

# DYNALYZER

## *Dynalyzer IIIU High Voltage Unit*



**OPERATION MANUAL**

**Radcal**

## **Warranty for the Model M-96311 Dynalyzer High-Voltage Unit**

Radcal Corporation warrants that, in the event that any defects in material or workmanship should develop within one year of the date of shipment, the company assumes full responsibility for servicing equipment of its manufacture without charge upon return of the equipment to Radcal, with shipping costs prepaid by the customer. Costs to return-ship by ground to customers will be paid by Radcal if the repairs are warranty-applicable.

Radcal shall not be held liable for damages or delays caused by defects beyond making repairs or furnishing replacement parts, nor shall Radcal be liable for any defective material replaced without Radcal's consent during the period of this warranty. Radcal reserves the right to perform warranty services at its own factory.

### **Non-Warranty Repairs**

The calibration of this instrument was correct within specified limits when the instrument left our factory. Radcal cannot be responsible for injury or damage resulting from improper use or calibration errors which develop subsequent to our shipment of the instrument.

If Radcal determines that a fault has been caused by misuse, abnormal operating conditions, or repairs by unauthorized personnel during the warranty period, repairs and shipping costs will be billed at normal rates.

If the equipment is found to be in proper working condition, Radcal will return-ship the equipment at customer expense.

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## Preface

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 **IMPORTANT:** ALWAYS PLUG DYNALYZER, SCOPE, AND DISPLAY INTO SAME OUTLET.

## Safety Notice

This unit is designed to operate at hazardous voltages found in x-ray generators. The operator is cautioned to observe all safety practices normally associated with x-ray equipment. Among these precautions are:

1. Never make or break connections in the high voltage circuit when the generator is energized. In spite of all interlocks present, it is still possible for an accidental firing to occur.
2. Never assume that a cable voltage is discharged. There is sufficient capacitance in the x-ray cable to maintain a lethal charge. Touch the pins of any cable to ground to be sure that there is no residual charge.
3. Inspect cables often. Do not use any cables with a broken braid at the connectors or in the cable.
4. Always tighten the locking ring of the cable connector to ensure a good ground connection. Do not overtighten the ring.
5. Use oil or vaporizing compound on all high-voltage connectors to prevent flashover.
6. Keep away from x-ray beam. This system is designed for remote reading so the equipment should not be placed near the x-ray beam path.
7. Do not knowingly operate this unit in excess of 150 kVp, or in equipment with unstable x-ray tubes. Severe damage to the equipment may result from an overvoltage condition.
8. Be sure of your grounds. When in doubt, ground tank to transformer.
9. Always monitor tank pressure. Do not use the system if the pressure reads less than 22 psig. Read the maintenance section for refilling or return to the factory.

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 **CAUTION:** **IMPORTANT HANDLING NOTICE:** This unit is a precision high-voltage measurement instrument and must be handled with as much care as one would handle an oscilloscope. While it is portable and is designed to sustain normal handling and transportation shock and vibration, it must not be subjected to excessive shock or vibration. The precision electronic assemblies contained inside the tank are subject to damage from abnormal shock transmitted from the heavy flanges on the tank. Improper handling can cause tank failure and loss of warranty protection.

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## **Introduction**

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### **General**

The Dynalyzer III High Voltage Unit is capable of providing isolated signals analogous to:

1. Anode, Cathode, and Anode + Cathode kilovoltages
2. Anode Current
3. Filament Current (AC)

These signals may be viewed on an oscilloscope, may be measured with a voltmeter, or may be processed and displayed with the Dynalyzer Digital Display.

This unit has been designed as a calibration instrument and as a diagnostic tool for servicing x-ray equipment.

This unit is designed for continuous duty, and may be left in the high-voltage circuit indefinitely, if desired. This feature is desirable in special applications where frequent calibration is required.

This unit is portable. It weighs 32 pounds and is designed to simplify servicing and repair.

### **Basic Principle of Operation**

The Dynalyzer High Voltage Unit is built in two sections. All high-voltage components are located in a tank pressurized with 30 psig of Sulfur Hexafluoride (SF<sub>6</sub>) gas. In the base of the unit are power supplies and buffer amplifiers to adjust the levels of the isolated signals, provide buffering against cable and instrument loading effects, and provide frequency compensation. In addition, there is an oscillator which in conjunction with a high-frequency isolation transformer located in the tank, provides power to operate the anode current sensing system.

#### ***Anode Current Sensor***

The anode current sensor is an optically-coupled device that is capable of providing an isolated signal that represents the anode current waveform. The sensor is capable of measuring current in the range of 1 mA to 2 Amperes with a 2% absolute accuracy  $\pm$  zero offset. The output conversion factor is 1 mV/mA for fluoroscopic measurements. The insertion impedance of the unit is 200 ohms  $\pm$  5%. The average power rating of this resistor network is 10 watts, and is the only duty cycle limitation on this unit. The kVp rating is 150.

#### ***High-Voltage Divider***

The divider consists of two 1000 megaohm sections that are connected between the anode and ground, and cathode and ground. Each section contains ten (10) 100 megaohm resistors connected in series. The geometry of the structure provides distributed capacitance that allows a frequency response of 100 kHz to be obtained by adjustment of the buffer amplifier compensation capacitor.

#### ***Filament Current***

Filament current is measured in the common lead of the cathode circuit using an insulated AC toroidal transformer. The output of the transformer, which is loaded with a 1 ohm resistor, is

amplified to a signal level of 0.1 volt (p-p), and is frequency compensated to a maximum frequency of 20 kHz.

## Equipment Supplied

As supplied, the High Voltage Unit is shipped with the following components:

- High Voltage Unit Assembly
- 12 ft. Coaxial Cable, BNC Connectors each end (2 each)
- Vaporproofing Compound (2 [two] 1.5 oz. tubes)
- Line cord (6 ft.)
- Dummy plugs (2)

Additional equipment required for use includes:

- Dual-trace oscilloscope to display mA and kV waveforms  
Optionally, a digital voltmeter (DVM) or the Dynalyzer III Digital Display
- Two (2) 3-conductor, 5-foot long high-voltage x-ray cables, Federal Standard Connector

## Specifications

<b>Calibration Standard</b>	Factory calibrated, all output parameters traceable to National Bureau of Standards
<b>Electrical Rating (maximum peak voltages)</b>	Anode to cathode: 150 kVp  Anode to ground: 85 kVp  Cathode to ground: 85 kVp
<b>Current from x-ray to Generator (max)</b>	Anode (peak): 2 amps for 8 msec  Anode (continuous): 100 mA  Filament: 10 amps (ac rms)
<b>D.C. Voltage Division Ration</b>	10,000: 1 $\pm$ 1% (10kV to 75 kV plus & minus polarity)
<b>Voltage Divider Load</b>	1000 megohms to ground  2000 megohms anode-cathode
<b>Duty Cycle</b>	Continuous
<b>Frequency Response</b>	Voltage: 0-1 kHz $\pm$ 2.9% 1 kHz – 100 kHz $\pm$ 12.2%  Anode current: 0-5 kHz $\pm$ 1db, $\pm$ 2% to 300 Hz (Rad. Range) 0-500 Hz $\pm$ 1 db, $\pm$ 2% to 100 Hz (Fluoro. Range)  Filament current: 20 Hz to 20 kHz, $\pm$ 1db
<b>Filament Current Sensor</b>	Output level: 0.1 volt (p-p) per ampere (p-p)  Ratio: 0.1 volt/ampere ( $\pm$ 5% + zero offset)  Noise level: 0.1 ampere, rms
<b>Anode Current Sensor</b>	Current rating: 1 mA to 2 amps  Insertion impedance: 200 ohms $\pm$ 5% Power rating: 10 watts

