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Measured responsivities of generation II and hybrid image intensifiers

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ABSTRACT

We have measured the absolute and coupled system responsivities of several image intensifier types at several wavelengths in the visible spectrum. Intensifiers characterized include microchannel plate (MCP) generation II proximity-focused and hybrid generation I/generation II electrostatic-focused designs. Configurations including single plate, double plate, nominal and high strip current MCPs, and standard S20 and super generation II enhanced S-20 photocathodes were evaluated. Absolute responsivity measurements were performed using NIST-traceable radiometry instrumentation. The normalized relative sensitivities and overall optical luminous gain performance provided by individual intensifiers when similarly coupled to either high resolution 10-bit RS-170 CCD or FPS cameras are presented along with their radiometric data.

Key words: hybrid generation I/generation II image intensifiers, high strip current and double plate MCPs, absolute/relative responsivities.

1. INTRODUCTION

Image intensifiers for low light level imaging applications were evaluated primarily for relative responsivity in a coupled system configuration. Measurements of signal-to-noise were obtained for several different designs and combinations of image intensifiers when gated and illuminated with short-duration visible wavelength monochromatic light pulses approaching photon-limited flux. The first set of experiments involved measuring the dynamic range for proximity-focused microchannel plate (MCP) intensifiers using single pulse illumination. A subset of these intensifiers were evaluated for repetitive pulse operation. A second set of experiments measured individual single pixel responsivities for an MCP intensifier and its CCD readout camera using micron-range pinhole patterns. For another experiment, various intensifiers were fiber optically coupled to a CCD camera and the video outputs were digitized and synthesized into background, signal, and random shot noise components. A final experiment investigated the responsivity of a hybrid intensifier as function of the kinetic energy of photoelectrons imaged onto its MCP. The absolute parameters of the various light sources used were measured with a spectrometer/radiometer system traceable to NIST.

2. MEASUREMENTS ON PROXIMITY-FOCUSED IMAGE INTENSIFIERS

2.1. Single pulse mode responses

This experiment compared relative responsivities and dynamic ranges of four ITT 18mm diameter proximity-focused microchannel plate image intensifiers (MCPIIs) with S-20 photocathodes and P-20 phosphors. The MCPIIs included (1) one with a standard strip current, single plate MCP, (2) one with a standard strip current, double plate MCP, and (3) two with high strip current, single plate MCPs.

The MCPIIs were tested by illuminating their photocathodes with light pulses from a Spectra-Physics 2030 argon/dye laser which provided 30 ps FWHM pulses at 600 nm. This setup was previously described in our earlier work¹. The MCPIIs were operated in the shuttered mode with 20 ns FWHM optical gates. The laser pulse was centered within the optical gate. The transfer curves were generated by varying the laser irradiance with neutral density filters which restricted the optical energy density pulse to the range of ≈ 10 to 200 pJ/cm^2 . The area of illumination was a 1 cm diameter spot. The MCP phosphor brightness was measured by lens coupling to a focus projection and scan (FPS) vidicon camera and digitizing the camera video. The transfer curves using the indicated MCP voltage (nominal value recommended by ITT) are shown in Fig. 1. The dual plate MCP (ITT SN XXC3482) produced the brightest phosphor output for a given input irradiance. The main response expected from the double plate MCP was improved sensitivity from increased electron multiplication gain. The different slopes of the transfer curves observed between the double plate and single plate MCPIIs was unexpected, although steeper gain curves versus MCP voltage are expected from the double plate MCP because of larger length/diameter (L/D) ratios.² The next brightest signal was obtained from the standard single plate MCP (ITT SN XXB2006). For small signal levels, just above the FPS vidicon camera noise floor, this unit was $\approx 40\times$ less sensitive than the dual plate unit. Similarly, the two high strip current single plate MCPIIs were measured to have responsivities from $2\times$ to $4\times$ lower than the standard single plate MCP. These data points are highlighted in Fig. 1. Our measurements are in good agreement with ITT's "typical" luminous gain curves for generic designs using single and double plate MCPs,² although the measured saturation levels did not agree with ITT's specifications. The two high strip current MCPIIs had 50% transmissive Ni photocathode underlays whereas the two standard MCPIIs had 80% transmissive layers.

