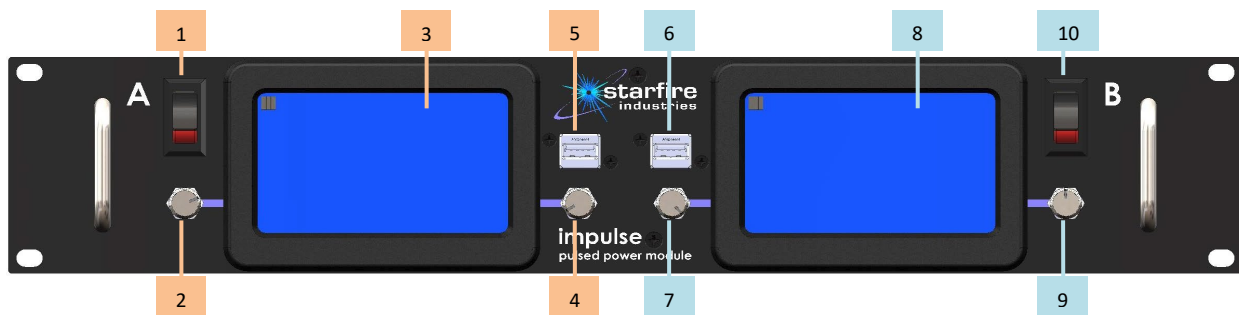


Figure 2. Front view of dual unit (models SF-IMPULSE2GX-DH-SE or SF-IMPULSE2KX-DH-SE)

### Controls for module A (present in single and dual models)

1. Power on/off switch
2. Knob for adjusting the setting indicated on the left-side of the user interface
3. LCD touchscreen
4. Knob for adjusting the setting indicated on the right-side of the user interface
5. USB type A receptacle for in-field software updates

### Controls for module B (present in dual models)

6. USB type A receptacle for in-field software updates
7. Knob for adjusting the setting indicated on the left-side of the user interface
8. LCD touchscreen
9. Knob for adjusting the setting indicated on the right-side of the user interface
10. Power on/off switch



## Back Panel

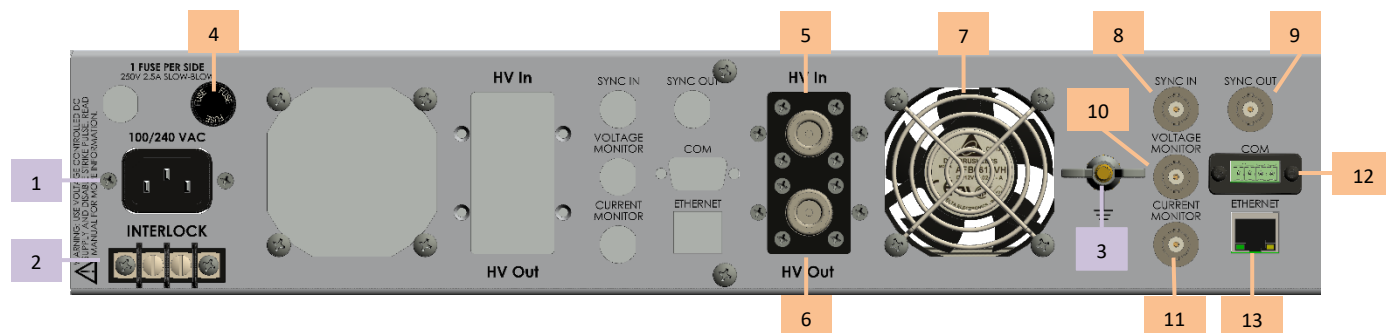


Figure 3. Rear view of single unit (models SF-IMPULSE2GX-SH-SE or SH-IMPULSE2KX-SH-SE)

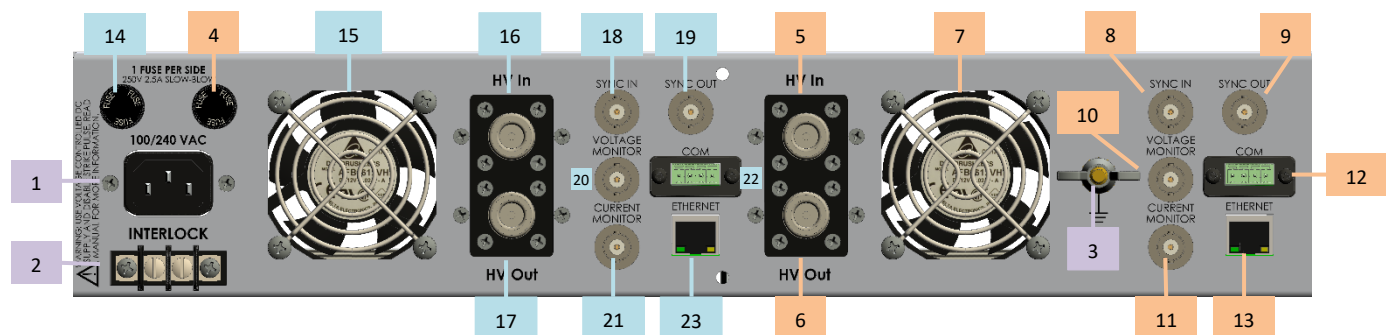


Figure 4. Rear view of dual unit (models SF-IMPULSE2GX-DH-SE or SF-IMPULSE2KX-DH-SE)

Common features and connections (present in single and dual models)

1. Main wall power to IMPULSE™ – labeled 100/240 VAC
2. Interlock
3. Grounding stub (attach grounding strap to equipment common point here)

Features and connections for module A (present in -SH and -DH models)

4. Fuse A: 250V, 2.5A, Slo-Blo
5. HV input from external DC power supply, N-type connector
6. HV output to magnetron cathode or substrate, N-type connector
7. Cooling fan
8. Master/slave sync in, BNC connector
9. Master/slave sync out, BNC connector
10. Voltage monitoring output to oscilloscope, BNC connector, 2.20V = 1000V actual

11. Current monitoring output to oscilloscope, BNC connector, 1.15V = 100A actual
12. RS-422 Serial port to external monitoring and control
13. RJ45 Ethernet port to external monitoring and control

Features and connections for module B (present in -DH models)

14. Fuse B: 250V, 2.5A, Slo-Blo
15. Cooling fan
16. HV input from external DC power supply, N-type connector
17. HV output to magnetron cathode or substrate, N-type connector
18. Master/slave sync in, BNC connector
19. Master/slave sync out, BNC connector
20. Voltage monitoring output to oscilloscope, BNC connector, 2.20V = 1000V actual
21. Current monitoring output to oscilloscope, BNC connector, 1.15V = 100A actual
22. RS-422 Serial port to external monitoring and control
23. RJ45 Ethernet port to external monitoring and control

## Functional Description

The IMPULSE™ is designed for use in High Power Impulse Magnetron Sputter (HiPIMS) deposition. It switches power from an external negative high-voltage supply to form a timed pulse train of negative voltage at its High-Voltage output connector. Between output power pulses, the HV output floats at high impedance to ground, resulting in a voltage decay depending upon the load at the HV output connector. This allows an afterglow plasma to persist at the sputter cathode. If the IMPULSE™ unit is equipped with the “Kick” option, an internal positive voltage source can be pulsed following a short delay after each negative pulse to control the afterglow plasma. Without the “Kick” option, the output can be shorted to ground during this timeframe to quench the afterglow plasma.

Each IMPULSE™ 2-2 module is rated at 1000V maximum negative input/output voltage, 4A maximum average input current, and 2kW maximum average input power. The corresponding output pulse current and power limitations are dependent upon pulse width and repetition rate. The IMPULSE™ module supports either High-Frequency or High-Current operation. High-Frequency operation allows up to 4KHz repetition rate and 200A peak output pulse. High-Current operation allows a 400A peak output pulse with 2kHz repetition rate. Operation with all output parameters at their maximum level simultaneously (e.g., 1000V, 400A, 2kHz) is not sustainable and will lead to overheating of the IMPULSE™. One of these three parameters must be reduced to allow sustained operation with the remaining two parameters at their maximum.



The “Current Limiter” feature monitors the instantaneous output current and immediately sets the output to a high impedance state if the preset limit is exceeded. This feature cuts off the output pulse within approximately 2 $\mu$ s if high current pulses are present to prevent damage to the target. Different limits can be independently set for the negative main pulse and the positive kick pulse (if installed). This current limit feature is useful for stepwise increases in plasma density for conditioning the sputtering target at a specific operation voltage.

The “Arc-Arrest” feature prevents damage to both the IMPULSE™ system and the target surface from high-current arcs. Unlike the instantaneous monitoring provided by the current limiting feature, it monitors the rate of change in the output current to quickly detect and arrest arcs. When the system detects the output current increasing faster than a standard high current HiPIMS discharge pulse, it recognizes an arc event and sets the output to a high impedance state within 500ns which, for most plasma discharges, stops the current flow at the time of the arc before it can rise to 150A over the discharge current. This reduces target surface crater formation and debris generation, enabling faster HiPIMS target conditioning. This feature requires no user setup and is always active in all operating modes.

The “Power Control” feature automatically adjusts the pulse repetition rate to maintain the average input power at or below the user-specified power setting. The IMPULSE™ also maintains the pulse repetition rate at or below the user-specified frequency. Therefore, the IMPULSE™ will automatically cross over from constant-frequency to constant-power operation as the plasma load changes. The automatic crossover mitigates sudden changes in the output power caused by external supply switch-on or gas pressure thresholds in a plasma chamber. Note there is a factory-set PID setting for this power control for use over a wide range of operational conditions.

When a user’s application requires synchronized pulses from multiple IMPULSE™ modules, whether they are within a dual-module IMPULSE™ unit or within multiple diverse units, one module acts as a Master to synchronize the timing of one or more Slave modules, providing many application system setup options for the user. Each module is independently controlled with settings for operating mode, timing, voltage, and current settings and limits. Each module also independently outputs real-time monitoring information with measurements of input and Kick (if so equipped) voltages and currents, overcurrent events, and fault conditions. Note that a Slave module does not have a pulse frequency setting or Power Control feature because the Master module controls the operating frequency.

### **Operating Modes and Options**

Each IMPULSE™ module can independently operate in either Master or Slave mode, as required by the application and external equipment interconnections. Each module, whether configured Master or Slave can use either High-Current or High-Frequency operation. Within each of these modes, the unit operates either with full Afterglow or with a timed Quench (or Kick, if installed) pulse. The options available in each operating mode are outlined in *Table 1* and discussed later in this document.



**CAUTION: REGARDLESS OF THE OPERATING MODE SELECTED, THE USER MUST ENSURE THE INPUT POWER SUPPLY IS SET UP SUCH THAT IT WILL NOT EXCEED THE OPERATIONAL LIMITS OF THE IMPULSE™: (-1000V, 4A, 2kW)**

When setting up operation of an IMPULSE™ module, the user must select the primary operating mode before starting the output operation. Depending upon the mode selected, the other operating options and their associated settings can be preset before initiating output operation or dynamically changed while the output is active.

*Table 1. Operating Options for Each Pulse Mode*

MODE	OPTION	High-Frequency	High-Current	Afterglow Quench	Afterglow Kick (if installed)	Current Limiter
Master		Yes <sup>1</sup>	Yes <sup>1</sup>	Yes	Yes	Yes
Slave		Yes <sup>1</sup>	Yes <sup>1</sup>	Yes	Yes	Yes

Notes:

1. The High-Frequency and High-Current options are mutually exclusive at 1000V

### User-Controlled Settings and Limits

Various settings and operating limits are available to the user depending upon the operating mode that is selected. These are summarized in **Error! Reference source not found.**, below, as items that the user can “Set” or “Limit”, or as Not Applicable or Not Available (“N/A”) to the user.

Setting Description	Master		Slave	
	After-glow	Kick or Quench	After-glow	Kick or Quench
Timing Frequency/Period <sup>1</sup>	Limit	Limit	N/A <sup>2</sup>	N/A <sup>2</sup>
Main Pulse Average Power	Limit	Limit	Limit <sup>3</sup>	Limit <sup>3</sup>
Main Pulse Width	Set	Set	Set	Set
Afterglow Time	N/A <sup>4</sup>	Set	N/A <sup>4</sup>	Set
Kick or Quench Pulse Width	N/A	Set	N/A	Set
Slave Delay	N/A	N/A	Set	Set
Peak Output Current	Limit	Limit	Limit	Limit
Kick Voltage <sup>5</sup>	N/A	Set <sup>5</sup>	N/A	Set <sup>5</sup>
Kick or Quench Pulse Current	N/A	Limit	N/A	Limit

# Installation, Startup and Use Instructions

## Installation

1. Carefully take the IMPULSE™ unit out of its packaging and inspect for any damage that may have occurred during shipping.
2. Secure IMPULSE™ unit in rack with appropriate mounting hardware and ensure the unit is stable.



**CAUTION: ENSURE ADEQUATE AIRFLOW AROUND UNIT WHILE IN OPERATION**

Please see the **Important Setup and Use Information** section for details on how to promote safe levels of ventilation.

## Rear Panel Connections

### 1. Grounding

- a. Ground must be connected to a facility common point before anything else is connected. Multiple IMPULSE™ units must be grounded together with an appropriate grounding strap (multiconductor braided 6 AWG or better) following the shortest path between the units, as shown below.



**CAUTION: ENSURE ADEQUATE GROUNDING TO PROTECT UNIT WHILE IN OPERATION**

Please see the **Important Setup and Use Information** section for details on adequate grounding.

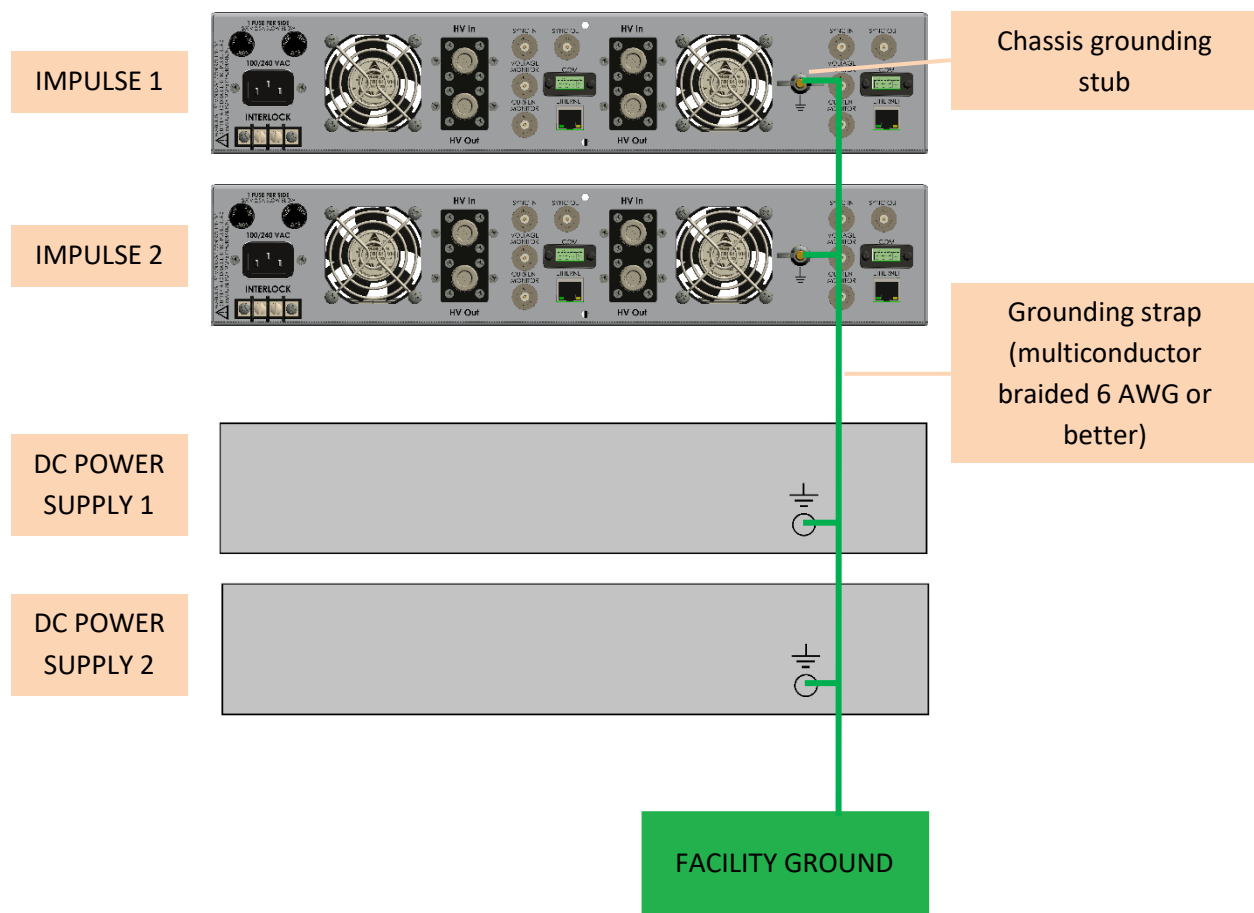


Figure 5. Proper grounding of multiple IMPULSE™ units and DC power supplies when used together

## 2. Voltage and Current Monitoring

- a. If monitoring of instantaneous voltage and current pulses is desired, connect the voltage and current monitor outputs from the IMPULSE™ module to separate channels of an oscilloscope (not included) using a RG-58 coaxial cable with BNC connectors, as shown below. This is optional, and the presence or lack of these connections does not affect operation of the unit.

