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Introduction

Fast high-gain photon detectors, such as photomultipliers and electron multipliers are one of the fastest and most sensitive means for recording the collision of a photon, electron, atom, or energetic ion with a target surface. Consequently, these devices have received considerable attention and have gained wide acceptance in research instrumentation, particularly in mass spectroscopy,[1] and scintillation spectroscopy,[2] as well as in optical ranging[3] and optical communication systems.[4]

Detection of signals in experimental research instrumentation systems requires photon detectors with high quantum efficiency, high gain, fast time response and high data-rate capabilities. They should also have good output pulse height and time resolution and low noise (or spurious signal effects). In many cases large detector sensitive areas are required. Position-sensitive detection or imaging of the incident radiation pattern is also sometimes required. Newly-emerging fields of optical ranging and communication require photon detectors which combine bandwidths greater than 1 GHz with high sensitivity to light input signals. In practically all these applications a minimum amount of noise should be added by the detection and amplification processes. For more than forty years research applications have used the phenomenon of photoemission to convert absorbed incident radiation into an electron stream which is then amplified by a secondary emission system. A simplified arrangement implementing photoemission and secondary emission is shown in Fig. 1.

Generally, the detection process begins with a cathode where the incident radiation produces photoelectrons. The emitted electrons are directed to a surface which has been treated to have a high secondary electron emission. The secondary electrons produced by this first dynode are then directed to another secondary emission surface. The process is repeated as many times as are required to amplify the initial electron stream by the desired amount. Finally, the output current from the electron multiplier feeds external circuitry to provide the output signal. Statistical variations inherent in conversion of incident photons to photoelectrons and the statistical nature of the secondary emission process cause the output signal to vary from one pulse to the next, even when a constant number of incident photons or or primary particles. The resulting distribution in output pulse height limits both the pulse height and time resolution of the detector.

The present paper reviews the basic characteristics of a new type of photoemission detector which uses microchannel plates for electron multiplication or even for direct detection of the incoming radiation. This type of detector can be used to detect a wide range of photon energies ranging from soft X-rays and extreme ultraviolet rays through the near ultraviolet, visible and near-infrared portions of the electromagnetic spectrum.

The recent development of combining single channel multipliers into microchannel plate[5,6] offer the unique possibility of combining image intensification with high time resolution capability, and with inherently low noise, in one device. Consequently, the microchannel plate possesses a major advantage over conventional discrete-dynode electron multiplier, particularly for imaging position-sensitive and high-time resolution detection systems.

Description of Microchannel Plate Electron Multiplier

A microchannel plate consists of a two dimensional array of thousands (or millions) of very small diameter short channel electron multipliers closely packed parallel to each other.[5,6] Figure 2 shows a typical configuration.

Each electron multiplier channel is a continuous glass tube whose inside surface has a high resistance semiconductor coating which is used as a secondary electron-emitting surface. The array of glass microchannels are connected electrically in parallel by metal electrodes on opposite faces of the plate which is operated in high vacuum with a voltage applied between the two faces. When a voltage of about 1000V is applied between the electrodes, the semiconducting coating inside each microchannel provides a continuous potential gradient along its length. Figure 3 shows the cross-section of the microchannel with electron trajectories. Incident radiation at the input end of the microchannel ejects electrons which are accelerated down the channel toward the positive end; the electrons collide with the wall of the channel many times while passing down the channel. The voltage gradient and channel diameter are adjusted so that, on the average, substantially more than one secondary electron is released at each collision. The voltage gradient along the microchannel must be sufficient to accelerate the secondary electrons through 20 to 50 volts before collision with the wall.

A large pulse of output electrons is ejected from the positive voltage end of the microchannel into a collector structure containing an electrode which is positively biased with respect to the channel plate output potential to give maximum collection efficiency. Depending on the application, the amplified electron output from the plate may be collected by a single anode, a multi-segment anode or by a phosphor screen. The output current of the microchannel plate must be supplied from the conduction current in the channel walls which therefore must combine the functions of both the dynodes and the resistor divider chain in the classical multi-dynode electron multiplier. Microchannels typically have diameters ranging from 15 to 50 μm and are spaced by distances ranging from 20 to 60 μm. The channel lengths are between 0.5 to 2.0 mm. Typically, a potential difference of 1000V across the microchannel plate will produce gains of about 10^3 to 10^4 for straight microchannels with a channel length-to-diameter ratio of 40. Because of the small channel size and high voltage involved, the total electron transit time is much shorter than for a conventional electron multiplier structure having the same gain.

Since the microchannels operate independently and gain is available at each microchannel location in the array, the microchannel plate is well suited for a number of applications where the incident radiation pattern must be preserved during amplification. The plate can resolve simultaneous events that are spacially separated by distances on the order of the channel size. In such cases a multi-segment anode or a phosphor screen, appropriately biased with respect to the output of microchannel plate, is used for the collection of the amplified electron output from the channel plate.

For the straight channels the gain of the microchannel plate electron multiplier is limited to approximately 10^4. Although this gain is adequate for some imaging applications; it is not adequate for high-gain electron multipliers. The major reason for the gain limitation is positive ion feedback caused by electrons at the output end of the channels ionizing residual gas atoms inside the microchannel and ejecting atoms absorbed on the channel walls. Positive ions, thereby produced, are accelerated to the input end of the channels where they may impact into the channel wall with a sufficient energy to eject a secondary electron or escape from the channel to a possible photocathode causing damage. In either case afterpulses will be initiated causing noise at the channel output end. Positive ion feedback noise depends on the gain, on the pressure and nature of any residual gas and on the surface properties of the channel wall. Operating single plates with gains in the range 10^4 and 10^5 produces positive ion feedback and causes a very noisy amplification as shown in Fig. 4. Ion feedback noise can be reduced considerably by using two microchannel plates in a "chevron" configuration, as shown in Fig. 5. This is formed by assembling two $\sim$ 2 mm thick microchannel plates in close proximity. The plates are separated from each other by a thin stainless-stell ring which also serves as electrical contact. The first microchannel plate is fabricated so that its channel axes are at a slight angle with respect to the output plate channels. It can be seen from Fig. 5 that no straight path exists for either electrons or ions. This does not significantly inhibit the passage of secondary electrons from the input to the output plate. However, the angle of the channels is such that the low-initial-energy positive ions travel only a short distance before striking a channel wall. Therefore, they do not have enough energy to produce a significant number of secondary electrons. Gains of 10^7 or more can be achieved with this configuration with no observable ion feedback noise.

Positive ion feedback can also be inhibited by curving the microchannels. The first practical plates of this type were made at the Laboratoires d'Electronique et de Physique Appliquée, and preliminary results have been reported in literature.[8,9] Plates with curved microchannels have demonstrated superior performance over those with straight channels in gain, in lower statistical fluctuations of gain and in the background noise level. However, additional improvements are necessary, particularly with respect to charge saturation effects. Successful high-gain microchannel plate multiplier have also been made using three plates at angles in a so called Z-configuration.[10] This configuration exhibits a gain value larger than 10^6 without positive ion feedback.

Most of the plates manufactured recently use channels at a bias angle of 5^{o} to 8^{o} with respect to the parallel input and output surfaces. This reduces ion feedback, increases the probability of impact of the incoming radiation with the channel surface and reduces direct light feedback from any output phosphor screen in imaging applications.

Basically two fabrication techniques are used for manufacturing microchannel plates. The first uses a core which is water soluble or etchable and which is surrounded by a thin-walled cylinder made of glass containing lead oxide. The glass cylinder will later become the electrical and mechanical structure of the microchannel plate. The glass-clad core is drawn to a small diameter and many rods are fused together into a bundle. In a second drawing operation the diameter of the bundle is reduced to the required size. Small diameter bundles are again fused together into a larger final bundle size. The final bundle is then sliced into wafers of the desired thickness which are polished to the final dimensions. Cores are then dissolved or etched away to open the microchannels forming the final microchannel plate structure. A heat treatment in a hydrogen atmosphere then produces a semiconductive layer which has a secondary emission coefficient between 1.1 and 3.5 on the walls of the microchannels. Nickel-chromium electrodes are then vacuum-deposited on both faces of a microchannel plate. Finally, plates undergo a cleaning and outgassing process which consists of baking for approximately 10 hours at a temperature of 300 C. Microchannel plates produced by this technique have ratios of the open area to the total area of the plate near to 60%.

