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TITLE: QUANTITATIVE COMPARISON OF DIFFERENT MICROCHANNEL PLATE IMAGE INTENSIFIER TUBES AS NANOSECOND LIGHT SHUTTERS IN COUPLED VIDEO SYSTEMS

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Quantitative comparison of different microchannel plate image intensifier tubes as nanosecond light shutters in coupled video systems

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Abstract

A comparison of different manufacturers' microchannel plate image intensifier tubes (MCPTs) in coupled video systems is presented. Comparative performances in the areas of optical gating speed, resolution, gain, and phosphor efficiency are discussed. Relative sensitivities for various combinations of coupled MCPT/TV imager systems including P-20 and P-20R phosphors cascaded to FPS (focus projection and scan) electrostatic vidicons with silicon or Sb_2S_3 targets and CID (charge injection devices) solid state imagers are included.

Introduction

Optical shuttering properties of nanosecond gated MCPTs and SITVs (Silicon-Intensified-Target Vidicons) have been measured and reported in our previous works.¹⁻⁵ In order to identify performance of standard night vision goggle Generation II 18-mm-diam MCPTs (with S-20 photocathodes and P-20 phosphors) from various manufacturers, we initially evaluated samples from ITT, Varo, Delli Delti, and RTC-Phillips. Later, we evaluated a larger lot (15 units) from Delli Delti. Results from the earliest of those evaluations are reported in this paper. We also report on the merits of MCPTs with P-20 (green) vs P-20R (red) when coupled to various TV sensors including Sb_2S_3 or silicon vidicons and CID imagers.

Initial MCPT comparisons

Most of our measurements have been on ITT units which historically were used exclusively in our imaging experiments. Therefore, responses of new devices are normalized to the F4111 response. Initial comparisons, reported earlier,⁵ are briefly summarized.

The shortest gating period of a typical "double undercoated" (photocathode underlay or substrate) ITT F4111 18-mm-diameter MCPT was compared with similar sized MCPTs from Varo (Model 5772-II), Delli Delti (Model 8306), and RTC-Phillips (XX1410/SP 21120-210 II). Using the criteria that a fully open shutter is the condition where uniform optical transmission occurs over the total photocathode area, the "narrowest" gate widths are in Table 1. The times required for each MCPT to achieve approximately equal resolution or CTF (contrast-transfer-function) at 4.5 lp/mm are also found in Table 1.

Table 1. Optical gate speed and gated resolution.

MCPT	<u>GATE WIDTH (ns)</u>		CTF(% OF DC response)
	NARROWEST 4.5lp/mm		
ITT	2.0"	2.5-5.4	40-60
RTC-PHILLIPS	1.0	2.7-4.8	55-60
DELLI DELTI	2.9	3.7-5.0	35-40
VARO	2.1	2.7- <u>5.0</u>	<u>40-50</u>

The relative sensitivities of the MCPTs were compared by coupling to a silicon target FPS (Focus projection and scan) vidicon for readout. Neutral density filter were used to attenuate the light until the same video amplitudes were recorded from all MCPTs. The results are in Table 2. The relative opacity to CW white light was also measured and tabulated in Table 3.

It should be noted that the various manufacturers used different transmissivity and conductivity photocathode undercoatings which we believe accounts for the observed differences in gate speed, sensitivity, and opacity. For example, the RTC-Phillips MCPT gated the fastest, was the least sensitive but the most opaque; all three responses are as expected from heavy undercoating, that promotes (1) higher gate speed (from higher gate conductivity), (2) less optical transmission (hence higher opacity), and (3) lower sensitivity (from reduced flux reaching the photocathode).

Table 2. Conditions for approximately equal optical sensitivity at 610 nm for optical gates in the indicated ranges.

MCPT	GATE WIDTH RANGE (NS)	EQUALIZING FILTER (ND)	NORMALIZED (ITT = 1)
ITT	2.0-5.4	2.2	1.0
RTC-PHILLIPS	1.0-2.0	0.6	0.025
DELLI DELTI	2.9-4.3	1.9	0.5
VARO	2.1-3.7	0.9	0.05

Table 3. Opacity measurements, performed using a CW incandescent source.

MCPT	AVERAGE OPTICAL POWER ($\mu\text{W}/\text{cm}^2$)		ATTENUATION
	INPUT	OUTPUT	
ITT	1.27×10^3	2.1×10^{-3}	6.1×10^5
RTC-PHILLIPS	1.35×10^3	4.0×10^{-5}	3.4×10^7
DELLI DELTI	1.28×10^3	2.5×10^{-4}	5.1×10^6
VARO	1.30×10^3	2.1×10^{-4}	6.2×10^6

Table 4. Optical gate range for typical Delli Delti MCPTs.

