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### **Title**

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PHOTOMULTIPLIER

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AMPEREX XP2020 PHOTOMULTIPLIER

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**MASTER**



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## PERFORMANCE STUDIES OF THE NEW GENERATION AMPEREX XP2020 PHOTOMULTIPLIER

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### Abstract

Characteristics have been measured for the new generation Amperex XP2020 45 mm-diameter photomultiplier. Some typical photomultiplier characteristics--such as gain, dark current, transit and rise times--are compared with data provided by the manufacturer. Photomultiplier characteristics generally not available from the manufacturer, such as the single photoelectron time spread for the full photocathode illumination, the relative collection efficiency as a function of the voltage between photocathode and focusing electrode, were measured and are discussed, particularly with respect to the optimization of photomultiplier operating conditions for timing applications. Measurements were also made on the photomultiplier's high repetition rate counting performance as well as the rate dependent photomultiplier gain.

### Introduction

The new generation Amperex XP2020 is a 12 stage head-on type photomultiplier having a semi-transparent bialkali (S24) photocathode with a useful diameter of 45 mm. The tube is intended to be used in applications such as high time resolution measurements, fast coincidences, time-of-flight measurements, and detecting very low luminous fluxes. The five tubes evaluated have copper beryllium dynodes instead of AgMgOCs dynodes. The peak spectral response is at 4000 Å with a quantum efficiency of 26% at this wavelength.

All measurements except those for high repetition rates were made with the three dividers shown in Fig. 1. The performance of all three dividers are given and the results are the average data on five tubes.

### Gain and Dark Current Measurements

Measurements of gain and dark current were made with the system described in Ref. 1. Figure 2 shows the gain and dark current characteristics of the photomultiplier as functions of voltage applied between cathode and anode. All photomultipliers have very similar dc gain characteristics. For divider A, the measured gain was  $1 \times 10^8$  at 2200 V and the dark current was  $2 \times 10^{-8}$  amps. For divider B (the high current divider) the gain at 3000 V was  $1.2 \times 10^7$  while the dark current was  $5 \times 10^{-9}$  amps. Divider B' is an optimized divider which provides good timing characteristics as well as a higher current output as shown in the measurements.

### Peak Anode Output Current Measurements

The peak anode output current measurements were made with the system described in Ref. 1. A light pulse generator capable of producing high light intensity pulses was used as the light source and calibrated neutral density filters were used to accurately atten-

uate the light. As shown in Fig. 3, the high current divider, B, made possible a maximum linear anode output current of 590 mA where as divider B' and A gave 210 mA and 80 mA, respectively. Divider B, however, could yield a nonlinear peak current over 800 mA.

### Single Photoelectron Time Spread Measurements

The time spread of a photomultiplier output pulse depends upon photomultiplier geometric characteristics, and its operating conditions. Since the timing accuracy varies approximately inversely as the square root of the number of photoelectrons, the time-behavior information of single photoelectrons 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 determining the optimum operating conditions in critical timing applications.<sup>2</sup>

The system as described in Ref. 3 was used for single photoelectron measurements. For all five tubes, the full photocathode illumination was used. The measuring system has a time resolution of 25 ps. Divider A only was used for this measurement. Figure 4 shows the single photoelectron pulse response of XP2020. Figure 5 shows two single photoelectron time spectra spaced 4 ns apart.

Since the input electron optics has a profound influence on single photoelectron time resolution, the focus electrode voltage was varied and the single photoelectron time resolution was measured as a function of this voltage which is expressed as the photocathode-focusing electrode to photocathode - first dynode voltage ratio. Figure 6 and 7 are the results of these measurements. Using divider A and B, the photomultipliers had a minimum time spread at ratios of 0.25 and 0.3, respectively, although the peak collection efficiency for divider A occurred at a ratio of 0.275. The minimum single photoelectron time spread for divider A and B' were 500 ps and 520 ps, respectively. With the high current divider B, the photomultipliers had a minimum time spread of 880 ps at the ratio of 0.27. Hence, in a particular application if good time resolution is desired, divider A should be used, but if high current is desired, B should be used. For critical applications calling for the best performance, the optimum voltage ratio should be determined and applied. The results presented here are the average data of five tubes; it was found that the variations between the tubes are within 25%.