The second fabrication technique is similar except that each microchannel wall is constructed from three different glass layers. The inner surface layer is semiconducting and this determines the secondary emitting properties of the channel. The second layer provides the structure of each microchannel and comprises most of the volume of the plate. The third layer, consisting of a glass which has low viscosity at the forming temperatures, fuses the microchannels together during the manufacturing process. The three-layer glass plates have ratios of the open area to the total area of the plate near to 55%.

Characteristics of Microchannel Plate Electron Multiplier

1. Gain, Saturation Effects, and Pulse Repetition Rate Considerations

Typical electron gain voltage characteristics of single microchannel plates with straight and curved channels, and for channel chevron plates are shown in Fig. 6. The characteristics are given for an input signal current density of 10^{-12}A/cm^2 and with an input electron energy of 300 eV for both the straight channel plate and the chevron plate. Both types of plates have a total standing current along the walls of channels (total of all channels) of 0.8 μA. The straight channel plate has a bias angle of 5%. The front-to-back relative channel bias angle for the chevron plate if 15°. The gain characteristic of a plate with curved channels is also given in this figure. This plate has an input bias angle of 25° and an output angle of 2°.

It can be seen that the electron gain of the microchannel plate is determined by the applied voltage and the length-to-diameter, L/d, of microchannels used in a particular plate. Above a certain value of the plate gain, the ion feedback in a straight channel plate becomes sufficient to cause saturation. Ion feedback leads to repetitive electron avalanches which saturate the channel, and cuase field distortion due to wall charging. Both effects lead to temporary loss of gain at the plate output. As expected, the curved channel plate can be operated at a much higher gain before ion feedback causes gain saturation effects.

Depending upon the mode of operation of the microchannel plate, gain saturation may be caused by the output current saturation, due to the finite conductivity of the glass, or by charge saturation, due to the positive charging of the walls of the microchannels. The saturation effects can be seen in the current transfer characteristics of the microchannel plate as shown in Fig. 7. In applications where continuous input occurs, such as in image intensifiers, a limit to the available output current from a channel is set by the current flowing in the channel wall. Since the wall resistance is high (10^{8} to 10^{11} Ω) the current available is very limited.

As the space charge increases toward the output of the channel, the depleted wall current reduces the field in the channel thereby dropping the secondary emission ratio and lowering the gain. The plate output current deviates appreciably from linearity when it approaches approximately 5-10% of the total plate dc current, which is typically about 10^{-11}A per individual channel. This guide is valid only for continuous (dc) input and with reasonably uniform illumination.

For pulse excitation, such as is encountered in particle or many detector applications, the ejected secondary electrons leave behind them positive charges at the surface of the channel wall. At the output end of the microchannels the positive charges existing on the surface of the channel cannot be neutralized by the conduction strip current in less than about a millisecond, due to the high resistivity of the channel surface. The positive wall charge, localized toward the output end of the channels, is responsible for transient saturation effect. Experimental data show that at low counting rates (where the interval between pulses is longer than the channel recovery time), a microchannel plate with 40 μm curved channel can deliver 1A peak output pulse current per cm^2 of useful area. At high input pulse rates departures from linear behavior are governed by the continuous input conditions discussed earlier. These saturation effects should be avoided by operating at the lowest acceptable gain.

Typically, the maximum pulse charge that can be extracted from a microchannel of 40 μm in diameter is in the order of 3×10^{-14}C or 2×10^{5} electrons. For chevron plate configuration the maximum long term counting rate in pulse mode is about 10^{6} counts/sec cm^{2} of active area. No gain suppression is observed for counting less than 10^{5} counts/sec cm^{2}.

2. Pulse-Height Resolution and Noise Characteristics Considerations

In the preceding sections, the average value of the gain of a microchannel plate has been implied whenever gain has been discussed. In fact, the gain varies from pulse to pulse because of the statistical nature of the secondary emission multiplication process. The statistical fluctuations of the gain of a microchannel plate about its mean value are best characterized by the relative variance of the output pulse-height spectrum when the output pulses are initiated by single electrons at the input. J. P. Boutot et al showed[8] that the variance of the gain of a microchannel plate with curved channels strongly depends on the operating voltage. When the microchannel operates in a nonsaturated mode, the output pulse amplitude distribution is exponential. The relative variance of such a distribution is equal one. With an increase in plate voltage the gain increases until saturation takes place. The saturation mode of operation reduces gain fluctuations from pulse to pulse as well as from one microchannel to another. The output pulse height distribution becomes strongly peaked and the variance of the gain decreases to a value less than 0.1 or the full width at half maximum (FWHM) of the output pulse-height distribution is 50%. Specifically, the gain variance decreases from 1 at gain value of 3.9×10^4 to 0.08 at gain of 1.5×10^6 for a plate with 40 μm curved channels. For chevron plates the FWHM of the output pulse-height distribution is typically 120%.

Noise in a microchannel plate is best characterized by the number of background output pulses counted per second per cm^2 of area. For a plate with 40 μm channels the dark pulse count is about 1 pulse/s cm^2 at a gain of 10^5, and less than 50 pulses/s cm^2 at the saturated gain level of 2×10^6. These measurements were made on a plate[8] which contained 8×10^4 microchannels/cm^2. A similar background count rate occurs in chevron plates. For a plate with 38 μm channels operating at a gain of 10^7 the noise pulse rate is 1 pulse/s cm^2. This plate had approximately 3.8×10^4 microchannels/cm^2.

3. Detection Efficiency of the Microchannel Plate to Various Types of Radiation

In addition to electrons, the semiconducting coating on the inside wall of a microchannel can directly detect photons varying from the soft X-ray region to the extreme ultraviolet, as well as protons, positive ions, energetic atomic hydrogen and metasable thermal molecules. The plates are not sensitive to very low energy electrons (such as thermal electrons) but these can be detected by a microchannel if their energy is sufficiently increased by an accelerating field before entering the microchannel.

When used as a photon detector, microchannel plates can operate efficiently at extreme ultraviolet and soft X-ray wavelengths in a windowless configuration or it can be combined with a photocathode in a sealed tube for use with ultraviolet, visible and near-infrared wavelengths of the electromagnetic spectrum. The detection efficiency, defined as the percentage of the input photons producing detectable pulses at the plate output, has been determined with single channel multipliers,[11] when photoelectrons are generated directly by incident radiation on the semiconducting coating. However, more recent measurements have shown,[12,13] that the efficiencies obtained on the microchannel plate are similar to those measured for single channel devices.

The measured detection efficiencies[12] of a two stage single channel multiplier and of a high gain microchannel plate configuration are shown in Fig. 8. For the extreme ultraviolet wavelengths the configuration consisted of three straight channel microchannel plates in cascade, having a total gain of 2.8×10^7. Individual plates had 11 μm diameter channels, with an open area ratio of approximately 66% and bias angle of 5°. Results of these measurements showed that the detection efficiency had a maximum value of about 16% at 60 nm and that the plate efficiency is greater than for the single channel multiplier efficiency at those wavelengths where measurements were made. The principal reason for this effect is the increase in the quantum yield of the plate as a function of the angle of incident radiation at wavelengths below 70 nm. The angle of incident radiation was 85° for the plate, while the single channel multiplier was illuminated at normal incidence. The detection efficiency difference between the single channel and plate becomes smaller as the wavelength increases. At wavelengths longer than 80 nm the detection efficiency of the plate can be expected to be approximately equal to that of the single channel multiplier.

Measurements of the efficiency of a microchannel plate as a function of wavelength of collimated monochromatic X-rays have shown that the peak efficiencies were from 3.5 to 16% in the range from 0.2 nm to 6.8 nm. These measurements were made on a 40 μm diameter channel plate operating at different angles of incident radiation. The peak efficiency was observed for an incident angle of approximately 6°. In general, studies of the variation of the detection efficiency with the angle of incidence of soft X-rays have shown that the efficiency peaks sharply at an angle of incidence of between 5° and 7° to the channel axis.

In the near ultraviolet, visible and near infrared wavelength region of the electromagnetic spectrum, the microchannel plate detection efficiencies are too small for practical applications and a photocathode with an appropriate spectral sensitivity should be combined with the plate.

