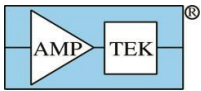


Mini-X2 User Manual

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1 PRECAUTIONS

CAUTION: The Mini-X2 is only one component of an X-ray instrument. It is the responsibility of the user to provide a fail-safe metal enclosure to prevent escaping radiation while using this product. The final product (turn-key system) must comply with local government regulations to protect personnel from exposure to radiation. Amptek Inc. bears no responsibility for the incorrect use of this product.

1.1 High Voltage

The Mini-X2 is designed to generate voltages up to 70 kV. The high voltage system is fully shielded inside the Mini-X2 X-ray Tube enclosure.

DO NOT ATTEMPT TO ACCESS OR MODIFY THE HIGH VOLTAGE SYSTEM.

DO NOT UNSCREW ANY OF THE SCREWS AT THE NECK OF THE TUBE.

TAMPERING WITH THESE SCREWS WILL VOID WARRANTY.



Caution



This device produces HIGH VOLTAGE when energized. To be operated only by qualified personnel.

The Mini-X2 X-ray Tube contains a high voltage power supply. High voltage is not exposed but the unit should be grounded as a precaution, mounted to a metal fixture via the provided brackets.

The high voltage power supply has been thoroughly tested and should not ever arc to its own case. However, if at any time any high voltage arcing or popping is heard, immediately discontinue use. High voltage arcing has a distinctive sharp cracking sound. Contact sales (Amptek.sales@ametek.com) if you suspect that the power supply is arcing.

1.2 Radiation

The Mini-X2 is intended to generate X-ray radiation during normal operation. It has been designed to focus radiation in the designated output direction, but radiation can be scattered in other directions and should be addressed with shielding and/or monitoring in the final application.



Caution



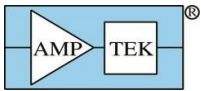
**This device produces X-RAYS when energized.
To be operated only by qualified personnel.**

Radiation levels external to the X-ray tube housing with the brass safety plug ON do not exceed 2.5 mrem/h measured 5 cm from the surface of the housing in accordance with Requirements 5.2.2.1.1 and 5.2.2.2.2 of the NBS Handbook for Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment. For more information please see ANSI N43.2 <https://www.fda.gov/media/75976/download>.

1.3 Beryllium Window

When unpacking the Mini-X2 pay careful attention to the Beryllium (Be) window on the front of the unit. This is a fragile window which can be damaged by impact. Beryllium (silver/gray and metallic) and beryllium oxide dust (normally a whitish powder) are harmful if inhaled or ingested.

AVOID ALL CONTACT WITH THIS PART OF THE X-RAY TUBE.



WARNING

This product contains the following chemicals, which are known to the State of California to cause cancer, birth defects or other reproductive harm if exposed to them through improper use, storage, or disposal of the product:

Prop 65 Chemical	Type of Toxicity	CAS No.	Product part containing the chemical
Beryllium	Cancer	--	X-ray tube window

Please consult this owner’s manual for proper use, storage, care and disposal of the product. For more information, go to: www.p65warnings.ca.gov

1.4 Heat and Temperature

The ambient temperature surrounding the Mini-X2 X-ray tube must not exceed 50°C. Improper cooling is the single highest cause of X-ray tube failures and is not covered under Warranty. It is the user’s responsibility to provide an adequate cooling system for the Mini-X2.

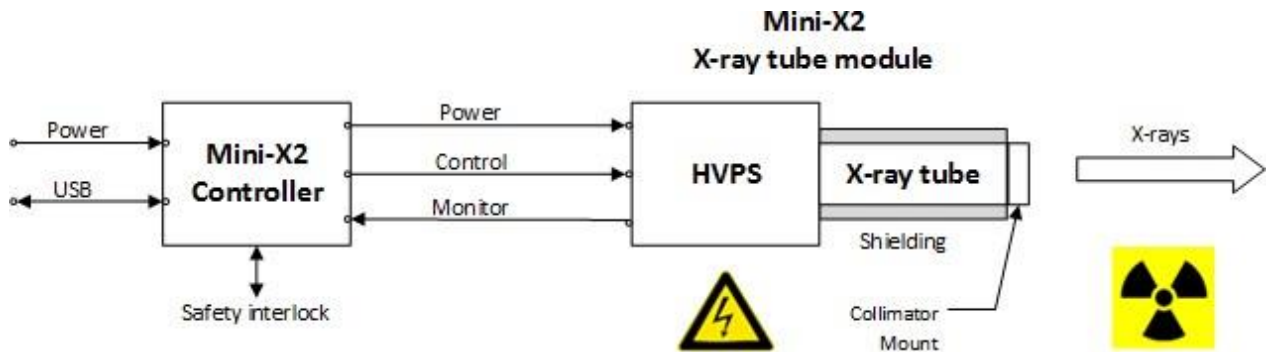
2 Introduction

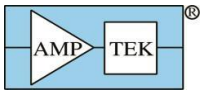
2.1 Description of Mini-X2

The Mini-X2 is a miniature X-ray tube system which includes the X-ray tube, the power supply, the control electronics, and the USB communications to the computer. It is optimized for compact X-ray fluorescence (XRF) applications. The Mini-X2 has been designed to simplify the XRF process by providing a grounded anode, USB control of current and voltage, a simple collimator mount, and ease of operation.

The Mini-X2 consists of two components: the Mini-X2 X-ray tube module and the Mini-X2 Controller. The X-ray tube module includes the tube and HVPS. Several different options are available: 1) maximum tube power can be 4W or 10W; 2) maximum HV can be 50kV or 70kV; and 3) the anode can be Ag, Au, Rh, or W. The Controller includes the USB communications and software control. It can be configured, via software, to support any of the X-ray tube modules. A 10-pin flex cable connects the Controller and the X-ray tube module. Connections to the Controller are 12 VDC power, USB for command and control, and an AUX connector with a safety interlock and a driver for a warning light.

The Mini-X2 is a replacement for Amptek’s previous Mini-X product family. The X-ray Tube Module is similar to the previous Mini-X-OEM. The Controller has significantly improved control features, including software configurability and faster control and readback. It utilizes a completely different software interface, based upon the FW6 protocol used with Amptek’s digital pulse processors.





2.2 Options and Variations

Mini-X2 X-ray Tube

Anode material: The Mini-X2 X-ray Tube is available with one of four anode materials: silver (Ag), gold (Au), rhodium (Rh), and tungsten (W).

Maximum Power: The Mini-X2 X-ray Tube is available with maximum power of 4 W or 10 W.

Maximum HV: Mini-X2 X-ray Tube is available with an HV range of either 10 to 50 kV or 35 to 70 kV.

- Note that the mechanical dimensions depend on the HV and power options.
- Note that the higher power and/or HV variants require more radiation shielding than the lower power and/or HV variants.

X-ray tube interface: The Mini-X2 interfaces with X-ray tubes supplied by NSI (Newton Scientific). Their standard tubes use an analog interface while their new UltraMini tubes use a digital (I2C) interface. Both are supported by the Mini-X2 Controller.

Mini-X2 Controller

There is a single Mini-X2 Controller which interfaces with all the Mini-X2 X-ray Tube modules. Each Controller is programmed, at Amptek, for a specific X-ray Tube module, with its P/N, S/N, maximum kV, maximum power, etc. Amptek's Firmware Manager software can be used to reconfigure the Controller for a different tube.

Amptek's standard Mini-X2 Controller supports only USB communication and only the standard X-ray tubes. Contact Amptek for Controllers which interface with the UltraMini and/or which support an RS232 interface.