MCPT	REVERSE BIAS	OFF-ON-OFF TIME	FULLY ON GATE TIME	TIME TO CENTER OF GATE
4.2S.3.7	11.4V	3.5ns	1.6ns	3.0ns
4.48.3.12	10.8V	4.0ns	0.7ns	2.5ns
4.48.3.15	8.1V	5.0ns	1.9ns	3.5ns
5.6.5.17	5.8V	5.0ns	1.5ns	3.5ns
5.10.5.22	11.8V	6.0ns	1.7ns	3.5ns

Delti delli MCPTs

The average off-on-off gating times for five conventional Delli Delti MCPTs was measured to be about 5.1ns. Table 4 shows the relative performances of the tested MCPTs.

The input light is a 20ps full width at half maximum (FWHM) pulse at 570nm. The response of each MCP to this input is characterized by digitizing its output profile (256 pixels by 256 lines) at 100ps or 500ps intervals - depending on the MCP - by stepping the gate pulse (150V, 200ps FWHM) across the light pulse.

Some gain shading was observed with several MCPTs. A typical example is shown in the shutter sequence of Fig. 1. We attribute this to non-uniform deposition of the S-20 or undercoating during manufacture. The peak intensity near the center of the photocathode is from non-uniform laser light. The resolution for most of this lot of MCPTs was from 30 to 40% CTF at 4.5 lp/mm.

Comparison of P-20 and P-20R phosphors in coupled MCPT intensifiers

The sensitivity of FPE S₁S₂ and silicon target vidicons when coupled to MCP intensifiers with either P-20 (560nm pk) or P-20 (675nm pk) phosphors was measured. The reason for these tests was prompted because of the better spectral matching between silicon and P-20R. Each intensifier was operated at its own suggested bias voltages for equal 10K luminous gain as measured with a photometer and CW white light. The two units selected were 25-mm-diam ITT model F4112 SN 14-885/1 (P-20R) and SN 14-451/2 (P-20).

Before coupling to the vidicons, the MCPT phosphor emission was measured with an Optronics 730A radiometer. These readings are compared with the measured input power (Table 5) in an attempt to establish absolute optical gain through both MCPTs. The input wavelength was varied between white, blue (400 $\pm$ 5nm), and green (530 $\pm$ 5nm) to identify differences in gain from different spectral sensitivities for the two photocathodes. Because the unfiltered Xenon flash is white light and the S-20 photocathodes have a range roughly from less than 350nm to greater than 900nm, the gain will be much less for white light than for either blue or green. The observed gain ratios for the two MCPTs for different phosphor accelerating voltages are in Table 6.

Fig 1. Shutter sequence of Delli Delti MCPT.

Table 5. Radiometer measurements of input vs output optical power for two MCPT intensifiers.

Light Source	Input (Watts/cm ²)	Output (Watts/cm ²)	Notes
White	2.75×10^{-9}	$.864 \times 10^{-7}$	5KV on Phos.
White	2.75×10^{-9}	1.42×10^{-7}	6KV on Phos.
Blue	2.20×10^{-9}	4.58×10^{-7}	5KV on Phos.
Blue	2.20×10^{-9}	7.65×10^{-7}	6KV on Phos.
Green	3.09×10^{-9}	3.50×10^{-7}	5KV on Phos.
Green	3.09×10^{-9}	5.81×10^{-7}	6KV on Phos.

MCP #14-885/1 (P-20R); $V_{cp} = 735V$, $V_{phos} = 4865V$, $V_{pc} = 175V$

White	2.75×10^{-9}	1.43×10^{-7}	5KV on Phos.
White	2.75×10^{-9}	2.19×10^{-7}	6KV on Phos.
Green	3.09×10^{-9}	7.62×10^{-7}	5KV on Phos.
Green	3.09×10^{-9}	1.15×10^{-6}	6KV on Phos.
Green	3.09×10^{-9}	1.57×10^{-6}	7KV on Phos.
Green	3.09×10^{-9}	2.09×10^{-6}	8KV on Phos.
Blue	2.51×10^{-9}	7.43×10^{-7}	5KV on Phos.
Blue	2.51×10^{-9}	1.12×10^{-6}	6KV on Phos.
Blue	2.51×10^{-9}	1.53×10^{-6}	7KV on Phos.
Blue	2.51×10^{-9}	2.03×10^{-6}	8KV on Phos.

Table 6. Intensifier gain (output/input) ratios for various input wavelengths.