	<p>Ratio: 1 millivolt/milliamper, (Rad. Range) 20 millivolts/milliamper (fluoro Range)</p> <p>Accuracy: 1 mA to 10 mA, <math>\pm 2\%</math> (<math>\pm</math> zero offset; Fluoro range) 10 mA to 2 Amp, <math>\pm 2\%</math> (<math>\pm</math> zero offset; Rad Range)</p> <p>Noise level: 2 mV (p-p) (Max)</p>
<b>Gas Volume</b>	0.5 cubic foot
<b>Pressure Gauge</b>	0-30 psig scale
<b>Insulation</b>	Sulfur Hexafluoride gas (SF <sub>6</sub> ) @ 25-30 psig
<b>Gas Relief Valve</b>	22 psig
<b>Gas Filling Valve</b>	Schrader type, spring loaded
<b>Test Level Connectors</b>	Scope inputs: 5-BNC type, insulated
	Digital display: 1-Bendix PT 02A-16-8P
<b>High Voltage Receptacles 3-conductor cables</b>	Receptacles conform to NEMA XR-7-1979
<b>Coaxial Cable</b>	Two 12-foot long cables RG-58/U with BNC connectors
<b>Temperature</b>	Operating: +15° to +30°C
	Storage: - 10° to + 50°C
<b>Dimensions</b>	See Outline Data
<b>Weight</b>	32 lbs (14 kg)
<b>Power Requirements</b>	104-125 or 208-240 VAC
	50-60 Hz, 50 watts
<b>Fuse</b>	0.25 amp for 120 VAC, or 0.25 amp for 240 VAC

Figure 1: Cabling Data

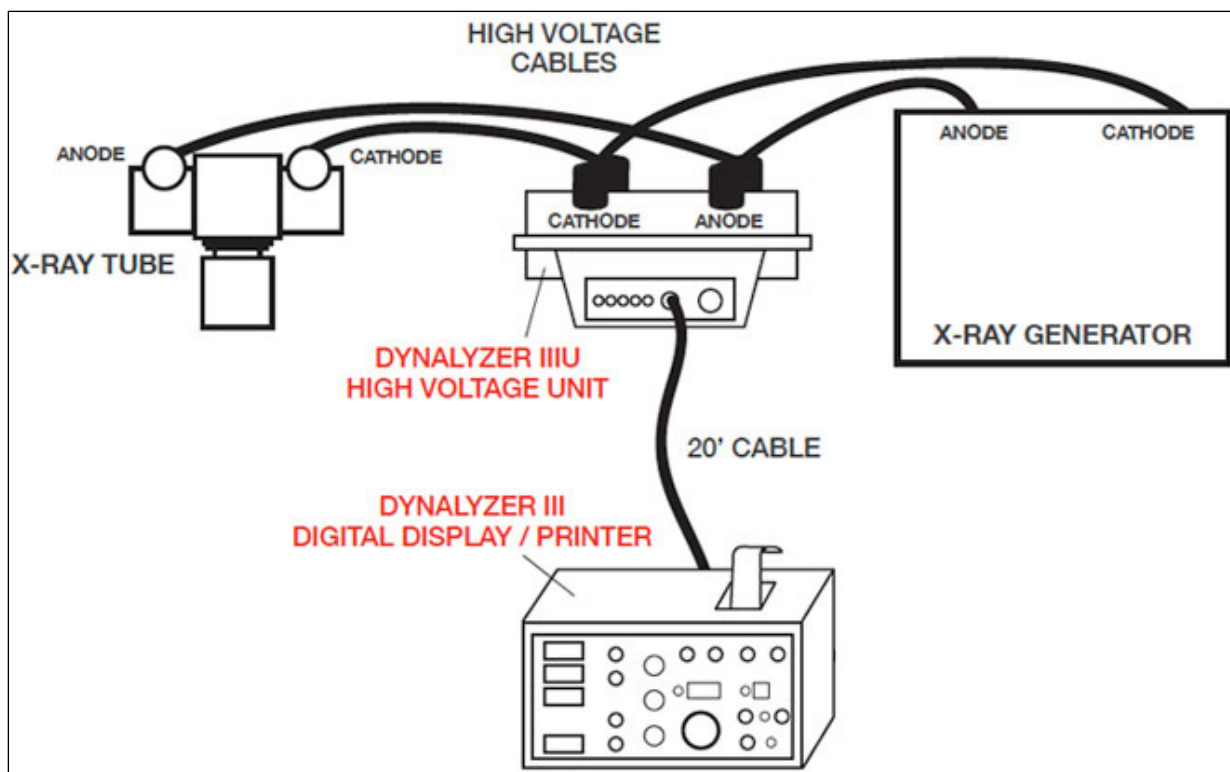
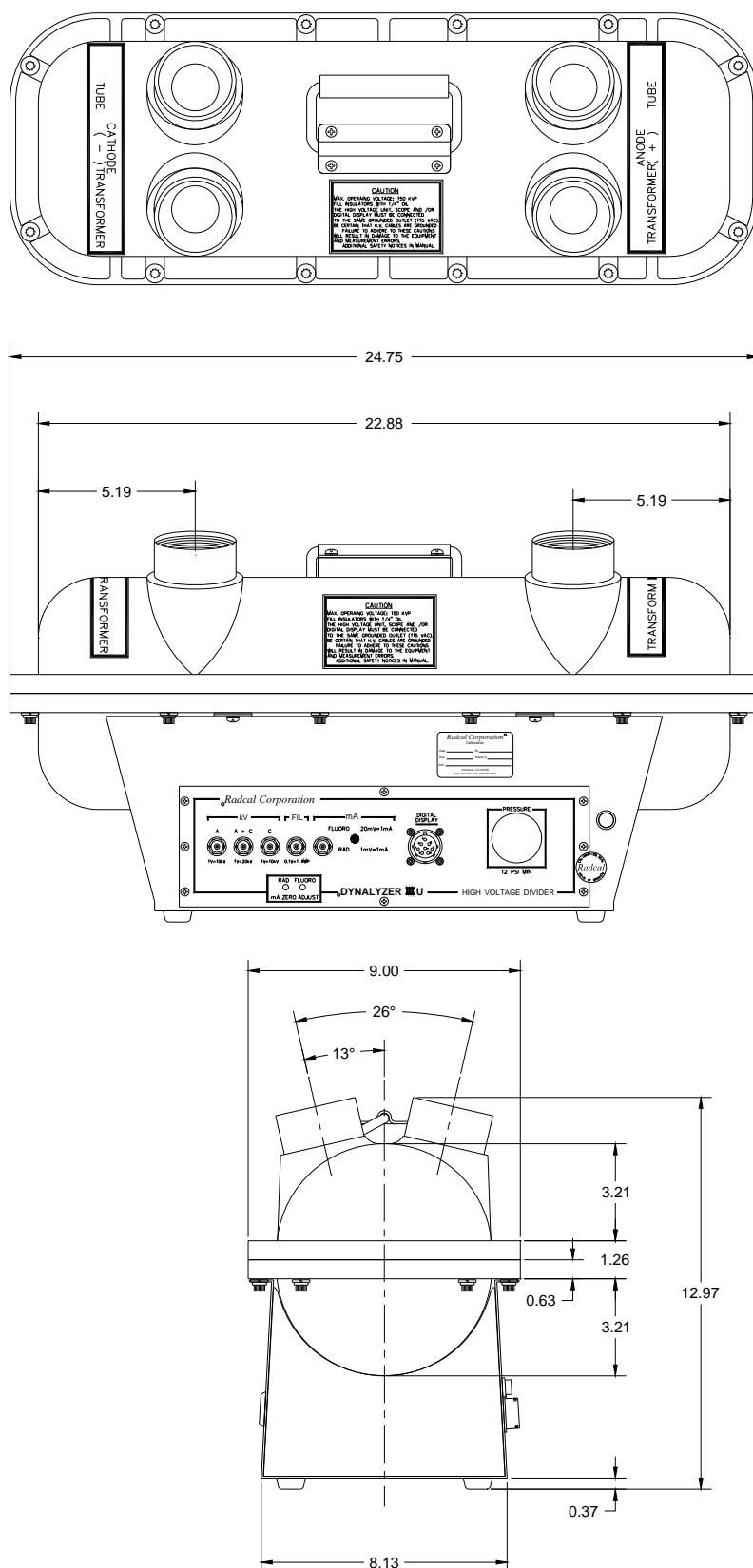




Figure 2: Outline Data (dimensions in inches)



## Installation

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### Inspection

Inspect the unit after receipt for signs of physical damage. Report any damage to the carrier at once if any occurred in shipping.

Observe that tank pressure is within the 15-30 psi range. If the pressure is below 10 psi, the unit should be recharged. Refer to the Maintenance section.

Verification of the operation of the unit may be made with the aid of a digital voltmeter (DVM). Plug the line cord into the 115 VAC, 60 Hz power source. Measure the output voltages from the BNC output connectors. All voltages should be within  $\pm 1$  millivolt with respect to ground. Operation may be verified by actual operation or by preliminary low-voltage calibration techniques.