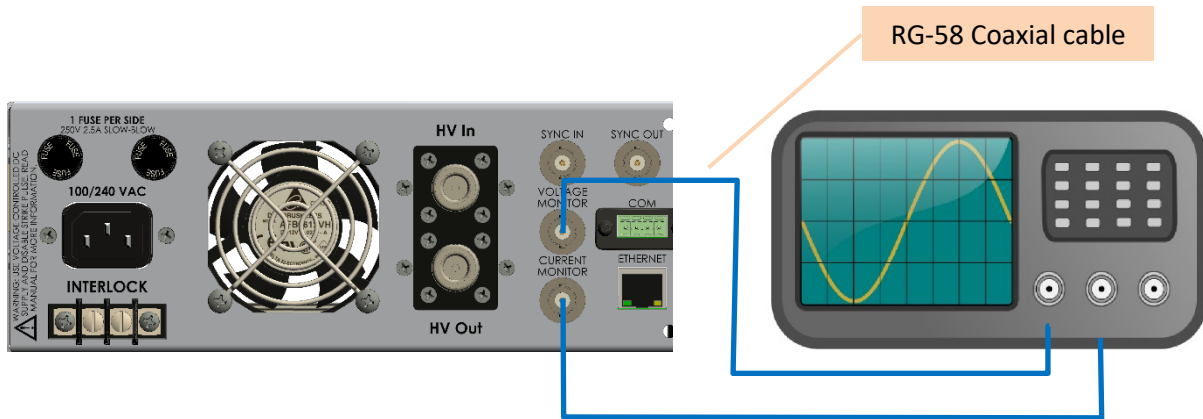


Figure 6. Instantaneous voltage and current monitoring with an oscilloscope

## 3. Synchronized Operation

- a. If using a dual IMPULSE™ system where one module will be the “Master” and one will be a “Slave”, connect a BNC cable from the “Sync out” on the “Master” to the “Sync in” on the “Slave” on the back of the units, as shown below.

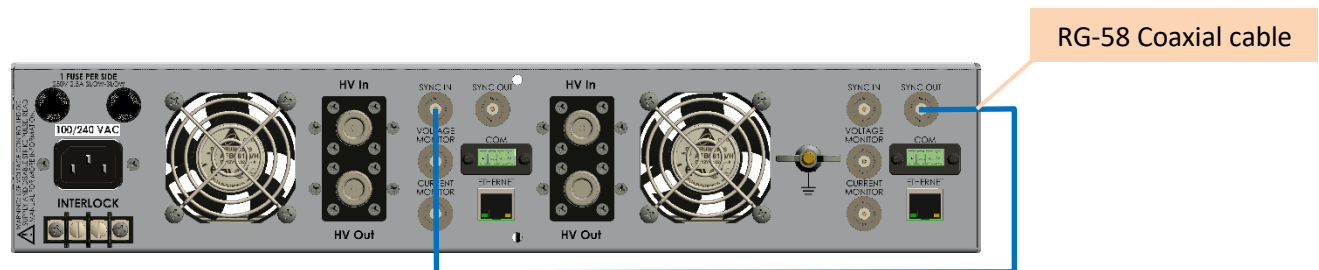


Figure 7. Proper connection of a dual IMPULSE unit's modules for Master/Slave synchronized operation. Module A shown as Master.

- b. If using multiple IMPULSE™ units (single or dual) together, connect all modules that are to be synchronized together with RG-58 cables, using BNC tees where necessary to form a sync bus, as shown below.



There must be exactly one “Master” present on the sync bus. The “Master” sync out must be connected to the “Slave” units’ sync in connectors. The unit will not operate correctly if configured as a “Master” while connected to another IMPULSE™ module that is also a “Master”, or if set to “Slave” mode when it is not connected to a “Master”. Please see Appendix C: Master/Slave Applications on page 72 for more information.

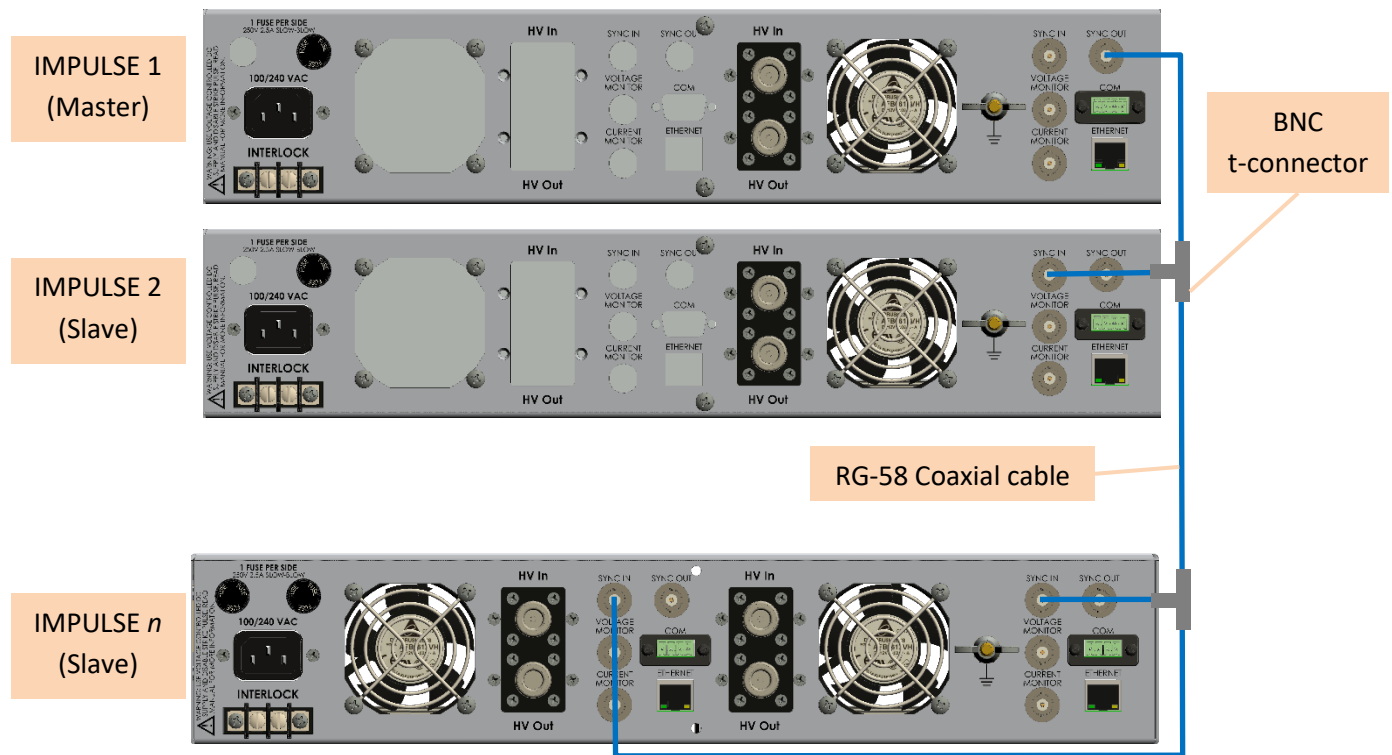


Figure 8. Proper connection of multiple IMPULSE™ units together for Master/Slave synchronized operation. NOTE: only one module can act as the master on a given sync bus.



#### 4. HV Output

- a. The high voltage output should be connected from the N-type connector labeled “HV Out” on IMPULSE™ to the magnetron cathode (not included), or substrate when providing a pulsed substrate bias, using an RG-8 coaxial cable (or multi-strand center conductor equivalent high-voltage cable), as shown below. The inner conductor of the coaxial cable will bias the magnetron cathode, while the outer conductor carries the current return path from the anode of the sputter system to the IMPULSE™ module.

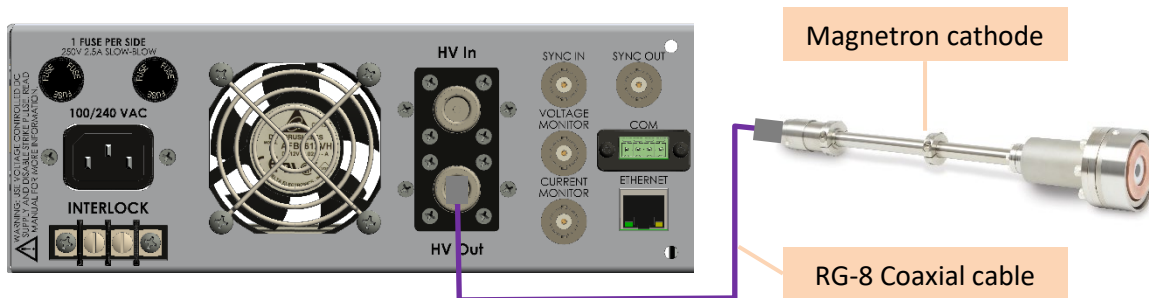


Figure 9. Connection of the high voltage output “HV Out” to a magnetron cathode

#### 5. HV Input

- a. The IMPULSE™ Pulsed Power Module requires a negative-polarity high voltage input from a DC power supply (not included). IMPULSE™ stores charge from this DC input, and releases it in short, intense pulses. The DC power supply’s output should connect to the N-type connector labeled “HV In” on the rear of the IMPULSE™ unit, as shown below.

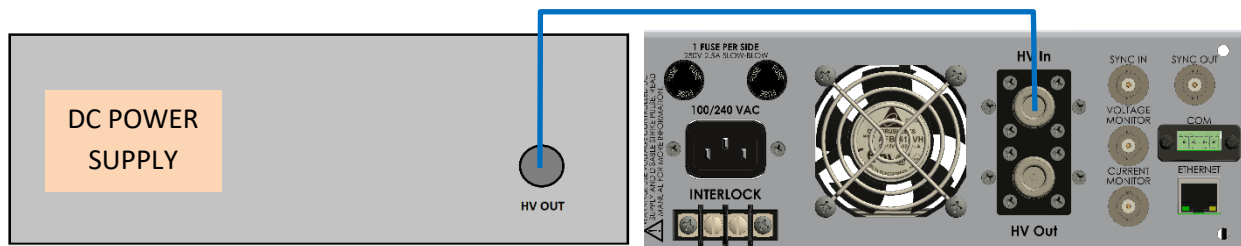


Figure 10. Connecting a DC high voltage power supply to IMPULSE™ “HV In”



**CAUTION: REGARDLESS OF THE OPERATING MODE SELECTED, THE USER MUST ENSURE THE INPUT POWER SUPPLY IS SET UP SUCH THAT IT WILL NOT EXCEED THE OPERATIONAL LIMITS OF THE IMPULSE™: (-1000V, 4A, 2kW)**

## 6. AC Power

- a. IMPULSE™ is powered by standard 100-240 VAC wall power at 50/60 Hz. Connect an AC power cable for your region to the “100-240 VAC” input on the rear panel (C13/14 IEC connector), and connect to a grounded power receptacle, as shown below.

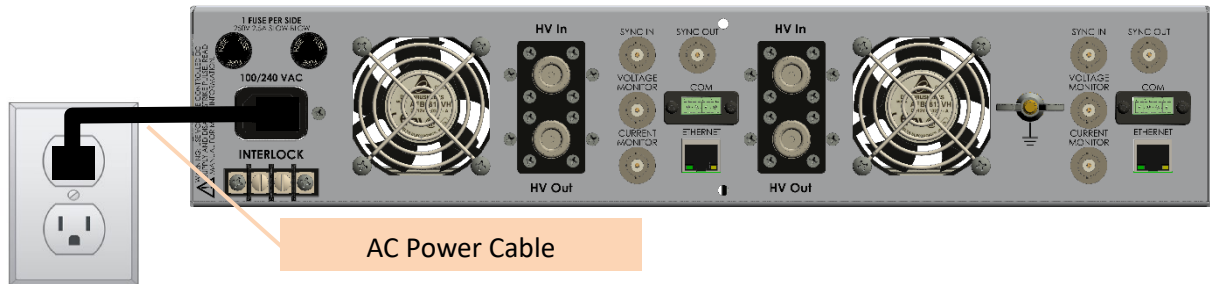


Figure 11. Powering IMPULSE™

## 7. Interlock

- a. A single interlock terminal block, located on the rear panel, is present for either single or dual IMPULSE™ configurations. When the electrical circuit between both terminal poles is completed, output pulsing is enabled for all modules in the IMPULSE™ unit.
- b. Connecting the interlock terminal block to a normally closed facility or equipment rack interlock switch will also enable output pulsing. Check with safety or facility personnel for proper wiring and installation of the IMPULSE™ interlock feature at your facility when replacing the factory jumper with your facility circuit loop.
- c. Output pulsing is disabled when the electrical circuit between terminal poles is open. The local user interface and internal control circuits continue to function, powered from the 120/240 VAC input, when the interlock circuit is open.



Figure 12: Interlock and factory-installed jumper.

## First Time Startup Procedure



**CAUTION: TURN OFF OR DISABLE OUTPUT OF ANY CONNECTED DC POWER SUPPLIES WHILE IMPULSE™ IS OFF**

Please see the **Important Setup and Use Information** section for details.

1. Adjust all external DC power supply operating parameters to be within the input voltage, current, and power operating limits of the IMPULSE™ unit, and disable any strike pulse function. Then turn off AC power to the external supply(s).
2. Connect all grounds, interlocks, and cabling between the IMPULSE™ unit(s) and external DC power supply and sputtering equipment. The IMPULSE™ factory-default initial configuration includes a jumper on the interlock which bypasses an external facility or equipment rack interlock, enabling the IMPULSE™ to pulse in the absence of an external interlock circuit.
3. Turn on the AC power to the IMPULSE™ unit(s) and wait for the “Settings” screen to appear, indicating that the boot up process is complete.
4. Turn on AC power to the external DC power supply(s) and verify that any strike pulse function is disabled and that the maximum voltage, current, and power settings are within the operating limits of the IMPULSE™ unit. Then enable output power from the external DC power supply(s).
5. The IMPULSE™ is shipped pre-programmed with operating parameters that are appropriate for a typical HiPIMS process. Use the IMPULSE™ unit’s Local User Interface and/or Remote User Interface to adjust the operating parameters to achieve the desired operation. Refer to the **Typical Operating Procedure**.

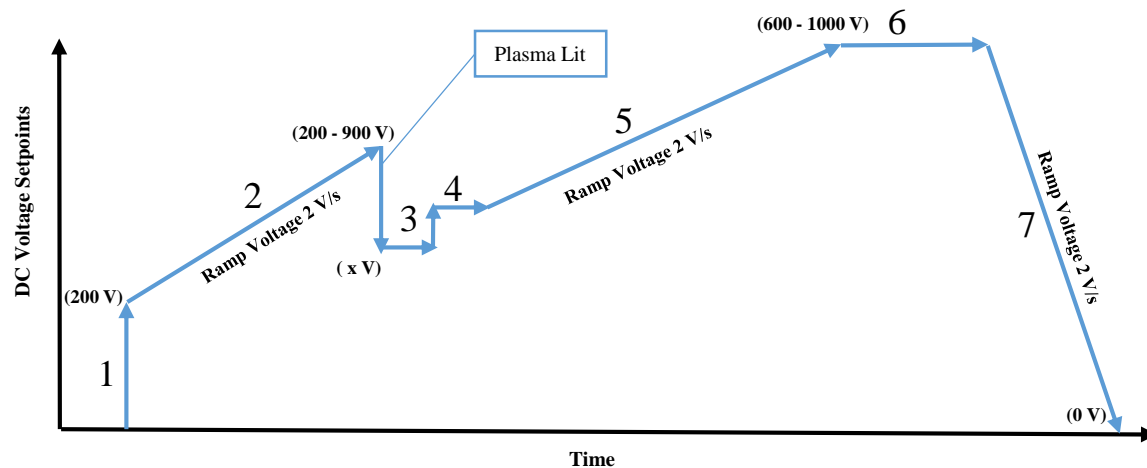
## Typical Startup Procedure



**CAUTION: TURN OFF OR DISABLE OUTPUT OF ANY CONNECTED DC POWER SUPPLIES WHILE IMPULSE™ IS OFF**

Please see the **Important Setup and Use Information** section for details.