The input irradiance was varied to give approximately the same brightness output from each MCP as tabulated in Table 1. The differences in input light (as selected by ND filters) give the relative responsivities near the midrange of the intensifier transfer curves. No attempt was made for these data to establish the same gain from each MCP, rather, each was operated near midrange of its recommended MCP voltage as indicated earlier. For all MCPIIs the phosphor accelerating voltage was held constant at approximately 5kV. The MCP gain is a function of the MCP voltage. Inspection of ITT data sheets for the MCPIIs tested indicate a large variance in the electron gains from their respective MCPs. The expected electron gains for the MCP voltages used in Fig. 1 are listed in Table I for each MCP. To illustrate the variance in MCP gains among the four MCPIIs, the maximums possible are 1.5×10^3 (xxB2006), 2.2×10^5 (xxC3482), 1.7×10^3 (14/386-3), and 0.95×10^3 (14/386-1).

To determine the MCP saturation trend of the single MCP units shown in Fig. 1, the phosphor accelerating voltage for the two high-strip current MCPIIs was increased from 5kV to 7kV. The resulting transfer curves are shown in Figs. 2 and 3. The basic shape of the transfer curves was conserved with

increased phosphor voltage, but the brightness increased, as expected. Therefore, the conclusion was that the MCP (not the phosphor) was responsible for the saturation.

Table 1. Normalized relative responsivities of the MCPs under study.
V refers to MCP bias voltage, I refers to MCP strip current @ V.

SN (ITT)	MCP type	I (μ A)	V (V)	Gain (e)	Filter (ND)	Video (mV)	Normalization (Gain)
XXB2006	Std Single	1.2	770	900	1.6	80	1
XXC3482	Std Dual	1.6	1500	3.6×10^4	3.2	80	40
14/386-3	High Single	8.2	710	825	1.3	80	0.5
14/386-1	High Single	28	810	450	1.0	80	0.25

The relative phosphor brightness was also measured with a ratiometer. These data confirmed the same saturated transfer curve slope in terms of phosphor emission energy density as the input irradiance was varied. The ratiometer data are plotted in the right hand ordinate of Fig. 3. The absolute gains of these four MCPs were not measured in this experiment, although the input intensity was measured at a single point for each MCP as indicated by the asterisk on Figs. 1, 2, and 3.

The calculated³ saturation charge density for MCPs is $\approx 4 \times 10^{-9} \text{ C/cm}^2$. Using the laser's 30 ps FWHM and 200 pJ/cm^2 input energy density, a photocathode QE of 10 mA/W, and an MCP gain of 1 to 2×10^3 to calculate the charge density at the MCP output, it appears our data were taken near saturation (i.e. 1.5 to 3 nC/cm^2), therefore the observed saturated curves are reasonable.

2.2. Repetitive mode responses

The preceding data indicate that the dual MCP is more sensitive than the standard or high strip current single plate MCPs. This was expected. The high strip current MCPs have one feature that is important for high repetition rate uses: the MCP gain remains essentially constant for repetition rates up to 10 KHz. Conversely, the standard plate MCP's gain began declining at a repetition rate of around 500 Hz to 1 KHz as shown later.

The absolute responsivity for one of the high strip current MCPs (SN 14/386-3) was measured using a Spectra Physics 7300 frequency-doubled Nd:Yag laser which provided 532 nm pulses of $\approx 10 \text{ ns}$ FWHM. The MCP was gated for $\approx 40 \text{ ns}$ and the laser pulse was time-phased to occur in the center of the MCP gate interval. The laser and MCP gate were operated at 100 Hz. The laser's average optical power was measured first with the Optronics 730A radiometer. The beam was concentrated in $\approx 0.2 \text{ cm}^2$ area. The setup is shown in Fig. 4. The total power was measured and the irradiance/ cm^2 was calculated. Next, the MCP phosphor (Lambertian source) was measured with optics with ≈ 0.264 steradians solid angle resulting in $\approx 23.8 \times$ correction for total average power which was again multiplied by 5x to give the emission/ cm^2 . The MCP's average output to input powers measured in this manner were plotted in Fig. 5.