Reasonable care should be taken in the handling of this unit as undue shock may loosen the integrated circuits from their sockets or upset the optical system in the current detection unit.

The equipment setup depends on the tests to be performed and the auxiliary equipment used. Details are contained in subsequent paragraphs.

This section describes the proper techniques for the installation of the High Voltage Unit for calibrating or diagnostic investigation of an x-ray installation. The user is again cautioned about possible safety hazards due to the presence of high voltage x-ray radiation, and is requested to review the safety notice in the Preface.

### Parts Necessary for Use

Two 12-foot long RG-58U cables with BNC connectors at each end for oscilloscope connections. (Supplied)

Besides the High Voltage Unit, the following parts are required:

- Two high-voltage cables, approximately 5 feet long with ASA (Federal) terminals at each end
- Two ASA (Federal) dummy high-voltage receptacle plugs (Supplied)
- Two 1.5 oz. tubes of vaporproofing compound for cables and plugs (Supplied)
- Small quantity of alcohol for cleaning high-voltage cable receptacles and terminals
- A piece of lead sheet 0.5 in. thick for blocking x-ray tube port, if no collimator is present
- A digital voltmeter

A differential input scope is not necessary as a composite A + C output is provided. Dual-trace or dual-beam capability is desirable to allow mA and kV to be viewed simultaneously.

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**NOTE:** If the oscilloscope does not have a storage feature, an oscilloscope camera will be useful to permit analysis of the waveform after the trace fades.

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- A BNC for binding post adapter (if needed)

## **Electrical Connections**

The electrical interconnections are dependent on the test equipment used and the tests that will be performed. The High Voltage Unit can be used with an oscilloscope, digital voltmeter of the Dynalyzer II or III Digital Display. These instructions will be directed primarily for use with an oscilloscope readout. The Digital Display unit operation is described in a separate document.

### ***Precautions***

X-ray equipment is operated at lethal voltages. The operator must make certain that the main power switch is off when making or breaking connections in the high-tension circuit and that the cables are discharged before touching any high-tension lines.

Damage to the high voltage unit, the transformer, and the x-ray tube can occur if the cable plugs are not properly handled. Cable plugs are usually treated with silicone oil, transformer oil, or a vaporproofing compound. This lubrication prevents corona or arcing from occurring in the receptacle. Oil is often used in vertically mounted receptacles while vaporproofing compound is used in conditions where the oil could seep out, such as in the horizontal plans when cables are installed upside down. If the cables in an installation have some vaporproofing compound on them, it would be in the best interest of system compatibility for the operator to insulate the cables from the Dynalyzer in a similar manner. If oil is used, and appears in to a depth of 1/8 in. in the receptacle, then additional oil is not necessary. Otherwise, add oil as necessary.

### ***High Voltage Cable Connections***

The Dynalyzer III High Voltage Unit can be connected into the high voltage circuit in several ways. Each configuration implements the best method of measurement for the particular selected application. The following paragraphs outline these methods.

#### **Series Connection (Figure 3)**

This method is most often used since all x-ray exposure parameters attainable with the High Voltage Unit are measured e.g., Anode kVp, Cathode kVp, Anode + Cathode kVp, mA and filament current. The High Voltage Unit should be connected as close to the x-ray tube as possible (5-foot cables recommended) in order to properly observe the possible effects of cable charging during exposures of less than 100 mA. The High Voltage Unit may be located at the transformer when it is physically impossible to locate it close to the x-ray tube, bearing in mind the effects of cable charging.

#### **Series Connection Anode Only (Figures 3 and 4)**

The addition of a short high voltage cable necessary to complete the cathode circuit between the High Voltage Unit and the x-ray tube may have an adverse effect in certain situations, predominantly due to contact resistance. The added impedance of this cable and connections in the filament circuit may have a loading affect on the filament transformer. Therefore, when the Dynalyzer and short high-voltage cable is removed from the circuit, the filament current may increase resulting in an increase in mA which will in turn load the high tension transformer resulting in a lower kVp. The percent error will vary as a function of the loading characteristics of the filament transformer and high tension transformer as well as the total length of the high-voltage cables already in the circuit.

Because of this phenomenon, the following procedure is recommended:

1. Use the shortest high-voltage cable jumper as physically possible between the High Voltage Unit and the x-ray tube (recommended length 5 feet).
2. Insert both the anode and cathode sections of the High Voltage Unit in the x-ray circuit. (See Figure 3).
3. For each desired measurement, record the anode kVp required to obtain the anode to cathode kVp at the mA of interest.
4. Remove the cathode side of the High Voltage Unit from the circuit, leaving the anode side connected, and complete the circuit from the high tension transformer to the x-ray tube. (See Figure 4).
5. Readjust the kVp and mA to precise values using the anode kVp readings and mA readings. This eliminates the effect of the added cathode cable insertion.

The setup as shown in Figure 4 may also be employed in grid-pulsed applications to accurately determine anode kVp and x-ray tube current. This technique does not measure cathode kVp or filament current because the cathode side of the Dynalyzer is not connected.

#### **Series Parallel Connection**

This method can only be used with x-ray generators having auxiliary high-voltage receptacles capable of simultaneous activation.


This setup shown in Figure 7 enables the measurement of all parameters except filament current and eliminates the possible adverse effect of an additional test cable in the filament circuit.

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**NOTE:** The Dynalyzer III has been designed for remote reading to minimize x-ray danger to the operator.

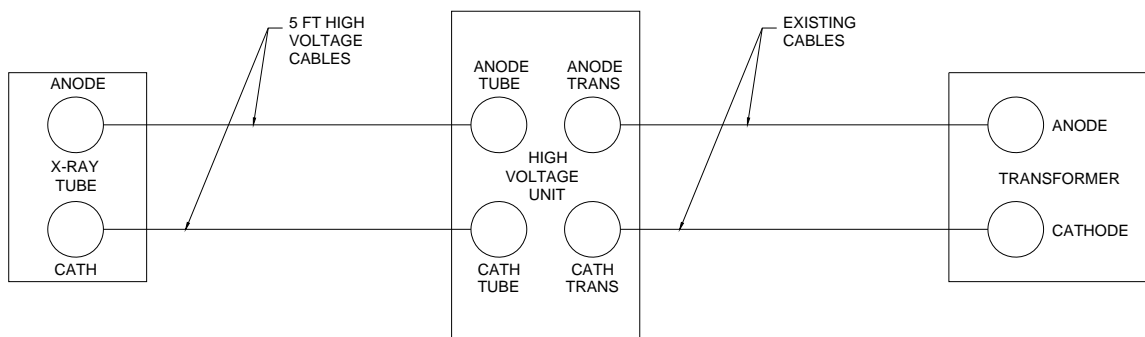
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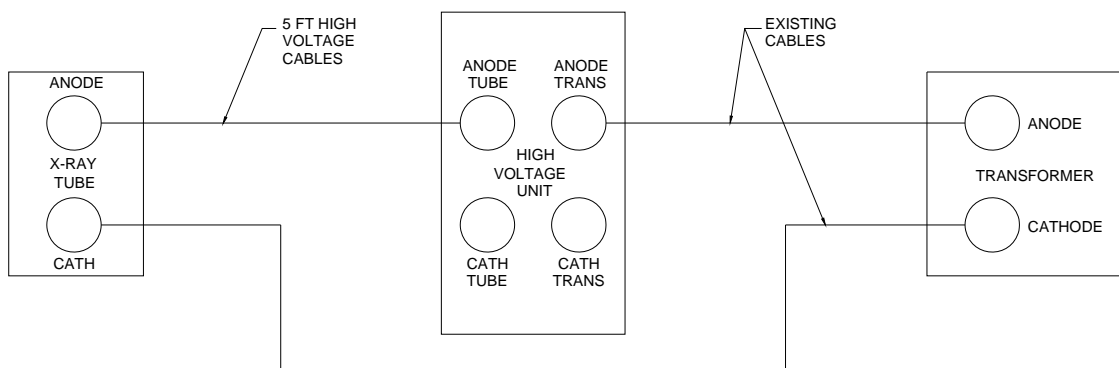
 **CAUTION:** The High Voltage Unit, Digital Display and oscilloscope must be connected to the same grounded outlet or damage may result to the equipment and/or the accuracy of the readings may be affected.