1. Ensure that all rear panel connections are properly made and secure.
2. Turn on the AC power to the IMPULSE™ module(s), and wait for the “Settings” screen to appear, indicating the module has fully booted up. The IMPULSE™ unit’s previously set operational settings, limits, and options will be restored.
3. After all IMPULSE™ modules have initialized, turn on the AC power to connected DC power supply(s) and verify that any strike pulse function is disabled and that the maximum voltage, current, and power settings are within the operating limits of the IMPULSE™ unit. Then enable output power from the external DC power supply(s). This latter action will charge up the IMPULSE™ internal energy storage. See the **Troubleshooting** section for issues on the DC power supply(s).



DC Power Supply



HiPIMS Unit

\*If using a dual HiPIMS unit two DC power supplies are required.



Sputter Cathode

Note: Use < 6-foot coax cable to connect HiPIMS unit to sputter cathode

## 1) Initial Setpoints

- Once parameters are set first enable/start HiPIMS before enabling DC output.

### PD500X3 DC Power Supply Limits

Voltage	200 V
Current	2.2 A
Power	20 W

### Process Chamber Parameters

Ignition Pressure	15 mTorr
Target Shutter	Open
Substrate Shutter	Closed

## 2) Ramp Voltage to Ignite Plasma

- Ramp up voltage on DC supply at 2V/s to a setpoint of 900 V.
- Voltage will increase until plasma has lit.
- The power limit on the DC supply will regulate power to 20 W.
- Strike voltage can be higher than voltage required to operate at 20 W.
- Dwell for 1 minute at 20 W for stabilization purposes.

## 3) Reduce Pressure

- Voltage is floating at this point in the process and as pressure is reduced the voltage will increase to maintain a power of 20 W.
- Depending on target size, target material, and duty cycle the minimum pressures vary.
- Magnetic target require higher deposition pressures. Please add 5 mTorr to the typical minimum pressure chart for the corresponding target size.

### Typical Minimum Pressures Based on Target Size

2 Inch	10 mTorr
3 Inch	5 mTorr
4 Inch	3 mTorr

### Typical HiPIMS Deposition Parameters

Pulse Width (μs)	10 – 50
Repetition Rate (Hz)	250 – 1000
Current Limit (A)	200 – 350
Voltage (V)	600 – 1000

## 6) Deposit a Film With HiPIMS

- Kick pulse can be enabled at this time.
- Open substrate shutter and deposit film.
- Use an oscilloscope to view waveform.

### Typical Kick Pulse Parameters

Voltage (V)	25 – 100
Pulse Width (μs)	10 – 150

## 4) Transfer from Power Control to Voltage Control

- All targets differ in the amount of voltage required to operate a 20 W plasma.
- After dwelling for 1 minute at reduced pressure change DC voltage setpoint to the voltage required to operate at 20 W.
  - (Use a ramp of 0 to immediately change voltage setpoint.)
- Once the voltage is limited on the DC supply, the power limit on the DC supply can be ramped up at 3 W/s to the maximum power density for your target material.
  - For maximum power densities refer to target information on Kurt Lesker website.

## 7) Ramp Down to Power Off

- Once substrate shutter closes can ramp down DC supply voltage at 2 V/s.
- Keep target shutter open.
- Once power has reached < 20 W DC supply output can be disabled.
- Once DC supply output is disabled the HiPIMS can be disabled.

### HiPIMS Setpoints

Pulse Width	100 μs
Repetition Rate	1000 Hz
Current Limit	20 A
Kick Pulse	Disabled
Power	Desired Deposition Power

\*To explore HiPIMS operating parameters suggested to keep target shutter open. Once stable operating parameters are found they can be used for the next deposition and target shutter can remain closed until deposition phase.

## Typical HiPIMS Ignition

Standard usage of the IMPULSE™ pulsed power module is to feed DC input power in voltage control mode. The strike-pulse initiation feature present in some high-end DC power supplies is incompatible with the IMPULSE™ hardware, energy storage and pulse timing. Therefore, ignition of the HiPIMS plasma will depend on voltage and local variables such as sputter cathode size, make of sputter cathode, target material, magnetic pack configuration and strength, pre-existing erosion of the target and process gas pressure. Generally-speaking, ignition can be achieved at a voltage higher than that typically used for DC sputtering under local conditions, but not too high to mitigate arcing during ignition. In some circumstances, the strike/ignition voltage can be higher than the required operating voltage to sputter at relatively low powers or for small diameter guns. Higher process gas pressures are typically used. As a result, the user should to experiment with their local variables, target material and process conditions to ignite at relatively low powers and then ramp up to prevent damage to the target. Once an ignition recipe is established, it is relatively straightforward to use and repeat.

The following procedure is designed to be a general approach to igniting a HiPIMS plasma on 2-4" targets to prevent damaging the target, IMPULSE™ unit, or sputter cathode:

1. Complete **Typical Startup Procedure**.
2. If the sputtering target is not conditioned, then refer to the **Typical Conditioning Procedure** first.
3. If a shutter is installed, have the shutter closed during the target ignition procedure. If no shutter is installed, it is recommended to not load a substrate until after target ignition recipe is determined.
4. Connect a laboratory oscilloscope to the current and voltage monitor outputs of the IMPULSE™ following the **Rear Panel Connections** section.
5. Set an argon gas flow rate into the sputtering chamber to achieve a chamber pressure of 20mTorr. For basic IMPULSE™ users, do not use any reactive gases for initial ignition recipe determination.
6. Set an initial pulse width of 50μs, an initial repetition rate of 500Hz, an initial current threshold value of 50A, a Power Limit of 50W, and Refer to the **Operations** section for detail on how to set these parameters.



**SET CURRENT THRESHOLD APPROPRIATELY AND ADJUST AS NEEDED FOR THE DESIRED HIPIMS I-V WAVEFORM TO LIMIT OVERCURRENT AND ARC EVENTS**

Please see the **Important Setup and Use Information** section for details on current threshold.

7. Disable any kick pulse feature or quench feature. After plasma has been ignited and the target has been conditioned (see Target Conditioning), these pulse options can be enabled.
8. Tap "Start" on the IMPULSE™ module used. Only at this point should there be any output to the cathode. Nothing should happen since the DC power supply is in standby or off. This is to prevent

excess charging of the capacitor banks of the IMPULSE™ unit if there is any strike pulse feature on the DC supply.

9. During operation, the elapsed time, voltage(s), time-averaged current(s), power(s) etc. can be monitored on the IMPULSE™ module(s). Refer to the section, **Using the “Monitor” Screen**. The instantaneous voltage and current traces can be monitored on an oscilloscope (see the **Rear Panel Connections** section).



**CAUTION: REGARDLESS OF THE OPERATING MODE SELECTED, THE USER MUST ENSURE THE INPUT POWER SUPPLY IS SET UP SUCH THAT IT WILL NOT EXCEED THE OPERATIONAL LIMITS OF THE IMPULSE™: (-1000V, 4A, 2kW)**

10. Arrange the DC input power supply to be configured in “all regulation mode” with an initial voltage setpoint of 400V, the power setpoint of 40W and the maximum DC current of 4A. If possible, disable or minimize any strike-pulse features on the DC supply. Note the input DC supply power regulation is lower than the IMPULSE™ unit. This setup allows the user to start at 400V on the cathode and increase voltage to breakdown the argon gas while maintaining a power limitation on the DC supply that will cause the voltage to drop once the plasma ignites. This voltage drop is very convenient to limit power density on the target surface for ignition since HiPIMS discharges require higher operating voltages. A balance between DC power supply setpoint and IMPULSE™ supply can be very effective at ignition and sustainment over a range of target materials.



**THE IMPULSE™ MODULE POWER SETPOINT HIGHER THAN THE DC POWER SUPPLY WILL CAUSE THE DC SUPPLY TO REACH ITS POWER MAXIMUM FIRST AND THROTTLE DOWN VOLTAGE TO MAINTAIN THE AVERAGE POWER LEVEL SETPOINT. THIS LIMITS THE PEAK CURRENT DRIVE AND POWER DELIVERY TO THE TARGET—IDEAL FOR CERAMIC OR HARD TO SPUTTER MATERIALS.**

11. Enable power to output from the DC power supply to the IMPULSE™ unit.
12. Slowly increase voltage on the DC power supply at a rate of 10-20V per minute. The DC power supply will charge up the IMPULSE™ energy storage capacitor bank until the plasma ignites. For a given sputter gun configuration, pressure, magnetic pack, target wear and target material there will be a range of voltages for breakdown and plasma ignition. When this is determined, subsequent ignitions can be dialed into this value without the need for a soft start with slow voltage ramp.
13. Indications that the plasma has ignited are as follows:
  - a. The HiPIMS unit will display a power greater than 30W on the “Monitor” tab.
  - b. The DC power supply will show an output of 40W.
  - c. Increasing the voltage setpoint on the DC power supply will not increase the actual voltage output since it is in power regulation mode.
  - d. Plasma is visible in the chamber through a viewport.



14. Record the ignition voltage and the sustainment voltage (e.g. 550V ignition, 485V sustainment) with these parameters as this will serve as a starting point for future reference with this target and setup.
15. Once plasma has ignited, the DC power supply will switch to power regulation mode to maintain the 40 W power limit that was imposed. The voltage output will be lower than the voltage setpoint that was used to ignite the plasma. Decrease the voltage setpoint to ~10V below the voltage required to operate at the 40W. This will make the DC power supply switch to voltage regulation mode.
16. With the DC power supply now in voltage regulation mode, the power limit on the DC power supply can be increased to a reasonable power limit for the target material and size. Refer to max power density charts. Setting the power limit to the max power density of the target adds a level of security to prevent damaging the target.
17. Voltage, repetition rate limit, pulse width, power limit, and current limits can then be adjusted to reach the desired output conditions. This generic stepwise approach is suitable for all target materials. It is up to the user to experiment with the ignition and sustainment approach most suitable for their application.
18. Arcing may occur while increasing power density/voltage on the cathode requiring conditioning of the target surface prior to deposition. See the section on Target Conditioning.

## Typical Operating Procedure

1. Complete **Typical Startup Procedure**.
2. If the sputtering target is not conditioned, then refer to the **Typical Conditioning Procedure**.
3. Set desired pulse parameters, such as pulsing mode, timing, and limits on IMPULSE™ module(s). Refer to the **Operations** section.



### SET CURRENT THRESHOLD APPROPRIATELY TO OPTIMIZE ARC DETECTION

Please see the **Important Setup and Use Information** section for details on current threshold.

4. For -KX models with kick pulse feature, set the desired voltage, pulse timing, and current limit for the kick pulse.
5. Tap “Start” on all IMPULSE™ modules that are configured as slaves. After being started, slave modules will not produce pulses until they receive the proper synchronization signal from the master IMPULSE™ module.
6. Tap “Start” on the master IMPULSE™ module. Only at this point should there be any output from any IMPULSE™ module(s) to the cathode(s) or substrate(s).
7. During operation, the elapsed time, voltage(s), time-averaged current(s), power(s) etc. can be monitored on the IMPULSE™ module(s). Refer to the section, **Using the “Monitor” Screen**. The

instantaneous voltage and current traces can be monitored on an oscilloscope (see the **Rear Panel Connections** section).



**CAUTION: REGARDLESS OF THE OPERATING MODE SELECTED, THE USER MUST ENSURE THE INPUT POWER SUPPLY IS SET UP SUCH THAT IT WILL NOT EXCEED THE OPERATIONAL LIMITS OF THE IMPULSE™: (-1000V, 4A, 2kW)**

8. Set desired voltages on connected DC power supply(s). If possible, disable or minimize any strike-pulse features on the DC supply (optionally, Steps 5-7 can be performed after Step 2 for a faster start-up if selected operating conditions are known to work appropriately).
9. Enable output on DC power supply(s).
10. Confirm input voltages to IMPULSE™ module(s) via the “Main (-V) Voltage (V)” measurement on the status bar or “Monitor” screen.
11. After the desired time has elapsed, pause or stop the master IMPULSE™ module to stop the deposition. Note: pausing allows the deposition to be resumed later without resetting the elapsed time and total overcurrent event counters.
12. Disable the output of DC power supply(s).

## Typical Conditioning Procedure

New sputtering targets are usually “conditioned” prior to actual deposition on the substrate. Conditioning is needed to softly remove surface contamination in the form of oils (fingerprints, machining oils), cleaning solvents, surface reactions in the form of oxides, nitrides and hydrides from air and moisture exposure, and reactions from the presence of other processing gases inside the deposition system. New targets also can have surface stresses, cracks and imperfections from the machining or material fabrication process, e.g. cutting, milling and polishing a 3-inch target. These microscopic target imperfections and contaminants lead to local field enhancement at the surface that can lead to cathodic arc formation, cratering, debris generation and even target crack failure.

The IMPULSE™ has three features used during conditioning, namely: the “Arc-Arrest” and “Current Limiter” features.”, and “Power Control” features. Once voltage conditioning is completed, then current conditioning can be attempted by increasing the pulse length to achieve higher peak currents or power conditioning can be attempted by increasing the repetition rate for time average power delivered to the cathode. Once a target is conditioned, it will not be necessary to repeat this procedure for each startup.

Like DC sputter conditioning, the process consists of igniting the plasma at a low power density and gradually ramping or stepwise increasing the voltage, peak current and total power delivered to the target over a given length of time (typically several minutes per increment). Because HiPIMS is inherently pulsed at higher voltages to generate high peak currents, the conditioning process highly voltage and time



dependent. Thus, the general conditioning sequence is to condition for voltage, then condition for peak current and lastly condition for power (thermal).

The general rule is to use short pulse widths (i.e. 10-25 $\mu$ s) at a low repetition rate of 50Hz such that peak current (i.e. 20-100A) is not reached before the pulse is turned off. Then stepwise increase operating voltage (i.e. 10-20V “rise”) until the number of overcurrent events per second is less than 1 arc/sec (e.g. a few minutes of “soak”). Use a standard noble sputtering gas, such as Argon, at a moderately high pressure (e.g. 20mTorr). The actual conditioning time and rate of rise will depend on the target material and the margin level desired, i.e. 20-50V over nominal operating level. With each stepwise “rise” will lead to more conditioning events on the target surface that will be cleaned off. The goal is to achieve desirable HiPIMS waveforms for standard operation and to condition the target above the voltage, pulse width and repetition rate values for this desired waveform condition. At some point the peak current limit will be reached and the user can reduce the pulse width to continue voltage conditioning the sputtering target.

In general voltage conditioning is sufficient to prepare a target for operation; however, some target materials require current and power conditioning to achieve a relatively quiescent state for very low event HiPIMS sputtering. The secondary steps of current (plasma density) and power (thermal) conditioning may be required. The process is similar where the user increases the current limit threshold value in stepwise increments of 10-20A and increases the pulse width to allow higher current density at the target surface. For power conditioning, the preferred method is to slowly increase the power limit in 10-20W intervals using the Power Limit feature and allow the IMPULSE™ to adjust the repetition rate until power is stabilized to the target. Note, the user can directly control power via pulse frequency by manually increasing the repetition rate in 1Hz intervals. A certain amount of power will be transferred to the target each HiPIMS pulse. Increasing the repetition rate will increase this linearly.

1. If the sputtering target is already conditioned, then refer to the **Typical Operating Procedure**.
2. If a shutter is installed, have the shutter closed during the target conditioning procedure. If no shutter is installed, it is recommended to not load a substrate until after target conditioning is completed.
3. Connect a laboratory oscilloscope to the current and voltage monitor outputs of the IMPULSE™ following the **Rear Panel Connections** section.
4. Set an initial pulse width of 20 $\mu$ s, an initial repetition rate of 50Hz, an initial current threshold value of 20A, and chamber pressure to 20mTorr argon. Set a Power Limit of 200W to start. Disable any kick pulse feature and disable any slave devices. Do not use any reactive gases for conditioning. Refer to the **Operations** section for detail on how to set these parameters.