The output energy per pulse was calculated by dividing the measured average output power by 100 Hz and then multiplying by the laser pulse width (10 ns FWHM). These data are shown as energy units in the right-hand ordinate of Fig. 5. Comparison of the MCPII's measured/calculated phosphor energy when operated at 100 Hz with similar measurements from single pulse operation indicate saturation thresholds about equal, indicating the high strip current MCP can provide undiminished performance at 100 Hz. The optical gain provided by the MCPII at various input irradiances is plotted in Fig. 6.

To examine the transition from single pulse response to repetitive pulse response, (where equilibrium is or may be reached) a gating arrangement was designed to provide a burst of seven consecutive gate pulses at a 500 Hz rate. A block diagram of the experimental setup is shown in Fig. 7 and the timing diagram is shown in Fig. 8. One 200 ps FWHM light pulse from a 670 nm laser diode was centered within each gate pulse. The standard MCPII, SN XXB2006 and one high-strip current MCPII, SN 14/386-1 were tested for gain as a function of the repetition rate of the gate and light pulses. For each MCPII, the input irradiance was held constant and the phosphor brightness in successive gates was measured with a PMT to look for the time required to establish an equilibrium condition where consecutive light pulses would produce the same amplitude (equivalent phosphor brightness). Figs. 9 and 10 show histograms of the PMT signals from both MCPIIs. The standard current MCPII showed significant loss of amplitude in the second pulse of the burst. The high-strip current MCPII, on the other hand, exhibited no reduction in luminous gain at the 500 Hz as shown by fairly consistent amplitude of all pulses within the burst gate. The amplitude variations from gate to gate appear to be random, although there may also be a "beat" from EM pick up. The data shown are peak signals and the base or dark level is not shown. Therefore, determining the ratio of first gate amplitude to succeeding gates is not possible from these data. The small charge storage capacity (capacitance) and low conductivity (high resistivity) of the standard MCP are factors governing the slow recharge time, which limits the intensifier's ability to maintain constant gain at high-repetition rates. The effect of the MCP recharge time on the MCPII luminous gain is due to the exponential charging behavior of the MCP and the dependence of the electron gain on the MCP voltages. As electrons (Δq) generated by the first light pulse leave the MCP to the phosphor, the voltage (V) across the MCP drops as its capacitance (c) discharges from full charge(q). To a first approximation, the MCP bias, V , equals $q - \Delta q / c$. The voltage drop is proportional to the input optical energy density. Following the first light pulse, the MCP recharges at a rate determined by its RC time constant. If this recharge time is longer than the period between successive gate (and light) pulses, then the MCP voltage will be lower for subsequent pulses than it was for the first pulse. This leads to a drop in optical gain for all but the first pulse in a repetitive train of optical pulses. The gain then reaches or approaches an equilibrium value that is different at each repetition rate.

The standard MCPII was tested next using two MCP bias voltages and several light levels. The input irradiance was varied by controlling the laser diode drive amplitudes and durations while monitoring its emission with a PMT. The illumination levels were sufficient to operate the MCPII between noise and saturation levels. The saturation threshold results for the standard MCPII are shown in Fig. 11. At lower input light levels corresponding to lower charge from the MCP, both transfer curves are well behaved, approaching unity gamma. But at higher light levels, the transfer curves diverge (saturate) sooner for the fifth light pulse than for the first. This is shown in Fig. 12 as raw port data.

Ignoring transition effects (from single pulse to multiple pulse modes), the two intensifiers were measured at even higher basic illumination frequencies where equilibrium (the magnitude of MCP voltage recharges to same value for all light pulses) has been established, including 1 to 10 KHz range. The most notable effect

observed for the standard MCP-II is a decline in luminous gain with increasing gate repetition rate and with higher input irradiances. The high strip current MCP, on the other hand, exhibited little or no reduction in gain for gating frequencies up to 10 KHz under similar test conditions ($\approx 60 \text{ pJ/cm}^2$ input energy at the photocathode) as shown in Fig. 13 adapted from our earlier work.⁴

2.3. Absolute sensitivity measurements for CCD camera and high-strip current ITT MCP-II

This series of experiments was performed to quantify the absolute sensitivity of a CCD camera and MCP-II components (individually and coupled) in radiometric terms. These included the use of Xenon strobe pulse of $10 \text{ }\mu\text{s}$ FWHM spectrally filtered to obtain $550 \text{ nm} \pm 5 \text{ nm}$ light; a 670 nm laser diode array for the initial rate effects studies; and a frequency-doubled Nd:Yag laser for 532 nm pulses of 10 ns FWHM. The complete comprehensive test results are in an internal Los Alamos National Laboratory report now in preparation, describing a LADAR system for the US Marine Corps which utilized a LANL-designed range-gated video system. The report, expected to be released in late 1995, describes the intensified MCP-II/CCD camera discussed next.