### Dark-Pulse Spectrum Measurements

Dark-pulse spectrum measurements were made by using the system described in Ref. 1. The spectrum is shown in Fig. 8. The photomultiplier pulse height resolution is not good enough to show one, two, and three photoelectron peaks in the measured spectrum. The dark-pulse summation, taken from 1/8 photoelectron to 16 photoelectrons, was measured at a photomultiplier temperature of 24°C. Calibration of the 1/8-photo-

electron point was made with an RCA 8850, whose excellent pulse height resolution made the calibration possible.<sup>4</sup> The average dark-pulse count for the photomultiplier was found to be

$$\frac{16 \text{ photoelectrons}}{\sum} \approx 450 \text{ counts per second}$$

$$\frac{1}{8} \text{ photoelectron}$$

### Multiphotoelectron Time Resolution

It is generally agreed that the variance,  $\sigma^2$ , of the photoelectron time spread of a photomultiplier is inversely proportional to the number of photoelectrons per pulse. This measurement was made using the mercury light pulse generator which was capable of producing thousands of photoelectrons per pulse from the photocathode of the photomultipliers. The system used was similar to the system in Ref. 5. The number of photoelectrons per pulse was calculated using the measured output pulse width and amplitude and knowing the gain of the photomultiplier at the operating voltage. Fig. 9 shows the plot of the time resolutions as a function of the number of photoelectrons per pulse from one photoelectron up to thousands of photoelectrons. The time resolution of the single photoelectron pulses was 2.2 nsec, FWHM, indicating the light pulse was very close to 2.2 nsec wide; the time resolution improved to approximately 120 psec, FWHM, with 2500 - photoelectron per pulse using divider B.

### Fatigue Measurements

The loss of anode sensitivity, i.e. tube fatigue, depends on operating output current level, dynode materials and previous operating history. The average current a tube can withstand varies widely from tube to tube even of the same type, hence the results will only represent the behavior of the tube being measured. Loss of sensitivity normally occurred rapidly at the beginning of operation, especially at high output current levels. The degradation then slowed down and some tubes would recover after given a resting period. All three tubes measured actually experienced increase in sensitivity for a period of time while in operation. The XP2020 has a maximum rated continuous anode output current of 0.2 mA, however, measurements were made operating two tubes at current levels twice as high as specified. The light source used in this measurement was one mCi of Cs<sup>137</sup> smeared on the back of a pilot F scintillator whose distance from the tube could be changed to adjust the output current.

In Figure 10, tube S/N 9275 was operated at 0.2 mA initially, the output current gradually decreases in the first minute and then took a dip in the second minute. From then on it recovered and the output current went up to 0.27 mA at the end of 400 minutes. Tubes S/N 9266 and S/N 9274, although were not tested as long at this output current level, they did indicate in Fig. 11 and 12 that they would perform well up to and beyond the 9000-minute mark.

In Figure 11 and 12 S/N 9266 and S/N 9274 were tested at 0.5 mA and 0.4 mA respectively. At the end of 300 minutes, operating at 0.5 mA, S/N 9266 was given a long rest of 3700 minutes. It was then operated at 0.5 mA again, its output decreased to 0.37 mA in 1000 minutes. In Figure 12 tube S/N 9274 was operated

at 0.4 mA and was given three resting periods. It recovered in the first two rests but did not in the third. The total charge extracted from S/N 9274 was approximately 51 Coulomb, solely from the fatigue tests. Assuming this was a new tube and another 4 Coulomb was extracted during the previous tests, a total of 55 Coulomb was extracted from this tube before it showed sign of permanent damage.