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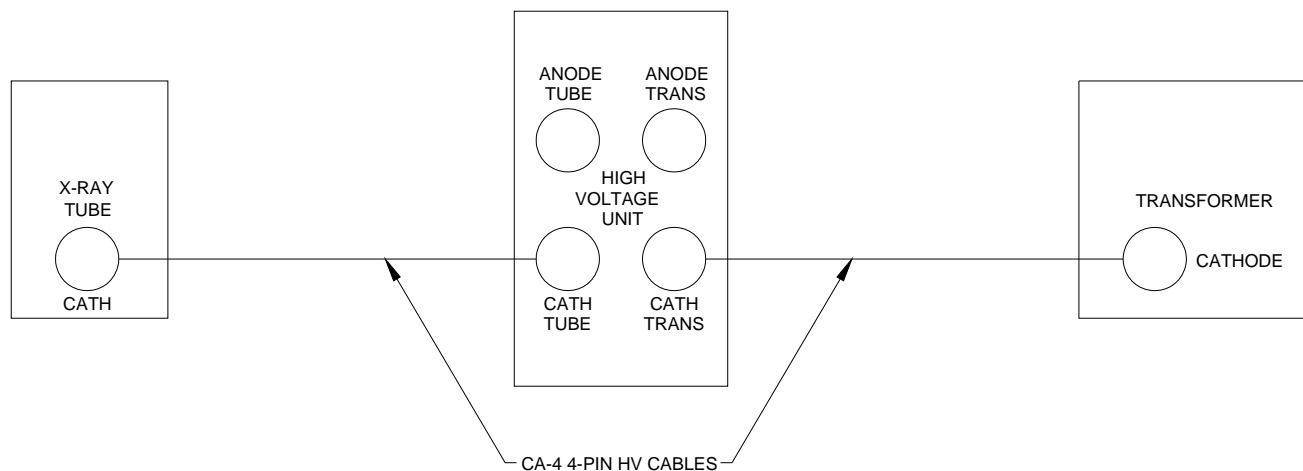
**Figure 3: Series Connection**



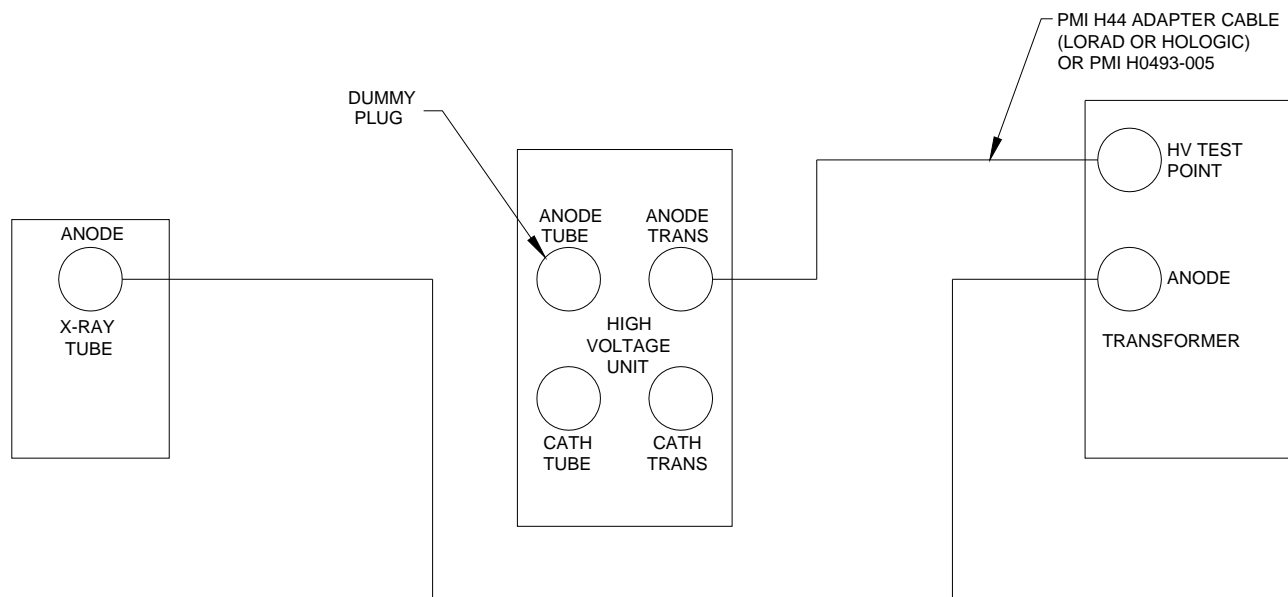
**Figure 4: Series Connection Anode Only**

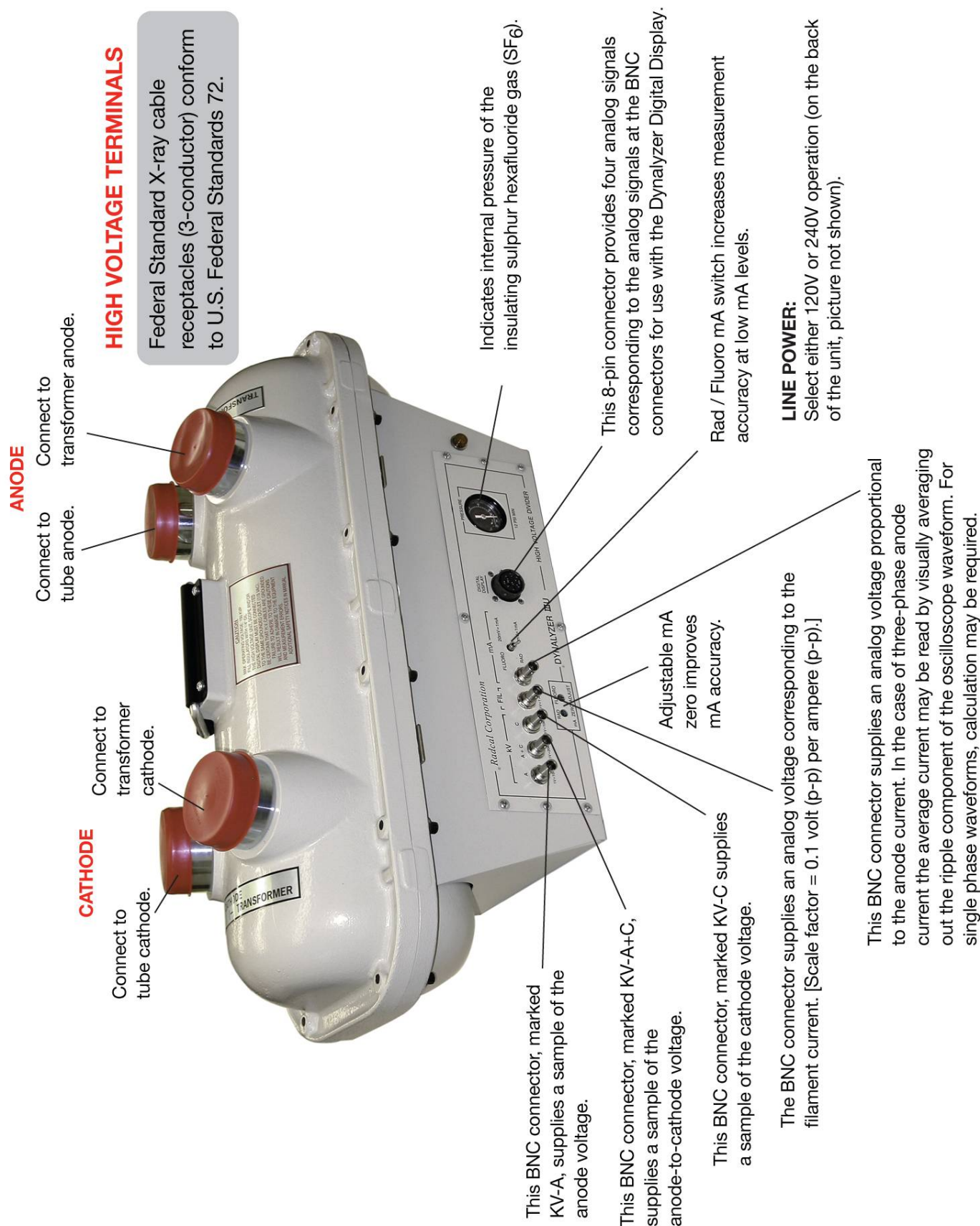


**Figure 5: Mammography Machine Connection**



**Figure 6: Mammography Machine Connection GR DMR Only**





## Operation

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This unit is designed to operate with three possible read-out devices:

1. A suitable oscilloscope
2. The Dynalyzer II or III Digital Display
3. A digital voltmeter

All measurements can be made with the optional Digital Display Unit and most measurements can be made with the oscilloscope (requiring interpretation contained in the Measurements with Suitable RMS Voltmeter section of this manual). In addition, some measurements can be made with a voltmeter readout.