The Nd:Yag laser setup and resulting data are covered in this section. After being expanded by a $10\times$ microscope objective lens, the laser light was imaged onto a Teflon diffuser to produce a uniform Lambertian source. A TV Optoliner precision optical system was used to house the diffuser and a special designed pinhole array pattern. The Optoliner was also used to project the array onto the CCD or MCP-II using $1:1$ relay lens. The input irradiance is attenuated with reflective ND filters. The CCD or MCP-II sensors were mounted on a precision micrometer optical mount for micron resolution positioning in horizontal and vertical directions to permit sensor alignment along the pinhole array optical axis. Special pinhole arrays were designed to simultaneously provide resolving power information along the vertical and horizontal axes of the sensors from a single pulse of light. The pinholes are separated by their same diameters in both directions. This geometry was originally designed to give point-spread function (PSF) directly⁵. We believe it can yield a more accurate measurement technique than single pinhole illumination with subsequent Fourier transform analysis to give spatial frequency response [or contrast transfer function (CTF)] of the sensors. The single pinhole method assumes no sensor pixel-to-pixel interferences, which is unlikely in real sensors. The pinholes are imaged as "point sources".

Single pixel responsivity measurements were made for the CCD camera, operated at 666 f/s with a single laser pulse per field, phased properly with respect to the CCD vertical transfer pulse to cause photosite transfer to occur immediately in the first field following arrival of the laser pulse at the array. The average laser energy per pulse required to give a $S/N \approx 1:1$ was measured with the Optronic 730A radiometer by integrating several pulses and dividing by the number of pulses to obtain total optical energy per pulse. In this manner, the average energy per pulse was measured as $\approx 4.88 \times 10^{-12} \text{ J}$. The peak optical power per pulse was found by dividing the energy per incident laser pulse by the 10 ns FWHM pulse width of the laser light. Using this calculation method⁶ for relating energy and power per pulse gave $4.88 \times 10^{-4} \text{ W}$.

The total energy or power incident on the CCD was over an area of $1256 \text{ }\mu\text{m}^2$ (four $20 \text{ }\mu\text{m}$ diameter pinholes) corresponding to slightly more than the area of 1 pixel ($1080 \text{ }\mu\text{m}^2$) but projected over several pixels (see pinhole array geometry in inset of Fig. 14). The light sensitive portion of each pixel (i.e. the photosite) accounts for 20% of the pixel area for interlaced operation. The energy and peak power were calculated as $2.04 \times 10^{-14} \text{ J/photosite}$ and $2.04 \times 10^{-6} \text{ W/photosite}$, respectively. This calculation is obtained

as shown below. Measurements by the radiometer collected light from all four pinholes in the array. Equal transmission through each pinhole was assumed for the following analysis. Video scan lines were taken across the illuminated pixels. A scan line taken horizontally across the middle of the projection of the pinhole array showed signal charge on eight adjacent pixels. The amplitude of each pixel was measured and plotted in the histogram of Fig. 14. To determine charge from individual pixels to estimate CCD single photosite video in mV/J, the following steps were used: (1) the sum of all amplitudes in the horizontal direction was 600 mV; (2) 1.2 V was assumed for the sum of all pixels along both axes because of identical illumination geometry in vertical direction (although pixel geometry is not identical); (3) the amplitude of pixel 6 (arbitrary pixel numbering was used) of Fig. 14 was selected (arbitrary choice) and measured to be ≈ 200 mV; (4) the ratio of pixel 6 amplitude to the composite amplitude of pixels 1 through 8 was 0.167; (5) the total energy/pulse was measured with the radiometer as $\approx 4.88 \times 10^{-12}$ J; (6) the energy responsible for the pixel 6 amplitude was calculated as 8.15×10^{-13} J; (7) the ratio of the pixel 6 amplitude to the CCD amplifier noise amplitude of 5 mV was determined to be 40 (i.e. 200 mV/5 mV); and (8) the single pixel sensitivity for a S/N of 1:1 was obtained by dividing the 8.15×10^{-13} J by 40 resulting in a measured/calculated sensitivity threshold of 2.04×10^{-14} J. The sensitivity in terms of peak power is 2.04×10^{-6} W.