**SET CURRENT THRESHOLD APPROPRIATELY TO FOCUS ON TARGET VOLTAGE  
CONDITIONING**

Please see the **Important Setup and Use Information** section for details on current threshold.

5. Tap “Start” on the IMPULSE™ module used for target conditioning. Only at this point should there be any output to the cathode.

6. During operation, the elapsed time, voltage(s), time-averaged current(s), power(s) etc. can be monitored on the IMPULSE™ module(s). Refer to the section, **Using the “Monitor” Screen**. The instantaneous voltage and current traces can be monitored on an oscilloscope (see the **Rear Panel Connections** section).



**CAUTION: REGARDLESS OF THE OPERATING MODE SELECTED, THE USER MUST ENSURE THE INPUT POWER SUPPLY IS SET UP SUCH THAT IT WILL NOT EXCEED THE OPERATIONAL LIMITS OF THE IMPULSE™: (-1000V, 4A, 2kW)**

7. Set an initial voltage of 400V on the connected DC power supply. If possible, disable or minimize any strike-pulse features on the DC supply (optionally, Steps 7-9 can be performed after Step 4 for a faster start-up if selected operating conditions are known to work appropriately).
8. Verify the DC supply is primarily set in voltage control mode with a secondary power limit not to exceed the thermal limitation of the sputtering target.
9. Enable output on DC power supply.
10. Confirm input voltages to IMPULSE™ module(s) via the “Main (-V) Voltage (V)” measurement on the status bar or “Monitor” screen and on the attached laboratory oscilloscope for I-V waveforms.
11. Increase the target voltage on the DC power supply gradually in 10-20V increments until initial plasma is struck.
12. Examine the I-V waveforms on the laboratory oscilloscope. The HiPIMS current waveform should show an increasing current ramp that is terminated at 20 $\mu$ s. If the HiPIMS pulse is less than the initial pulse width setting (i.e. 20 $\mu$ s), review the status bar or “Monitor” screen for the Overcurrent Count Rate (1/s) to determine if the Arc-Arrest or Current Limiter feature is measuring events. A value of  $\sim 20$  I>Ilim events is indicative of either significant target conditioning or the Current Threshold setpoint too low for this target material. Conditioning events will be correlated to exponential increases in current with an abrupt change in dI/dt slope. Very high plasma current density will have a current ramp exceeding the Current Threshold Setpoint. If the I-V waveform does not show abrupt changes in dI/dt, then the user has the option to decrease the pulse width in 1  $\mu$ s increments or increase the current threshold in 10A increments until a stable Overcurrent Count Rate (1/s) < 1 is reached.
13. Hold (“soak”) at this condition for 1 minute. Then increase the DC supply voltage stepwise in 10-20V increments. Each time voltage (and therefore peak current) is increased the rate of arcing will rise. Hold at this voltage until the Overcurrent Count Rate (1/s) reduces to a level of <1 for another minute. If the value is stays continuously at  $\sim 20$  I>Ilim then check on the oscilloscope to determine if the pulse width is too long to exceed the peak current setpoint. The user can adjust the peak current setpoint higher or decrease the pulse width (preferred).
14. Continue incremental “rises” in voltage and “soak” delays until the target cathode conditions off surface impurities, imperfections, oxides, nitrides, and thermally anneals. Typically condition 20-

50V over the desired operating point evidenced by I-V waveforms on the oscilloscope showing triangular-like current pulses.

15. Incrementally increase pulse width to increase peak current driven on each HiPIMS pulse to a desired value for plasma density near the target (e.g. 200A peak) with a corresponding increase in the overcurrent threshold.
16. Incrementally increase repetition rate (e.g. 1kHz) via direct numerical control or Power Limit mode to increase the total power delivered to the cathode without excessive current that can lead to striations and cathode instabilities.
17. Open shutter to begin deposition at the desired setpoint or pause or stop the master IMPULSE™ module to stop the deposition. Note: pausing allows the deposition to be resumed later without resetting the elapsed time and total overcurrent event counters.
18. When finished, follow the Shutdown Procedure.

## Typical Shutdown Procedure

1. Turn off the AC power to connected DC power supplies.
2. Turn off the AC power to the IMPULSE™ module(s).



**CAUTION: TURN OFF OR DISABLE OUTPUT OF ANY CONNECTED DC POWER SUPPLIES WHILE IMPULSE™ IS OFF, PREFERABLY BEFORE IMPULSE™ IS SHUT OFF.**



**WARNING: NEVER DISCONNECT CABLES WHEN HIGH-VOLTAGES ARE PRESENT**

# Operations

The IMPULSE™ unit's operational mode, options, settings, and limits are set either locally at the unit or remotely through either an Ethernet connection or a Serial RS-422 connection.

## Local User Interface

### General User Interface Operation

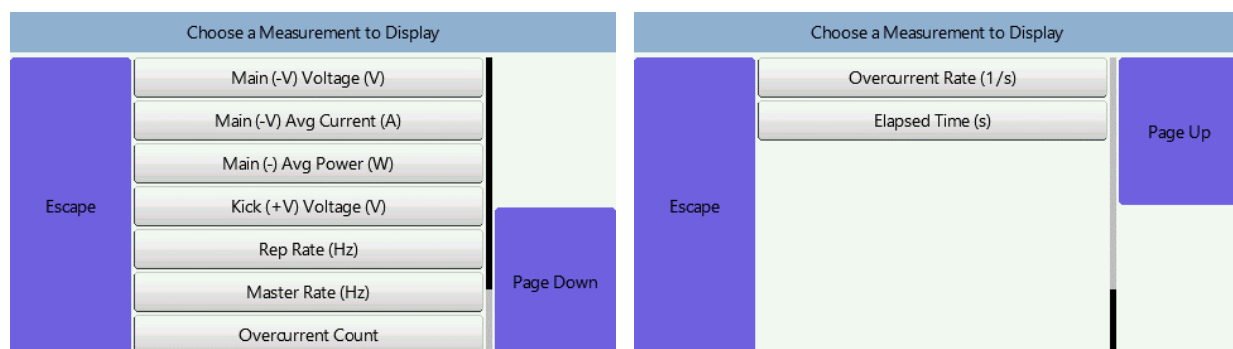
Each IMPULSE™ module is controlled and monitored through a capacitive touchscreen interface and two control knobs on the front panel. The interface displays one of six main screens, “Settings”, “Limits”, “Monitor”, “Faults”, “Configs”, and “System”. Select a screen to display by tapping the corresponding tab at the top of the display. Each screen contains controls, settings, and readouts that are relevant to that category of IMPULSE™ features. An “Activity” bar remains at the bottom of the display for all screens. It contains a Start/Pause button for starting and pausing pulse output and two user-selectable readouts that provide real-time monitoring of the system.

Operating mode controls and settings are accessed through drop-down list buttons and option check boxes. To select an operating mode, enable an option, or access a group of settings, tap the associated drop-down button or check box. To change a setting, tap on the desired setting and enter the new value in the on-screen numeric keypad that appears. Hardware capabilities and/or other system settings limit some settings. For example, the total duration of the pulse times and widths are limited by the pulse repetition rate limit. When a value outside of such a limit is entered from the keypad, the value will revert to its previous valid value and will flash **red** briefly. In contrast, when a valid value is typed in, the new value replaces the old value on the screen and blinks **green** briefly.

Settings displayed within a purple box on the left or right side of the screen can be adjusted by tapping them and using the keypad, as described above, or by turning the nearby knob on the front panel of the IMPULSE™ unit. If a value outside of the limit is reached while turning the knob, the value of the setting on-screen will turn **red** and the associated knob will have no further effect.

<i>Table 2. Measurements available for display in the Activity bar</i>	
Measurement Name	Description
Main (-V) Voltage (V)	The input/output voltage in Volts
Main (-V) Avg Current (A)	The time-averaged current in Amps
Main (-V) Avg Power (W)	The time-averaged power in Watts [product of “Main (-V) Voltage (V)” and “Main (-V) Current (A)”]
* Kick (+V) Voltage (V)	* The voltage delivered by the internal Kick power supply in Volts
Rep Rate (Hz)	The measured pulse repetition rate in cycles/second
Master Rate (Hz)	The pulse repetition rate of a connected Master
Overcurrent Count	The number of times the instantaneous current has exceeded the user-set current limit during the present run
Overcurrent Rate (1/s)	The approximate rate of overcurrent threshold events per second
Elapsed Time (s)	The elapsed time of the present run in seconds

The Activity bar at the bottom of the screen can display any two of the possible measurements shown in *Table 2*. Items marked with an asterisk (\*) are available only on units with the “Kick” option installed. To change a displayed measurement, tap the measurement name on either readout on the Activity bar to display a page-scrollable list of the available measurements, as shown in Figures 13a. and 13b. Tap the desired measurement on the list to select it for display in the chosen readout on the Activity bar.



*Figures 13a. and b. Measurement Selection*

If there is a warning or fault condition that prevents starting of the IMPULSE™ unit, an orange box with the error code will appear over the Start/Pause button on the Activity bar. See **Using the “Faults” Screen** and the **Errors and Fault Messages** section for more information.

### Using the “Settings” Screen

The “Settings” screen allows the user to set the pulse mode for the IMPULSE™ module and any relevant pulse timing, voltage, and power characteristics for the selected mode. The mode choices are “Master” and “Slave”. Depending on the mode chosen, the available settings will change, as will the pulse diagram (drawn in red, not to scale) to show the pulse settings for that mode. After selecting the operating mode,



choose which pulse to set up, either Main or Quench (or Kick, if installed) by tapping the button for the desired pulse.

Each IMPULSE™ unit configured in Master mode initiates the pulse cycles based upon the user's settings and generates a Sync pulse at the start of each pulse cycle. Any IMPULSE™ unit(s) configured as a Slave must be connected to the Sync pulse to allow synchronous operation with the Master IMPULSE™ unit. Refer to **Appendix C: Master/Slave Applications** for more information. The start of the pulse cycle is represented on the display by the vertical axis at the left-most edge of the pulse diagram, and always corresponds to the Master unit's Main pulse leading edge. When setting up the Main pulse on a Master module, use the left knob to adjust the pulse width to the desired time, in microseconds, of the "on" portion of the pulse, and use the right knob to adjust the Repetition Rate Limit, setting the maximum number of pulses output in one second. The IMPULSE™ will run at the Repetition Rate Limit unless maintaining the Power Limit requires a lower operating frequency, as described in Using the "Limits" Screen on page 30. The actual repetition rate used and the corresponding pulse cycle period are displayed on this screen for reference. Refer to Figure 14 for an example of the screen used for setting up a Master unit's Main pulse.

When setting up a Slave unit's Main pulse or any unit's Quench (or Kick, if installed) pulse, use the right knob to adjust the pulse width to the desired time, in microseconds, of the "on" portion of the pulse, and use the left knob to adjust the delay time, in microseconds, from the pictured event. The red pulse diagram changes to show a Slave's Main pulse that starts after the beginning of the pulse cycle. Refer to the screen examples in Figure 15 and Figure 16. In Slave mode, the pulse does not necessarily turn on at the same time as the master (but can). Setting the Slave's Main pulse delay to 0 makes the Slave's Main pulse start coincident with the Master's Main pulse. To maximize the extent of the Afterglow, the Quench or Kick pulse can be disabled, leaving the output in a high-impedance state for the duration of the pulse cycle. When the Quench or Kick pulse is enabled, the delay time defines the plasma Afterglow time.

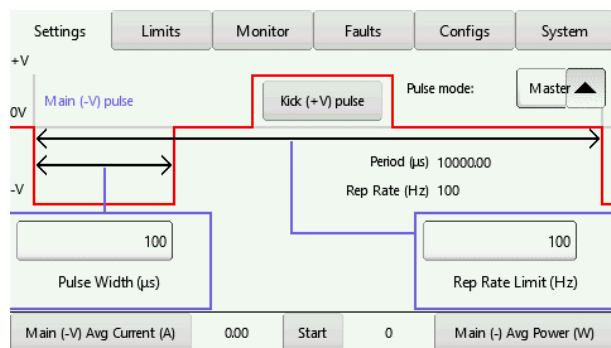


Figure 14. Settings screen in “Master” mode, setting up Main pulse

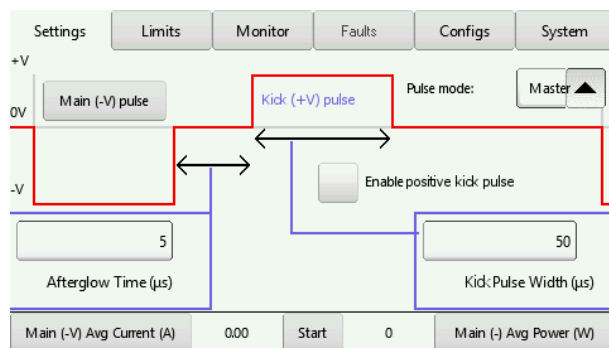


Figure 15. Settings screen in “Master” mode, setting up Kick pulse

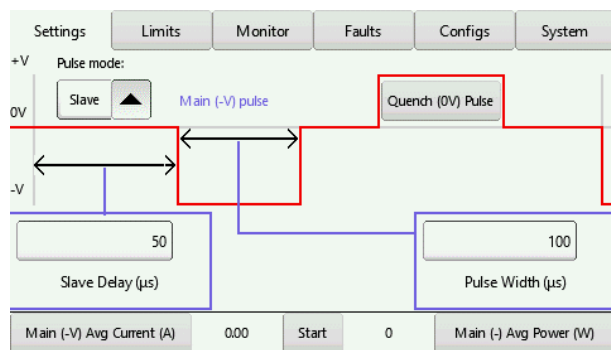


Figure 16. Settings screen in “Slave” mode, setting up Main pulse

### Using the “Limits” Screen

The “Limits” screen controls the maximum instantaneous output pulse current and average pulse power output by the IMPULSE™ module. It also allows the user to choose between “High Current” or “High Frequency” (also called “High Rep Rate”) operation and, for a Master unit, select “Power Control” upper limit, default at 2kW. The Main pulse current limit and Kick pulse current limit are set independently by tapping the button to select the desired pulse. Refer to the examples of the Limits screen in Figure 17 and Figure 18.

The Current limit for the selected pulse is shown within the purple box, so the value can also be adjusted with the knob to the left of the LCD screen. The IMPULSE™ hardware terminates any output pulse that reaches the set value of instantaneous current. Note: If the limit is set above 200A during High Current operation and the unit is then switched to High Frequency operation, the limit will be reduced to 200A. It will remain at 200A when the unit is returned to High Current operation until the user sets it.

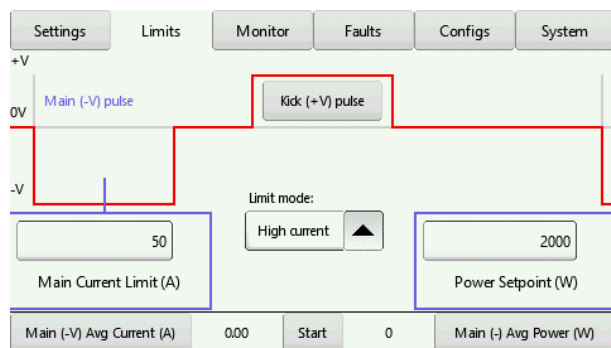


Figure 17. Limits screen in Master mode for the Main pulse

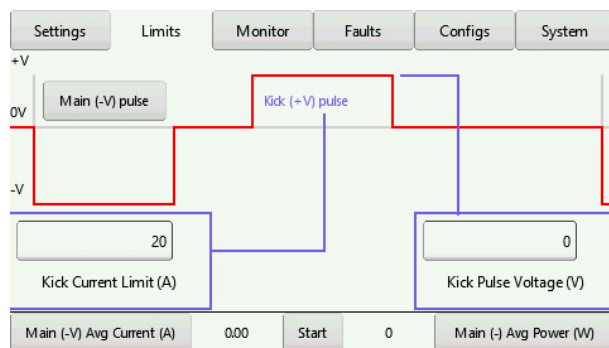


Figure 18. Limits screen for the Kick pulse

The Power setpoint causes a Master IMPULSE™ unit to adjust the repetition rate of pulses up or down to maintain the Main pulse at the set average power level. The average power is internally calculated as the multiple of the integrated input current and voltage for the Master IMPULSE™. This is ideal for users with a specific power level in mind for a given material and sputter cathode size, e.g. 500W on a 2" gun. In addition, the repetition rate is limited to the rate entered on the "Settings" screen. The unit will not exceed the repetition rate limit while attempting to attain the desired power. Since the Master IMPULSE™ sets the repetition rate for all Slave units, this Power Control feature will dynamically adjust the repetition rate for all connected IMPULSE™ units.