### High Repetition Rate Counting Measurements

More and more photomultiplier applications are for high frequency counting. The important factors in such applications are pulse response, high average output current capability, and gain stability. The pulse response determines the pulse pair resolution that can be obtained with the tube. For example, a tube having an output pulse of 5 ns, FWHM, would typically have a base width of 15 ns, hence the highest counting frequency of such a tube is approximately 66 MHz, assuming of course the tube has the current capability and the divider is properly designed to supply enough both steady current and pulse current to sustain the high counting rate. Depending on the application, if long life of the tube is not an important factor, the tube can be made to provide high average anode output current for a short period of time as long as a proper divider is used; however, if long tube life is important, the operating condition should be such that the output average current should not exceed a fraction of the maximum rating. This means a compromise between the duty cycle, the light source intensity, and the output pulse amplitude. The fatigue measurement described gives some insight of how the tube should be used. Figure 13 and 14 shows the anode output pulses at repetition frequencies of 1 MHz and 55 MHz, respectively. The upper trace is the anode output pulse, the lower trace is the driving electrical pulse. The light source was a light emitting diode, type XP21, driven by pulses with 3 ns width and approximately 10 V in amplitude. The XP21 diode was operated in an avalanche mode.<sup>3</sup> The divider used in this measurement was similar to the one described by C. R. Kerns in Ref. 6. The difference in output pulse amplitude of the tube operating at repetition frequencies of 1 MHz and 55 MHz is not readily noticeable. The average anode output current was 0.18 mA using an input light pulse repetition frequency of 55 MHz with a 2% duty cycle. Figure 15 and 16 shows a continuous counting (100% duty cycle) operation but at a much lower repetition frequency. Figure 16 is the output pulse at 5 MHz. The average anode output current in the 5 MHz case was 0.8 mA, four times higher than the maximum rating of XP2020.

### Gain Variation Measurements Using Cs<sup>137</sup> Source

One mCi Cs<sup>137</sup> source was used to irradiate a piece of pilot F scintillator which was attached to the photocathode face plate of the photomultiplier. The distance between the source and scintillator-photomultiplier could be changed to obtain different counting rates. In this particular case, the highest counting rate obtainable was approximately 70 kHz with the source a couple of inches away from the scintillator. The Cs<sup>137</sup> peak was observed at a count rate of 2 kHz and 60 kHz. The peak of the Cs<sup>137</sup> spectrum decreased by about 5% at 60 kHz although the average anode current at this point was a mere 0.01 mA. It is not clear at this time what was the principle contributing factor for this behavior.

## Conclusion

Our measurements have shown that basic characteristics of the XP2020 photomultipliers agree closely with those given by the manufacturers. The relatively critical setting of the focus electrode potential of all three dividers required to obtain the best performance in both single photoelectron time resolution and collection efficiency must be observed especially in applications which demand the most out of the device.

The fatigue measurements show that by operating the tubes at 0.2 mA, the absolute maximum rating of the manufacturer, all three tubes measured could supply this current to at least 1000 minutes and up to 10,000 minutes. Tube S/N 9274 showed signs of some permanent damage after approximately 55 Coulombs had been extracted from the tube. An anode output current of 0.4 mA was drawn from this tube prior to the permanent loss of sensitivity.

The high frequency counting measurements show that the XP2020 can be operated beyond pulse repetition frequency 55 MHz so long as the divider is capable of providing the current needed for the operation. Depending on the importance of long term stability, the XP2020 can provide anode output current many times higher than the 0.2 mA rating for some period of time with the consequence of eventual permanent loss in sensitivity. The short term gain variation under high frequency operation has not been investigated. Results of future studies will be reported in due course.

## Acknowledgements

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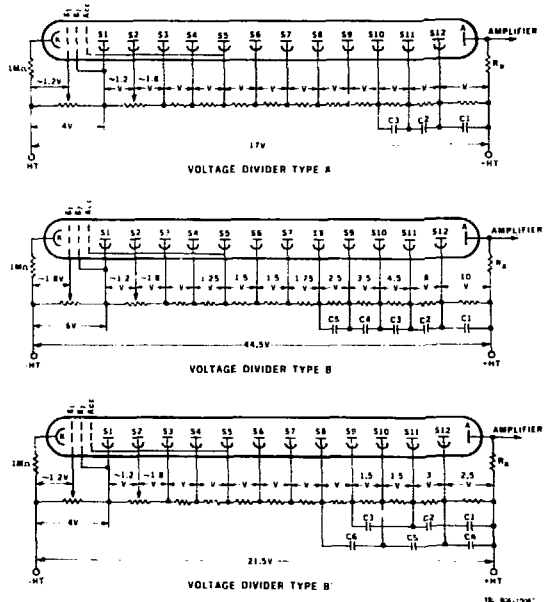


Fig. 1 Schematic diagram of dividers used in the measurements.