Using the same input setup and similar analyses, the coupled CCD/MCP-II system response was measured when the CCD was fiber optically coupled to the high strip current ITT MCP-II (SN14/386-2.) Threshold sensitivity was determined to be $\approx 1.05 \times 10^{-15}$ J/photosite/pulse. Comparing this value with that determined for the CCD alone, 2.04×10^{-14} J/photosite/pulse, indicates an overall gain from the intensifier of only 20. It was noted that during some of the experiments preceding this one, the MCP-II was damaged by prolonged irradiation with an area (not pinhole array) source, which caused a significant "burned" area of reduced brightness. It is speculated that the pinhole data above were likely taken on this area of this MCP-II resulting in the low gain observed.

Described next is the coupled system response using an area source measurement and calculated photosite response. The light source used was the frequency-doubled Nd:Yag laser operating at 100 Hz and a new "unburned" area on the MCP-II was illuminated with a 16 mm^2 spot of light. The MCP-II was gated for 40 ns with the 10 ns laser pulse centered within the gate pulse. For this data set, the laser irradiance was measured with the radiometer as average power and converted to energy (by dividing the average laser power by the laser frequency) and to peak power (by dividing the laser period by the laser pulse FWHM), for obtaining optical stimulus per MCP-II gate per CCD field. For laser irradiance of $\approx 1 \times 10^{-10}$ W average power, the MCP-II phosphor average power brightness excitance was $\approx 5 \times 10^{-7}$ W, which gives the luminous gain from the MCP-II of approximately 5×10^3 .

The MCP-II was then coupled to the CCD and its video output was measured to ascertain responsivity of the coupled system. The camera was operated at 1.5 ms field period for this data set. The CCD pixel dimensions, the light source area and power, and the measured signal amplitudes per photosite are tabulated in Table 2. Using these values, the sensitivity threshold was calculated to be approximately 2.72×10^{-18} J/photosite required at the MCP-II photocathode to give S/N $\approx 1:1$ from the CCD.

Table 2. Single pixel response of CCD with MCPH

Light source:

Laser period = 10 ms (100 Hz)
 Phased $\approx 350 \mu\text{s}$ past CCD vert sync
 Laser average power $\approx 1 \times 10^{-10}\text{W}$
 532 nm, 10 ns FWHM, 16 mm^2 area spot

MCPH:

Gate width = 40 ns FWHM
 P-20 persistence $\approx 4 \text{ ms}$ (90% of total light)
 Phosphor average power $\approx 5.0 \pm 1 \times 10^{-7}\text{W}$ (from the $1 \times 10^{-10}\text{W}$ incident on the photocathode)
 MCP gain = maximum
 Luminous gain = 5×10^3

CCD:

Camera period = 1.5 ms (interlaced, 50 Mhz pixel rate)
 Integrate period $\approx 1.15 \text{ ms}$ ($1.5 \text{ ms} - 350 \mu\text{s}$)
 Area illuminated = 16 mm^2
 Pixel area $1080 \mu\text{m}$
 Photosite area/pixel area $\approx 20\%$
 Pixels illuminated $\approx 14,815$
 Integrated phosphor average power/pixel $\approx 33.5 \times 10^{-12}\text{W}^*$
 Equivalent laser average power/pixel $\approx 6.7 \times 10^{-15}\text{W}$ (from 5×10^3 MCPH gain)
 Equivalent laser average power/photosite $\approx 1.36 \times 10^{-15}\text{W}$
 Equivalent laser energy/photosite $\approx 1.36 \times 10^{-17}\text{J}$
 Equivalent laser peak power/photosite $\approx 1.36 \times 10^{-9}\text{W}$
 CCD signal $\approx 25 \text{ mV}$ peak
 CCD noise $\approx 5 \text{ mV}$ peak-to-peak
 CCD S/N $\approx 5:1$
 Sensitivity threshold $\approx 2.72 \times 10^{-10}\text{W/photosite}$ (peak power or power per pulse)
 $\approx 2.72 \times 10^{-18} \text{ J/photosite}$
 $\approx 1.25 \times 10^{-12} \text{ J/cm}^2$

*The percent of total P-20 light contained within the 1.15 ms integration interval of the CCD is uncertain and was not quantified for this experiment.