**CAUTION:**

As 5 foot long high voltage cables are normally used to connect the Dynalyzer III High Voltage Unit to the x-ray tube (necessitating that the HVU be placed on the table) the possibility exists that the HVU may be inadvertently left in the primary beam. If this occurs, the SF<sub>6</sub> gas used to insulate the internal components in the tank section of the HVU may become sufficiently ionized to cause gross measurement errors, e.g., 20 to 30 kV. In order to guard against this possibility, the user must be careful to angle the tube away from the HVU or close the collimator shutters.

## Readout Oscilloscope

- a. Measurement of kVp and exposure duration for both single-phase and three-phase machines may be read directly from the oscilloscope trace.
- b. Current measurements for radiographic exposures may be read from the oscilloscope trace.

### ***Measurement procedure for kVp and Exposure Time Using Oscilloscope***

- a. Connect the oscilloscope to the High Voltage Unit as shown in Figure 7.
- b. Adjust the gain of the preamp of the oscilloscope for 2-volts per division.
- c. Adjust the horizontal time base for 10 milliseconds per division.
- d. Connect the scope to the Anode + Cathode output or to the separate outputs if switching between individual and summed outputs is desired. The exact switching will vary due to differences in x-ray high-voltage generator controllers. Refer to specific instructions for the model being calibrated.

### **Anode + Cathode Output**

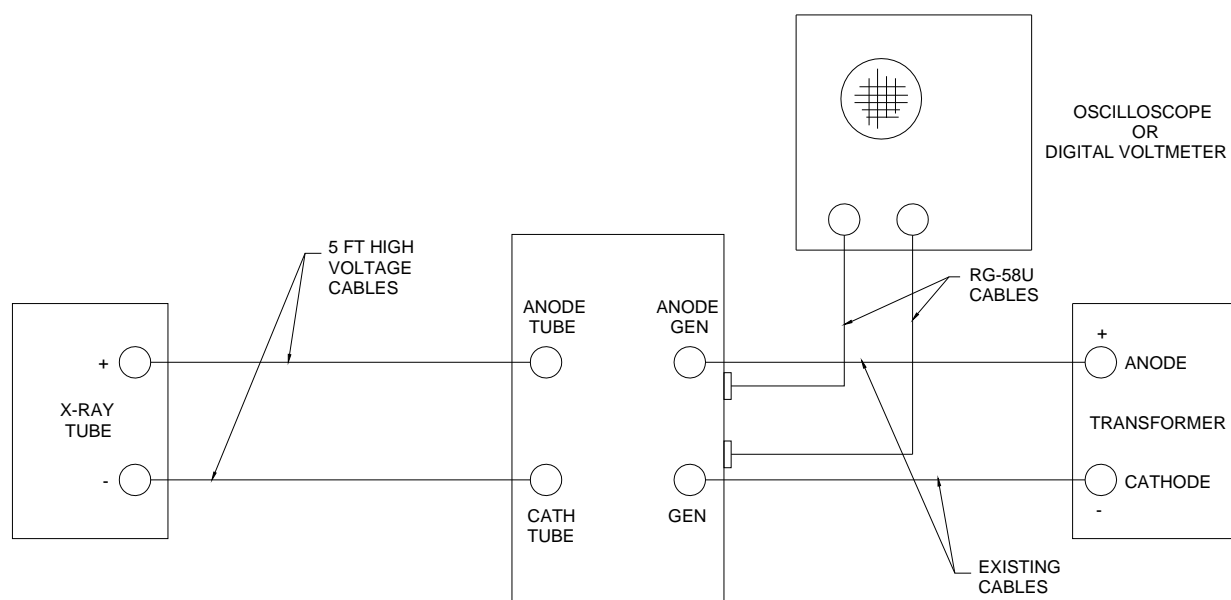
It is often necessary to view kVp and mA on the same dual trace oscilloscope. As this unit features a composite kV output with a separate BNC connector, the Anode + Cathode kV



waveform may be viewed on a conventional scope. The scale factor is 0.5 V/10 kVp (20000:1 ratio). The reduced scale factor is needed to prevent saturation of the amplifier.

The individual outputs are provided to allow checking transformer balance, or for use where multi-channel plug-in scopes are available for viewing all available data, or where the operator wishes to switch between dual trace and the add/invert mode (allowing the summation to occur at the scope).

**Figure 7: Series Connection with Oscilloscope or Digital Voltmeter**



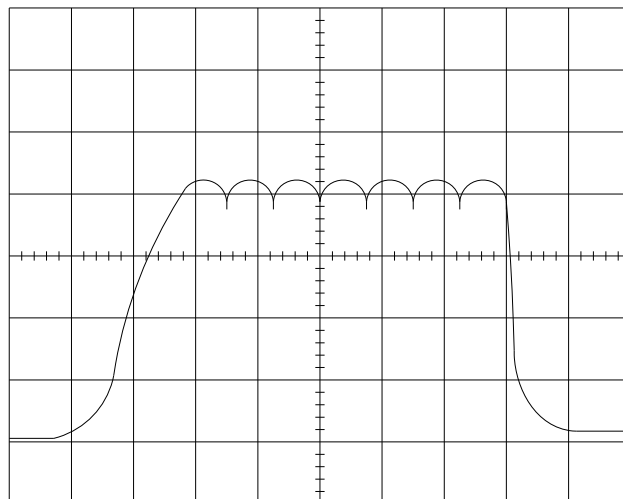
## Measurement Procedures for mA and mAs using Oscilloscope

This unit provides a unique means for viewing and measuring the current waveform in an x-ray generator. Interpretation may require some analysis on the part of the user. In general it will be found that three-pulse (constant potential) current measurements can be easily obtained from the oscilloscope trace while single-phase measurements will require some calculation.

A storage oscilloscope, or oscilloscope camera will significantly aid in analyzing single-phase measurements.

## Three-Phase Current Measurements (using Oscilloscope)

Current measurements in three-phase equipment may be read directly from the oscilloscope trace. Figure 8 shows a typical three-phase current waveform. By visual inspection, the average value may be read from the oscilloscope trace. The scale factor is 1 millivolt per milliampere. Through practice, the average area of ripple above and below the estimated current value should be equal. The x-ray tube is an emission limited device. Normally, the peaks of the current waveform have a lower slope than the voltage waveform and therefore the ripple in the current will be smaller than the ripple in the three-phase voltage.

**Figure 8: Typical Three-Phase Current Waveform*****Fluoroscopic Current Measurements (using Oscilloscope)***

For these measurements, the front panel switch should be set to the FLUORO position. Three-phase fluoroscopic current measurements can be evaluated per the Three-Phase Current Measurements section above. Single-phase fluoroscopic measurements may fall into two categories: 1) filtered and 2) unfiltered. At low current levels (below 5 mA) in systems with sufficient cable, or external capacitor banks, the voltage applied to the x-ray tube may appear to be purely direct current. The current waveform will depend on the location of the Dynalyzer High Voltage Unit with respect to the x-ray tube. Use the FLUORO position if there is significant low level noise filtering by the amplifier circuitry in the High Voltage Unit.

**Measurements with Digital Display**

The Dynalyzer II or III Digital Display can be used in conjunction with the high voltage unit to provide the following five measurements simultaneously:

1. mA and mAs
2. Exposure time (triggered by kV, mA, external trigger or internal (line) trigger)
3. kVp of anode or cathode only or both
4. Auxiliary readout of filament current or line voltage

An oscilloscope can be connected in conjunction with the Digital Display to obtain a visual image of the waveform measured. Refer to the Digital Display Instructions for additional information.

***Current Measurements with Dynalyzer III Digital Display (mA and mAs)***

The Dynalyzer III Digital Display contains all necessary signal processing required for accurate measurements of either mA or mAs in all modes described above. In operation, the incoming

analog signal is digitized, and the resulting pulses are stored. Thus, the pulse count gives a true indication of the mAs of an exposure. Simultaneously with the current integration, the exposure time is being counted by a digital clock. The average current is displayed by electronically dividing the mAs by time.