3 Specifications

3.1 Mini-X2 X-ray Tube Specifications

X-Ray Tube Performance	
Target Material	Silver (Ag), Gold (Au), Rhodium (Rh), Tungsten (W)
Target Type	Transmission
Tube Voltage	10 to 50 kV or 35 to 70 kV
Tube Power	4 W or 10 W available
Tube Current	5 μ A to 200 μ A (Fold back for power limit)
Typical Dose Rate	
Ag & Rh	1 Sv/hr (100 rem/hr) @ 30 cm on-axis, at 50 kV and 80 μ A (4W)
Au & W	2.2 Sv/hr (220 rem/hr) @ 30 cm on-axis, at 50 kV and 80 μ A (4W)
Typical Flux	
Ag & Rh	6×10^4 cps/mm ² / μ A @ 30 cm on axis (at 50 kV)
Au & W	2×10^5 cps/mm ² / μ A @ 30 cm on axis (at 50 kV)
Leakage Radiation	< 5 μ Sv/hr (0.5 mrem/hr) @ 5 cm with safety plug installed
Target Thickness	
Ag & Rh	0.75 ± 0.1 μ m
Au & W	1.0 ± 0.1 μ m

Window	125 mm Be (window grounded)
Focal Spot	Approx. 2 mm
Cathode Type	Tungsten filament
HV Polarity	Grounded anode
HV Stability	< 0.1%

Environmental and Physical	
Operating Temp	-10 to + 50 °C
Storage Temp	-25 to + 60 °C
Humidity	30 to 90% non-condensing
Cooling	Air cooled
Weight	< 400 g

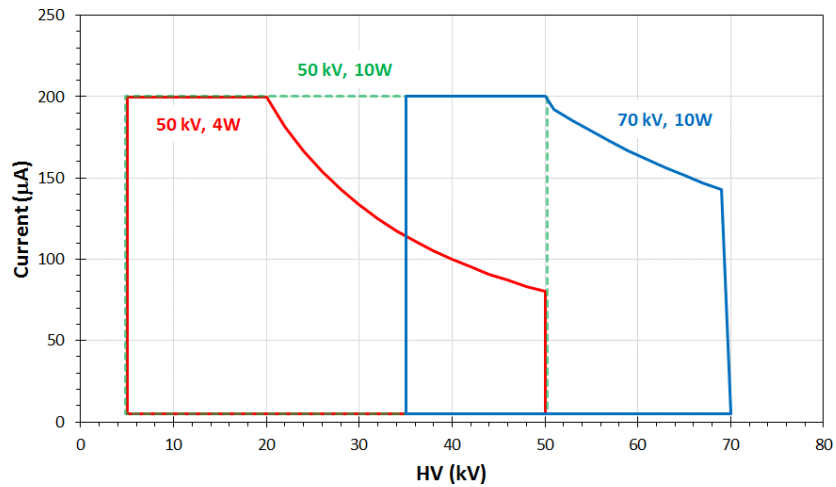


Figure 1. Mini-X Isopower. The current and voltage must be set in accordance with this curve or the Mini-X may be severely damaged. Damage of this kind is not covered under warranty. Amptek's control software limits the power to this curve. If one commands the system to a power exceeding the power limit, the software will use the commanded HV and rollback the current to meet the power limit. Note that the curves differ based on the tube.

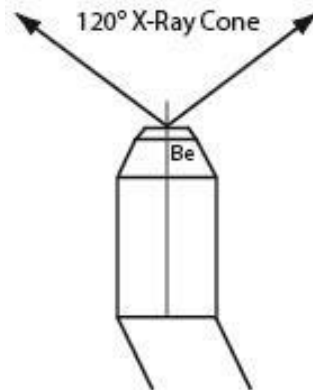


Figure 2. Mini-X2 Angular response. In the absence of a collimator, the Mini-X2 produces a conical response of 120°.

Output X-Ray Spectra

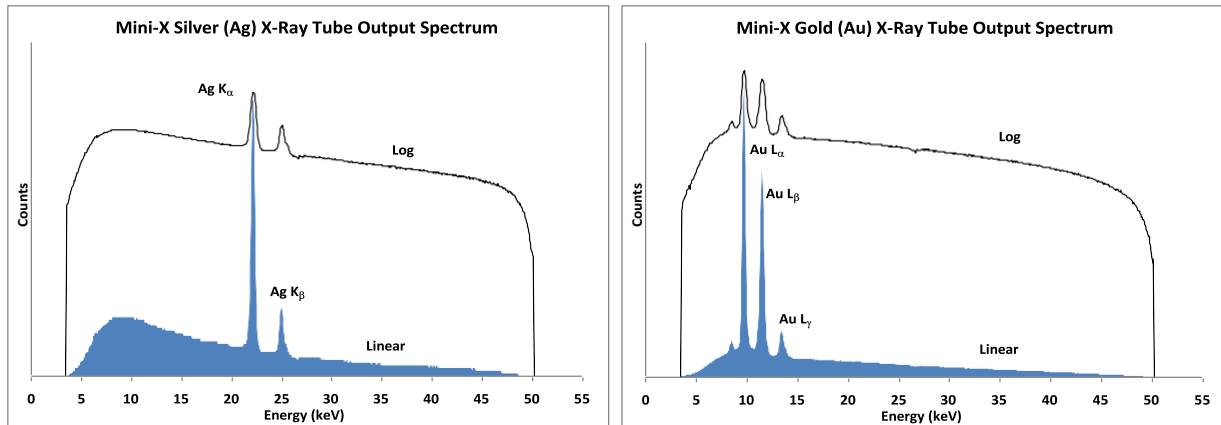


Figure 3. Output Spectrum with silver (Ag) target (left) and gold (Au) target (right). These were measured using a 1 mm thick CdTe detector located 1 meter from the Mini-X with a 1 mm pinhole collimator (made from tungsten) in front of the detector.