**CAUTION: Regardless of the operating mode selected, the user must ensure that the input power supply is set up such that it will not exceed the operational limits of the IMPULSE™: (-1000V, 4A, 2kW)**

### Using the "Monitor" Screen

The "Monitor" screen, as shown in Figure 19, displays all of the measured parameters at the same time. All the measurements listed in *Table 2* are displayed, in addition to an overcurrent event indicator. The colored "Overcurrent Arrested" circle on the right-side column of the "Monitor" screen turns blue when the pulse current exceeds the user-set limit or the "Arc-Arrest" feature has been activated. The "Overcurrent Count" indicator gives a proxy for the count of the over current events captured by the user software for the duration of the IMPULSE™ run (reset after each stop/start). The "Overcurrent Rate (1/s)" indicator gives an approximate average rate of software-captured overcurrent events per second. Comparing this rate to the actual instantaneous pulse repetition rate provides an indicator for evaluating magnetron cathode conditioning.

The Overcurrent Arrest and Arc-Arrest are physical hardware features that operate on each pulse (i.e. up to 4kHz); however, the software reporting for the monitoring screen is limited by software polling time with a maximum displayed Overcurrent Rate (1/s) of ~20 counts/second. For well-conditioned targets the displayed values are accurate; however, for targets experiencing many events, or the current setpoint is too low such that it is triggering an overcurrent each pulse, the displayed Overcurrent Count and



Overcurrent Rate (1/s) values will be significantly lower than actual due to the polling and counter reset time within the user software.



**INFORMATION:** The hardware Overcurrent and Arc-Arrest protection features operate on each pulse, however, the Monitor screen Overcurrent Rate (1/s) indicator has a maximum value of ~20 counts/second that can be polled and displayed. The actual value could be significantly higher and should be treated as such.

Settings	Limits	Monitor	Faults	Configs	System
Main (-) Voltage (V)	0		Pulse Mode:	Master	
Main (-) Current (A)	0.00		Overcurrent Arrested	<input type="checkbox"/>	
Main (-) Power (W)	0		Overcurrent Count	1	
Kick (+) Voltage (V)	0		Overcurrent Rate (1/s)	0	
			Running for (hh:mm:ss)	00:00:00	
Pulse Rep Rate (Hz)	0		<div>Stop</div> Resets overcurrent counter and run timer at next Start.		
Sync Rep Rate (Hz)	0				
Main (-V) Avg Current (A)	0.00	Start	0	Main (-) Avg Power (W)	

Figure 19. Monitor screen

Although the “Monitor” screen has no adjustable settings, it provides a button to “Stop” pulsing operation in addition to the Activity Bar’s “Start” and “Pause” operations. Using “Pause” maintains the values of cumulative counters (elapsed time and over-current count) when pulsing is restarted, while restarting after the “Stop” button has been pressed will reset all counters to 0.

### Using the “Faults” Screen

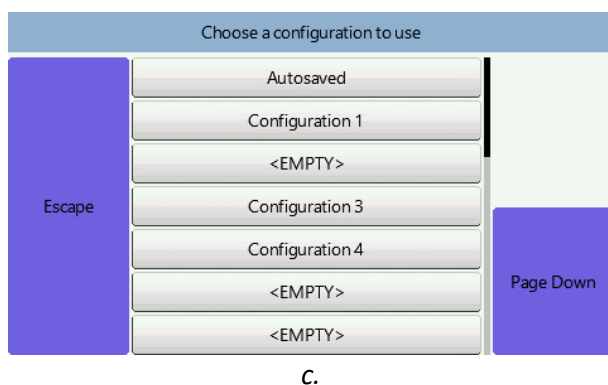
When the IMPULSE™ encounters a problem that prevents it from generating output pulses, the “Faults” screen, shown in Figure 20, provides detailed information of the error condition and what must be done to correct it. Refer to the “Faults” screen for assistance any time that an orange fault indication covers the Activity Bar’s Start/Pause button or when the “Faults” tab is red.

Settings	Limits	Monitor	Faults	Configs	System
Fault					
		Status	Action Required		
Other active master		None	Stop other master, check sync bus		
IMPULSE temperature		High	Wait for unit to cool down		
Safety interlocks		Safe	Close interlock, then Restart		
Kick Supply Voltage		Low	Reduce Pulse Repetition Rate (See Manual)		
Calibration Status		OK	Calibrated		
Main (-V) Avg Current (A)	0.00	T !	0	Main (-) Avg Power (W)	

Figure 20. Faults screen

## Using the “Configs” Screen

The “Configs” screen provides the capability to save the user-defined settings, which are established on the “Settings” and “Limits” screens, across power cycles. Refer to the screen examples in Figures 21a. and b. Select the dropdown to display a page-scrollable list of 21 selectable slots for saving configurations, as shown in Figures 21c. By default, these slots are named “Autosaved” and “Configuration 1” through “Configuration 20”. Note that all of the slots except the “Autosaved” slot can be renamed through the Remote User Interface using the “CONFIGURATION:SAVE” command.



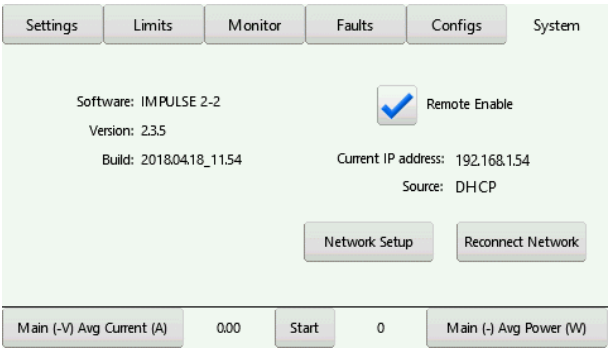
Figures 21a., b., and c. Configs screen and Configuration Selection

The IMPULSE™ automatically saves the active user settings in the “Autosaved” slot whenever pulsing is started, paused, or stopped, and automatically loads the last used (Autosaved) settings each time the unit is powered back on. In addition, the user can manually save, display, recall, and delete the settings in any configuration slot by tapping the drop-down box and selecting the desired slot from the list. Any slot marked “<EMPTY>” has not been used or has been deleted and is available for use. Selecting a slot displays the settings (if any) that are saved in that slot without modifying the active settings. Tap the “Save” button to save the active settings into the selected slot. Tap the “Recall” button to replace the active settings with those from the selected slot, and return to the “Settings” screen. Tap the “Delete” button if the settings in the selected slot are no longer needed. Note that the active settings can be saved into and recalled from the “Autosaved” slot, but the Autosaved settings cannot be deleted.



Using the “System” Screen

The “System” screen shows information about the IMPULSE™ system hardware and software, such as the version number of the currently installed IMPULSE™ software, to aid in receiving the most relevant customer service. This screen also allows the user to enable and disable the Remote User Interface, and to configure the network settings for the Remote User Interface. Refer to the **Remote User Interface** section for more information.



a.

Figure 22. System screen

## Errors and Fault Messages

Error code on status bar	Message on “Faults” screen	Explanation
#M !	“Another master was detected. Only one master can be pulsing at a time.”	The unit is configured to be a master, and detected sync pulses on the sync bus from another master. Reconfigure one of the master units to slave mode, or do not connect them via the sync bus.
T !	“IMPULSE temperature is too high. Pulsing can be resumed once the unit cools down.”	The IMPULSE™ pulsed power module contains an internal thermal switch to prevent components from overheating. During extreme pulsing conditions (high power, high rep rate, etc. – see derating curves) the thermal switch may trip. This message will be displayed on the screen. After the components have cooled down, the warning will be removed from the display and pulsing can be resumed.
F !	Numerous	Check Faults screen message

## Remote User Interface

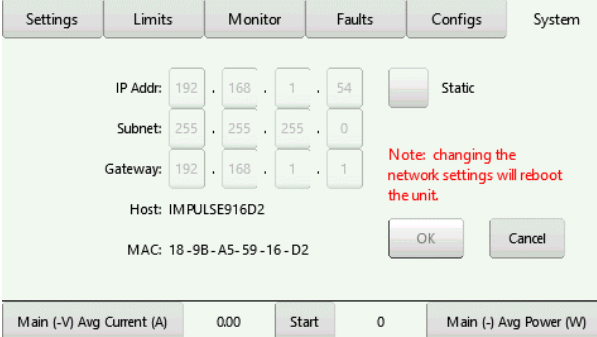
The IMPULSE™ 2-2 can be remotely operated either through a Telnet connection over an IEEE 802 Ethernet network or through an RS-422 Serial connection. Each side of a dual IMPULSE™ unit is independently controlled through a unique connection. The Remote User Interface connection uses the command syntax that is described in this Manual. Commands, queries, and responses are directly sent and received as 8-bit ASCII (UTF-8) character strings without any added protocol headers.

### Connecting to the IMPULSE™ Remote Interface via Ethernet

The IMPULSE™ 2-2 provides an RJ45 jack for connection to the network. Each side of a dual unit has a separate jack and is identified to the network with a unique network address. The specific address for each side of the unit may be supplied either from a DHCP server, if there is one on the network, or as a static address that is manually set from the front panel of the unit.

After the IMPULSE™ unit has been turned on, perform the following steps:

1. Select the “System” tab and enable the remote interface with the “Remote” checkbox.
2. Select the “Network Setup” button to display the screen shown in Figure 23 which shows the network addresses currently in use.



a.

Figure 23. Network Setup screen

3. To enable dynamic (DHCP) addressing, deselect the “Static” checkbox. The system will establish the IP addresses as follows:
  - a. If there is a DHCP address server on the local network and no static address has been previously set, the IP Address and Subnet mask assigned by the DHCP server are displayed, along with the address of the internet Gateway if one is present on the local network.
  - b. If there is no DHCP server found on the network or if it cannot provide an address, then the IMPULSE™ will use the most recently setup static addressing.
  - c. If there is no DHCP server or if it does not provide an Internet Gateway address, the Gateway address will be set to the most recently used Gateway address.



4. To set a specific Static address, select the “Static” checkbox and set the desired static IP Address, Subnet, and Gateway by tapping each address element and using the numeric keyboard that appears.
  - a. Each address element must be entered individually.
  - b. The “Cancel” button will return to the “System” screen without changing the network setup.
  - c. The “Use” button will make temporary changes to the network setup and return to the “System” screen.
  - d. The “Save” button will change the network setup, permanently save the setup in the IMPULSE™ unit for future use, and return to the “System” screen.

After the IMPULSE™ has been connected to the network and an address has been established, open a Telnet connection from the network computer that will control the IMPULSE™ unit. This can be done on a connected computer with a terminal program that supports the Telnet protocol. Open the connection using the address of the IMPULSE™ unit. If required, use port 23, the standard Telnet port. Note that two separate Telnet connections are required to control both sides of a dual IMPULSE™ unit.

When the connection is established, the IMPULSE™ responds with identification information that includes the firmware version and build date and time. This transmission can be recognized to verify the connection.

### **Connecting to the IMPULSE™ Remote Interface via Serial RS-422**

The IMPULSE™ 2-2 provides an RS-422 Serial connection through a standard 4-wire terminal block connector, allowing direct communication with an industrial controller or, through an appropriate RS-422 adapter cable, a computer. Each side of a dual unit has a separate connector, allowing independent control through, for example, multiple COM ports on a host computer.

The Serial Port is compatible with RS-422 ports commonly found on industrial control equipment and USB-to-RS-422 adapters and adapter cables. Connect RX+/RX- at either end of the connection to TX+/TX- respectively at the other end. No Ground or Power connections are provided at the IMPULSE™ to ensure electrical isolation between the IMPULSE™ and the connected remote controller. The port is configured at 9600 baud, 8-bits, no parity, and 1 stop bit. There is no hardware (DTR/DCS) or software (XON/XOFF) handshaking provided or expected.

During boot-up, the IMPULSE™ sends to the Serial port identification information that includes the firmware version and build date and time. If the host computer or terminal establishes the serial port connection prior to IMPULSE™ boot-up then this transmission can be recognized to verify the connection. If the terminal connection is established after boot-up, the connection can be verified by issuing an \*IDN? query from the host.



## Command Syntax

The IMPULSE™ 2-2 accepts programming commands and queries formatted according to the Standard Commands for Programmable Instruments (SCPI) specification. Programming commands cause the IMPUSLE™ 2-2 to either set up parametric values for operation, perform an action, or perform an action using specified values. Queries return information about the IMPULSE™ system's current setup and operating status.

SCPI syntax has the following properties:

1. Each input line must contain exactly one command or query and is terminated with a carriage return and line feed.
2. A command input line starts with keywords that define the scope of the command, possibly followed by an action keyword for the designated scope, with each keyword separated by a colon (:).
3. A command's keywords may be followed by a space and then one or more parameters, with each parameter separated by a comma. At least one space is required between the command's last keyword and any subsequent parameters.
4. An information query input line starts with keywords that define the scope of the query, with each keyword separated by a colon (:). A query has no parametric values and ends with a question mark (?).
5. The keywords are not case-sensitive, and the input line may contain extra spaces and/or tabs between keywords and delimiters.

After the IMPULSE™ 2-2 receives each SCPI input line, it responds with either "OK" to indicate that a command or operation completed successfully, or with the information requested by a query, or with an error message if it is unable to complete the command or query. The response may span several lines and will always be followed by a blank line. Each line of the response is terminated with a carriage return and line feed.

Below is an example of a series of IMPULSE™ 2-2 SCPI commands and responses:

```
CONFIG:MODE?  
MASTER  
  
CONFIG : REPRATE 500  
OK  
  
CONFIG: MAIN:  WIDTH 200  
OK  
  
CONFIG:KICK:ENABLED ?  
DISABLED  
  
OUTPUT:START
```



OK

OUTPUT ?

RUNNING

In this example, the configured mode is queried and the IMPULSE™ reports that it is in MASTER mode. Then the repetition rate limit is set to 500 Hz, the main pulse width is set to 200  $\mu$ s, and the kick pulse is queried to which the IMPULSE™ reports that it is disabled. Finally, output pulsing is started, the state of the output is queried, and the IMPULSE™ reports that it is pulsing.

The IMPULSE™ 2-2 command descriptions that follow and the complete lexicon in Appendix D use these syntax notations:

- Question mark (?) and colon (:) characters must be typed as shown.
- <n> represents a parameter that is specified as a decimal floating-point number.
- <s> represents a parameter that is specified as a character string; if the string contains any special characters (colon, comma, or question mark) or spaces it must be contained within double-quotes.
- <b> is a Boolean value, represented as 1, TRUE, YES, or ON; or 0, FALSE, NO, or OFF. Any equivalent Boolean value will be interpreted the same by SCPI.
- Square brackets, [ . . . ], designate optional keywords. The brackets are not entered on the command line.
- Curly braces, { . . . }, surround several options when one must be specified or when only one is returned in a response. The braces are not entered on the command line, nor are they returned in the response.
- A vertical bar, |, separates the options within braces; these are not entered on the command line, nor are they returned in the response, and only one of the options may be entered or returned.
- All keywords have acceptable three-character or four-character minimum abbreviations. These abbreviations are written in CAPITAL letters in the syntax descriptions, but they can be entered in lower or mixed case when input.
- Additional letters in keywords (written in lowercase in the syntax descriptions) are not required for any keyword but may be typed as shown (in upper, lower, or mixed case) or truncated.
- Keywords can be truncated to any number of characters between the required abbreviation and the full word.
- When an asterisk (\*) precedes a keyword, it is part of the keyword; it must be typed as shown without any adjacent whitespace.

In the command definitions below, many commands include multiple examples. Recall that each SCPI line is a separate command.

## Output Commands

The output commands and queries control and report whether the output is actively being pulsed.





## Start Output Pulses

### Description

This command starts pulsing the output using the current settings, and cumulative measurements begin accumulating data.

### Syntax

OUTPut:STArt

### Examples

OUTP:START

Output:sta

### Response

OK

## Pause Output Pulses

### Description

This command pauses the pulse output such that it may be resumed with a START command. Cumulative measurements such as elapsed time and the overcurrent event counter keep their current values. When pulsing resumes (with the START command), they will resume accumulating data.