Measurements of the detection efficiency for incident electrons were performed on single channel electron multiplier in the electron energy range of 1-50 keV. The results depend upon size of the multiplier funnel used, the angle of the incoming electrons and the detailed nature of the electrical field at the input end of the multiplier. In general, normalized experimental results have shown the usefulness of the single channel electron multiplier for detecting electrons from 1 to 50 keV with detection efficiencies varying from approximately 95% at the lower energies to 40% at high energies.

Measurements of the detection efficiency for hydrogen, argon and xenon ions as incident particles have also been recently performed[16] on a single channel electron multiplier in the ion energy range of 0.1-4 keV. The measurements indicate that ions of varying mass all reach plateau detection efficiency in the 50% range for energies larger than 2 keV. In the energy range below 2 keV, large variations in detection efficiency with ion mass are encountered. For an ion energy of 0.5 keV, the detection efficiency is 30% for hydrogen and

40% for xenon.

Applications of Microchannel Plate

Because of its small size, high current gain and excellent timing capabilities, the microchannel plate is a component specially well adapted for applications in high-gain imaging detectors and to very fast high-gain photomultipliers. Basic applications of the plate in imaging detectors are proximity, electrostatic and magnetic focused image intensifiers,[6,18] quantum position-sensitive detectors, X-ray imaging,[6] neutron radiography,[6] electron microscopy,[6] ultra fast cathode ray tubes[17] and streak cameras.[17] Only microchannel plate applications in image intensifiers, position-sensitivity detectors and photomultipliers will be discussed in this paper.

In image intensifier applications the output current of the microchannel plate and therefore the phosphor screen brightness is limited by the strip current of the plate. This provides an automatic high-light suppression. The gain can be varied by varying the microchannel plate voltage. Typical resolution for the 25 mm microchannel plate inverter image intensifier is from 28 line pairs/mm to 35 line pairs/mm for plates that have center-to-center spacing of less than 17 μm.[11] These resolutions were achieved with a straight channel plate operating at electron gains of 10^3 to 10^4 with an equivalent input noise of 10^{-16} to 10^{-15} A/cm^2.

In quantum position-sensitive detection applications it is often desirable to extract the output information from the microchannel plate in a form of electrical signals suitable for further data processing. In this case the position resolution is presently completely determined by two-dimensional readout system which is used in place of the output phosphor screen. One electronic readout system has been described having a position resolution of 50 μm over a 1.6 x 1.6 mm^2 area.[18] The system employs two sets of orthogaonal linear anodes insulated from each other and exposed to the output current of the microchannel plate. The output current from the plate is divided between anodes at the intersection where the event occurs. The position of an event is identified by the coincident arrival of pulses on the appropriate orthogonal anodes. Performance of the readout system was demonstrated on a two-dimensional (32 x 32 picture elements) array employing 64 charge-sensitive amplifiers and data processing electronics. A two-dimensional readout configuration has also been developed exhibiting a position resolution of approximately 10 μm in an overall field size of 420 μm.[19] This configuration uses a four-quadrant-electron-collecting anode located behind the output face of the microchannel plate, so that the electron cloud from each detected event is partly intercepted by each quadrant. The charge collected by each quadrant then depends on the event position, allowing each event to be localized using two ratio circuits. The field of view can be increased by employing an array of anodes.

Microchannel plate electron multipliers are particularly suitable for applications in high-gain photon detectors, such as fast photomultipliers, where the time resolution capabilities of the detector are of a prime importance. The time-resolution capabilities of fast photomultipliers are the primary limitation in the precision of many time measurements and have been the subject for many years of intensive experimental and theretical investigations. A comprehensive survey of the literature has been given.[20] Time measurements are important in many research areas, such as atomic and molecular subnanosecond fluorescence decay time measurements,[21] nuclear research,[22] optical ranging experiments,[3] and optical communication.[4] The time resolution capabilities of photomultipliers are essentially determined by random deviations in the transit time of electrons traveling from photocathode to collector and by possible variable delays in electron emission. The electron transit time spread is mainly caused by fluctuations of the individual times of flight of photoelectrons and secondary electrons due to their different trajectories and initial velocity differences. Generally, the transit time depends on the photomultiplier geometry, its operating conditions, and the number of photoelectrons released from the photocathode.

Since the time spread varies approximately inversely as the square root of the number of photoelectrons, the time behavior information of a single photoelectron is particularly helpful in predicting the transit time spread for an arbitrary number of photoelectrons. Furthermore, it is also helpful in the evaluation, selection and comparison of photomultipliers as well as in determination of photomultiplier optimum operating conditions in critical applications. Consequently, the best characterization of the photomultiplier electron transit time spread is given by the single photoelectron time performance.[20]

The microchannel plate multiplier has excellent timing capabilities resulting from it small thickness (approximately 2 mm) and very strong applied electric field (5 to 10 kV/cm). As a result, the electron transit time and transit time spread in the plate are smaller than 1 ns and 100 ps, respectively. High-speed prototype photomultipliers, using curved channel plates and proximity focusing for the input and collector stages, with an electronic gain higher than 10^6 and a photocathode useful diameter of 13 and 15 mm, were developed by the Laboratories d'Electronique et de Physique Appliquée (LEP).[8,17] In the U.S.A. prototype high-gain photomultipliers using microchannel plate in Z-configuration with an electron gain of 10^6, photocathode active diameter of 18 mm, and proximity focusing, are under development[10] at the ITT, Electro-Optical Product Division, Fort Wayne, Indiana.

The dc gain and anode dark current were measured as a function of plate voltage for the curved channel and Z-configuration plates; results are shown in Fig. 9. In both cases the photocathode anode dark current was completely determined by the photocathode temperature. Measurements of the curved channel plate photomultiplier show that the device exhibits very good timing capabilities and very low sensitivity to ambient magnetic fields compared with the best conventional photomultipliers.[23] Figure 10 shows the single photoelectron pulse shape of the photomultiplier. The 10-90% risetime is approximately 0.76 ps; correcting for the system's 0.40 ns risetime, the single photoelectron pulse risetime of the multiplier is 0.64 ns, and the pulse width (FWHM) is 1.25 ns ± 0.2 ns. Figure 11 shows a single photoelectron time spread spectrum. With full photocathode illumination, and using a light pulse produced by a 200 ps electrical pulse, the single photoelectron time spread is approximately 250 ps. In this case, the measuring system time resolution was approximately 25 ps (FWHM). The multi-photoelectron time spread was approximately 30 ps (FWHM) under conditions producing 6000 photoelectrons per pulse. These results compare very favorably with those obtained using conventional high-gain fast photomultipliers, where single photoelectron time spreads of approximately 300 ps can be expected using very small area illumination of the photocathode and optimum operating conditions.[20]

The maximum axial magnetic flux density which did not affect the gain of curved channel photomultipliers was found to vary from 900 to 2000 Gauss. The transverse magnetic flux density which reduces the dc gain of the photomultiplier to half of its initial value was found to be between 500 and 780 Gauss. These results also compare extremely favorably with the characteristics of conventional discrete-dynode photomultipliers, where magnetic flux densities in the range of 1 Gauss seriously reduce the gain.

Future Developments

From the above given account it is evident that great progress has been made in the technology and applications of microchannel plate photon detectors. The plates, particularly those with a low gain, have been used extensively in scientific research. Nevertheless, the plates need to be further improved particularly with respect to the maximum continuous current which limit the gain for a given pulse repetition rate (dynamic range limitation), and to the gain degradation due to their operation at moderate levels of output current. The dynamic range can be increased by increasing the current through the walls of the microchannels. There is a need for better secondary emitters which will allow higher channel wall current. Concerning the gain degradation process of the microchannel plate, an earlier investigation showed[11] that the plate operational life is longer than 7000 hours at input current densities of $3 \times 10^{-12} A/cm^2$. However, recent investigations indicated[24] a more rapid gain decay and a gain dependence upon the total charge per unit area extracted from the plate. Further efforts are necessary to better understand this phenomenon.

Figure Captions

Fig. 1 Simplified component arrangement of a high-gain photon detector.

Fig. 2 Microchannel plate electron multiplier.

Fig. 3 Multiplication and collection processes in a straight microchannel plate electron multiplier.

Fig. 4 Ion feedback for a straight channel microchannel plate and two microchannel plates in chevron configuration.

Fig. 5 Multiplication process and positive ion feedback phenomena for microchannel plates in the chevron configuration.