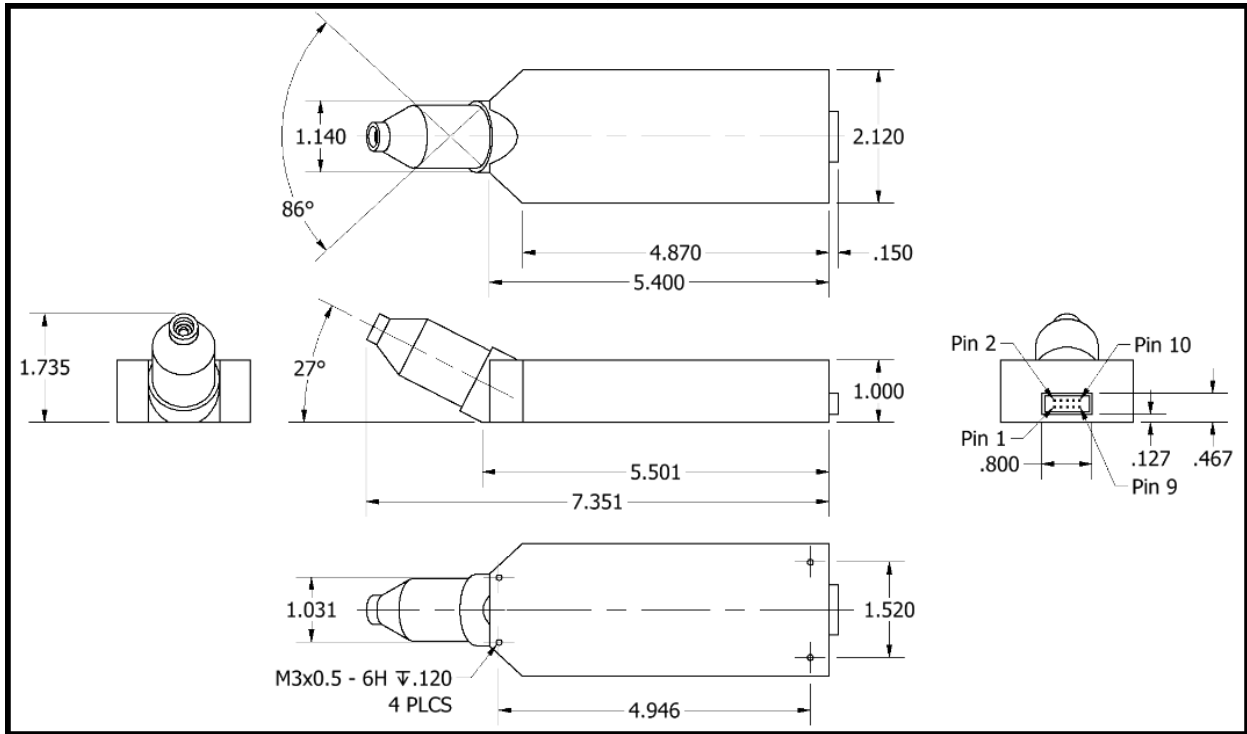
3.2 Mini-X2 Controller Specifications

Connectors	
Power	3 pos receptacle, 0.031" (Hirose)
USB	Standard Mini-USB
Interlock	4 pos terminal block, female sockets, 0.15" pitch
Mini-X2	10 pos latching ribbon, male, 0.10" pitch
Power	
Input Voltage	11.5 V to 12.5 V
Input Current	1.5 A max
Power consumption	4 W tubes: 9 W @ full power 10 W tubes: 18 W @ full power
Safety	
Controls	1) Safety interlock (with fail-safe lamp driver) 2) USB enable command (shuts off if USB is lost) 3) Watchdog timers
Indicators	1) Flashing LED 2) Beeper 3) External driver
Physical	
Dimensions	2.27 x 2.77 x 0.77 in
Weight	85 g

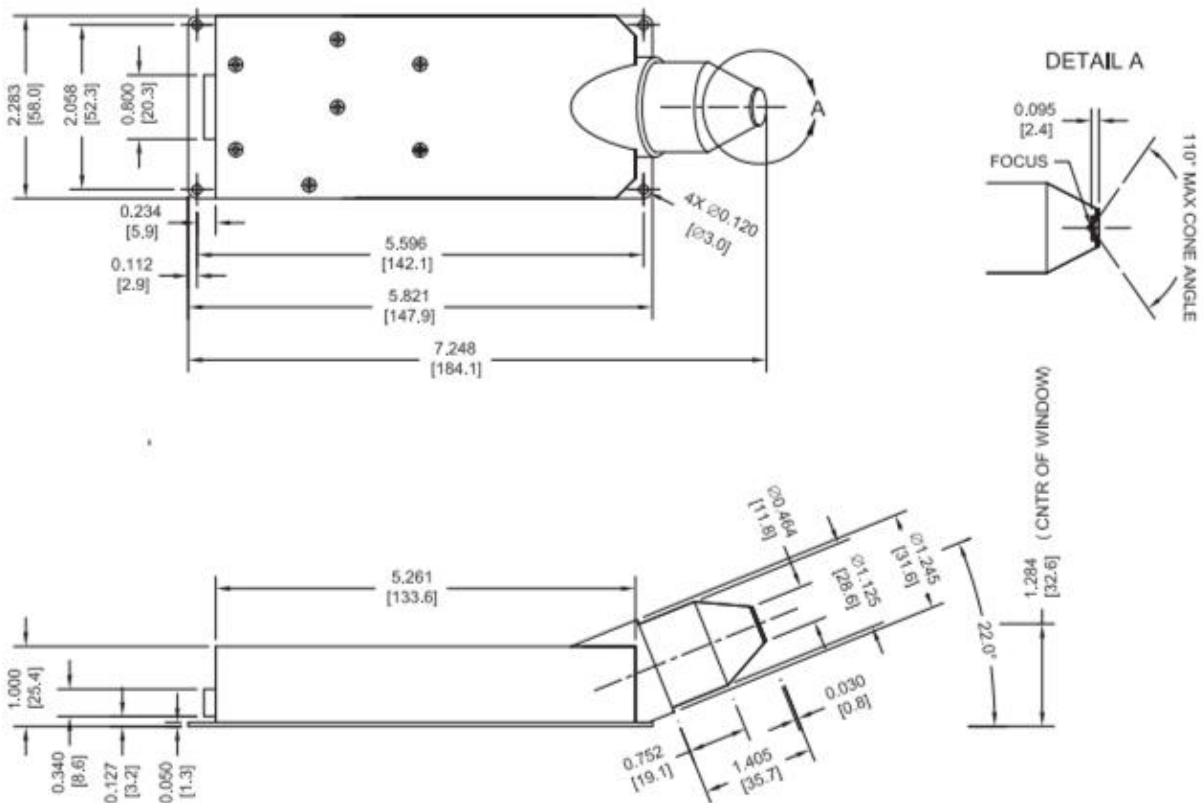
4 Mechanical Interface

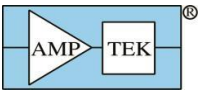
4.1 Dimensional Diagrams

- 50kV 4W Mechanicals (measurements are in inches)

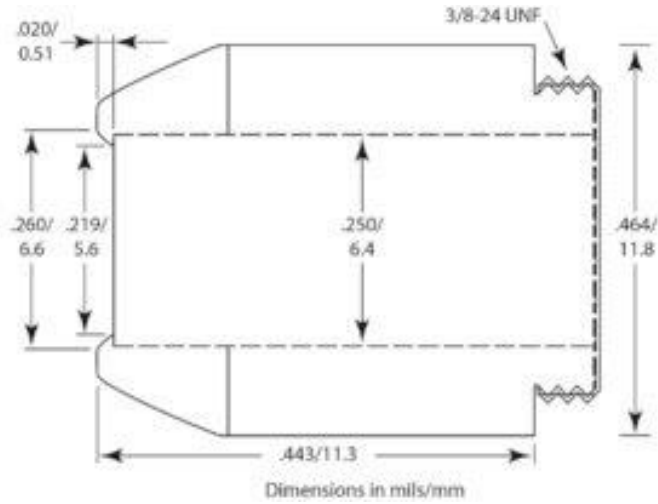


- 50kV 10W Mechanicals (measurements shown are in inches, [mm] in brackets)