### Syntax

OUTPut:PAUse

### Example

Outp:pau

### Response

OK

## Stop Output Pulses

### Description

This command stops the pulse output. When pulsing is resumed with a START command, cumulative measurements such as elapsed time and the overcurrent event counter are reset to 0 before data accumulation starts.

### Syntax

OUTPut:STOp

### Example

Output:STOP

### Response

OK

## Query Output State

### Description

This query returns the output state of the IMPULSE™ unit.

### Syntax

OUTPut?

### Example

OUTP?

### Response

{ RUNNING | PAUSED | STOPPED }

## Configuration Commands

Use the configuration commands and queries to setup the IMPULSE™ features and parameters that define how the unit will control output pulses.

## Query Complete Configuration

### Description

This query returns a complete description of the current configuration of the IMPULSE™ unit.

### Syntax

CONFigure?

### Example

CONF?

### Response

CONFIGURATION:

NAME: Autosaved

MODE: { MASTER | SLAVE }

OPTION: { HIGH REP RATE | HIGH CURRENT }

REPRATELIMIT: <n>

POWERLIMIT: <n>

MAINPULSE:

MASTER:

WIDTH: <n>

SLAVE:

WIDTH: <n>

DELAY: <n>

CURRENTLIMIT: <n>

AFTERGLOW: <n>

{ KICK | QUENCH } PULSE:

WIDTH: <n>

VOLTAGE: <n>



```
CURRENTLIMIT: <n>
{ENABLED|DISABLED}
CATALOG: 0 Entries
20 empty local configurations.
```

## Configure Operating Mode

### Description

This command sets the primary operating mode of the IMPULSE™ unit to either Master or Slave. Some other elements of the configuration, such as current limits and pulse widths, may also change, depending upon programmed settings.

### Syntax

```
[CONFigure:]MODE:{MASTER|SLAVE}
```

### Examples

```
CONF:MOD:MAST
Mode: Slave
```

### Response

```
OK
```

## Query Operating Mode

### Description

This query returns the current primary operating mode of the IMPULSE™ unit.

### Syntax

```
[CONFigure:]MODE?
```

### Examples

```
CONF :MOD ?
MODE?
```

### Response

```
MODE = {MASTER|SLAVE}
```

## Configure Limits Option

### Description

This command sets the limits Option which allows the IMPULSE™ unit to operate with either a high current limit or a high pulse repetition rate (high frequency). The REPRate and FREQUENCY options are identical.

### Syntax

```
[CONFigure:]OPTion:{CURRent|REPRate|FREQUENCY}
```

### Examples

```
CONF:opt:current
```



```
option: rebrate  
OPT:FREQ  
OPT :CURR
```

### Response

OK

## Query Limits Option

### Description

This query returns the limits Option setting of the current configuration.

### Syntax

```
[CONFigure:]OPTion?
```

### Examples

```
CONFIG:OPTION?  
OPT?
```

### Response

```
{HIGH REP RATE|HIGH CURRENT}
```

## Configure Pulse Repetition Rate (Frequency) Limit

### Description

This command sets the maximum Pulse Repetition Rate (Pulse Frequency) in Hertz (HZ) at which the IMPULSE™ unit will operate. Either REPratelimit or FREquencylimit may be used to set this operating parameter.

### Syntax

```
[CONFigure:]{REPratelimit|FREquencylimit} <n>
```

### Examples

```
CONF:REP 100  
Rebrate 250  
FREQ 150
```

### Response

<n>

## Query Pulse Repetition Rate (Frequency) Limit

### Description

This query returns the maximum Pulse Repetition Rate (Pulse Frequency) in Hertz (Hz) at which the IMPULSE™ will operate. REPratelimit and FREquencylimit both query the same operating parameter.

### Syntax

```
[CONFigure:]{REPratelimit|FREquencylimit}?
```



### Examples

CONF:REP?

Freq?

### Response

<n>

## Configure Average Output Power Limit

### Description

This command sets the maximum average output power in Watts (W) at which the IMPULSE™ unit will operate.

### Syntax

[CONFigure:]POWerlimit <n>

### Examples

CONF:POW 1000

pow 1500

### Response

OK

## Query Average Output Power Limit

### Description

This query reports the maximum average output power in Watts (W) that the IMPULSE™ will supply.

### Syntax

[CONFigure:]POWerlimit?

### Examples

CONF:POW?

pow?

### Response

<n>

## Query Main Pulse Configuration

### Description

This query returns the current configuration of the Main pulse, including the independent timing settings that are maintained for the Main pulse for both the Master and Slave mode.

### Syntax

[CONFigure:]MAInpulse?

### Examples

CONFIG:MAIN?

MAI?



### Response

```
MAINPULSE:
  MASTER:
    WIDTH: <n>
  SLAVE:
    DELAY: <n>
    WIDTH: <n>
  CURRENTLIMIT: <n>
```

## Configure Main Pulse, Master Mode

### Description

This command sets the width of the main output pulse when operating in Master mode. The pulse width is specified in microseconds.

### Syntax

```
[CONFigure:]MAInpulse:[MASTer:]WIDTh <n>
```

### Examples

```
Conf:main:width 50
MAIN:Master:Width 25
MAIN:WIDT 100
```

### Response

```
OK
```

## Query Main Pulse Configuration, Master Mode

### Description

This query returns the width of the main output pulse when operating in Master mode. The pulse width is specified in microseconds.

### Syntax

```
[CONFigure:]MAInpulse:MASTer?
```

### Examples

```
Conf:main:mast?
MAIN:Master ?
MAIN: master?
```

### Response

```
MAIN:
  WIDTH: <n>
```



## Configure Main Pulse, Slave Mode

### Description

This command sets the width and delay of the main output pulse when operating in Slave mode. Both the pulse width and the delay are specified in microseconds, and the delay specifies the time between the start of the Master's main pulse and the Slave's main pulse.

### Syntax

```
[CONFigure:]MAInpulse:SLAVe:{WIDTh|DELAy} <n>
```

### Examples

```
Conf:main:slave:width 50  
MAIN: SLAV:DELA 25  
MAIN : SLAVE:Width 100
```

### Response

OK

## Query Main Pulse Configuration, Slave Mode

### Description

This query returns the width and delay of the main output pulse when operating in Slave mode. The pulse width is specified in microseconds.

### Syntax

```
[CONFigure:]MAInpulse:SLAVe?
```

### Examples

```
Conf:main:SLAV?  
MAIN : Slave ?  
MAIN: slav?
```

### Response

```
SLAVE:  
  WIDTH: <n>  
  DELAY: <n>
```

## Query Main Pulse Configuration Parameter, Slave Mode

### Description

This query returns the width and delay of the main output pulse when operating in Slave mode. The pulse width is specified in microseconds.

### Syntax

```
[CONFigure:]MAInpulse:SLAVe:{WIDTh|DELAy}?
```

### Examples

```
Conf:main:SLAV:WIDT?  
MAIN:Slave : Delay ?
```

### Response

<n>

## Configure Main Pulse Current Limit

### Description

This command sets the current limit of the main output pulse. The limit, specified in Amperes (A), establishes the output current at which the pulse output is interrupted.

### Syntax

```
[CONFigure:]MAInpulse:CURRentlimit <n>
```

### Examples

```
Conf :main:current 50
```

```
MAIN : CURR 25
```

### Response

OK

## Query Main Pulse Current Limit

### Description

This query returns the current limit of the main output pulse. The limit, specified in Amperes (A), establishes the output current at which the pulse output is interrupted.

### Syntax

```
[CONFigure:]MAInpulse:CURRentlimit ?
```

### Examples

```
Conf:main:current ?
```

```
MAIN:CURR ?
```

### Response

<n>

## Configure Afterglow Time

### Description

This command sets the time that a plasma afterglow will be allowed to persist before it is terminated with a Quench pulse (or Kick pulse, if installed). The afterglow time is specified in microseconds.

### Syntax

```
[CONFigure:]AFTerglow <n>
```

### Examples

```
Conf:afterglow 50
```

```
AFT 25
```

### Response

OK



## Query Afterglow Time

### Description

This query returns the time that a plasma afterglow will be allowed to persist before it is terminated with a Quench pulse (or Kick pulse, if installed). The afterglow time is specified in microseconds.

### Syntax

```
[CONFigure:]AFTerglow?
```

### Examples

```
Conf:afterglow ?
```

```
AFT ?
```

### Response

```
<n>
```

## Query Kick Pulse Configuration

### Description

If the Kick option is installed, this query returns the current configuration of the Kick Pulse, including the pulse width, voltage, current limit, and whether it is enabled or not. The Kick pulse width is shown in microseconds (us), the pulse voltage is shown in Volts (V), and the pulse current limit is shown in Amperes (A).

### Syntax

```
[CONFigure:]KICKpulse?
```

### Examples

```
Conf:kic?
```

```
KICK?
```

### Response

```
KICKPULSE:
```

```
  WIDTH: <n>
```

```
  VOLTAGE: <n>
```

```
  CURRENTLIMIT: <n>
```

```
  {ENABLED|DISABLED}
```

## Configure Kick Pulse

### Description

This command configures the Kick Pulse width, voltage, and current limit if the Kick option is installed. The Kick pulse width is specified in microseconds (us), the pulse voltage is specified in Volts (V), and the pulse current limit is specified in Amperes (A).

### Syntax

```
[CONFigure:]KICKpulse:{WIDTh|VOLTage|CURRentlimit} <n>
```

### Examples

```
conf : kic : widt 50
KICK:VOLT 100
KICK:current 20
```

### Response

OK

## Enable or Disable Kick Pulse

### Description

This command determines whether each successfully complete main pulse is followed by a Kick pulse or not if the Kick option is installed. The Kick pulse reverses the polarity of the magnetron cathode to kick the plasma afterglow towards the substrate after the specified Afterglow time.

### Syntax

```
[CONFigure:]KICKpulse <b>
```

### Examples

```
CONF:KICK ON
Kick off
KIC true
Config:kic yes
Kick 0
```

### Response

OK

## Query Kick Pulse Configuration Parameters

### Description

This query returns a single, specified parameter from the current Kick pulse configuration if the Kick option is installed. The Kick pulse width is reported in microseconds (us), the pulse voltage is reported in Volts (V), and the pulse current limit is reported in Amperes (A).

### Syntax

```
[CONFigure:]KICKpulse:{WIDTH|VOLTage|CURRentlimit|ENABled}?
```

### Examples

```
CONF : KICK : WIDTH ?
kic : volt ?
KICK:CURRENT?
CONFIG:KIC:ENABLED?
```

### Response

```
{<n>|ENABLED|DISABLED}
```

## Query Quench Pulse Configuration

### Description

This query returns the current configuration of the Quench pulse, including the pulse width, current limit, and whether it is enabled or not. The Quench pulse width is reported in microseconds (us), and the pulse current limit is reported in Amperes (A). If the Kick option is installed, it returns the corresponding information about the Kick pulse.

### Syntax

```
[CONFigure:]QUEnchpulse?
```

### Examples

```
Conf:que?  
QUENCH?
```

### Response

```
QUENCHPULSE:  
  WIDTH: <n>  
  CURRENTLIMIT: <n>  
  {ENABLED|DISABLED}
```

## Configure Quench Pulse

### Description

This command configures the Quench Pulse width, and current limit. The Quench pulse width is specified in microseconds (us), and the pulse current limit is specified in Amperes (A). If the Kick option is installed, it configures the corresponding information about the Kick pulse.

### Syntax

```
[CONFigure:]QUEnchpulse:{WIDTh|CURRentlimit} <n>
```

### Examples

```
conf : que : widt 50  
QUENCH:VOLT 100  
QUENCH:current 20
```

### Response

```
OK
```

## Enable or Disable Quench Pulse

### Description

This command determines whether each successfully completed main pulse is followed by a Quench pulse (or Kick pulse, if the Kick option is installed), or not. The Quench pulse grounds the magnetron cathode to quench the plasma afterglow after the specified Afterglow time.

### Syntax

```
[CONFigure:]QUEnchpulse <b>
```



### Examples

```
CONF:QUENCH ON
Quench off
QUE true
Config:que yes
Quench 0
```

### Response

```
OK
```

## Query Quench Pulse Configuration Parameters

### Description

This query returns a single, specified parameter from the current Quench pulse configuration. The Quench pulse width is reported in microseconds (us), and the pulse current limit is reported in Amperes (A). If the Kick option is installed, it returns the corresponding information about the Kick pulse.

### Syntax

```
[CONFigure:]QUEnchpulse:{WIDTh|CURRentlimit|ENABled}?
```

### Examples

```
CONF : QUENCH : WIDTH ?
que : volt ?
QUENCH:CURRENT?
CONFIG:QUE:ENABLED?
```

### Response

```
{<n>|ENABLED|DISABLED}
```

## Query Configuration Catalog

### Description

This query returns a list of the configurations that have been stored in each of the 20 available locations on the IMPULSE™ unit. Any location which does not contain a valid configuration is shown as <EMPTY>.

### Syntax

```
[CONFigure:]CATalog?
```

### Examples

```
CONF : CATALOG ?
cat?
```

### Response

```
<n> Entries
(1) <s>
(2) <s>
(3) <s>
```

```
...
```



(<n>) <s>

### Response Example

3 Entries

(1) "Configuration 1"

(2) "Titanium 3um"

(3) "Sam's Experiment"

17 empty local configurations

## Save Configuration

### Description

This command will save the current configuration of the IMPULSE™ to a named location in the IMPULSE™ nonvolatile memory. A maximum of 20 named configurations can be stored in the IMPULSE™. The command's first parameter specified the name to be given to the configuration, and the second parameter specifies whether an existing configuration of the same name should be overwritten. If the second parameter is not specified, a like-named configuration will be overwritten.

### Syntax

[CONFigure:]SAVe <s>[,<b>]

### Examples

CONF : SAVE "Sam's Experiment"

Save Defaults,no

### Response

OK

## Recall Configuration

### Description

This command will set the IMPULSE™ operating parameters as specified in a named configuration in the IMPULSE nonvolatile memory. A maximum of 20 named configurations can be stored in the IMPULSE™. The command's first parameter specified the name of the configuration to be recalled. The Autosaved configuration can also be recalled with this command.

### Syntax

[CONFigure:]RECall <s>

### Examples

CONF : Recall "Sam's Experiment"

REC Autosaved

### Response

OK



## Delete Configuration

### Description

This command will delete the specified named configuration from the IMPULSE™ nonvolatile memory. A maximum of 20 named configurations can be stored in the IMPULSE™. The command's first parameter specifies the name of the configuration to be deleted. The Autosaved configuration cannot be deleted.

### Syntax

```
[CONFigure:]DELeTe <s>
```

### Examples

```
CONF : DEL "Sam's Experiment"  
del "Configuration 3"
```

### Response

```
OK
```

## Measure Queries

The measure queries report the operational metrics that are available on the Monitor screen using the same units used on the Monitor screen.

### Query All Measurements

#### Description

This query reports all the operational metrics that are available on the Monitor screen. Note that the Kick Supply Voltage is not reported on systems that do not have the Kick option installed.

#### Syntax

```
MEASure?
```

#### Examples

```
Measure?
```

```
meas?
```

#### Response

```
MEASURE:
```

```
INPUT:
```

```
VOLTAGE: <n>
```

```
CURRENT: <n>
```

```
POWER: <n>
```

```
[ KICKSUPPLY:
```

```
VOLTAGE: <n>]
```

```
OUTPUT:
```

```
REPRATE: <n>
```

```
OVERCURRENT:
```

```
COUNT: <n>
```

```
RATE: <n>  
TIME: <n>
```

## Query All Input Measurements

### Description

This query reports the measurements observed at the main power input.

### Syntax

```
MEASure:INPut?
```

### Examples

```
Measure:inp?
```

```
Meas:INPUT?
```

### Response

```
INPUT:  
  VOLTAGE: <n>  
  CURRENT: <n>  
  POWER: <n>
```

## Query a Specific Input Measurement

### Description

This query reports one of the measurements observed at the main power input.

### Syntax

```
MEASure:INPut:{VOLTage | CURRent | POWer}?
```

### Examples

```
MEAS:INP:CURR?
```

```
Meas:INPUT:POW?
```

### Response

```
<n>
```

## Query Kick Supply Voltage

### Description

This query reports the voltage measurements observed at the kick power supply. If the VOLTage keyword is specified, then the voltage value is returned without the "VOLTAGE:" label.