**It should be noted that the MCPH gate width of 40 ns and the camera field period of 1.5 ms do not show up in any of the calculations because the laser period of 10 ms assures that a single pulse occurs only once per gate per field.

For comparison, the MCPH gain was calculated using the calculated single-pixel threshold irradiance for the CCD without the MCPH and the calculated single-pixel threshold irradiance for the CCD coupled with the MCPH. The MCPH gain is equal to the threshold sensitivity of the CCD alone divided by the threshold sensitivity of the coupled MCPH/CCD. This is $2.04 \times 10^{-14}\text{J}$ divided by $2.72 \times 10^{-18}\text{J}$ which gives 7.5×10^3 for gain from the MCPH.

This compares reasonably well with the 5×10^3 gain measured for the MCP-II itself, considering the complexity of the experiments and uncertainties associated with precise area-wise MCP-II-to-CCD coupling (some damaged area of the MCP-II could erroneously calculate as losses in phosphor light), and effects from the ≈ 1.15 ms integration time for the CCD-222 versus the MCP-II's phosphor persistence of ≈ 4 ms. The quantum efficiency (QE) of the CCD at the MCP-II phosphor wavelength versus the QE at the laser wavelength were also assumed equal, which is an oversimplification for convenience purposes. This also compares well with our previous measurements where we indicate MCP-II saturation at ≈ 100 to 200 nJ/cm². Here, the MCP-II/CCD photosite threshold level signal was ≈ 1.25 pJ/cm². Estimating dynamic range $\approx 100/1$ to $200/1$, coupled with MCP-II gain of $\approx 5 \times 10^3$, and MCP-II photocathode QE of $\approx 10\%$, gives 100 nJ/cm² at saturation.

2.4 Coupled system cascaded/MCP-II response for photon-limited flux

This experiment was designed to test sensitivity of several cascaded double and triple stage MCP-II combinations coupled to a PbO FPS vidicon. The light flux was emission from a plastic scintillator fluor Bicron BC430, when irradiated with 14 MeV neutrons. The BC430 emission spectra has three prominent peaks ≈ 50 nm wide at 350 nm, at 450 nm, with a major peak at 560 nm. The light level from the BC430 in the experiment geometry produced essentially photon-limited flux incident on the MCP-II photocathode. The absolute power was not measured here because these tests involved measuring relative responsivities of the various combinations, illuminated in this manner.

When evaluating intensifiers in essentially photon-limited situations, the intensifier's MCP gain is related to its pulse height distribution^{2,3} characteristic. Individual photoelectrons are amplified by different amounts by the MCP, depending upon their angle of entrance to the MCP capillaries. Those which enter at shallow angles strike the wall well into the capillary and have fewer bounces to create secondary electrons than photoelectrons that enter at steeper angles. The resulting spread in secondary emission is the pulse height distribution which illustrates the variance in gain because of the statistical nature of the multiplication process in this (photon-limited, i.e., single or a few photoelectrons) mode of operation.

Photocathodes evaluated included S-20, S-25, and super generation II S-20. The MCP-IIs with the best QE at 560 nm were selected for the first stage. These were either Philips XX1610 or DEP XX1450 intensifiers with super generation II S-20 photocathodes. The second stages were intensifiers with best S-20/S-25 response at the P-20 emission wavelength of the super generation II MCP-IIs. For both stages the MCP-IIs with lowest EBI and highest MCP gain were selected.