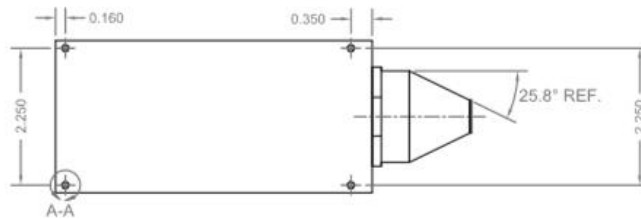
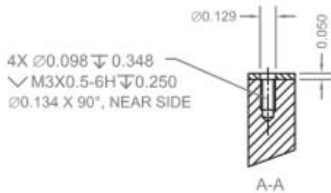
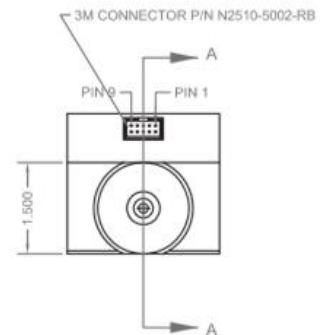
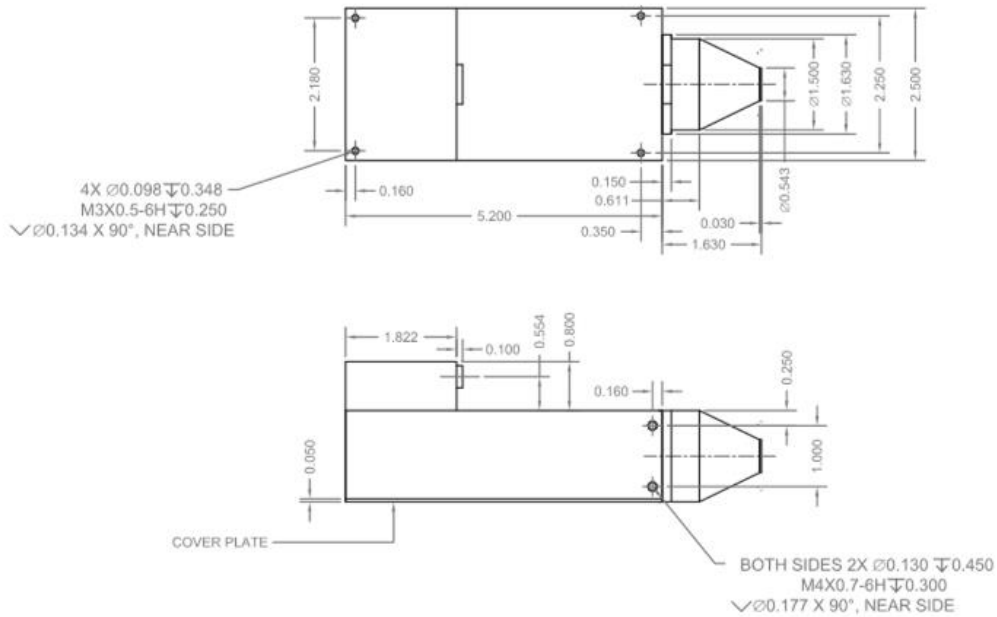


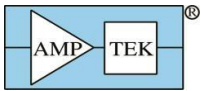


- Threaded Collimator Adapter Mechanicals, for use with 50kV models.



- 70kV 10W Mechanicals (measurements are in inches)





4.2 Connectors



Figure 6. Front (left) and rear (right) connector panels of the Mini-X2 Controller.

Controller to tube connectors

10 Positions Header, Shrouded Connector 0.100" (2.54mm)

Sample mating connector: 3M P/N 89110-0101, 10 Position IDC Socket

Pin #	Name	Type
1	V+	PWR, 6 to 12 VDC
2	V+	PWR, 6 to 12 VDC
3	GND	GND
4	GND	GND
5	TUBE I CONTROL	ANALOG IN, 0 to 4 VDC
6	TUBE HV CONTROL	ANALOG IN, 0 to 4 VDC
7	TUBE READY	DIGITAL OUT, TTL
8	TUBE ENABLE	DIGITAL IN, TTL
9	TUBE HV MONITOR	ANALOG OUT, 0 to 4 VDC
10	TUBE I MONITOR	ANALOG OUT, 0 to 4 VDC

Power

Power Jack on MX-50: Hirose MQ172-3PA(55).

Mating Plug: MQ172-3SA-CV

Pin #	Name
1	VIN (+12 V DC)
2	Do Not Connect
3	GND

Interlock

OST, EDSTLZ1550/4

Mating Plug: OST, EDZ1550/4

Pin #	Name
1	PWR to interlock (optional)
2	supply voltage to interlock switch/lamp
3	Accessory drive (Q3) DRAIN
4	GND

The function of the interlock is described in section 5.2.

USB

Standard USB 'mini-B' jack.

RS232 and I2C

The Mini-X2 has optional RS232 support – this option must be ordered, as it isn’t supported by the standard Mini-X2. With this option, either USB or RS232 signals can be fed into the USB connector J3.

Pin	USB Signal	RS232 Signal
1	VBUS	No connect
2	D-	TXD output (connect to RXD pin 2 on PC 9-pin D)
3	D+	RXD input (connect to TXD pin 3 on PC 9-pin D)
4	No connect	No connect
5	GND	GND

Connector P3 is also optional. It is used to connect power and I2C to an UltraMini tube. The Mini-X2 supports generic I2C transfers (as a master only), so this connector could be used for other functions.

Pin #	Name	Type
1	V+	PWR, 6 to 12 VDC
2	V+	PWR, 6 to 12 VDC
3	GND	GND
4	GND	GND
5	5V	5V power to tube I2C logic
6	GND	GND
7	TUBE READY	DIGITAL OUT, TTL
8	TUBE ENABLE	DIGITAL IN, TTL
9	I2C SCL	I2C clock, 5V logic
10	I2C SDA	I2C data, 5V logic

4.2 Thermal

The Mini-X2 requires proper and adequate cooling for maximum life. As such, it is the user’s responsibility to provide a cooling design, such that the ambient temperature of the X-ray tube does not exceed 50 °C. Air cooling via a small fan is recommended. Improper cooling is the single highest cause of X-ray tube failures. Improper cooling is not covered under the warranty.

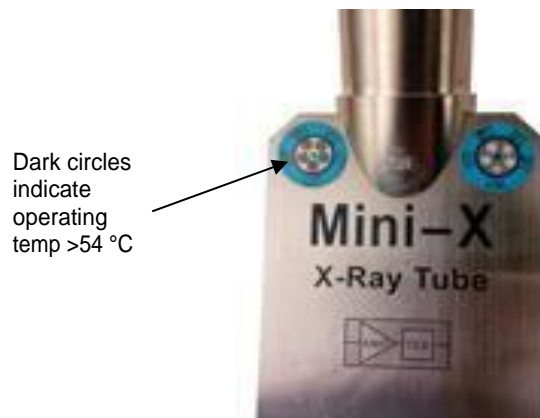
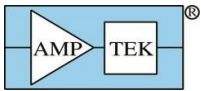


Figure 7. Temperature sensors. The maximum operating temperature of the Mini-X is 50 °C. The Temperature Sensors in this example show the Mini-X exceeded 54 °C.

This voids the warranty.



5 Electrical Interface

5.1 Power Interface

Nominal input voltage: 12 VDC

Absolute Maximum Power Supply Voltage: +12.5 VDC

Absolute Minimum Power Supply Voltage: + 11.5 VDC

Input power outside this range will damage Mini-X2 components.

5.2 Mini-X2 Tube Voltages

PIN	NAME	50 kV, 4W	50 kV, 10W	70 kV
1	V+	12 VDC		
2	V+	12 VDC		
3	GND	GND		
4	GND	GND		
5	TUBE I CONTROL	0.1 - 4 V → 5 - 200 μA	0.1 - 4 V → 5 - 200 μA	0 - 3 V → 0 - 150 μA
6	TUBE HV CONTROL	0.4 - 4 V → 5 - 50 kV	0.4 - 4 V → 5 - 50 kV	1.8 - 3.5 V → 35 - 70 kV
7	TUBE READY	Low=Not Ready, High=Ready		
8	TUBE ENABLE	Low = Off, High = Enable		
9	TUBE HV MONITOR	0.4 - 4 V → 5 - 50 kV	0.4 - 4 V → 5 - 50 kV	1.8 - 3.5 V → 35 - 70 kV
10	TUBE I MONITOR	0.1 - 4 V → 5 - 200 μA	0.1 - 4 V → 5 - 200 μA	0 - 3 V → 0 - 150 μA
	Power	4 W	10 W	10 W

The “power” listed here is the power delivered to the target, i.e. the product of the HV setting and the current of electrons reaching the target. The power drawn by the X-ray tube is roughly 2x: operating the tube at 4W of X-rays will require about 8W of input power.