### Syntax

```
MEASure:KICKsupply[:VOLTage]?
```

### Examples

```
Measure:KICK:volt?
```

```
MEAS:KICK?
```



## Response

```
[KICK:  
  VOLTAGE:] <n>
```

## Query All Output Measurements

### Description

This query reports the measurements observed at the pulse output terminals. These measurements include the actual instantaneous pulse repetition rate (frequency), the accumulated number of overcurrent and/or arc arrest events that have occurred and their time-averaged rate of occurrence, and the accumulated pulsing time. Note that all of these measurements are reset when an "OUTPUT:STOP" command is issued.

### Syntax

```
MEASure:OUTput?
```

### Examples

```
measure:out?
```

```
Meas:OUT?
```

### Response

```
OUTPUT:  
  REPRATE: <n>  
  OVERCURRENT:  
    COUNT: <n>  
    RATE: <n>  
  TIME: <n>
```

## Query Output Overcurrent Statistics

### Description

This query reports the statistics of the overcurrent and/or arc arrest events observed at the pulse output terminals. These measurements include the accumulated number of overcurrent and/or arc arrest events that have occurred and their time-averaged rate of occurrence. Note that these measurements are reset when an "OUTPUT:STOP" command is issued.

### Syntax

```
MEASure:OUTput:OVERcurrent?
```

### Examples

```
MEAS:out:over?
```

```
Meas:OUTPUT:OVER?
```

### Response

```
OVERCURRENT:  
  COUNT: <n>
```



RATE: <n>

## Query a Specific Output Measurement

### Description

This query reports one of the measurements observed at the pulse output terminals. These measurements include that actual instantaneous pulse repetition rate (frequency), the accumulated number of overcurrent and/or arc arrest events that have occurred and their time-averaged rate of occurrence, and the accumulated pulsing time. The requested measurement is reported as a numeric value without any label. Note that all of these measurements are reset when an “OUTPUT:STOP” command is issued.

### Syntax

MEASure:OUTput:{REPRate | OVERcurrent:{COUNT | RATE} | TIME }?

### Examples

measure:out?

Meas:REP?

### Response

<n>

## Display Control Commands

The Display Control commands are used to select which screen is displayed on the Local User Interface and query the screen that is currently displayed.

## Display a Specific Screen

### Description

This command changes the screen that is displayed on the Local User Interface.

### Syntax

DISPlay:{SETtings|LIMits|MONitor|FAULts|CONfigs|SYStem}

### Examples

DISP:SYS

disp:mon

### Response

OK

## Query Which Screen is Active

### Description

This returns the tab name associated with the screen that is displayed on the Local User Interface. If the screen has more than one type of display, such as the Setting screen which shows different settings

depending upon the Pulse Mode selected and can show either Main Pulse or Kick Pulse settings, then type is also reported.

#### Syntax

DISPlay?

#### Examples

DISPLAY?

Disp?

#### Response

```
{Settings:{ {Master | Slave} : {Main | Kick | Quench} }
  | Limits:{ Main | Kick | Quench }
  | Monitor
  | Faults
  | System
  | Network
}
```

## System Commands

The system commands and queries control various communication options for the remote user interface.

### Test the Remote Connection

#### Description

This command returns a quick response that can be used for verifying and timing the remote connection.

#### Syntax

SYSTem:NETwork:PING [<s>]

#### Examples

SYST:NET:PING

Syst:network:ping "cycle 1"

#### Response

Ping response [to <s>]

### Set Network Watchdog Time

#### Description

This command sets the time, in seconds, for the Watchdog Timer on the Remote User Interface. When the Watchdog Timer is enabled, the IMPULSE™ must receive a command or query over the Remote UI

within this specified time to continue normal operation. Otherwise the system will attempt to restart the network connection.

#### Syntax

```
SYSTem:NETwork:WATCHdog:TIME <n>
```

#### Examples

```
SYSTEM:NET:WATCH:TIME 10
```

```
sys:network:watch:time 0.5
```

#### Response

OK

### Query Network Watchdog Time

#### Description

This query returns the time, in seconds, that is permitted between Remote commands and queries when the Remote Watchdog Timer is enabled.

#### Syntax

```
SYSTem:NETwork:WATCHdog:TIME?
```

#### Examples

```
Syst:net:watc:time?
```

```
sYST:NET:watch:Time?
```

#### Response

```
NETWORK WATCHDOG TIME = <n> sec
```

### Enable and Disable Network Watchdog

#### Description

This command enables or disables the Watchdog Timer on the Remote User Interface. When the Watchdog Timer is enabled, the IMPULSE™ must receive a command or query over the Remote UI within the specified time to continue normal operation. Otherwise the system will attempt to restart the network connection.

#### Syntax

```
SYSTem:NETwork:WATCHdog <b>
```

#### Examples

```
SYSTEM:NET:WATCH on
```

```
sys:network:watch off
```

```
sys:net:watch yes
```

```
SYST:network:watc 0
```

## Response

<n>

### Query Network Watchdog Status

#### Description

This query reports whether the Remote Watchdog Timer is enabled or disabled and returns the time, in milliseconds, that is permitted between Remote commands and queries when the Remote Watchdog Timer is enabled.

#### Syntax

```
SYSTem:NETwork:WATChdog:ENABle?
```

#### Examples

```
SYST:net:watc:enable?
```

```
syst:NET:watch:Enab?
```

#### Response

```
{ENABLED | DISABLED}
```

### Start or Stop a Query Stream

#### Description

This command starts or stops a continuously repeating stream of responses to a pre-defined list of queries at a pre-defined interval.

#### Syntax

```
SYSTem:REMote:STREam:{START | STOP}
```

#### Examples

```
SYST:REM:STREAM:START
```

```
Syst:remote:stre:stop
```

#### Response

```
Streaming data {started | stopped}.
```

### Set the Query Stream Repetition Interval

#### Description

This command establishes the time interval, in milliseconds, between repeated streams of responses to a pre-defined list of queries.

#### Syntax

```
SYSTem:REMote:STREam:INTERval <n>
```

#### Examples

```
SYST:REM:STREAM:inter 100
```

```
Syst:rem:stre:inte 250
```

### Response

OK

## Report the Query Stream Repetition Interval

### Description

This query returns the time interval, in milliseconds, between repeated streams of responses to a pre-defined list of queries.

### Syntax

```
SYSTem:REMOte:STREam:INTERval?
```

### Examples

```
SYST:REM:STREAM:interval?
```

```
Syst:remote:stre:inte?
```

### Response

<n>

## Add a Query to the Query Stream

### Description

This command adds a query to a pre-defined list of queries for repetition at a pre-defined interval. Any valid query that is defined for the remote interface may be used, but each query is allowed only once in the query stream. If a query is repeated, then the existing query is moved to the end of the query stream. Note that the string which defines the query must be enclosed in quotes, because it will contain a question mark and possibly one or more colons or other special characters.

### Syntax

```
SYSTem:REMOte:STREam:ADD <s>
```

### Examples

```
SYST:REM:STREAM:add "outp?"
```

```
Syst:remote:stre:Add "MEASURE:OUT:REPRATE?"
```

### Response

OK

## Remove a Query from the Query Stream

### Description

This command removes a query from the pre-defined list of queries for repetition at a pre-defined interval. The query must be entered exactly as it was entered with the SYSTem:NETwork:STREAm:ADD command. Note that the string which defines the query must be enclosed in quotes, because it will contain a question mark and possibly one or more colons or other special characters.

### Syntax

```
SYSTem:REMOte:STREAm:REMOve <s>
```

### Examples

```
SYST:REM:STREAM:remove "outp?"
```

```
Syst:remote:stre:remo "MEASURE:OUT:REPRATE?"
```

### Response

```
OK
```

## List the Queries in the Query Stream

### Description

This command returns the pre-defined list of queries that may be automatically repeated at a pre-defined interval.

### Syntax

```
SYSTem:REMOte:STREAm:LIST
```

### Examples

```
SYST:REM:STREAM:LSIT
```

```
Syst:remote:stre:list
```

### Response

```
List of active streaming data queries:  
outp?  
MEASURE:OUT:REPRATE?
```

## Identify the System

### Description

This query identifies the system as required by the IEEE-488.2 specification. It may be entered in either upper-case or lower-case but must not have any space following the asterisk (\*).

### Syntax

```
*IDN?
```

### Examples

```
*idn?
```

```
*IDN?
```

### Response

```
Starfire Industries IMPULSE 2-2, System ID: IMPULSExxxxxx, Firmware  
Version: x.y.z, Build: yyyy.mm.dd_hh.mm
```



## Error Messages

When the IMPULSE™ unit is unable to process a command or query that is sent through the Telnet connection it will respond with an error message which begins with the string, "ERROR:", followed by text which describes the problem. There are two types of error messages:

- 1) Syntax Error Messages report problems with the way a command was formatted or the order of keywords, which prevent proper interpretation of the command. When possible the message will include the portion of the command which was incorrect. If not possible, then it will merely return a "Command Syntax Error" message.
- 2) Operation Error Messages are used either when the command is recognized but cannot be executed or when Remote operation has been disabled at the IMPULSE™ unit on the System screen. Examples of commands that cannot be performed are:
  - a. any KICK command on a unit that does not have the Kick pulse option installed;
  - b. any attempt to adjust a setting beyond its minimum and maximum limits;
  - c. any attempt to save more than 20 configurations or delete a configuration that has not been saved.

## Troubleshooting

Symptom	Possible Cause or Solution
Microcontroller (touchscreen) hangs/freezes during boot-up or operation	Try turning off the power switch, wait a couple of seconds, and turn the power back on
	If the problem is not resolved, contact customer service through your sales representative
Too many arc events	Try decreasing the DC power supply voltage connected to the IMPULSE
	The peak current threshold is set too low
	Adjust gas pressure to the sputtering cathode
Repetition rate automatically changing	Power setpoint enabled
Touchscreen not illuminated	Ensure unit is plugged in
	Ensure power switch is on
	Check fuses
Unit not pulsing	Check for Fault messages on Faults screen
	If operating as Slave, verify unit is receiving sync pulses



## Periodic Inspection Instructions

Inspection	Frequency
Ensure rack mounting hardware is not loose	Before each use
Ensure vents on top and side of unit are not obstructed	Before each use

# Physical and Performance Specifications

## SF-IMPULSE2GX-SH-SE and SF-IMPULSE2GX-DH-SE Base Models

Parameter	IMPULSE™ System
Input Power Specifications	1 Phase, 100-240 VAC, 50/60 Hz, 2.5 A per module
Input Charging Supply	-1000 VDC nominal, -1250 VDC tolerant
Time-Average Power	~2 kW; subject to duty factor and rep rate
Output Peak Voltage	-1000 V nominal, -1250 V tolerant
Output Peak Current	200 A nominal, 400 A tolerant
Arc Detection Time	< 200 ns
Arc Arrest Time	< 500 ns
Over Current Response Time	< 2 $\mu$ s
Peak Current Limiter	User selectable up to 400 A in High Current operation, 200 A in High Frequency operation
Power Limit	User selectable up to 2kW
Pulse Frequency	User selectable; 1 Hz to 2 kHz (high current mode) or 1Hz to 4kHz (high frequency mode) nominal range, subject to power derating curve
Pulse Width	User selectable, 2 $\mu$ s to 500 $\mu$ s nominal range
Afterglow Time	Minimum of 4 $\mu$ s; User selectable in 1 $\mu$ s increments
Quench Pulse Set points	On/Off; User selectable in 1 $\mu$ s increments for pulse width
External Communications	RJ-45 and RS-422 control I/O, USB Type A, BNC sync line, BNC I-V monitor out
Pulse Module Sync	< 0.1 $\mu$ s latency
Cabling	N-type HV connector standard
Configuration Storage	Onboard storage for 20 user selectable presets
Physical Dimensions	2U rack; 19" (W) x 3.5" (H) x 22.5" (L) including handles and plugins 482.6 mm (W) x 88.9 mm (H) x 571.5 mm (L)
Weight	Single Module: 26 lbs., 1.8 oz. 11.84 kg Dual Module: 30 lbs., 3.0 oz. 13.69 kg
Operating Temperature	+5C to +40C, forced air cooling

## SF-IMPULSE2KX-SH-SE and SF-IMPULSE2KX-DH-SE Advanced Kick Models

Parameter	IMPULSE™ System
Input Power Specifications	1 Phase, 100-240 VAC, 50/60 Hz, 2.5 A per module
Input Charging Supply	-1000 VDC nominal, -1250 VDC tolerant
Time-Average Power	~2 kW; subject to duty factor and rep rate
Output Peak Voltage	-1000 V nominal, -1250 V tolerant
Output Peak Current	200 A nominal, 400 A tolerant
Arc Detection Time	< 200 ns
Arc Arrest Time	< 500 ns
Over Current Response Time	< 2 $\mu$ s
Peak Current Limiter	User selectable up to 400 A in High Current operation, 200 A in High Frequency operation
Power Limit	User selectable up to 2kW
Pulse Frequency	User selectable; 1 Hz to 2 kHz (high current mode) or 1Hz to 4kHz (high frequency mode) nominal range, subject to power derating curve
Pulse Width	User selectable, 2 $\mu$ s to 500 $\mu$ s nominal range
Afterglow Time	Minimum of 4 $\mu$ s; User selectable in 1 $\mu$ s increments
Positive Kick Pulse Voltage	User selectable in 1V increments from 0 to +200V using internal supply
Kick Pulse Set points	On/Off; User selectable in 1 $\mu$ s increments for pulse width
External Communications	RJ-45 and RS-422 control I/O, USB Type A, BNC sync line, BNC I-V monitor out
Pulse Module Sync	< 0.1 $\mu$ s latency
Cathode Cabling	N-type HV connector standard
Configuration Storage	Onboard storage for 20 user selectable presets
Physical Dimensions	2U rack; 19" (W) x 3.5" (H) x 22.5" (L) including handles and plugins 482.6 mm (W) x 88.9 mm (H) x 571.5 mm (L)
Weight	Single Module: 26 lbs., 14.8 oz. 12.21 kg Dual Module: 31 lbs., 13.0 oz. 14.43 kg
Operating Temperature	+5C to +40C, forced air cooling



## Default Operation Settings

Master: Pulse width: 100 $\mu$ s, Repetition rate: 100Hz

Slave: Pulse width: 50 $\mu$ s, Slave delay: 50 $\mu$ s

Current Mode: High current

Main Current Limit: 50A

Afterglow Time: 5  $\mu$ s

Kick/Quench Pulse width: 50  $\mu$ s

Kick/Quench Current Limit: 20A

Kick/Quench Voltage: 0V

## Output Scaling

The voltage and current monitor outputs provide signals for monitoring the output voltage and current waveforms delivered to the sputter cathode by the IMPULSE™. The monitor BNC outputs can be connected directly to oscilloscope BNC inputs set up for 1M $\Omega$  input impedance on a 1:1 scale.

- The scaling on the voltage-monitor output is 2.20V indicated per 1000V actual.
- The scaling on the current-monitor output is 1.15V indicated per 100A actual.

## Appendix A: In-Field Firmware Updates

The IMPULSE™ unit is equipped with a USB type-A receptacle on the front panel for the connection of a USB flash memory device containing updated IMPULSE™ firmware. To update the firmware, when available, follow the steps below once each for both the “A” and “B” (if present) sides of the unit:

1. Obtain the updated firmware file from Starfire Industries LLC®.
2. Place the firmware file in a subdirectory of the root of a FAT-32 formatted USB flash drive named "IMPULSE 2-2 Firmware".
3. If the IMPULSE™ unit is on, stop any running deposition, de-energize any connected DC supplies, and turn off the main power switch on the front panel of the IMPULSE™ unit.
4. Insert the USB flash drive.
5. Turn on the main power switch on the front panel of the IMPULSE™ unit.
6. A prompt will appear asking you if you want to perform the update. To update, choose “Yes” and follow the on-screen prompts. This process must be completed within 15 seconds to ensure a successful firmware update.
7. Any time after the progress bar reaches 100%, the USB flash drive can be removed.
  - a. If the progress bar does not move or an error is reported, cycle the main power switch off and on to restart the firmware loading process.
8. IMPULSE™ will restart to run the updated firmware.
9. If the flash drive was left in the USB port, you will be prompted to update the firmware again. Answer “No” and remove the flash drive to continue normal operation of the unit.

## Appendix B: High-Power Impulse Magnetron Sputtering (HIPIMS)

High Power Pulsed Magnetron Sputtering (HIPIMS) is a type of magnetron sputtering technique where high power pulses are applied to the magnetron target. Typical pulse widths are a few tens to hundreds of microseconds, and typical pulse repetition frequencies range from tens to hundreds of Hz. Figure 24 shows a characteristic voltage and current waveform from the IMPULSE™ HIPIMS power supply operating with intense, short pulses. In such a discharge, the target peak power densities during the pulse can be in the order of several tens of kilowatts per square centimeter whereas the average power densities are comparable or equal to that of Direct Current Magnetron Sputtering (dcMS) discharges.