Fig. 6 Microchannel plate gain as a function of the applied voltage per plate.

Fig. 7 Output current of curved channel microchannel plate as a function of the input current, with plate voltage as the parameter.

Fig. 8 Detection efficiency of a high-gain microchannel plate configuration and a two stage single channel multiplier as a function of wavelength.

Fig. 9 DC gain and dark current as a function of the microchannel plate voltage for photomultipliers using curved channel plate and plates in Z-configuration.

Fig.10 Typical single photoelectron pulse from a photomultiplier employing curved channel plate operated at V_m=1600V.A 200 psec light impulse from the reversed-biased electroluminescent diode was used for excitation.

Fig. 11 Single photoelectron time spread of a photomultiplier using curved channel plate with full photocathode illumination.

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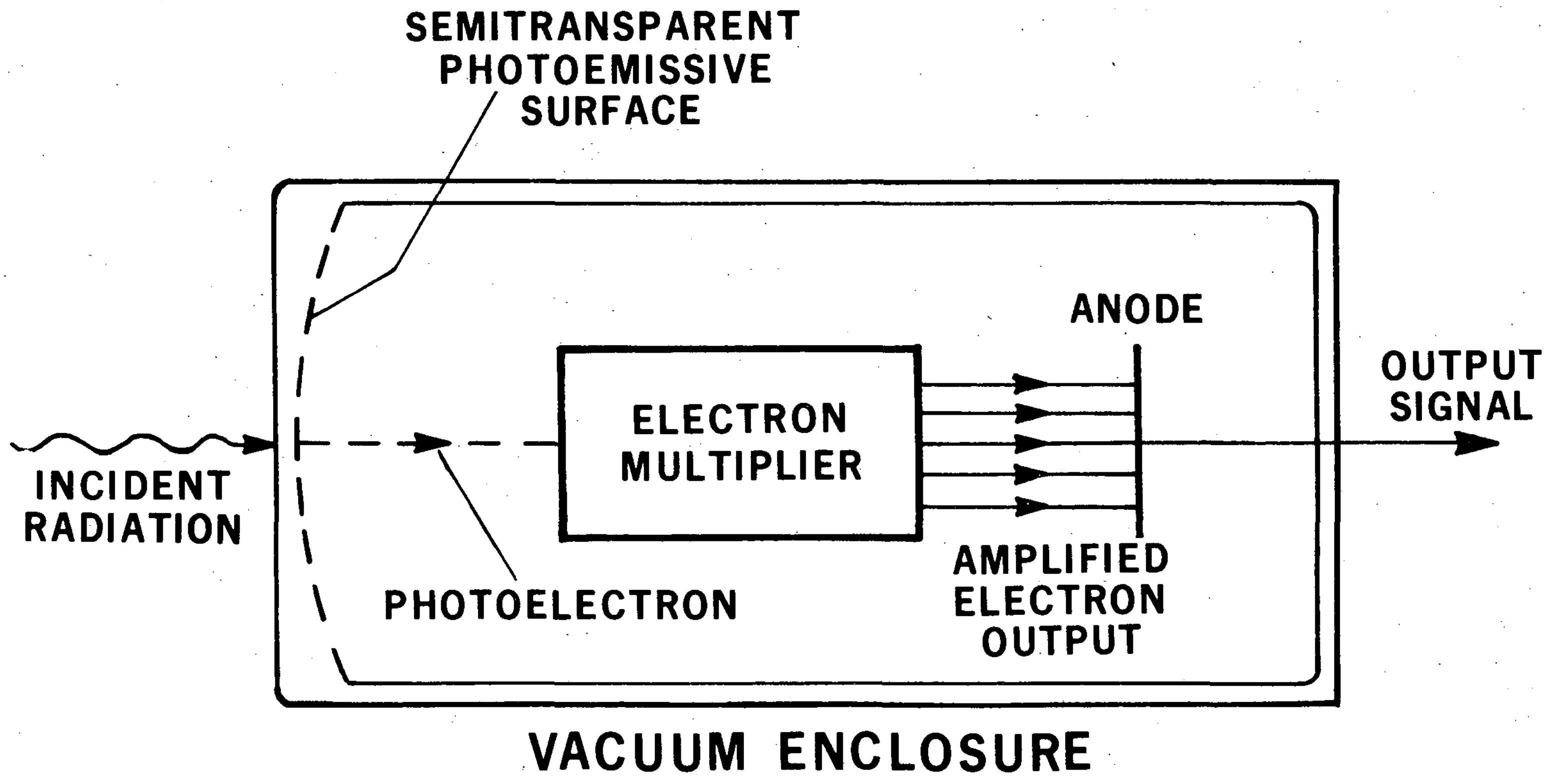