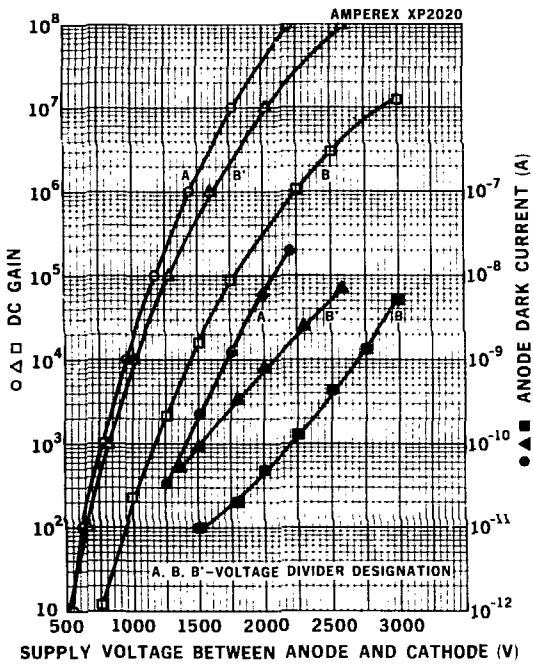


Fig. 2 Gain and dark current as a function of voltage between anode and cathode.

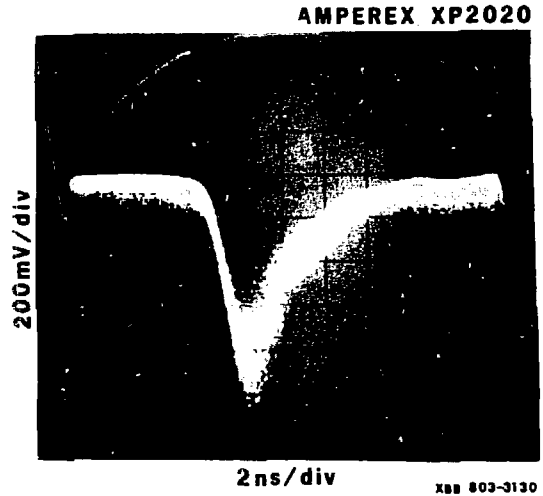
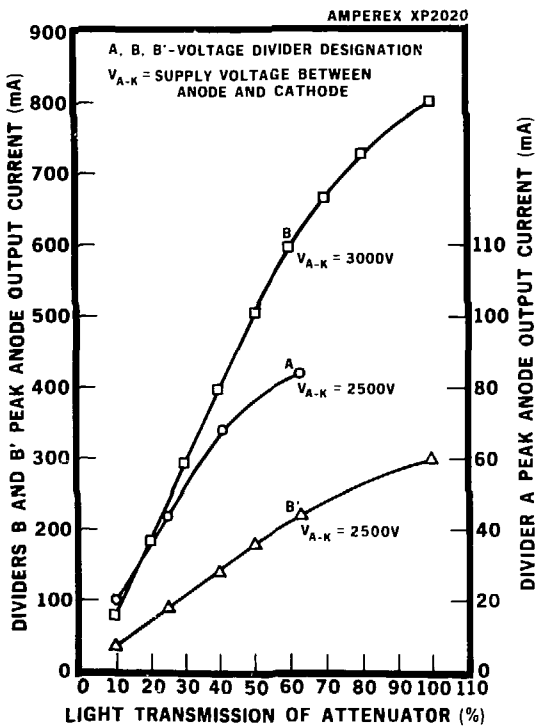


Fig. 4 Single photoelectron pulses from XP2020 using a 200 ps light impulse excitation.