The highest responsivity with the best signal-to-noise ratio and the least peak-to-peak dark current was obtained with a super generation II MCP-II fiber coupled to a double plate MCP-II. One such combination is shown in Fig. 15. The video signals are shown in Fig. 16. It is important to stress that gain is not the principal requirement, rather, high responsivity, low noise, and the most consistent gain behavior from the MCP are dominant. This requires the use of the highest QE photocathode in a single MCP intensifier for the first stage (double plate MCPs have poorer pulse height distribution, therefore potentially larger variance in gain^{2,3}), and a double plate MCP-II for the second stage (double plate MCPs provide the highest gain for a given background noise due to fewer coupling losses as compared to a cascaded pair of single MCP intensifiers).

3. HYBRID IMAGE INTENSIFIER MEASUREMENTS

A hybrid intensifier, designated the "40/30 grid-gated electrostatic-focused intensifier," was evaluated for its responsivity, optical gain, and gain as a function of the kinetic energy (in the 3 KV range) of photoelectrons incident on its MCP. The interest in accelerating potentials of a few KV is because this type of electrostatic-focused intensifier design usually employs a voltage of this magnitude in this section of the tube. This is in contrast to proximity-focused intensifiers which use a few hundred volts between the photocathode and the MCP input.

The total MCP gain dependency on the incident primary photoelectron energy has been estimated^{3,10} for primaries in the 100 to 700 volt range, but not for the KV range. Estimates are based upon the gain effect from the first impact, i.e., "first dynode" gain for the MCP. The "first dynode" gain, σ_1 , is defined³ as $\sigma_1 = [(V_i/V_c) + (V_m/20V_c)]^{1/2}$ where V_i is the voltage through which the incident primary electron is accelerated (at impact), V_m is the voltage across the MCP, and V_c is the "first cross-over potential" (22V for these devices) where the secondary emission ratio is unity, and the quantity of 20 in the second denominator is the estimated number of dynode impacts (wall bounces that the electron packet makes) for the full length of the MCP. This gain equation was derived (and holds) for voltages where V_m ($\approx$ 600 to 1000 volts) and is larger than V_i ($\approx$ 100 to 200 volts). Secondary emission curves¹⁰ appear to peak for V_i approximately 300 volts with a broad peak to $\approx$ 700 volts with a fairly flat response or slight decline in gain. However, we find no references that address the question of primary electrons accelerated to a few KV prior to impacting the MCP.

The intensifier, designed by Los Alamos National Laboratory and manufactured by Photek Limited of the UK, is based upon our previous grid-gated Silicon-Intensified-Target (SIT) FPS vidicon⁹ designed jointly by LANL and GE Co. The design utilizes electrostatic focus for high resolution and incorporates a high pitch grid/mesh $\approx$ 50 mil from the photocathode for fast shuttering. The intensifier shown in Fig. 17 has a 40 mm S-20 photocathode, demagnifying electron optics $\approx$ 1.25:1 which relay the image to a 30 mm MCP which is then accelerated onto a 30 mm P-20 or P-43 phosphor.

The test setup (Fig. 18) used a TV Optoliner with $\approx$ 3:1 demagnification. A pinhole of $\approx$ 3.18 mm (1/8") diameter was used to provide a virtual image of 1.06 mm diameter at the intensifier's focal plane. The optical power was measured at this location using the Optronic 730A radiometer. The intensifier was then illuminated using CW white light and its phosphor emission was measured with the radiometer using a 1:1 relay lens with $\approx$ 6.2% collection efficiency from solid angle of $\approx$ 0.39 rad². The measurement units were in terms of average power for both input and output. Solid angle calculations were verified by placing the relay lens at the MCP-II focal plane and measuring the Optoliner flux with the radiometer. This indicated a 5.8% collection efficiency.

The input flux was varied by using ND filters of optical density 0, 1.0 and 1.5, and the intensifier's output was measured at three different input voltages to the MCP: 1.3 kV, 2.3 kV, and 3.3 kV. The other two intensifier voltages which control gain, i.e. the voltage across the MCP and the voltage from MCP to phosphor were held constant at 900 V and 5.5 kV, respectively, for these tests. Analysis of the data shown in Table 3 indicate gain dependence of $\approx$ 10x/kV of incident photoelectron acceleration voltage. The data for 1.3 kV acceleration voltage were too close to the noise level of the intensifier's EBI, especially at low input illumination, so they were not used.