XBL 778-2579

Fig. 1

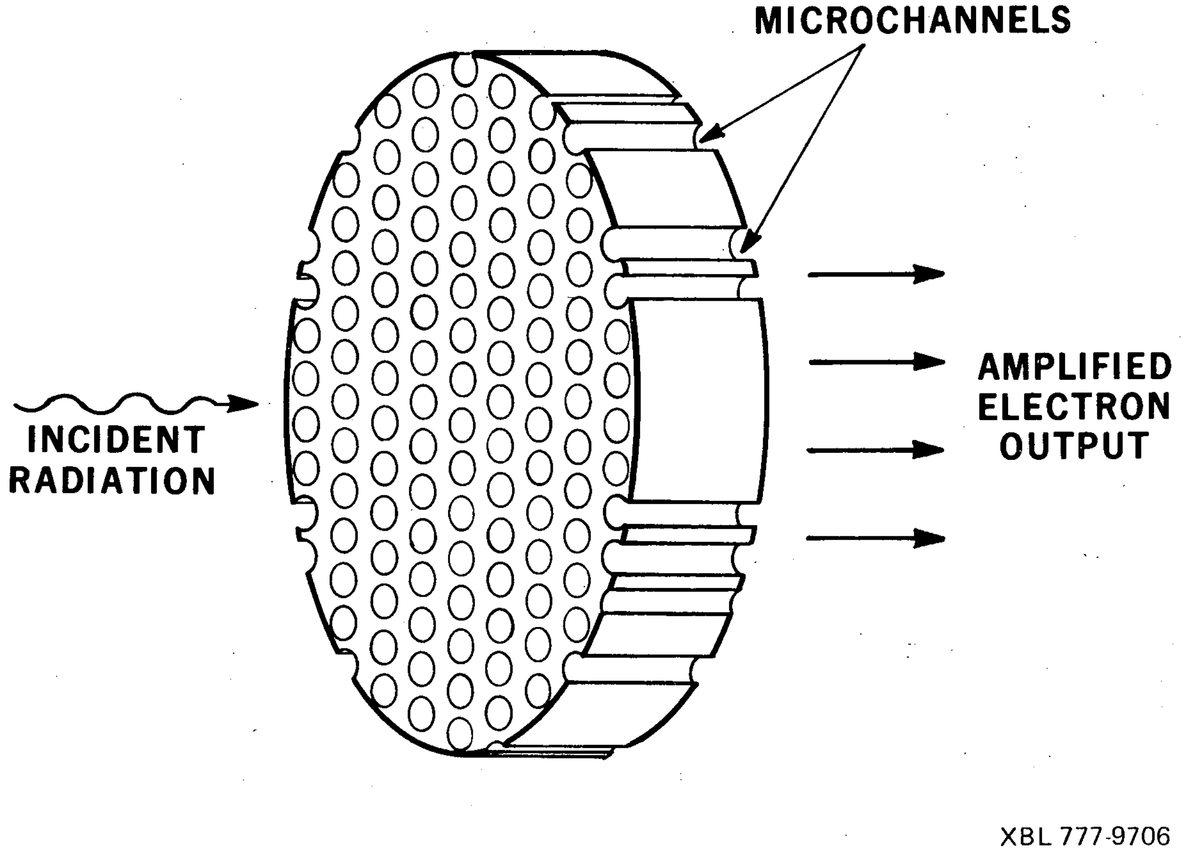

MICROCHANNELS
INCIDENT RADIATION
AMPLIFIED ELECTRON OUTPUT
XBL 777-9706

Fig. 2

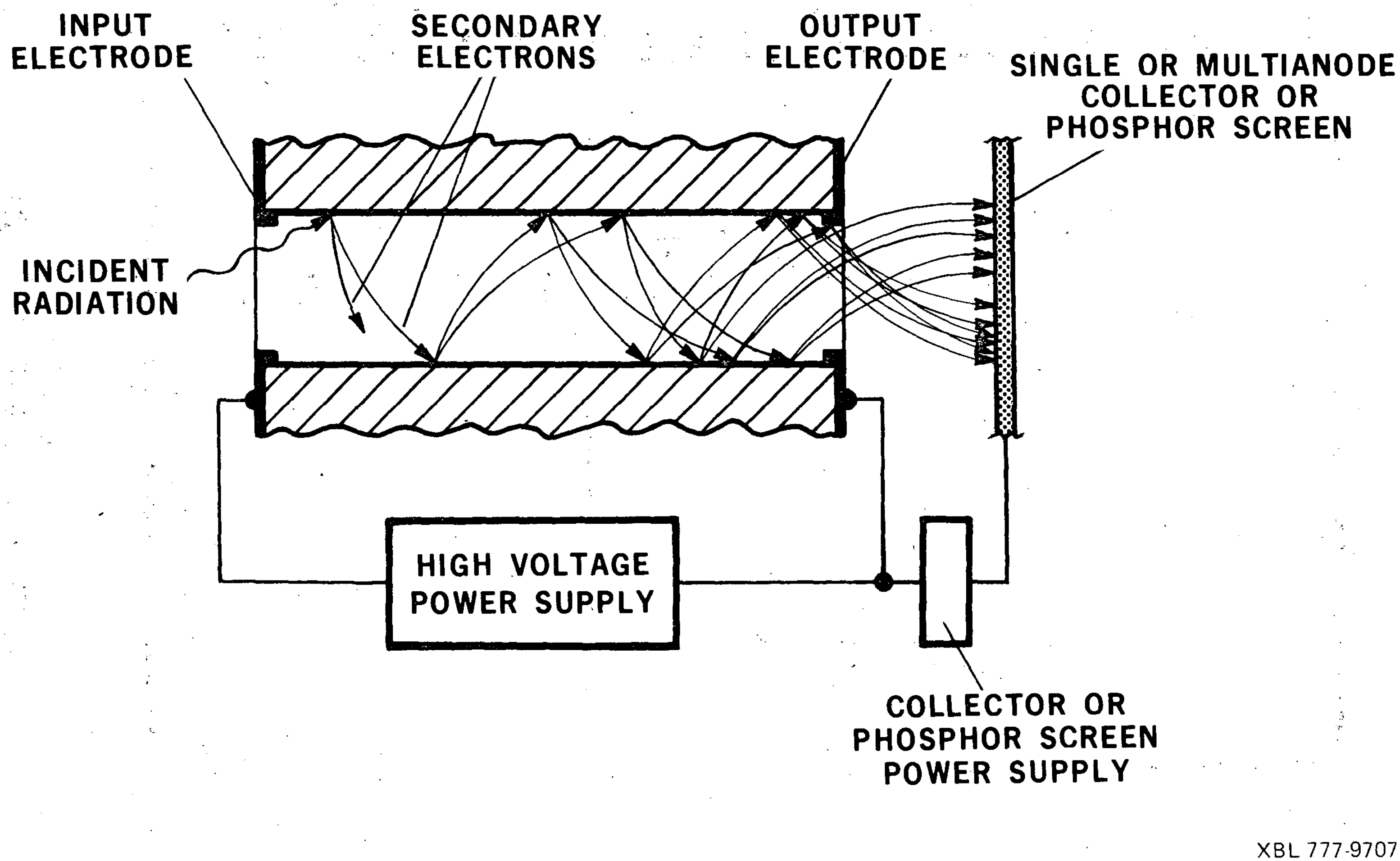
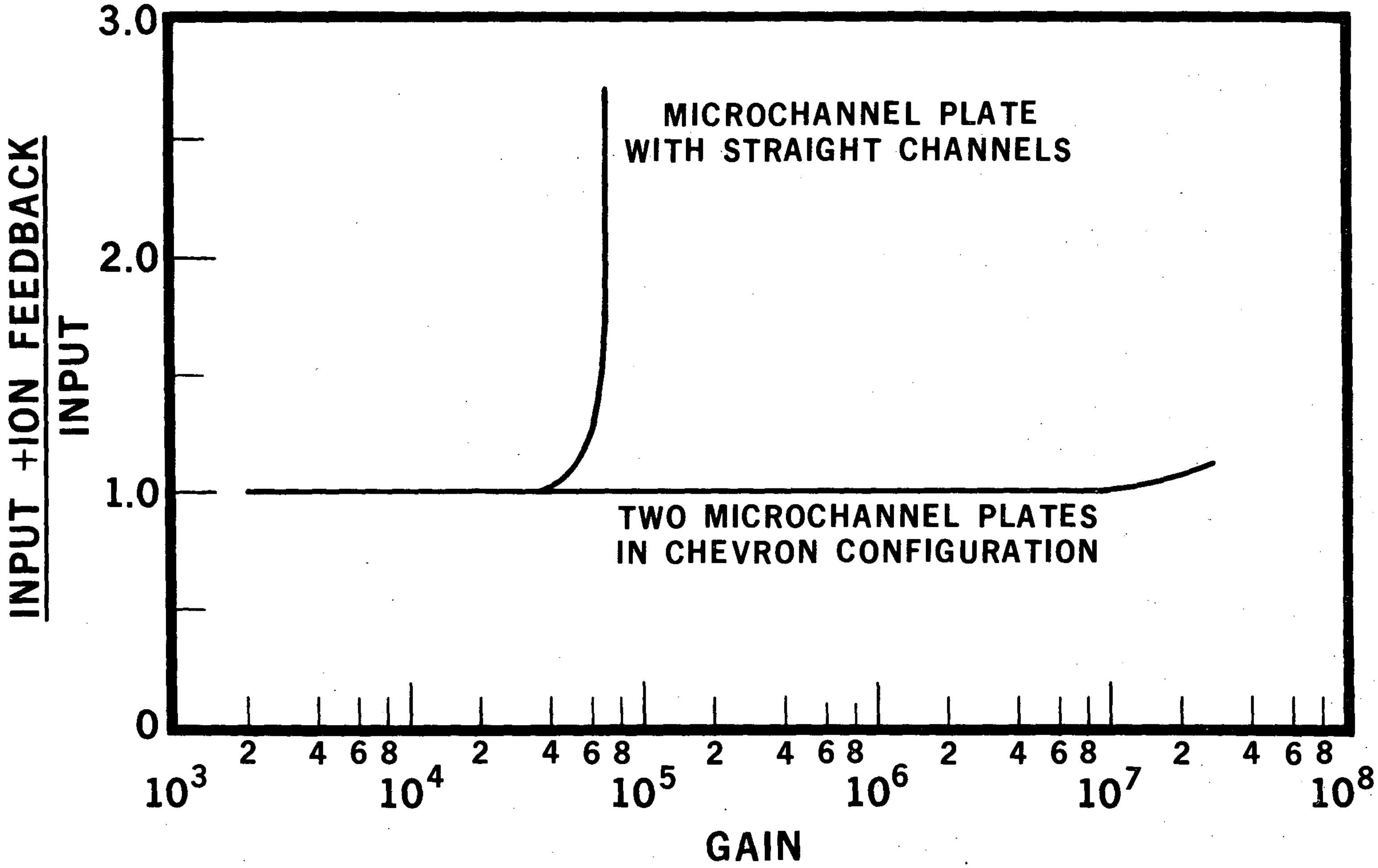

INPUT ELECTRODE
SECONDARY ELECTRONS
OUTPUT ELECTRODE
SINGLE OR MULTIANODE COLLECTOR OR PHOSPHOR SCREEN
INCIDENT RADIATION
HIGH VOLTAGE POWER SUPPLY
COLLECTOR OR PHOSPHOR SCREEN POWER SUPPLY
XBL 777-9707