	HV		HV			
	5KV	6KV	5KV	6KV	7KV	8KV
White	31	52	52	80	--	--
Blue	208	348	297	446	609	808
Green	113	188	247	372	508	676

MCPT/P-20

MCPT/P-20R

The higher gain in the blue for both MCPTs is due to their higher quantum efficiency at this wavelength. The measured absolute gain values at phosphor voltages of 5KV are $\approx 200\times$ to $300\times$ for blue light. Considering S-20 quantum efficiency of $\approx 10\%$ and MCP gain of 1000, additional gains of 2 to 3 from the phosphor could give these results. Our earlier measurements of Sb_2S_3 or Si blue sensitivity along and when coupled to an MCP showed increased gain of $500\times$ to $1500\times$ with $\approx 1000\times$ considered typical average. If we recognize that these photoconductors have quantum efficiencies for blue light of the order of 25% , then coupled gains of $800\times$ to $1200\times$ seem reasonable.

The MCP intensifiers were then individually coupled to (1) Sb_2S_3 vidicon, (2) Si vidicon, (3) CID solid state imager. The same input light intensity was imaged onto both MCPTs and the video from each sensor was measured. Two things were observed from these tests: (1) Sb_2S_3 gives 3 to 5 times larger signals from P-20 than from P-20R, and (2) both silicon sensors give 2 to 3 times as large signals from P-20R as from P-20.

The above reflect results possible from operating the intensifiers per manufacture-suggested biases as indicated earlier. However, we also wanted to see the actual gain difference when both intensifiers were operated with the identical biases across the photocathode, MCP and phosphor. The MCPT with P-20R was constructed slightly different in the MCP-to-phosphor region to allow higher accelerating voltages. Otherwise, the units were identical. The increased phosphor spacing should not affect gain in this region because for the same kinetic energy for both units before impacting the phosphor.

The raw data for these tests are in Fig. 2. The intensifiers were operated at the values used for the P-20 intensifier: $V_{pc} = 175\text{V}$, $V_{cp} = 680\text{V}$, $P_{phos} = 4920\text{V}$. The video amplitudes for the P-20 unit were slightly higher (they should have repeated the values obtained from the first tests) apparently because of slightly different operating and imaging conditions. In any case, it is the relative responses (taken at the same time) of the TV sensors to the two phosphors that is of interest.

The results are interesting. The Sb_2S_3 response to P-20 now appears to be only 2 to 3 times that for P-20R. The silicon and CID sensors give nearly the same signal (more from P-20R for green input but less from P-20R for blue input) from either phosphor.

In summary, the better spectral matching between the silicon and P-20R doesn't appear to give substantially increased sensitivity, probably because of less efficient conversion (radiated watts/excitation watts) for P-20R than for P-20. Additional gain provided by larger MCP-to-phosphor gaps with larger possible accelerating voltages should give more output from either phosphor. As for Sb_2S_3 vidicons, the P-20 gives the best spectral match. Commercial data also indicates that P-20 efficiency ($\approx 11\%$) is among the highest. No data is currently available for P-20R for comparison.

These measurements may be inconclusive for a general statement of relative performance from P-20 and P-20R. More samples should be characterized. However, based on this limited sampling, we recommend continued use of P-20 for either Sb_2S_3 or silicon-based imagers.

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14 - 451/2 + Si Vidicon
White Light, P-20

14 - 451/2 + Si Vidicon
Blue Light, P-20

14 - 451/2 + Si Vidicon
Green Light, P-20

14 - 451/2 + Sb₂S₃ Vidicon
White Light, P-20

14 - 451/2 + Sb₂S₃ Vidicon
Blue Light, P-20

14 - 451/2 + Sb₂S₃ Vidicon
Green Light, P-20

14 - 451/2 + CID
White Light, P-20

14 - 451/2 + CID
Blue Light, P-20

14 - 451/2 + CID
Green Light, P-20

14 - 885/1 + CID
Blue Light, P-20R

14 - 885/1 + CID
White Light, P-20R

14 - 885/1 + CID
Green Light, P-20R

14 - 885/1 + Si Vidicon
White Light, P-20R

14 - 885/1 + Si Vidicon
Blue Light, P-20R

14 - 885/1 + Si Vidicon
Green Light, P-20R

14 - 885/1 + Sb₂S₃ Vidicon
White Light, P-20R

14 - 885/1 + Sb₂S₃ Vidicon
Blue Light, P-20R

14 - 885/1 + Sb₂S₃ Vidicon
Green Light, P-20R

Fig. 2. Raw video data for the three imagers.

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