The input powers measured for the three ND filters are $1.32 \times 10^{-6} \text{ W}$ (ND0), $1.21 \times 10^{-7} \text{ W}$ (ND 1.0), and $0.49 \times 10^{-7} \text{ W}$ (ND 1.5). These were for an illuminated area $\approx 0.88 \text{ mm}^2$. Referring to Table 3, the $1.21 \times 10^{-7} \text{ W}$ input power was normalized to $1.39 \times 10^{-5} \text{ W/cm}^2$. The output power measured from this input was similarly normalized for the area after first normalizing for the intensifier's demagnification, and correcting for "dark" intensifier noise or EBI ($\approx 1.1 \times 10^{-9} \text{ W}$ with the intensifier active but with input light off). The data were then corrected for solid angle and entered in Table 3.

By comparison with the high strip current MCP-II intensifier, this intensifier's output was $\approx 79\%$ for $\approx 40\%$ more input power, or $\approx 57\%$ as sensitive. This measurement, however was for CW white light input with the intensifier not gated which could place a higher demand on its MCP than for the MCP-II which was gated and strobed with 10 ns FWHM pulses at either 100 Hz or single pulse. Note that for similar high level inputs such as in Table 3, the optical gain is $\approx 6\times$ as compared with $\approx 10\times$ for the high strip current MCP-II, as indicated in Figs. 3, 4, and 5. This low gain is expected as the MCP nears saturation, but the high strip current MCP should have larger dynamic range, therefore more gain at this end of its transfer curve. There was no attempt to compare gains obtainable from either intensifier at lower gains for comparison of their respective responsivities.

Table 3. Gain measurements for the Photek 40/30-mm hybrid grid-gated intensifier as function of photoelectron accelerating voltage from photocathode to MCP input with input irradiance of $\approx 1.39 \times 10^{-5} \text{ W/cm}^2$.

<u>PC</u>	<u>Gate</u>	<u>Focus</u>	<u>MCPin</u>	<u>MCPout</u>	<u>Phosphor</u>	<u>Output Power</u>
-40V	OV	50V	2.4KV	3.3KV	8.8KV	$7.4 \times 10^{-6} \text{ W/Cm}^2$
-40V	OV	50V	3.4KV	4.3KV	9.8KV	$7.9 \times 10^{-5} \text{ W/Cm}^2$

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Fig. 1. Responsivity curves for several ITT image intensifiers. The dashed line is included to illustrate their relative sensitivities.

Fig. 3. Expanded portion of saturated region for one transfer curve of Fig. 2 to back up measurements from video with radiometer data.

Fig. 5. Transfer curve of output versus input power for high strip current MCP II operated at 100Hz gate and laser rate.

Fig. 2. Increases in MCP II phosphor brightness from increasing phosphor high voltage for extension of dynamic range.

Fig. 4. Responsivity measurement set-up for medium repetition rate (100Hz) studies for standard and high strip current MCP IIs.

Fig. 6. Transfer curve of Fig. 5 depicting MCP II optical gain as function of input irradiance.

Fig. 7. Responsivity measurement setup for 100-500 Hz repetition rates in burst mode to examine single pulse-to-multiple pulse transition.

Fig. 9. Phosphor brightness for consecutive gates within a burst for the standard strip current MCP.

Fig. 11. Standard MCP phosphor output versus input intensity for pulses #1 and #5 within the burst for two MCP voltages.

Fig. 8. Wavetrains depicting time phasing among the components used for measuring phosphor brightness in consecutive gates, within the burst.

Fig. 10. Phosphor brightness for consecutive gates within a burst for the high strip current MCP.

Fig. 12. Raw PMT data obtained from standard MCP for the first and fifth gates at two input light levels.

Fig. 13. Normalized optical gain for standard and high strip current MCPs.

Fig. 14. Histogram of individual CCD photosite signals from illumination thru pinhole array (inset).

Fig. 15. Test setup for weak flux photon-limited MCP II signal-to-noise characterization.

Fig. 16. Typical video waveform (experiment of Fig. 15), depicting signal mean and variance.

Fig. 17. The Los Alamos National Laboratory/Photek Ltd. "40/30" hybrid image intensifier.

Fig. 18. Test setup for the "40/30" hybrid image intensifier responsivity measurements.