Fig. 3



XBL 777-9709

Fig. 4

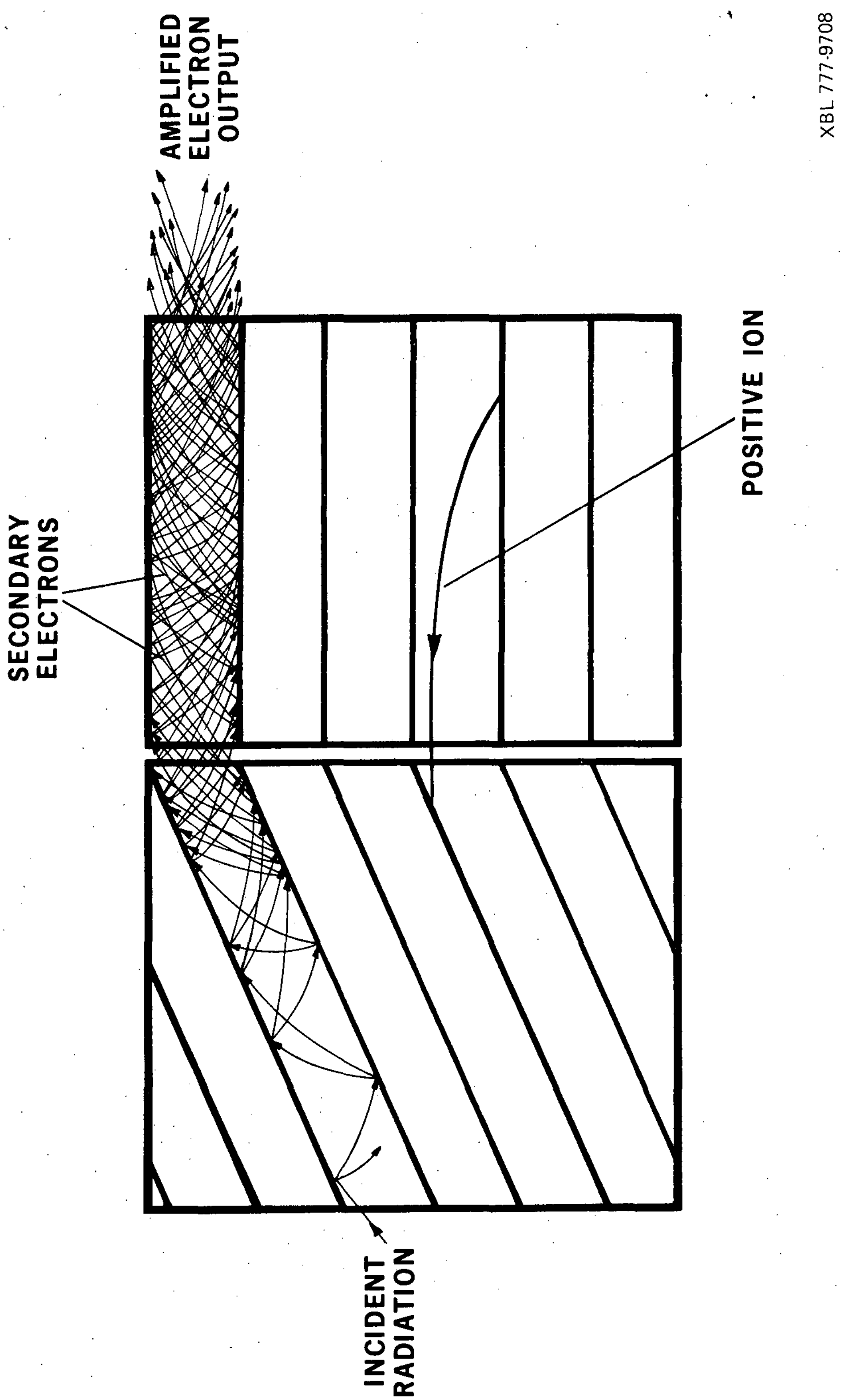

AMPLIFIED ELECTRON OUTPUT
SECONDARY ELECTRONS
POSITIVE ION
INCIDENT RADIATION
XBL 777-9708

Fig. 5

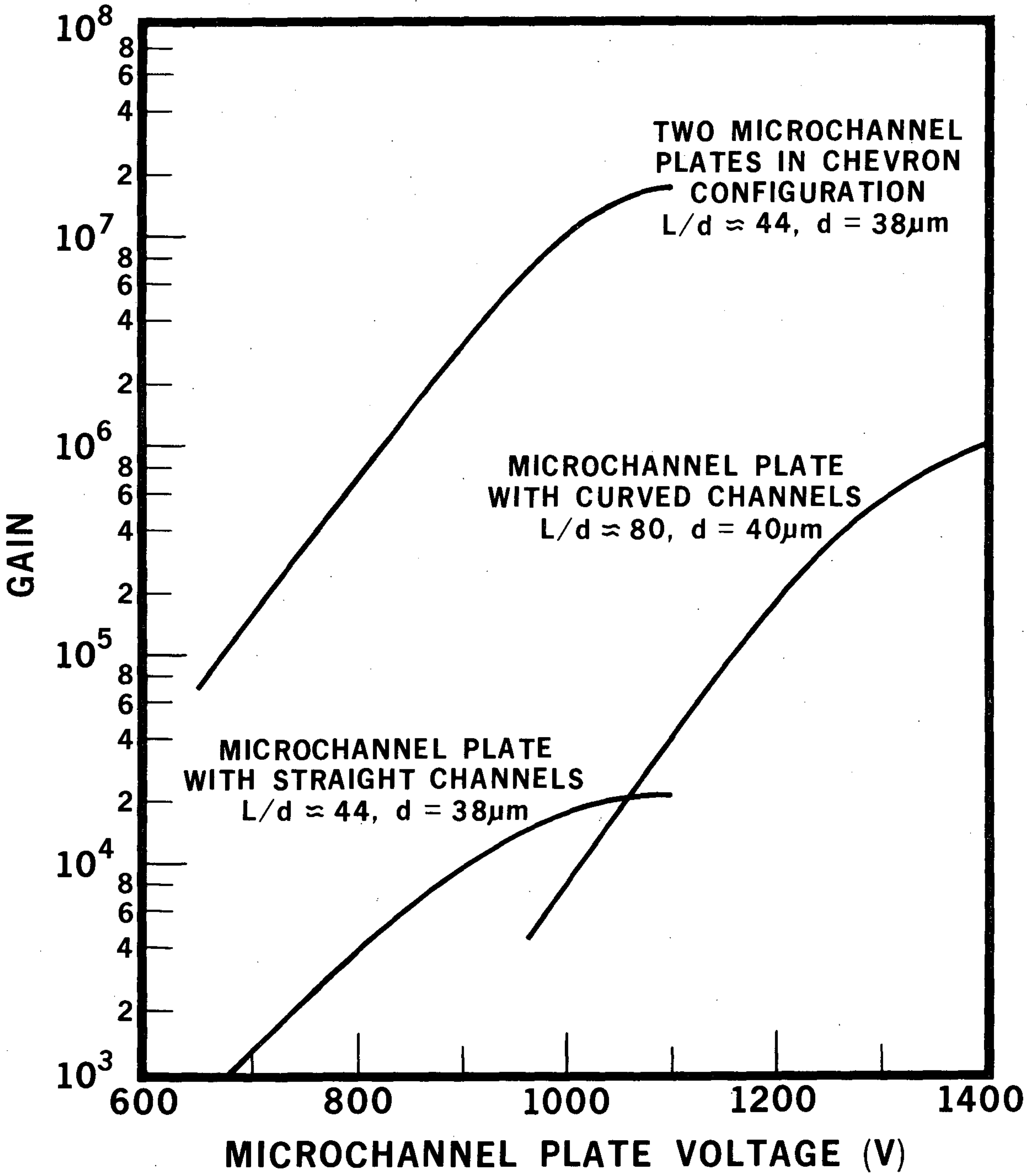

TWO MICROCHANNEL PLATES IN CHEVRON CONFIGURATION
L/d ≈ 44, d = 38μm
MICROCHANNEL PLATE WITH CURVED CHANNELS
L/d ≈ 80, d = 40μm
MICROCHANNEL PLATE WITH STRAIGHT CHANNELS
L/d ≈ 44, d = 38μm
GAIN
MICROCHANNEL PLATE VOLTAGE (V)
600
800
1000
1200
1400
XBL 778-2580