Triggering for this measurement may be made with current, voltage, external trigger, or manually (auto mode).

### ***Exposure Duration (Time)***

The third line of the display is the exposure time that is triggered by the kV, mA, auto (internal), or an external signal.

### ***Dynalyzer Digital Display of kVp Measurements***

The Dynalyzer Digital Display is interconnected to the High Voltage Unit with a 20-foot long shielded cable. The Digital Display is powered from the 120/240 VAC, 50/60 Hz line.

kVp measurements are made by selecting either the sum of Anode + Cathode or the individual terminals with respect to ground. The Digital Display is triggered by dialing in the fraction of the peak or preset (absolute) amount of kVp or mA that is considered the beginning of the exposure, i.e., 0-10% for single-phase and 75% for three-phase operation. A test exposure is made to set the gain factor of the display. Each subsequent exposure will trigger both the peak detector circuit and the electronic time clock. Both kVp and time in milliseconds will be displayed. (Current and filament will also be displayed.) A delay, adjustable up to 20 milliseconds, is provided to prevent measurement of the leading edge which may contain substantial overshoot of a three-phase exposure.

In both single and three-phase exposures, the kVp displayed will be the highest value within the exposure, with the exception of the kVp present during the delayed period.

Details on operation are supplied in the Digital Display Instruction Manual supplied with the Display Unit.

### ***Filament Current Measurement with the Dynalyzer Digital Display***

Pressing MANUAL TRIGGER after selecting AUTO at the TRIGGER SOURCE switch on the display causes the filament current to be displayed at an update rate of 0.5 second.

## **Measurements with Suitable RMS Voltmeter**

An ac rms voltmeter, such as the Data Technology Model 31 may be used to obtain a readout of the filament current.

Rms conversion modules are available from Analog Devices, Burr-Brown, and Intronic, as well as other manufacturers. These modules require  $\pm 15$  VDC power to operate and a digital voltmeter to display their output.

## Removing High Voltage Unit from X-ray Installation

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**⚠ CAUTION:** Turn off the main power before removing the Dynalyzer. At the completion of testing remove the cables in the sequence provided to prevent any possible cross connection of anode and cathode cables.

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1. Remove anode cable first. The jumper cable from the Dynalyzer to either the x-ray tube or high-voltage transformer, depending on test configuration, should be disconnected. Do not handle the insulator.
2. Touch the pins of the cable to ground to remove any residual charge remaining in the cable.

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**NOTE:** Grid bias operation often causes large residual cable voltages if no bleeder resistance is present at the high tension transformer.

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3. Clean off the oil or grease and place a protective cover over the cable ends.
4. Disconnect the system cable from the other anode connector of the Dynalyzer.
5. Reconnect the x-ray tube to the high-voltage transformer. Be sure sufficient oil or vaporproofing compound remains in the receptacle or on the cable.
6. Repeat the procedure for the cathode cables.

## Interpreting Oscilloscope Measurement Waveforms

Three-phase current waveforms are generally easier to interpret than single-phase waveforms, however, following the procedure outlined, measurements may be made for both waveforms. Fluoroscopic exposure current values may be read directly on the DVM. The scale factor is 20 mV/mA. Filament current may be viewed on the scope, or may be measured with a digital voltmeter connected to the High Voltage Unit readout terminal. The waveform of the filament current will to some extent influence the accuracy of the reading of the peak reading as ac rectifier circuit used in most DVMs. For low current level exposures, the zeroing of the High Voltage Unit should be checked and adjusted, if necessary, through the access hole on the base. Fluoro gain should be selected. The limiting parameter for measurements will be the response time of the DVM. In general, exposures having a duration of at least 3 seconds should be adequate for most DVMs to integrate and display.

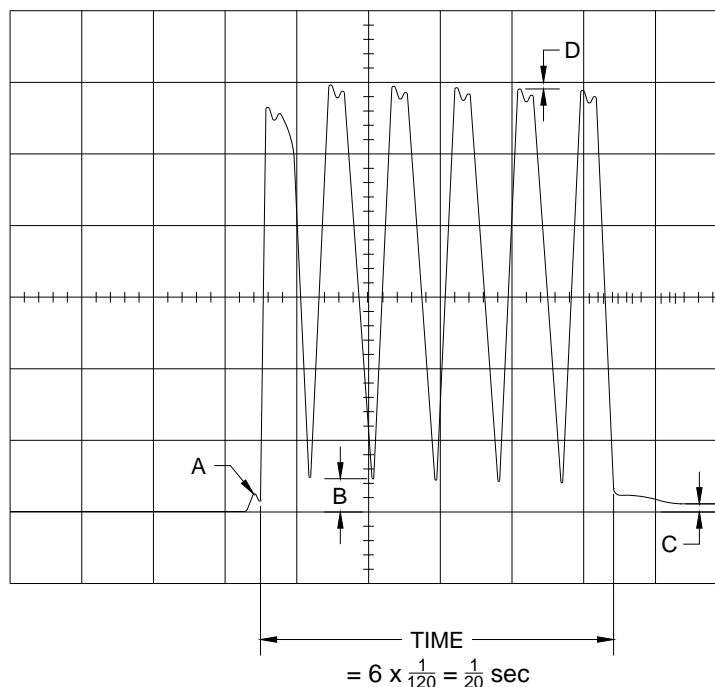
### **Single-Phase Current Waveform**

Figure 9 illustrates the waveform of a typical single-phase generator for an exposure of 200 mA, 120 kVp, 1/20 sec. A properly timed single-phase generator will contain one or more complete pulses, each lasting 1/120 of a second on a 60 Hz power line, or 1/100 of a second on a 50 Hz system. Thus, a single-phase exposure time for normally operating equipment is  $N \times 1/120$ , where N is the number of pulses. For longer exposures, the time may be read from the start of the first major pulse to the end of the last pulse. The trailing off of the voltage, (region C of Figure 9), is due to cable capacitance. Cable capacitance is also responsible for the failure of the voltage to drop to zero at the end of each pulse.

In low-level fluoroscopic systems, or in systems with a capacitor bank, level B may be equal to the kVp. By convention, kVp is the greatest amplitude value observed, which may vary by amount D. Pulse A is due to the system of contacting which provides for the closing of the contactor during the end of the last pulse preceding the beginning of the exposure. This is done to minimize the

overloading of the contactor and reduce the development of high-voltage transients. This pulse typically is 5-20% of the peak amplitude. A higher pulse indicates mis-adjustment of the contactor timing. (Refer to the manufacturer's specifications before readjusting.) This pulse should not be counted in the total exposure time, if sufficiently small. At low voltages, the x-radiation produced by this pulse will either be filtered out, or will not produce x-rays. The intent of the exposure time measurements is to measure the effective x-ray generating period.

**Figure 9: Typical Single-Phase Waveform**



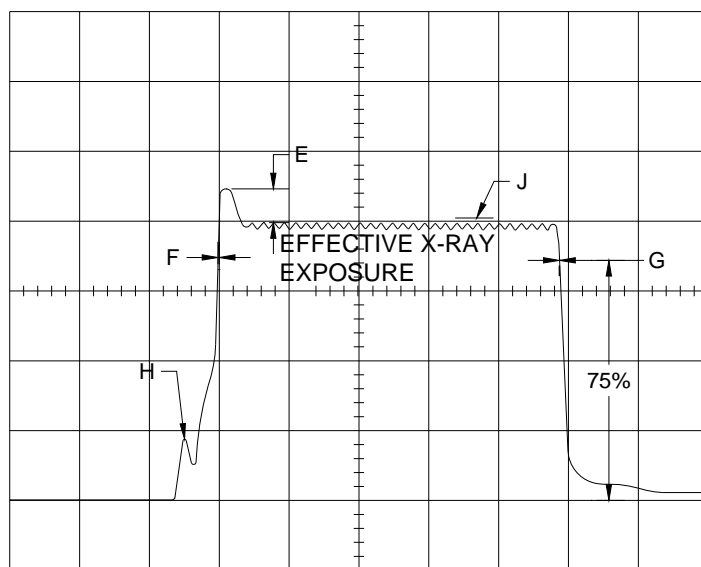
## Three-Phase Current Waveforms

Figure 10 illustrates the waveform of a typical three-phase generator for an exposure of 700 mA, 80 kVp, 1/20 second. The kVp for this exposure would be the amplitude of area J. The overshoot area, E, is not significant in this particular exposure because the dominant radiation is of the lower kVp value. The peak value must not, however, exceed the rating of the tube of generator, as it does contribute to the voltage stress on the system.