5.3 Mini-X2 Interlock and Accessory Drive

The AUX connector on the Mini-X2 contains a safety interlock, designed for use with a fail-safe warning lamp, and an accessory drive, which can be used to switch an external lamp, beeper or other indicator. Typical application circuits are sketched below and discussed in more detail in section 0.

In the interlock circuit shown, the Controller applies a configurable voltage across pins 2 and 4 then monitors the current. The tube is enabled only if the current is within the correct (programmable) range. The tube is disabled if the switch is open or if the lamp fails (either open or shorted). In the accessory circuit shown, the FET switches on whenever the tube is enabled. The FET can switch up to 30 V at 0.25 A. This can be used to energize an external warning lamp or other hardware.

See section 10 for more details on using the interlock.

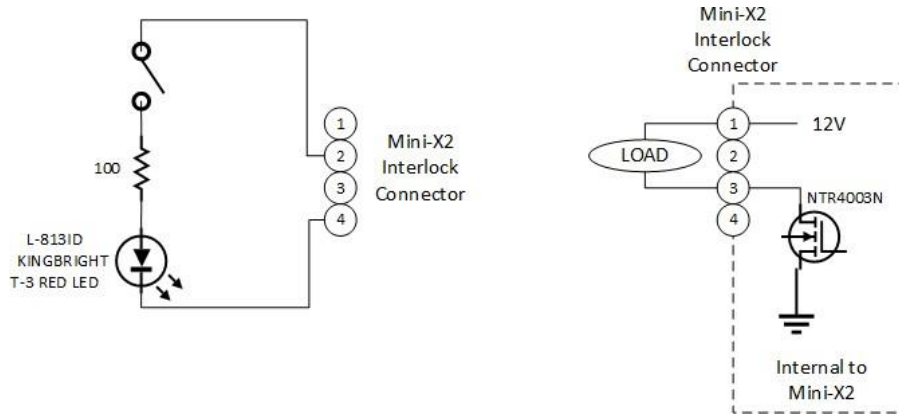


Figure 8. Sample interlock and accessory drive circuits.

6 Mini-X2 Software

6.1 Software Installation

1. Install the WINUSB driver. We strongly recommend that you use Windows Update to install the USB driver!! If your computer is on the Internet, Windows will find the driver on its update site and install it. Alternatively for a manual installation, this web page has the USB drivers <https://www.amptek.com/software/dp5-digital-pulse-processor-software/dpp-installation-instructions> Please see the “WINUSB Driver Installation Instructions” included in the driver download.
2. The Mini-X2 control software can be downloaded from <https://www.amptek.com/software/mini-x2-x-ray-tube-software>. Run the setup program to install the Mini-X2 control software.

6.2 Operating the Mini-X2

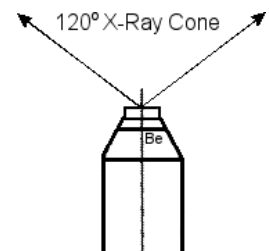
SAFETY PRECAUTIONS MUST BE USED FOR EQUIPMENT PRODUCING X-RAYS.

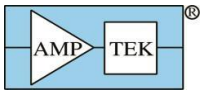
MINIMIZE HUMAN EXPOSURE TO X-RAYS.

USE A GEIGER COUNTER TO MONITOR RADIATION.

STOP: ONLY QUALIFIED PERSONNEL SHOULD PROCEED BEYOND THIS POINT.

1. Install the software as described in Section 6.1.
2. Connect the Mini-X2 Controller to the computer with the USB cable.
3. Connect the AC power adapter to the Mini-X Controller and plug it into an appropriate 110/220 AC power outlet.
4. Connect the ten-pin connector from the Mini-X2 Controller to the Mini-X2 X-ray tube module.
*Note that the connectors on each end are polarized and can only be inserted one way.
5. Remove the safety plug from the cover attached to the Mini-X2 X-ray tube. Either install the collimator into the cover or leave the cover empty. Re-attach the cover to the X-ray tube.
6. Make sure that you have verified the anticipated direction of the X-ray beam as described above.



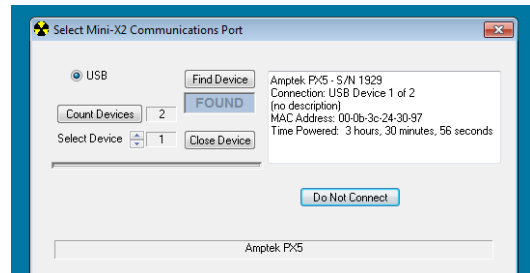
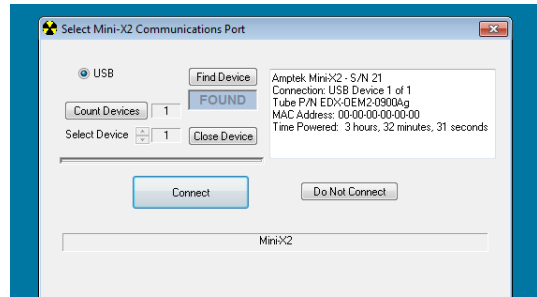


7. The Mini-X2 Controller has a hardware interlock to prevent accidental radiation exposure. This interlock must be enabled, connected through a series resistance, to produce X-rays (as discussed in sections 5.3 and 0). Install the interlock plug to produce X-rays.

8. Open the Amptek Mini-X Controller Software. It will appear as shown to the right.

9. If it displays the "Mini-X2" in the box, as shown, then click the "Connect" button.

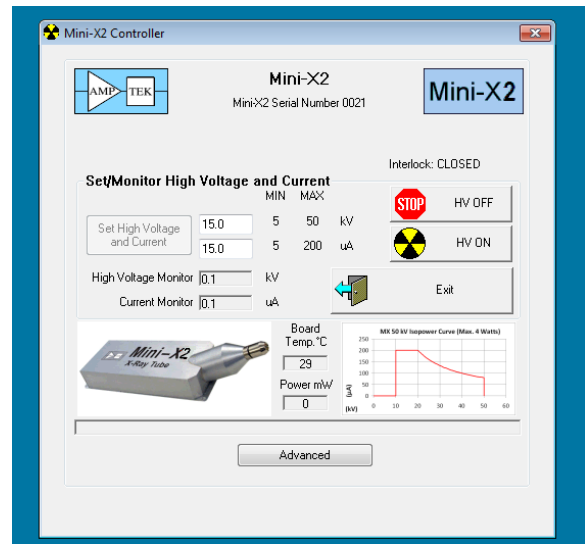
10. If you are operating another Amptek device, for example an X123 spectrometer, you will see a display like one on the right. The software has found the digital processor. The "count" is 2 and it does not say Mini-X2 in the dialog. Increment "Select Device" to 2 and it should display the "Mini-X2" information. Then click "Connect".



11. Now you will see the screen to the right. The software will display the serial number of the Mini-X2. It also displays the status of the Interlock; it must be "Closed" to enable the tube.