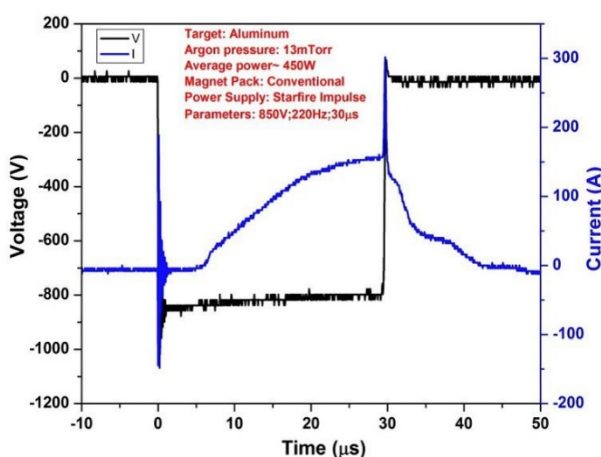


Figure 24. Characteristic voltage and current waveform from the IMPULSE™ for a reference case.<sup>1</sup>

The HIPIMS discharge exists in the same pressure regime as dcMS, and the existing magnetic field assemblies which are used for dcMS sputtering can provide stable ignition and operation of HIPIMS discharge. Therefore, by just changing the power supply in the exact same sputtering system the characteristics of the plasma can be changed and therefore the properties of the films as well. See Table 3 below for a comparison of parameters between HIPIMS and dcMS discharges. Some of the most interesting qualities of the HIPIMS discharge is its high plasma density and ionization fraction of the sputter target material.

The high peak power pulses on the target in HIPIMS result in plasma electron densities up to  $10^{19} \text{ m}^{-3}$  which is three orders of magnitude higher compared to dcMS Sputtering. These high plasma densities promote ionization of the sputtered material forming an ionized sputtered material flux, where the ionization fraction can reach 90%. The ion flux is subject to electric and magnetic force so its direction and energy can be controlled. Being precisely controlled the target material ion flux can be used to

<sup>1</sup> Priya Raman, Magnetic Field Optimization for High Power Impulse Magnetron Sputtering, Doctoral Dissertation, University of Illinois at Urbana-Champaign, 2016

perform substrate pre-treatment as well as to enhance film and device properties. Examples of enhancements are increased film density as well as significant improvements in film adhesion.

Parameter	HIPIMS	DC Magnetron
<b>Working Pressure</b>	$10^{-4} - 10^{-2}$ Torr	$10^{-4} - 10^{-2}$ Torr
<b>Cathode Current Density</b>	$J_{MAX} \geq 0.1 \text{ A/cm}^2$	$J_{MAX} \leq 0.1 \text{ A/cm}^2$
<b>Discharge Voltage</b>	0.3 – 1.2 kV	0.3 – 0.6 kV
<b>Plasma Density</b>	$\leq 10^{13} \text{ cm}^{-3}$	$\leq 10^{11} \text{ cm}^{-3}$
<b>Cathode Power Density</b>	0.5 – 3 kW/cm <sup>2</sup>	< 0.1 kW/cm <sup>2</sup>
<b>Ionization Fraction</b>	30% – 90%	< 1%

*Table 3. HIPIMS vs DC Magnetron Parameters Comparison*

### Typical Operating Conditions Of HIPIMS vs. dcMS

The IMPULSE™ power supply converts low-current DC power (from an external DC power supply) into high-power pulses sufficient to push the plasma state into the HIPIMS regime. This does not necessarily mean the operating power levels need to be increased because the time average power can be similar while compressing the energy into many intense pulses.

It takes a little time and patience to explore operating parameter spaces to transition from dcMS to HIPIMS deposition for your application. Users new to HIPIMS are encouraged to start at lower voltages and work up in voltage/power to determine optimal operating conditions. Some users report achieving a HIPIMS mode at similar or even lower voltages than required with conventional dcMS (e.g. Cu target on 2" TORUS high-field, balanced). Others report improved film deposition using very short pulses at much higher voltages than could be used with dcMS (e.g. Ti target on 1" TORUS, normal-field, balanced). The IMPULSE™ can provide very short pulses < 10μsec at very high voltages and repetition rates.

Starfire Industries designed the IMPULSE™ pulse power module to be an enabler for HIPIMS and give the researcher or process developer many knobs to turn to explore the parameter space. If you are fortunate to have a process window to observe the discharge color, an immediate change can be observed in the transition from the sputtering gas (e.g. Argon) to the sputtered-material-dominated plasma under intense HIPIMS modes. In addition, pulse waveform outputs can be monitored for transition from “gas-dominated” to “metal-vapor dominated” to “self-sputtering” modes. Also, consult the plethora of academic literature available for starting points with various materials.<sup>2</sup>

As detailed later in this manual, a dual IMPULSE™ configuration (SF-IMPULSE-DH) can provide synchronized pulses to a cathode and to a substrate bias for ion implantation. The slave (follower) configuration can be delayed and windowed in time to produce a specific pulse to the substrate to drive mostly ions generated during the HIPIMS pulse on the cathode and limit sputtering gas implantation or plasma generated from other cathodes present in the system.

<sup>2</sup> <http://www.hipimsconference.com/>



Operating in standard mode, the peak current can be set as high as 400A. In bias mode, the peak current can be set as high as 200A. Users should typically set this limit lower than the default setting to minimize damaging arc events during cathode conditioning or to lower the peak value for 2" magnetron cathodes vs. 4" cathodes. It is up to the user to decide what parameter is best for their process conditions, but the current limit is typically set just above the normal-pulse peak current to detect arcs as quickly as possible.



## Appendix C: Master/Slave Applications

Many applications can benefit from synchronized pulses from multiple IMPULSE™ modules as found within a dual-module IMPULSE™ unit or within multiple units. Examples of such applications include:

1. Ion implantation, where the cathode and substrate are pulsed at different times to control the ionic concentration, energy, and direction,
2. Large-area sputter deposition systems with multiple cathodes, and
3. Multiple cathode systems which simultaneously sputter different materials onto the substrate.

In these applications, one IMPULSE™ module acts as a master to synchronize the timing of one or more slave modules, providing many application system setup options for the user. Each module is independently controlled with settings for operating mode, timing, kick voltage (if the kick option is installed), and current limits. Each module also independently outputs real-time monitoring information with measurements of input and Kick (if so equipped) voltages and currents, overcurrent events, and fault conditions.

### System Configuration

A Master/Slave application system that is configured correctly will have one IMPULSE™ module dedicated as the master and the remaining IMPULSE™ modules dedicated as slaves. The master module will have the coaxial sync cable connected to its SYNC OUT terminal, and each of the slaves will connect to the coaxial sync cable on its SYNC IN terminal, as shown in Figure 15. The master must be configured as a master through the local or remote interface, and each slave must be configured as a slave.

It is possible to configure more than one IMPULSE™ module to be used as the master. However only one master unit may be pulsing at any given time. Any unit that is configured as a master with its Sync In connected to another master's Sync Out will be disabled when the other master begins pulsing.

### System Operation

A unit operating in slave mode will only output a single pulse sequence of one main pulse optionally followed by a kick or quench pulse each time it receives a sync pulse from the master. Therefore, if the master unit is not pulsing there will not be output pulses from any slave even if the slave has been started. This allows a user to simultaneously start pulsing from multiple units by starting the slaves first, followed by the master.

Also, since a slave will not pulse until it has been started, it is possible to allow the master (and any pre-started slaves) to run for a period, and then start other slave units. In general, for complex systems that could benefit from this type of operation it is recommended to use an external automated controller with the IMPULSE™ units' remote interface to ensure proper system timing.

## **Master/Slave Pulse Timing Relationships and Restrictions**

In a Master/Slave application, the master is the primary controller of the pulse repetition rate. The slaves are synchronized to the leading edge of the master's main pulse, which defines the start of a pulse cycle, noted as  $T_0$ . The slave's main pulse starts after a specified delay from  $T_0$ . The main pulse delay, pulse width, afterglow time, and kick/quench pulse width specifications are individually set for each slave. To allow the slave to complete its pulse cycle and resynchronize with the master for each pulse cycle, the slave's pulse timings must be set up such that the trailing edge of the final pulse occurs a minimum of 100 $\mu$ s prior to the beginning of the subsequent pulse cycle, and the slaves pulse repetition rate must not be limited below the rate established by the master.

If the pulse timings and/or repetition rate of any slave in a Master/Slave application do not fit within the pulse repetition period of the master, then that slave's pulse repetition period will be extended to a multiple of the master's period as required to maintain the pulse timings set up for the slave. Each slave reports on the Monitor screen both the master's repetition rate and the actual repetition rate that the slave attains. When the slave cannot operate at the master's repetition rate for any reason, these values are highlighted in yellow. If the Monitor screen is not active when this occurs, the Monitor tab is highlighted in yellow.

## **Pulse Repetition Rate Considerations**

In a typical Master/Slave application the slave is expected to run at the same repetition rate as the master. The master's repetition rate is determined by an upper limit set by the user unless the average output power set by the user is exceeded. Note that a module configured as a slave also permits the user to set a maximum pulse repetition rate. High-Frequency operation or High-Current operation is also set independently on each IMPULSE™ module regardless of the Master/Slave mode set up. If the master is set up for High-Frequency operation, then it could operate at a frequency above the frequency limitation of any slave set up for High-Current operation. In such situations, the slave will operate with a pulse repetition period that is extended to a multiple of the master's period as required to maintain the frequency limitation of the slave, and the condition will be highlighted on the Monitor tab and screen.

## **Power Control Considerations**

When a process needs to be optimized by controlling the average power to each of the various elements in the chamber, the Power Control limit should be specified for the master, causing the master's pulse repetition rate to be controlled internal to the IMPULSE™ module to establish the desired power. After the master module's output power has stabilized, the power level for each of the slaves can be adjusted with the input voltage and pulse width to establish the desired deposition process. In general, each slave's pulse repetition rate limit and power limit should be set to the maximum allowed values. As the chamber conditions change through time, the master's power control feature will vary the pulse repetition rate to maintain the master's average power output as set by the user. This varies the sync



pulse rate to all connected slave units. In most cases this will also maintain a constant average power output of each slave.

The timing restrictions of the slave remain true when the master is using the Power Control option. Note that a module configured as a slave also permits the user to set a maximum pulse repetition rate and a maximum power output. Since each slave is subject to the pulse repetition period adjustments of the master, if the master's period drops below the time required by the slave's pulse timing setup, that slave will skip pulse cycles as required. In addition, if the slave unit exceeds its power setpoint the slave will limit power by skipping pulse cycles as required. In either case the slave will establish a pulse repetition period that is a multiple of the master's pulse repetition period and will highlight the condition on the Monitor tab and screen.

Over time, target erosion will result in an increased discharge current and a resulting power increase for the same chamber conditions and run parameters. In a multi-cathode system, if different target materials are used, or if different power settings are desired for each cathode, each target's material wear rate may be different. This will cause the relationship between average output power and pulse repetition rate at each cathode to change with time, requiring a recalibration of the input voltage and/or pulse width of each slave IMPULSE™ module at regular intervals to maintain the desired deposition process. The calibration intervals should be determined experimentally by monitoring the cathode wear rates and/or average output power over time and comparing these with the resulting quality of the deposition process.

# Appendix D: Complete Remote User Interface

## SCPI Lexicon

The IMPULSE™ 2-2 accepts programming commands and queries formatted according to the SCPI specification. Each input line constitutes one command or query and is terminated with a carriage return and line feed. Details of the commands, queries, and responses with their uses and effects are provided in the Remote User Interface section of this manual. This command lexicon provides a quick reference to aid in building syntactically correct commands.

The IMPULSE™ 2-2 complete command lexicon below uses the following syntax notations:

- Question mark (?) and colon (:) characters must be typed as shown.
- <n> represents a parameter that is specified as a decimal floating-point number.
- <s> represents a parameter that is specified as a character string; if the string contains any special characters (colon, comma, or question mark) or spaces it must be contained within double-quotes.
- <b> is a Boolean value, represented as 1, TRUE, YES, or ON; or 0, FALSE, NO, or OFF. Any equivalent Boolean value will be interpreted the same by SCPI.
- Square brackets, [ . . . ], designate optional keywords. The brackets are not entered on the command line.
- Curly braces, { . . . }, surround several options when one must be specified or when only one is returned in a response. The braces are not entered on the command line, nor are they returned in the response.
- A vertical bar, |, separates the options within braces; these are not entered on the command line, nor are they returned in the response, and only one of the options may be entered or returned.
- All keywords have acceptable three-character or four-character minimum abbreviations. These abbreviations are written in CAPITAL letters in the syntax descriptions, but they can be entered in lower or mixed case when input.
- Additional letters in keywords (written in lowercase in the syntax descriptions) are not required for any keyword but may be typed as shown (in upper, lower, or mixed case) or truncated.
- Keywords can be truncated to any number of characters between the required abbreviation and the full word.
- When an asterisk (\*) precedes a keyword, it is part of the keyword; it must be typed as shown without any adjacent whitespace.

```

{ *IDN ?
| SYSTem { ?
    | :VERSion ?
    | :REMOte { ?
        | :STREam { ?
            | :ADD <s>
            | :REMOve <s>
            | :INTERval { ? | <n> }
            | :LIST ?
            | :STARt
            | :STOP }
        | :PROMpt { ? | <s> }
        | :LOCK <b> }
    | :NETwork { ?
        | :PING [<s>]
        | :WATChdog { ? | <b>
            | :TIME { ? | <n> }
            | }
        | :ADDress ?
        | :MASK ?
        | :GATEway ?
        | :DHCP ?
        | } }
| OUTPut { ?
    | :STARt
    | :STOP
    | :PAUSE }
| [CONFigure] { ?
    | :NAME ?
    | :MODE { ?
        | :MASTer
        | :SLAVE }
    | :OPTion { ?
        | :CURrent [<n>]
        | :REPrate [<n>]
        | }
    | :REPratelimit { ? | <n> }
    | :POWerlimit { ? | <n> }
    | [:MAInpulse] { ?
        | [:MASTer] { ?
            | :WIDTh { ? | <n> } }
        | :SLAVE { ?
            | :WIDTh { ? | <n> }
            | :DELAy { ? | <n> } }
    }
}

```

```

| :CURRENTlimit { ? | <n> } }
| :AFTerglow { ? | <n> }
| :QUEnchpulse { ?
| :WIDTh { ? | <n> }
| :CURRentlimit { ? | <n> }
| :ENABled { ? | <n> } }
| :CATalog ?
| :SElect <s>
| :RECall [<s>]
| :SAVe <s>,<b>]
| :DELeTe { <s>
| :ALL }
| }
| DISPlay { ?
| :SETtings
| :LIMits
| :MONitor
| :FAULts
| :CONfigs [<s>]
| :SYStem }
| MEASure { ?
| :INPut { ?
| :VOLTage ?
| :CURRent ?
| :POWER ? }
| [:OUTput] { ?
| :REPRate ?
| :OVERcurrent { ?
| :COUNT ?
| :RATE ? }
| :TIME ? } } }

```

# Declaration of Conformity



<http://www.starfireindustries.com/>

Manufacturer:

Starfire Industries, LLC  
2109 S. Oak St.  
Champaign, Illinois 61820, USA  
Telephone No. (217) 721-4165

Product:

IMPULSE™ Pulsed Power Module for HIPIMS

Model Numbers:

SF-IMPULSE2GX-SH, SF-IMPULSE2GX-DH, SF-IMPULSE2KX-SH, SF-IMPULSE2KX-DH

The undersigned hereby declares, on behalf of Starfire Industries, LLC of Champaign, Illinois, that the above-referenced product, to which this declaration relates, is in conformity with the provisions of the following directives and related standards:

Directive 2014/35/EU on Low Voltage Equipment Safety

EN 61010-1:2010

Directive 2014/30/EU on Electromagnetic Compatibility

EN 61326-1:2013

RoHS Directive 76/769/EC

WEEE Directive 2002/96/EC

The Technical Construction File required by these Directives is maintained at the corporate headquarters of Starfire Industries, LLC, 2109 S. Oak St., Champaign, Illinois.

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Brian Jurczyk  
President - CEO