Although there is some deviation from this value, the effective exposure time of a three-phase generator should be measured between the intersection of 75% or the kVp value with time. This allows the start-up pulse area H (and the capacitance trailing effects) to be ignored.

In three-phase exposures, in the order of 1/120-1/60 second, the overshoot, area E, contributes a significant portion of the total radiation. This may present a problem in calibration were the effective kV is assumed to be independent of exposure time. Overshoot should be eliminated, if possible, by adjustment of the contractor or SCR phasing circuit.

Figure 10: Typical Three-Phase Waveform



### ***kVp Calibration for X-Ray Generator***

This should be done for each mA station. In general, voltage decreases with increasing current. If the converse is found, the system is overcompensated. Refer to the manufacturer's specifications to determine if the system is operation properly.

### ***Equipment Fault Diagnosis by Voltage Waveform Analysis***

The High Voltage Unit is a useful service aid. Among the faults possible in an x-ray controller, the following are listed as an aid:

#### **Transient Detection**

Transient irregularities in the waveform seen on the oscilloscope may be due to a variety of causes. These transient conditions may produce voltages which are considerably in excess of the kVp setting and may damage the x-ray tube, high-voltage cables, or high-voltage transformer.

Transient voltages in the high-voltage circuit may occur at a very high frequency so that the trace on the oscilloscope is very low in intensity or may not show at all with normal adjustments. Whenever a pulse or portion of a pulse is missing from the trace, some improvement may be obtained if the exposure is repeated with the intensity control set to a higher level. The trace obtained should be examined closely for excessive voltages.

#### **Defective X-ray Tube**

Gas in any x-ray produces a waveform which is very irregular at high kVp. "Kicking" (arc-over) of the x-ray tube is accompanied by rapid oscillations which may show up as a missing pulse.

**Defective Valve Tube**

If a valve tube in a full-wave rectified circuit is defective, pulses may be unequal in amplitude or missing entirely. If a valve tube is gassy, it may produce irregularities in wave form which are similar to those produced by a gassy x-ray tube.

**Improper Closing of Primary Contactor**

If the contacts of the x-ray primary contactor close at an improper phase angle, the first pulse may be considerably higher than succeeding pulses and irregular in shape. If the contactor opens too early or too late, an irregularity will occur at the end of the trace accompanied by arcing of the contacts in mechanical contacting systems.

**Single-Phase Operation of Three-Phase X-ray Generators**

A three-phase x-ray unit operating as a single-phase unit can readily be detected by observing that only two pulses are produced per cycle on the oscilloscope trace rather than six or twelve, and therefore the waveform looks identical to that of a single-phase generator.

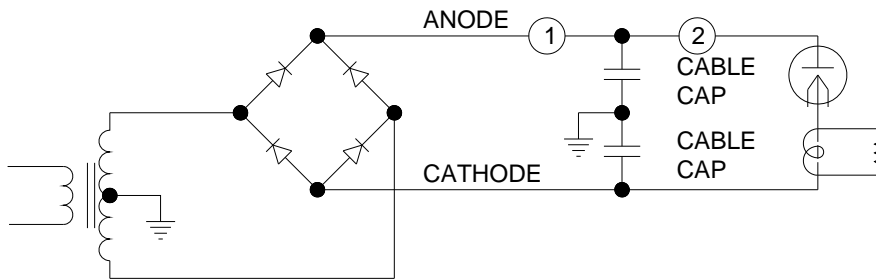
***Evaluating Fluoroscopic Current Measurements***

The FLUORO mode should be selected for this test. Circuit analysis would show that the system is an RC filter circuit (Figure 11). If the High Voltage Unit is located near the transformer, the current waveform will include the charging current of the cables. With a capacitance of 30 pf/ft., a 50-foot cable will present a load of 1500 pf. The RC time constant of the system is 30 milliseconds. From circuit analysis, the expected voltage ripple factor would be 10%. A peak current of 35 milliamps could be observed if measurements were performed at the transformer.

Thus, measurement of the current at the transformer will show peaks in the order of 35 milliamperes, while measurement at or near the x-ray tube will show a relatively constant current in the order of 5 milliamperes.

As fluoroscopic exposures may be of an extended period, a digital voltmeter may be used to measure the average voltage output of the High Voltage Unit. The zero setting of the High Voltage Unit should be checked, and reset if necessary. The DVM will read current at a scale factor of 20 millivolts per millampere.

Figure 11: Schematic Diagram of a Typical X-ray Generator Circuit



### Single-Phase Radiographic Current Measurements using Oscilloscope

When the current level is sufficiently high, the effect of cable capacitance may be neglected. If the load is resistive, the current waveform would follow the voltage. For a full-wave rectified sine wave, the average current should be:

$$I_o = 2I_m / \pi = 0.636 \times I_m$$

However, close inspection will reveal that this is not the case. Because the current is emission limited, the current will increase with the lower kV values, but at some point, will saturate (see Figure 12). The formula above is thus no longer valid and graphical integration of similar areas will yield a better value. Figure 13 illustrates the sectioning of the current waveform into triangular and rectangular areas for integration. Division of the waveform into equal width segments is a second approach to graphical integration as shown in Figure 14. The easiest approach would be to take 10 values of the current, equally spaced in time in the period of one cycle, and add them together and divide by ten.

The peak current is different in each pulse, while the form factor or waveshape remains the same. If graphical integrations are used at maximum accuracy, the ratio of peak to average value of one pulse will be obtained, and this ratio used to determine the average value of each pulse. Then the average value of the entire exposure can be approximated.

Under certain conditions it may be possible to make extended radiographic exposures without exceeding the instantaneous loading and the target heat storage capacities. In general this procedure would be limited to exposures under 200 mA, and under 6 seconds. The rating sheet of the tube unit should be consulted.

A DVM may be used to measure the current. The user is cautioned that the current measured during long exposures may not accurately equal the current measured in shorter exposures, especially in falling load type generators, or in generators with mA stabilizers. Heating effects in the target and cathode assembly may affect the exposure as well.



Figure 12: Typical Single-Phase Waveform

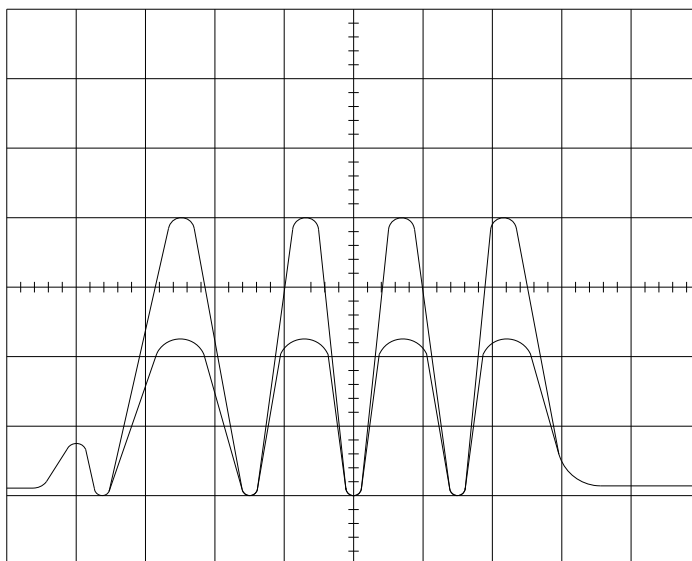
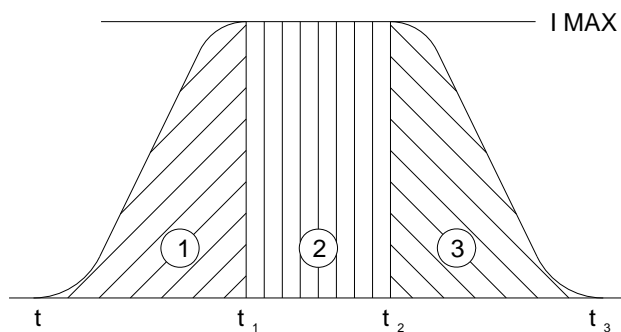