12. The software defaults to a setting of 15 kV and 15 µA. To change the values, click into the appropriate text box and type in the desired number.

IMPORTANT: Do not enter a voltage higher than is rated for your unit. In addition, the total power is governed by the Isopower curve. If a requested current is too high, the software will automatically adjust it to the maximum allowed value. Do not attempt to enter a current that exceeds the indicated value for that voltage.



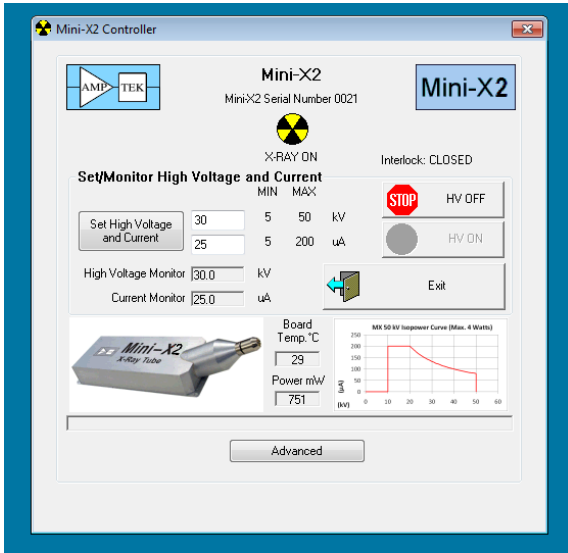
13. Click the HV ON button to turn on the tube. The software will ask you to confirm. Click Yes.



THE MINI-X2 IS NOW PRODUCING X-RAYS



14. The Mini-X2 will start to beep and the red LED on the end panel of the unit will flash. In addition the yellow and black "Radiation Symbol" will blink in the Mini-X Software and the words "X-Ray ON" will appear. Note: The LED changes color and flashing to indicate system status, as described in section 0.



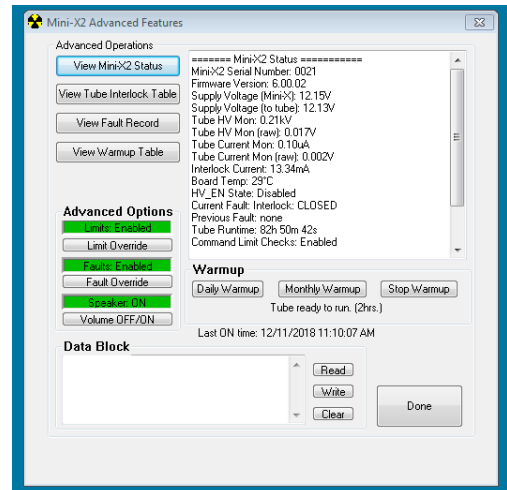
15. The Voltage and Current monitors now show the actual X-ray tube condition. Although the values for Voltage and Current might be slightly different from the requested values, these are the actual values of the tube.
16. To change the high voltage and current, click into the appropriate text box and enter the number. Then click the Set High Voltage and Current button.
17. To turn off the Mini-X2 click the HV OFF button, then click the Exit button to exit the software. Always unplug the Mini-X-2, install the safety plug, and disable the interlock when not in use.

6.3 Advanced Operation

- Clicking on the “Advanced” button on the main Mini-X2 screen brings up the screen shown on the right, which offers access to additional data and settings.
- “View Mini-X2 Status” will read the status of the unit and several monitored values.
- “View Interlock Table” will read the interlock settings and monitored values.

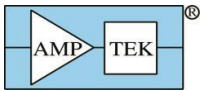
Fault Record

- If the Mini-X2 shuts off for any reason (open interlock, voltage out of range, current out of range, etc), the Controller captures and stores a snapshot of monitored values at the time of the fault.
- Clicking “View Fault Record” will display these values. This is useful for resolving anomalies. You can select the information in this box and paste it into a text file for future reference.



Warm-up

- The manufacturer of the tube, Newton Scientific, recommends that customers run a “warmup” sequence if the tube has been off for an extended time. This warm up slowly increases the voltage and current rather than going straight to high power and may extend operating life.



- There is a “daily warm-up” which is recommended if the unit has been off for a day, which takes approximately 30 seconds to run.
- There is a “monthly warm-up” which is recommended if the unit has been off for a month. This takes much longer to run, on the order of 30-45 minutes
- To run either warm-up, simply press the appropriate button (the system will check for interlock status and such). To view the warm-up settings, click “View Warmup Table”.
- Changing the HV/current settings or turning the tube off will cancel the warmup cycle.

Over-rides

- Limits: Each tube has certain specified voltage and current limits. The 50 kV tube, for example, is guaranteed to operate within specs from 10 to 50 kV and from 5 to 200 μ A. Some users want to operate outside the guaranteed specs, say below 10 kV or 5 μ A. Clicking the “Limit Override” button will tell the software to ignore the built-in limits. We cannot guarantee any operation outside the limits.
- Faults: When the Controller sets a commanded kV and current, it reads back monitor values on these. If they are outside a certain tolerance, the software concludes there was a fault and turns off the tube. Clicking the “Fault Override” button will tell the software to ignore the monitor checking. This means that the reported current and/or HV do not match the commanded values.
- Speaker: Clicking the “Volume OFF/ON” button will disable the beeper, which is one of the safety devices on the Mini-X2.

Reconfiguring the Controller for a different X-ray Tube

- This is carried out using a different program, Amptek’s **Firmware Manager**, available on the Amptek website <https://ametekamptek.preview.ametekweb.com/software/dp5-digital-pulse-processor-software>.
- Instructions can be found in a separate application note.

7 Mini-X2 Design

7.1 X-ray tube

The heart of the Mini-X2 is a compact X-ray tube which uses a transmission target. The high voltage power supply (HVPS) produces a bias voltage between the target (which is grounded) and the filament. This voltage accelerates electrons produced at the filament into the target. When these electrons decelerate in the target material, they produce bremsstrahlung radiation, X-rays with a continuous energy spectrum. They also produce X-rays at the characteristic energy of the target material. Many of these X-rays are directed towards the window, made of Be (beryllium), where they can be collimated into the sample. The X-ray tube contains shielding which stops X-rays outside of the 120° cone.

7.2 High Voltage Power Supply

The HVPS takes the 12 VDC input and steps it up to the commanded bias (10kV to 50kV). It is a switch mode regulator with a conventional Cockcroft-Walton multiplier, operating between 40 and 100 kHz.

There are three inputs to the HVPS: an analog voltage which sets the HV, an analog voltage which sets the current, and an ON/OFF logic signal. The HV and current signals have a range of 0 to 4V, which correspond to the HPVS settings: a 2V input to the HV results in a half-scale output of 25 kV. There are three outputs from the HVPS: an analog voltage reading the HV, an analog voltage reading the current, and a STATUS logic signal. These have the same scale factors as the inputs.

The Mini-X2 X-ray tube modules are supplied by NSI. NSI's standard X-ray tube modules have analog inputs and outputs, which are the Mini-X2 Controller's standard inputs and outputs. NSI has recently released a smaller tube, called the "UltraMini", which uses a digital I2C interface. Amptek's Mini-X2 controller can also support the I2C interface to the UltraMini.