Fig. 6

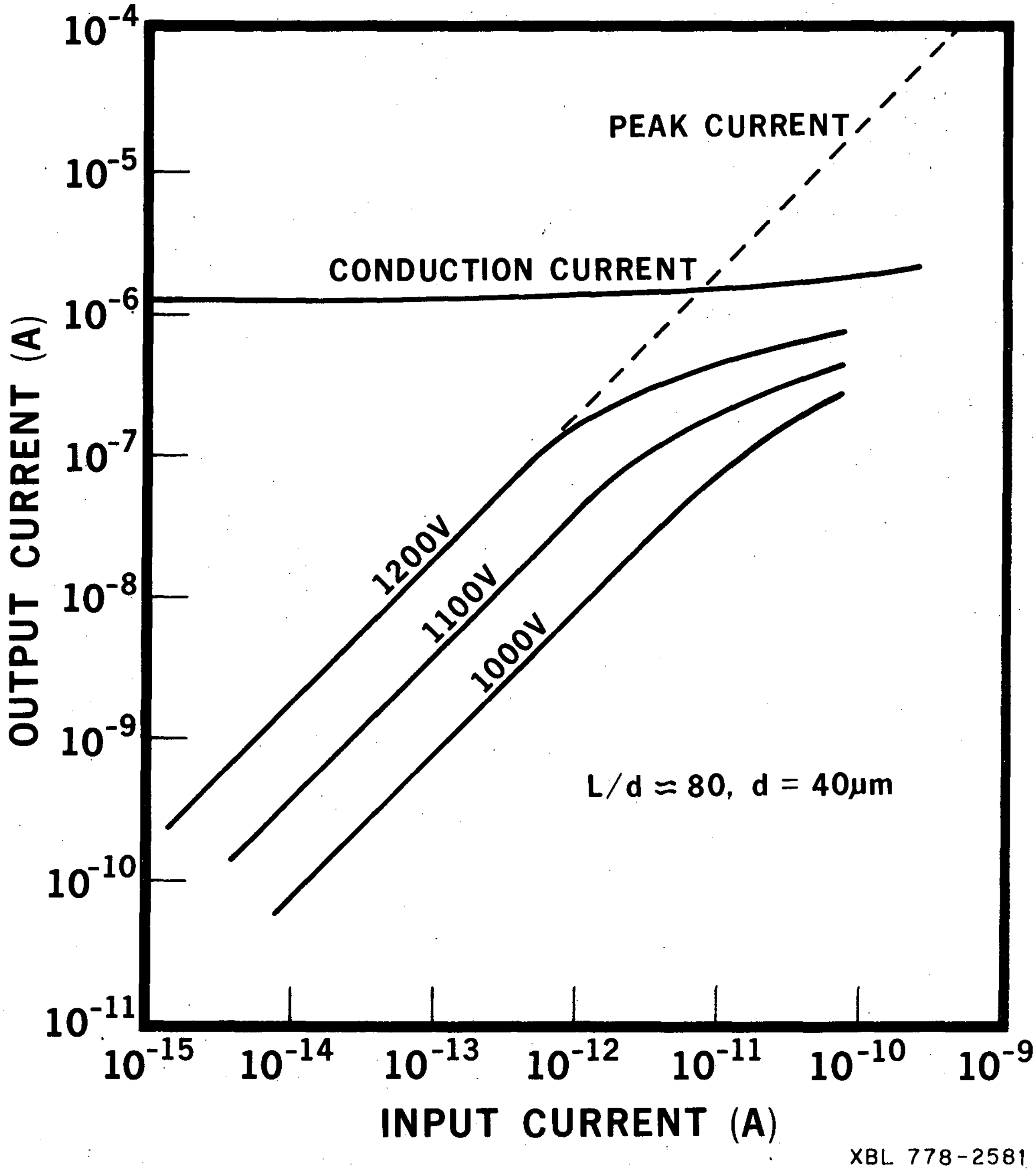

PEAK CURRENT
CONDUCTION CURRENT
1200V
1100V
1000V
L/d ≃ 80, d = 40μm
OUTPUT CURRENT (A)
INPUT CURRENT (A)
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-15
10^-14
10^-13
10^-12
10^-11
10^-10
10^-9
XBL 778-2581

Fig. 7

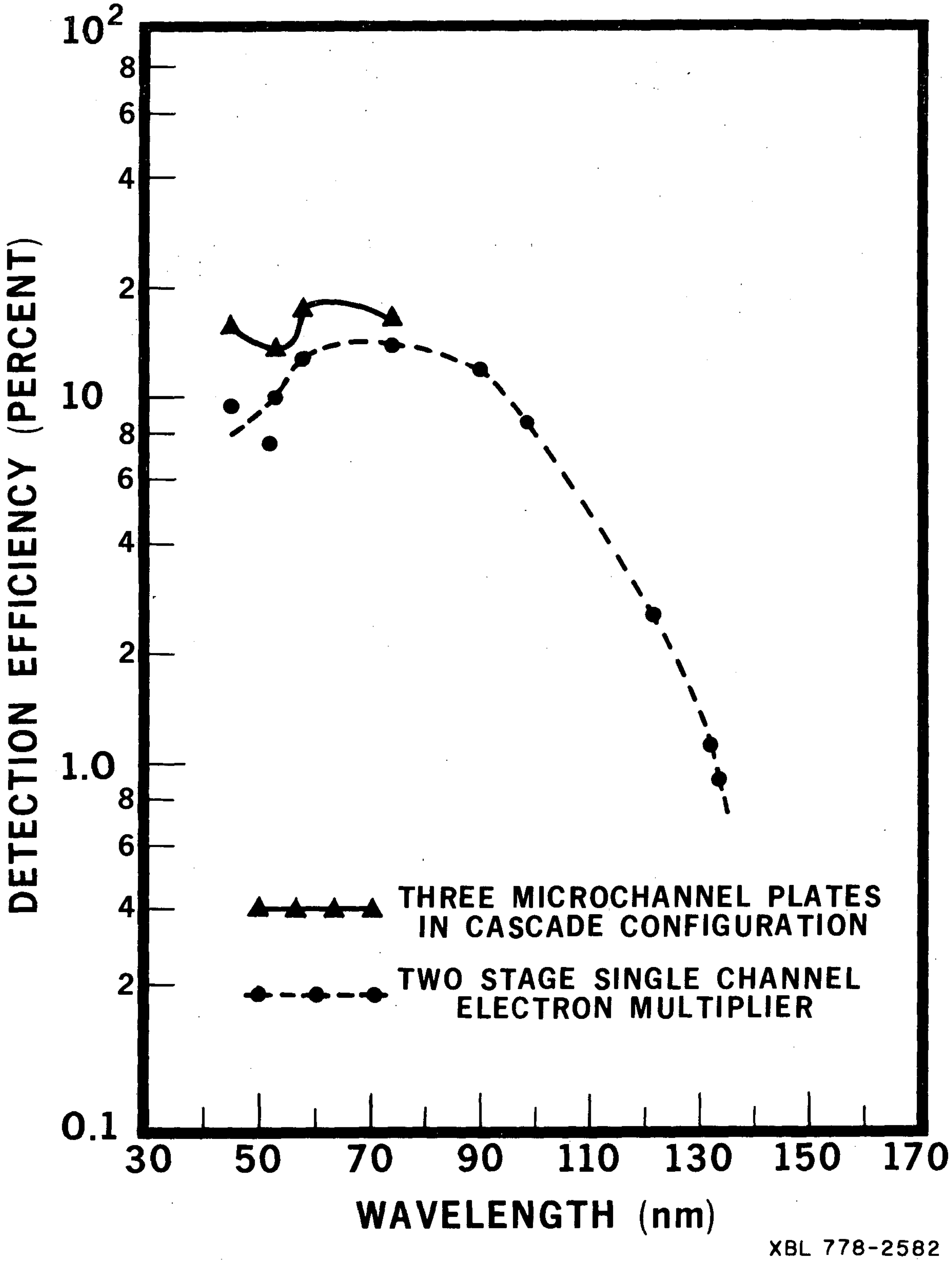

10^2
8
6
4
2
10
8
6
4
2
1.0
8
6
4
2
0.1
DETECTION EFFICIENCY (PERCENT)
THREE MICROCHANNEL PLATES IN CASCADE CONFIGURATION
TWO STAGE SINGLE CHANNEL ELECTRON MULTIPLIER
30
50
70
90
110
130
150
170
WAVELENGTH (nm)
XBL 778-2582