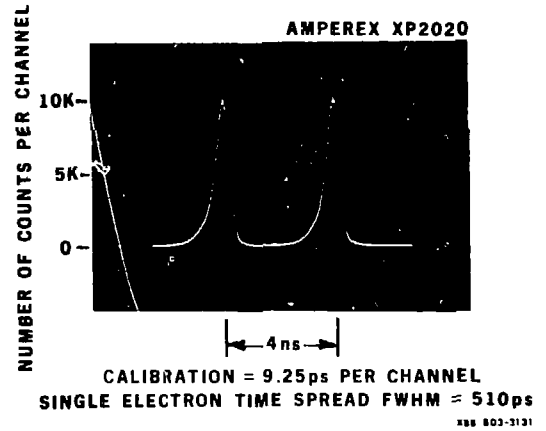


Fig. 5 Single electron time spread of XP2020 photomultiplier with full photocathode illumination.

Fig. 3 Peak anode pulse amplitude as a function of light transmission of the optical attenuator.

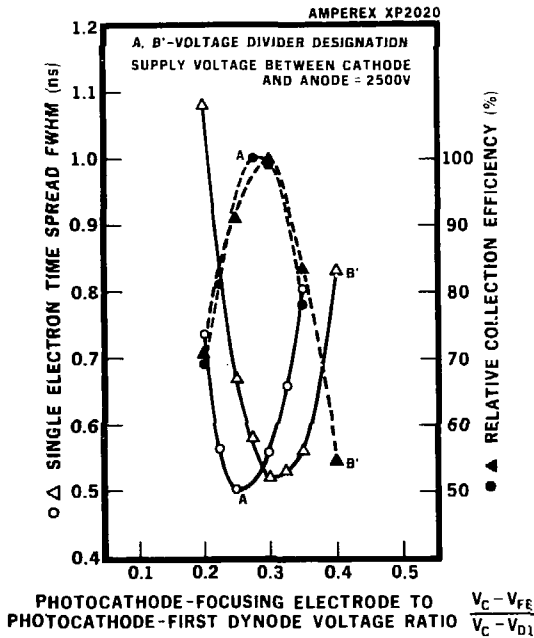


Fig. 6 Single electron time spread and relative collection efficiency as a function of the voltage ratio between the photocathode-focusing electrode and photocathode-first dynode for full photocathode illumination using voltage dividers A and B'.

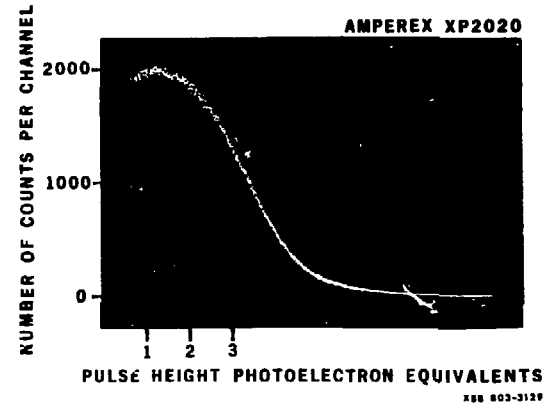
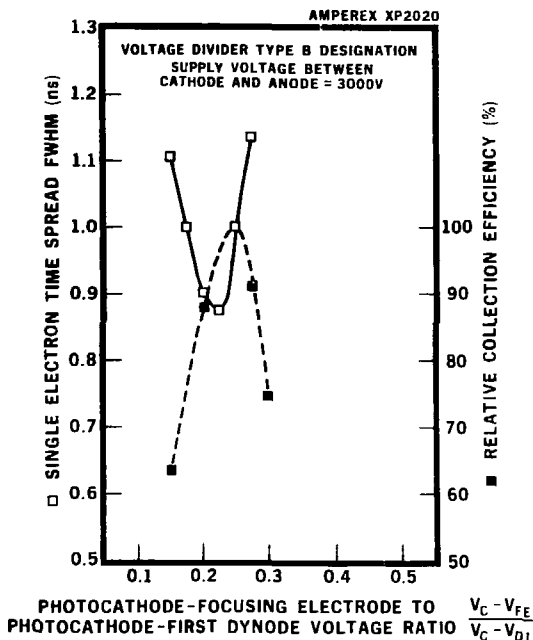


Fig. 8 Pulse-height spectrum for XP2020 photomultiplier.