7.3 Mini-X2 Controller

The Controller takes the control values commanded via USB and uses these to set the proper control voltages and to send the ON/OFF command. It also reads the outputs. There are a few key details to the control and interface module:

- The interlock circuit is very important, both for radiation safety and for successful operation of the Mini-X2. Please refer to sections 4.2 and 10 for details.
- The software compares the commanded values for HV and current to the outputs. If the inputs and outputs differ (outside of tolerance limits and sustained for a certain time), the HVPS is disabled.
- The Mini-X2 Controller is based on a Silicon Labs 8051 microcontroller, running the same communications software as Amptek's digital pulse processors (DP5, X123, PX5, etc). This software interface is called FW6 and is described in the *Amptek Digital Products Programmer's Guide*.

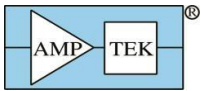
8 Mini-X2 Accessories

8.1 Collimator

The Mini-X2 (50kV models only) are provided with two collimators to facilitate its use in XRF applications. They consist of brass collimators with aluminum (Al) inserts and a cover that screws into the Mini-X2. The collimators have 1 and 2 mm diameter holes. A brass safety plug is also provided which, when installed, reduces the flux from an operating tube to less than 25 $\mu\text{Sv/h}$ (2.5 mrem/hr) at 5 cm away in accordance with Requirements 5.2.2.1.1 and 5.2.2.2.2 of the NBS Handbook for Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment. Insert the collimator into the cover and then carefully screw the assembly onto the Mini-X2. The collimator has a 2 mm diameter hole.



Figure 9. Left photo shows the Mini-X2 collimators, safety plug, and cover. The middle photo shows the safety plug installed in the cover and attached to the Mini-X2. This configuration meets the radiation requirements discussed above. The Mini-X2 ships from the factory in this configuration. The right photo shows the collimator installed in the cover.



The collimator is very important for obtaining high quality results in XRF analysis; you may obtain better results by using a customized collimator rather than Amptek’s default. Please refer to Amptek’s application note, “X-ray Tube Collimators FAQ”, for more information.

8.2 Brass Safety Plug

When the brass safety plug is installed in the cover (Figure 9. Left photo shows the Mini-X2 collimators, safety plug, and cover. The middle photo shows the safety plug installed in the cover and attached to the Mini-X2. This configuration meets the radiation requirements discussed above. The Mini-X2 ships from the factory in this configuration. The right photo shows the collimator installed in the cover., middle) and screwed onto the Mini-X2 it meets the radiation safety requirements of Section 1.2. For personal protection always install the safety plug into the cover and attach to the Mini-X2 when not in use. The Mini-X2 ships from the factory in this configuration.

8.3 Filters

The Mini-X2 is shipped with a set of filters to modify the output spectrum of the tube to better suit a particular application. The use of any filter will reduce the flux, so the current may have to be increased to obtain an appropriate flux. Install the filter at the Mini-X2 screw base. Then screw on the cover with the collimator. Make sure that the cover screws all the way down, otherwise radiation will leak through the gap. All filter thicknesses will fit except for the 40 mil Al. This filter must be installed on the outside output aperture of the collimator and held in place with the black cap provided.

Filters are very important for obtaining high quality results in XRF analysis. Using the correct filter can greatly improve the signal to background ratio for the photopeaks of interest, thus improving the precision, accuracy, and detection limits of the XRF measurements. Please refer to Amptek’s application note, “X-ray Tube Filters FAQ”, for more information.

Material	Thickness μm/mils	# Included
Al	1016 / 40	5
Al	254 / 10	5
Cu	25.4 / 1	3
Mo	25.4 / 1	2
Ag	25.4 / 1	1
W	25.4 / 1	1

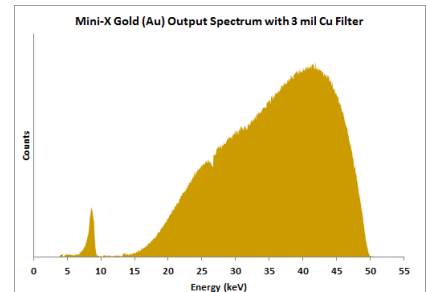
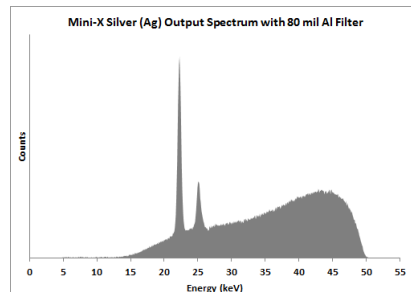
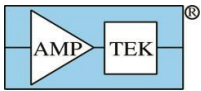


Figure 10. Sample filtered spectra.



9 Radiation Precautions

By its very nature, the Mini-X2 X-ray tube's produce ionizing radiation at a level that would be hazardous to personnel, if appropriate precautions are not taken. The hardware and software include interlocks and other features to mitigate these hazards but it is the user's responsibility to ensure safe operations.

9.1 Safety Standards

Radiation safety requirements for X-ray tubes in analytical instruments vary from country to country and from institution to institution. There are suggested standards. For example:

- The National Bureau of Standards (NBS) Handbook for Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment specifies that radiation levels should not exceed 25 $\mu\text{Sv/h}$ (2.5 mrem/h) measured 5 cm from the surface of the housing (Requirements 5.2.2.1.1 and 5.2.2.2.2).

9.2 Safety Plug

The Mini-X2 X-ray tube is shipped with a safety plug that essentially blocks the X-rays. At full power, the dose meets the requirements of the NBS standard (< 2.5 mrem/h @ 5 cm). This safety plug will need to be removed for normal operation.

9.3 Shielding

How much shielding is needed? This depends on the HV setting and the current/power settings. It also depends on the sample used: many samples will block much of the X-ray tube flux – and scatter much of the flux back. We can provide some example shielding here, for a specific case, but it is the user's responsibility to ensure that your equipment meets your requirements.

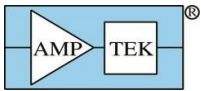
Examples of Shielding, that comply with the above standard, for a 50 kV tube running at 80 μA (4W). Note that 10W or 70 kV tubes will need more shielding.

- 1 mm (0.040 inch) of Pb will result in radiation levels of 0.5 mrem/h.
- 6.35 mm (0.250 inch) of Fe will result in radiation levels of 0.5 mrem/h.
- 3.18 mm (0.125 inch) of Brass will result in radiation levels of 2.5 mrem/h.

The inside of the housing can also be lined with 3.18 mm (0.125 inch) of aluminum (Al) in order to absorb the XRF from the shielding material.

The shielding needs to fully enclose the X-ray cone and sample. X-rays are scattered in all directions, 4π steradians. In many cases, the most intense radiation hazard is from backscattered radiation (often where the operator is located). Any gaps in the shielding, e.g. for the tube or a spectrometer or sensor wires, will pass radiation. Where possible, use a jog in such gaps rather than a direct path.

CAUTION: The Mini-X2 is only one component of an X-ray instrument. It is the responsibility of the user, to provide a fail-safe metal enclosure to prevent escaping radiation while using this product. The final product (turn-key system) must comply with local government regulations to protect personnel from exposure to radiation. Amptek Inc. bears no responsibility for the incorrect use of this product.