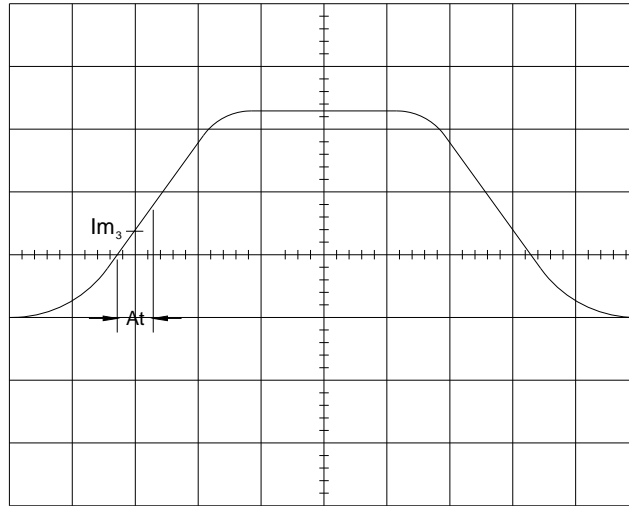
Figure 13: Current Waveform Analysis by Triangulation



$$I_{AV} = \frac{I}{t_3} (I \text{ MAX}) \left[ \frac{1}{2} t_1 + t_2 - t_1 + \frac{1}{2} t_3 - t_2 \right]$$

$$= \frac{I}{t_3} I \text{ MAX} \left( \frac{1}{2} t_2 + \frac{1}{2} t_3 - \frac{1}{2} t_1 \right)$$

Figure 14: Current Waveform Analysis by Integration



$$I_{AV} = \frac{1}{T} \sum_{n=0}^{n=n \max} I_{m_n}$$

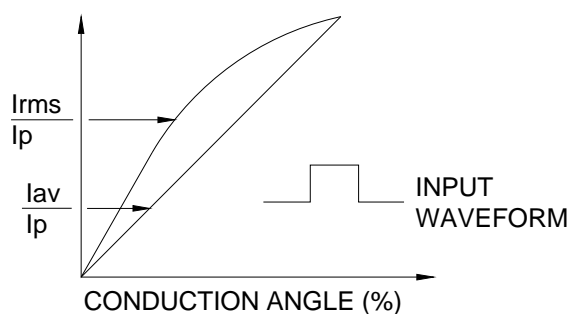
$I_{m_n}$  = MEAN VALUE OF CURRENT IN nth DIVISION

## Filament Current Measurements using Oscilloscope

Connection of an oscilloscope to the filament output terminals will allow viewing of the amplitude and waveform of the filament current. With an oscilloscope one may observe the sequencing of the filament boost circuit, the operation of the current stabilization circuit, if any, and the type of waveform present.

Many x-ray generators use saturable reactors, or other non-linear control means to control the current in the x-ray tube filament. This results in distortion of the input sine wave into a waveform approximating a square wave. If this occurs, the rms current would be equal to  $\frac{1}{2}$  the peak current, assuming a 100% conduction angle. If the wave form is sinusoidal, the rms current is 0.353 x the peak-to-peak current viewed on an oscilloscope. Figure 15 is a graph of the rms and average values of a square wave as a function of conduction angle. The scale factor of the current waveform is 0.1 volt per ampere.

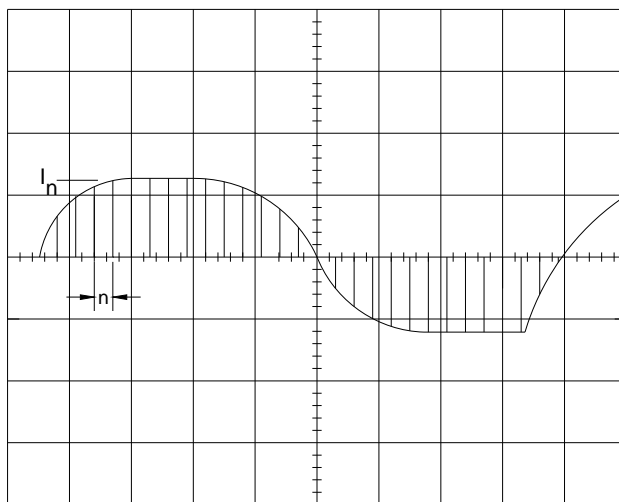
Figure 15: Current vs. Conduction Angle



Rms (root means squared) current measurement is essential. Rms current is the heating value of that current. In the relationship  $I^2R = \text{power}$ , the current is assumed to be the DC or rms value. Most DVMs or VOMs have their ac average value of a rectified sine wave. Measurement of other waveforms results in an erroneous, and often misleading answer. Other DVMs and VTVMs are calibrated on the basis of peak voltage of a rectified sine wave. The use of these meters with phase-controlled waveforms, often found in SCR circuitry will be totally misleading, as no change in voltage will be measured until the SCR is phased back to  $90^\circ$  or less.

If desired, a graphical integration technique, similar to that described for mA measurement may be used. In the case of rms measurement, divide one complete cycle (1/60 sec.) into 20 parts. Measure the amplitude at each point and square it. Take the sum of the squares and divide it by the number of points being counted (20 for example). Take the square root of this number. This is the rms current. The procedure is outlined in Figure 16.

**Figure 16: Calculation of RMS Current from Square Root of Sum of Square of N Intervals**



$$I_{RMS} = \sqrt{\frac{1}{N} \sum_{n=1}^N I_n^2}$$

## How to Select Operating Voltage

1. Open the cover door and rotate fuse-pull to left.
2. Select the operating voltage by orienting PC Board to position desired voltage on top left side. Push board firmly into module slot.
3. Rotate fuse-pull back into normal position and re-insert fuse into holders, using caution to select correct fuse value.

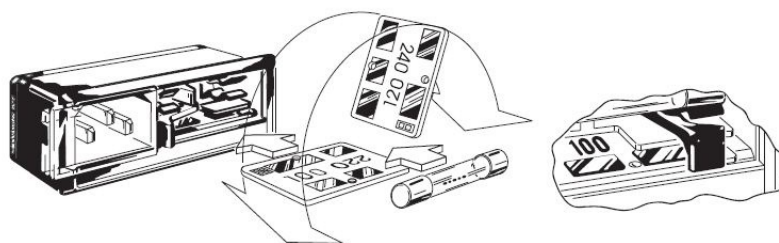
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**CAUTION:** Before operating, check that the operating voltage protection circuit is set for 240 volt operation. Only the selections marked "120" and "240" are applicable.

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Figure 17: Voltage Selection

### Voltage Selection



Open cover door and slide fuse-pull lever to left. Select operating voltage by orienting voltage selection card with the desired voltage on top left side. Push card firmly into module slot. Slide fuse-pull lever to right into normal position and re-insert fuse into holders.

**Use caution in selecting correct fuse value.**  
Only the selections marked "120" and "240" are applicable.

## **Maintenance**

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### **System Pressure**

The High Voltage Unit is insulated with pressurized Sulfur Hexafluoride Gas ( $\text{SF}_6$ ). Every effort has been made to ensure a leak-tight system. The unit is pressurized to 30 psig when shipped and contains a relief valve set at 30 psi. The unit is filled at sea level. Transportation in unpressurized aircraft, or in cargo holds with reduced pressure, will result in an increase in the differential pressure as compared to sea level (14.7 psi).

Effects of altitude variation such that the sum of internal pressure plus atmospheric pressure is greater than 22 psi will result in satisfactory operation at voltages up to 150 kVp. If there is a loss in pressure due to this effect, the unit should be recharged to 30 psi. Any leak due to other causes should be identified. Recharging may be accomplished with the contents of a lecture bottle of Sulfur Hexafluoride, C.P. gas, available from Matheson Gas Products Company. The contents of one lecture bottle of  $\text{SF}_6$  ( $\frac{1}{2}$  pound) is adequate to completely fill the system. As long as there is positive pressure in the High Voltage Unit, purging of the unit will not be necessary.

### **Failure Modes**

Protective circuitry in the High Voltage Unit has been incorporated to suppress high voltage transients that may be generated under fault conditions. The anode current transmitter, under extreme operating conditions, can sustain damage. This would be evidenced by either saturation of the mA output signal, or a negative offset of 100 mV.

Loss of internal pressure will result in a decrease in the insulation properties of the internal gas ( $\text{SF}_6$ ) which could reflect itself as internal arcing between components, or to ground. This could result in the destruction of some semi-conductor elements.