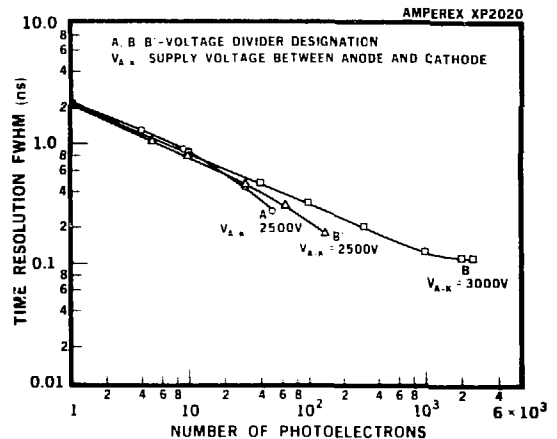


Fig. 9 Multiphotoelectron time resolution as a function of the number of photoelectrons per pulse measured with a 200 ns light pulse width, and a supply voltage between anode and cathode of 2500V and 3000V.

Fig. 7 Single electron time spread and relative collection efficiency as a function of the voltage ratio between the photocathode-focusing electrode and photocathode-first dynode for full photocathode illumination using voltage divider b.

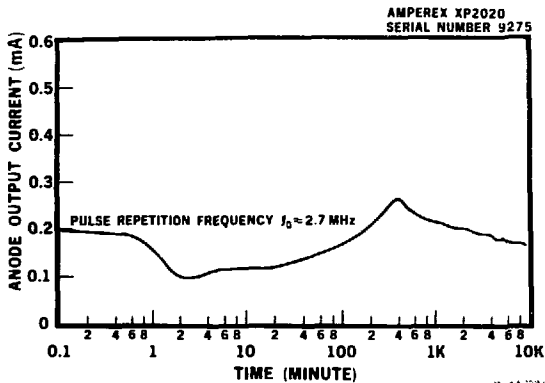


Fig. 10 Anode output current as a function of time measured with input light pulse repetition frequency of 2.7 MHz for photomultiplier S/N 9275.

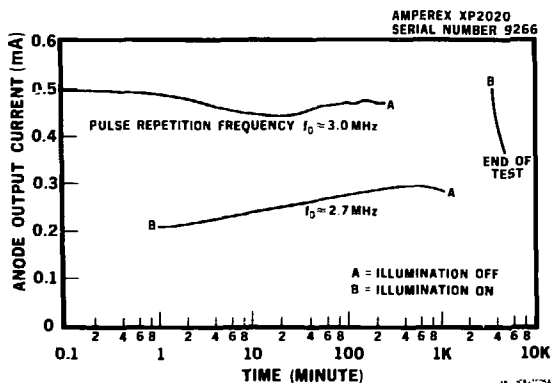


Fig. 11 Anode output current as a function of time measured with input light pulse repetition frequency of 2.7 and 3.0 MHz with operating interruptions for photomultiplier S/N 9266.

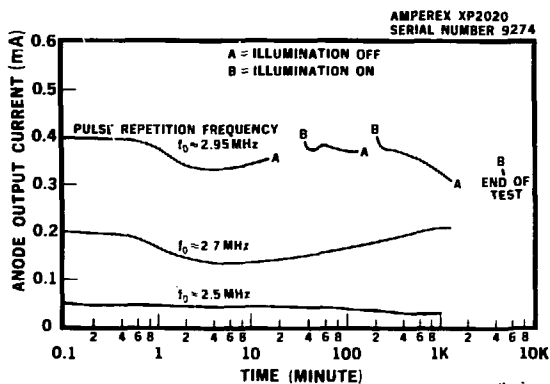


Fig. 12 Anode output current as a function of time measured with input light pulse repetition frequency of 2.5 MHz, 2.7 MHz and 2.95 MHz with operation interruptions for photomultiplier S/N 9274.