10 Understanding the Interlock and Alarm

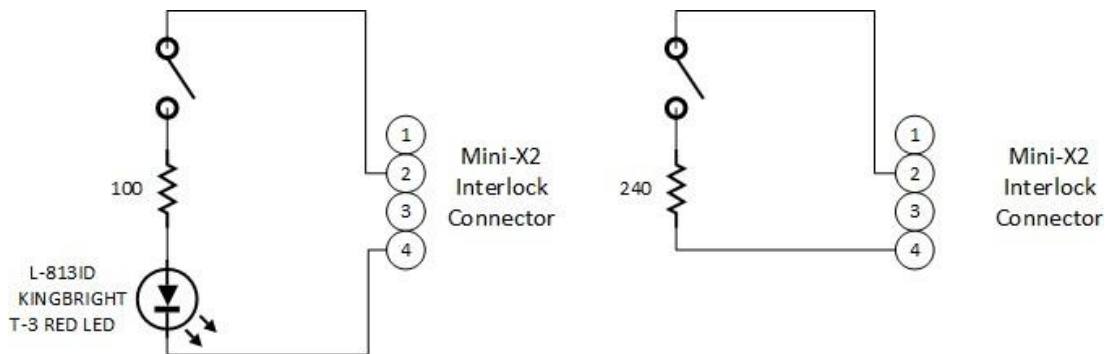
Safety is an important consideration with the Mini-X2. Key elements in the safety system include the interlock, an accessory drive circuit, and the alarm (the light and the beeper).

10.1 Interlock

The Mini-X2 employs an active interlock circuit: it drives a programmable voltage (typically 3.5 V) into the external interlock circuit and measures the resulting current. If the measured current is within the programmable acceptance range (typically 15mA+/- 5mA), then the interlock is considered 'closed', and X-ray tube operation is allowed. If the measured current is below the programmed range, then the interlock is considered 'open', and x-ray tube operation is not allowed. Likewise, if the current is above the programmed range, then the interlock is considered 'shorted', and tube operation is not allowed.

- The interlock current is sampled at a 10 Hz rate. This implies that there is a maximum delay of ~100ms from the interlock switch being opened and the x-ray tube being switched off.
- The programmable interlock voltage is supplied on Pin 2 of the Interlock connector and should be returned to Pin 4, which is ground.
- The interlock circuit can be programmed to output a maximum of 4.5 V, and the highest current the circuit can reliably support is around 35mA. Incandescent lamps are not recommended for use with the Mini-X2 interlock circuit, as not adequate power can be driven for adequate brightness. Programming new interlock voltage and current parameters can be performed by the end user, under the guidance of Amptek. Contact Amptek for more information.

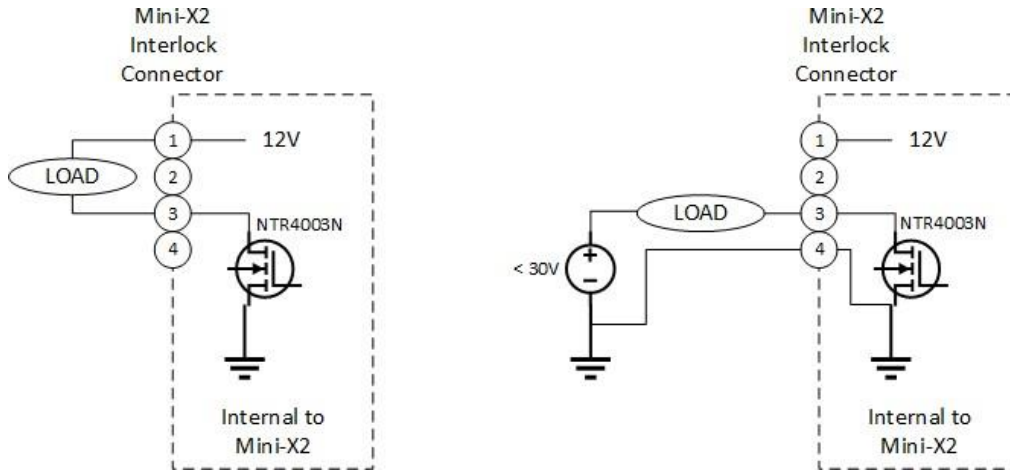
Two interlock circuits are shown below. The first uses a large 10mm high-intensity LED in series with a switch and current-limiting resistor. In this configuration, the LED is fault-tolerant – if the LED fails either open or shorted, then the resulting interlock current is out of range, and x-ray tube operation is not allowed. If a different LED is used, the current-limiting resistor should be adjusted for ~15mA of LED current. This is particularly true if a different LED color is selected, as different colors typically have different forward voltages. The second shows a pure interlock, without the failsafe lamp. Note that the user cannot simply connect the interlock switch between pins 2 and 4; a series resistance is needed to limit the current.



10.2 Accessory Drive

The Mini-X2 can also switch an external load (relay, lamp, etc). As shown in the following schematic, the Mini-X2 has a N-channel MOSFET from Pin 3 of the interlock connector to ground. The FET can reliably switch up to 30 V, 0.25 A. This FET is turned on whenever the x-ray tube is energized. The accessory power can be sourced from interlock connector Pin 1 (12 V), as long as the maximum power of the input supply isn't exceeded. Note that if driving a lamp or other warning device, this is not fault-tolerant as the current

isn't monitored. An external supply can also be used to power the external load. It should be referenced to Pin 4 of the Interlock connector, which is GND.



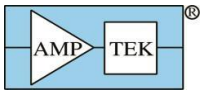
10.3 LED and Beeper

The Mini-X2 has a dual-color (red/blue) LED on-board. The following table lists the various states indicated by the LED.

Display	Meaning
Off	No power.
Solid blue	Input power supply is within range specified in tube table; interlock is not valid OR no communication interface (USB/RS232) connected => tube power is off (no X-rays)
Flashing blue	Input power supply is outside range => tube power is off (no X-rays)
Solid red	Input power supply is within range specified in tube table; interlock is valid (closed) => tube power is ON, though tube has not been enabled (no X-rays)
Flashing red	Input power supply is within range specified in tube table; interlock is valid (closed), tube has been commanded on; application is talking to Mini-X2 => tube power is ON, tube is enabled (X-rays are ON)

The speaker is silent, except when x-rays are being produced, in which case it beeps at a 1Hz rate. If an error occurs while the tube is on, a 1-second warbling warning tone is sounded, and the x-ray tube is turned off. The possible errors that cause this are:

- Loss of communication (either USB/RS232 unplugged)
- The application software stopped talking
- The interlock transitioned from closed to open or shorted
- The HV or current monitor from the tube is outside of range (sampling starts 2 seconds after the tube is commanded on).



10.4 Watchdog timers

- If the USB or RS232 electrical connection is lost, the Mini-2 microcontroller turns off the tube immediately.
- As long as there is a USB or RS232 connection, the application in the PC must request device status about once per second. If 3 seconds pass with no status request, the Mini-X2 microcontroller turns off the tube.
- There is a 1 second watchdog timer on the Mini-X2 microcontroller; if the controller does not reset the watchdog, then after one second, there is a hardware reset of the controller, which disables the tube.

11 Warranty and Technical Questions

WARRANTY

AMPTEK, INC. warrants to the original purchaser this instrument to be free from defects in materials and workmanship for a period of one year from shipment or 2000 hours, whichever comes first. AMPTEK, INC. will, without charge, repair or replace (at its option) a defective instrument upon return to the factory. This warranty does not apply in the event of misuse or abuse of the instrument or unauthorized alterations or repair. AMPTEK, INC. shall not be liable for any consequential damages, including without limitation, damages resulting from the loss of use due to failure of this instrument. All products returned under the warranty must be shipped prepaid to the factory with documentation describing the problem and the circumstances under which it was observed. The factory MUST be notified prior to return shipment. The instrument will be evaluated, repaired or replaced, and promptly returned if the warranty claims are substantiated. A nominal fee will be charged for unsubstantiated claims. Please include the model and serial number in all correspondence with the factory.

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