Fig. 8

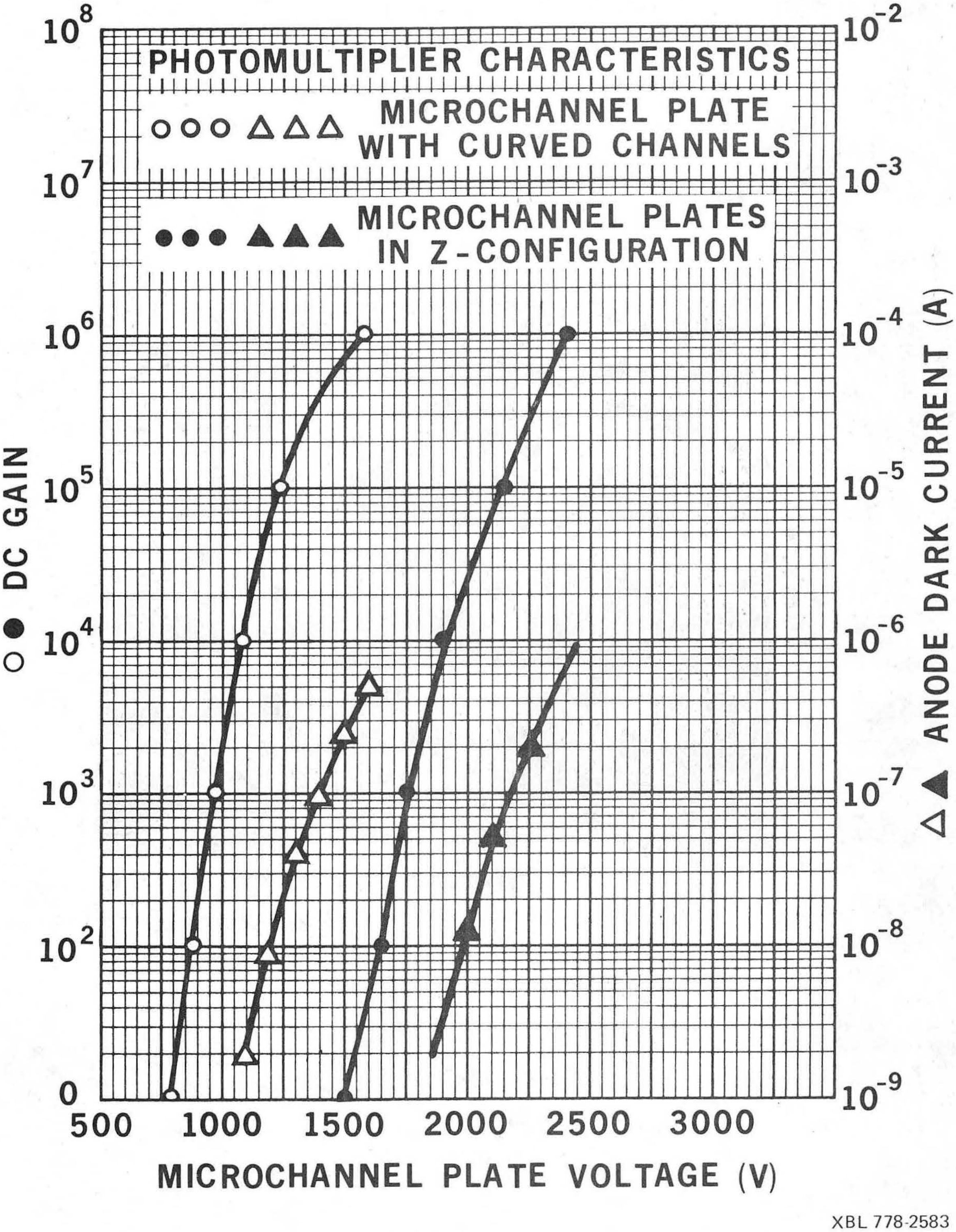

PHOTOMULTIPLIER CHARACTERISTICS
○○○ △△△ MICROCHANNEL PLATE WITH CURVED CHANNELS
●●● ▲▲▲ MICROCHANNEL PLATES IN Z-CONFIGURATION
○● DC GAIN
△▲ ANODE DARK CURRENT (A)
MICROCHANNEL PLATE VOLTAGE (V)
500
1000
1500
2000
2500
3000
0
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
XBL 778-2583

Fig. 9

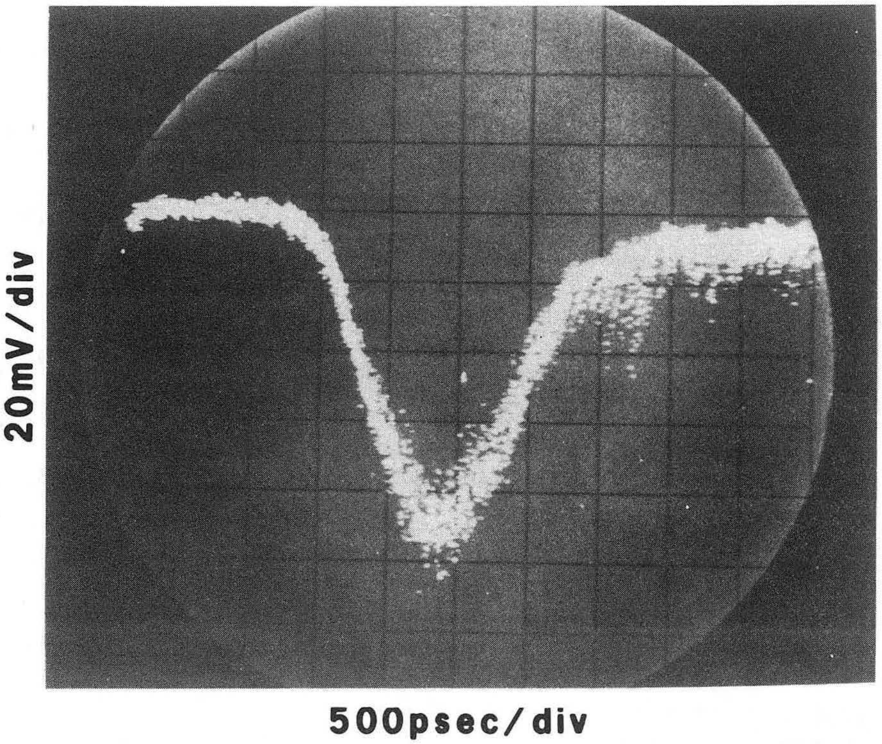
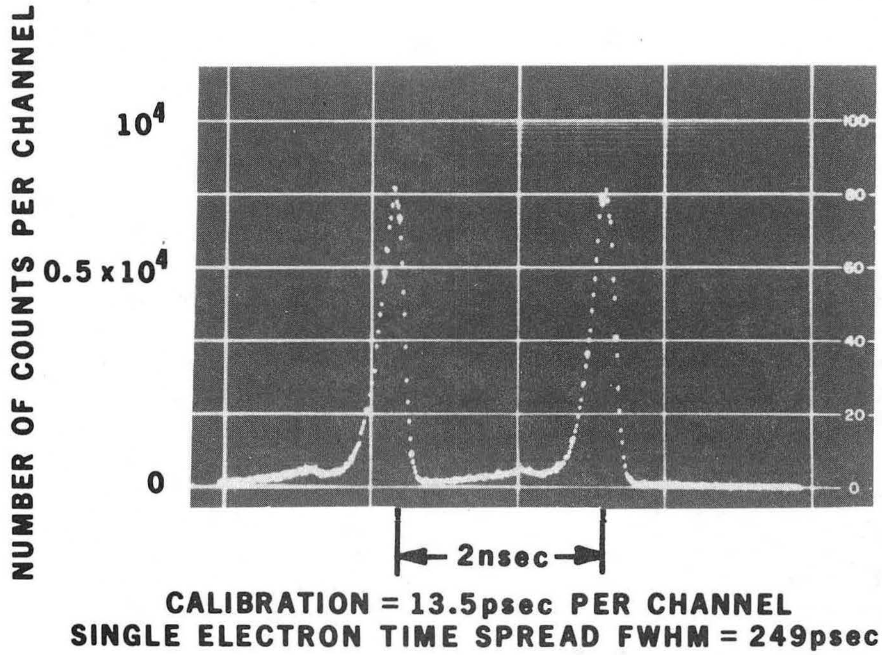


Fig. 10



XBB 7610-9219A

Fig. 11

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