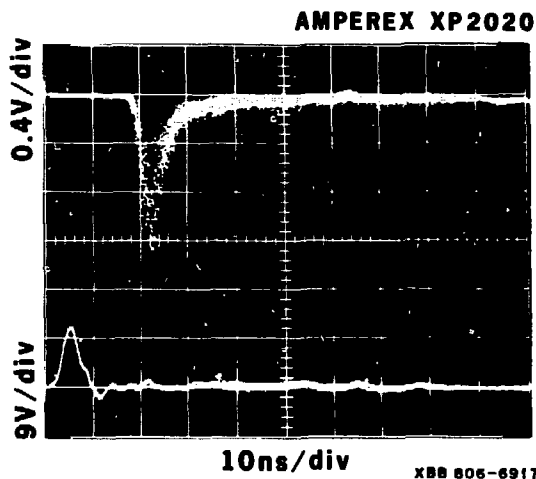


Fig. 13 Anode output pulses (upper trace) using input light pulse repetition frequency of 1 MHz with 20% duty cycle.

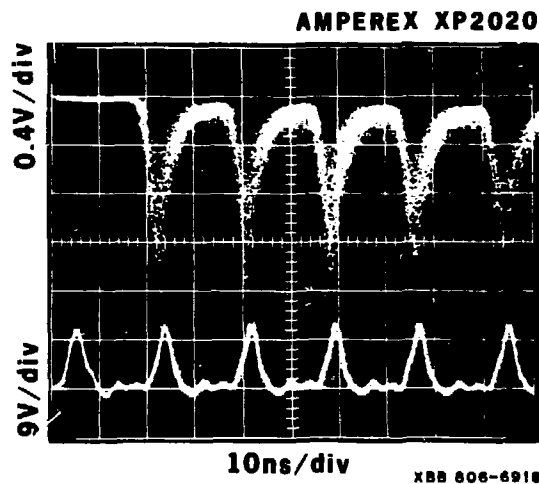


Fig. 14 Anode output pulses (upper trace) using input light pulse repetition frequency of 55 MHz with 2% duty cycle.



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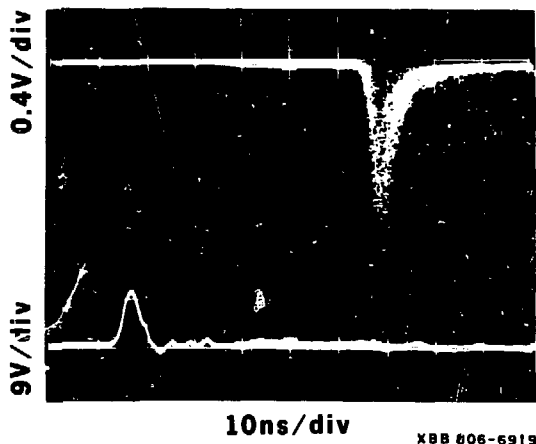


Fig. 15 Anode output pulses (upper trace) using a continuous input light pulse repetition frequency of 1 MHz.

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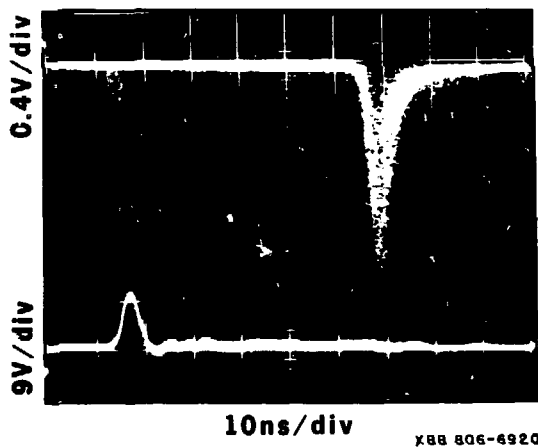


Fig. 16 Anode output pulses (upper trace) using a continuous input light pulse repetition frequency of 5 MHz.