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TITLE: STRIPLINE MICROCHANNEL PLATE IMAGE INTENSIFIER TUBES (MCPTS) FOR
NANOSECOND OPTICAL GATING APPLICATIONS

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Stripline microchannel plate image intensifier tubes (MCPTS) for nanosecond optical gating applications

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Abstract

Shuttering characteristics of low impedance stripline geometry microchannel plate image intensifier tubes (MCPTS) with 50% transmissive nickel undercoated S-20 photocathodes are discussed. Iris-free shutter sequences with 50 to 75 micron resolution at optical gate times of 500ps to 2ns were measured for typical samples from two manufacturers. Shutter sequences clearly showing gate pulse propagation velocities for this MCPT design when externally driven by impedance matched circuitry are contrasted with non-directional sequences obtained from unmatched coupling of the gate pulse.

Introduction

An improved design for subnanosecond gating of proximity-focused microchannel plate image intensifier tubes (MCPTS) features stripline geometry for impedance matching to external gate generators. The new design is a modified version of the Generation II 18-mm-diameter wafer tube used for night vision goggles. For economic reasons, minimal changes in the standard design were incorporated.

For this design, low contact resistance to the photocathode and microchannel plate surfaces are provided by replacing the standard single wire connections with flat wide low-inductance tabs. This provides a large area for electrical contact between the gate electrodes and external pulse generators for the high conductivity required for efficient coupling. A highly conductive nickel layer (50% optical transmission) is evaporated on the input window prior to photocathode (S-20) deposition to provide a low sheet resistance plate ($\sim 90 \Omega$ per square) for efficient pulse transmission across the photocathode. Similarly, gold flashing on the microchannel plate input surface provides $\sim 35 \Omega$ per square sheet resistance for an effective ground plane for the pulse reference.

Because of the large perimeter capacitance due to the geometry of Generation II intensifiers the perimeter structure was modified by increasing the spacing between the photocathode and microchannel plate external connections. Although a more efficient lower capacitance gate structure was obtained (more of the charge in the gate pulse is available to charge the photocathode-to-microchannel plate gap capacitance), this resulted in increased impedance at the perimeter.

Gate interface design

In our application, the image intensifiers are shuttered off by reverse biasing the photocathode with respect to the microchannel plate input which prevents photoemission from reaching the electron multiplier. For shuttering on, a forward-biasing gate pulse is applied. For one standard design, the ITT model F4111, the gate interface has been modeled¹ as a distributed RC network with radial transmission line characteristics. This model predicts a shuttering sequence which exhibits iris behavior during the turn-on phase with the photocathode gating from the perimeter inward as the gate voltage pulse propagates radially inward. Our earliest experimental work^{2,3,4} with the Generation II design MCPTS verified the iris characteristic. More recently we reported⁵ lateral or transverse as well as radial wave propagation from prototype stripline MCPTS of various geometries.

With the observation of lateral propagation, we believe that the radial model does not fully describe the actual behavior although it accurately predicts the gate voltage propagation speed of some stripline MCPTS⁵. The lower sheet and contact resistances allow the stripline MCPT gate interface to function as a continuation or extension of external microstrip transmission lines used for gate pulse injection. This would result in the lateral propagation observed in experiment.

Fig. 1. Cross sectional view of MCPT. Region A is the photocathode-to-channel plate gap that is electrically biased for shuttering. Region B is the perimeter structure.

Referring to Figure 1, region A, the photocathode-to-microchannel plate gap appears as two parallel plates of 17-mm-diam., 10 mils separation, and a dielectric constant of unity.

For this geometry, where the plate separation is equal to or less than 10% of the plate width, the impedance can be approximated by⁶:

$$Z_0 = 377 \left(\frac{W}{L} \right) \left(\frac{1}{\epsilon} \right)^{1/2} \quad (1)$$

where W is the distance between the two plates, L is the diameter of the plates, and ϵ is the di-electric constant of the material between the plates. Using the appropriate values of W, L, and ϵ in region A, $Z_0 \sim 6.2\Omega$.

Region B is more complicated because of the conical taper on the input glass window, and the fact that in this region there are two di-electric constants, 1 for vacuum, and 8.8 for the ceramic spacers used at the perimeter. In addition, there are several different conductors in this region: the inconel coating which is deposited on the taper and on the two adjacent flat surfaces to provide electrical contact for the nickel underlayer and the copper perimeter photocathode ring and tabs; the microchannel plate connections which are gold across the surface, stainless steel for the perimeter ring, and Kovar tabs at the perimeter.

Assume, that when viewed from the perimeter, the photocathode and microchannel plate rings appear as plates of 1.22-in-diam. separated by 80 mils of ceramic spacer. This geometry results in $Z_0 \sim 8.4\Omega$ near the perimeter for region B. However, this analysis is correct only if the gate pulse arrives simultaneously everywhere along the perimeter. For practical MCPTs, the pulse reaches the taper sooner near the tab center (~25ps) than it does 90 degrees around the perimeter (from ~50ps to 100ps later) where transit times are tab-width dependant. Therefore, for approximately 75ps to 125ps the gate pulse sees a complex time-dependent impedance. Because the duration is relatively short compared to anticipated gate widths (~700ps to 2ns) the mismatch is considered trivial although a better match is essential for shorter gate times.

The external transmission line is of microstrip design. For this type of transmission line, the impedance can be estimated from the family of curves shown in Figure 2 (adapted from Ref. 2). Our microstrips use base material of 32-mils thick cuclad #250GT, Teflon/glass laminate manufactured by 3M corporation. This material has di-electric constant of 2.55 at GHz frequencies. A microstrip of 6 to 8 Ω impedance corresponds to W/H ratio of 30/1 as shown in Figure 2. A tapered microstrip is used to gradually increase the

Fig. 2. Microstrip impedances for various di-electrics and W/H ratios. The dashed line plot is for the Teflon/glass laminate used in our transmission lines.

impedance to 50Ω (W/H-3/1) for matching with an external gate generator of 50Ω source impedance. This results in a microstrip with 0.9-in. width at the MCPT connection and 0.1 in. at the generator end. The transmission line is symmetric on either side of the MCPT, allowing for 50Ω termination at the exit (opposite) end of the microstrip.

Electrical and optical measurements

Time domain reflectometry (TDR) measurements of the microstrips verified the impedance changes along the strip as shown in Figure 3. With the MCPT in place, some dispersion of the gate pulse (~ 550 ps FWHM) was noted with wider FWHM leaving the MCPT (~ 898 ps) than entering it (~ 586 ps) as shown in Figure 4. However, the improvement is significant when compared with pulse dispersion noted (≥ 2 ns) for the same MCPT when in non-microstrip configuration. It is obvious, that if subnanosecond gate times are required, these stripline MCPTS must be driven in some transmission line geometry.

a) Open termination at input to microstrip.

b) Underterminated microstrip

c) Terminated microstrip

Fig. 3. TDR measurements taken for the dual impedance microstrip used to impedance match the 6-8 Ω MCPT with external 50Ω generators. Part "a" shows intentional open circuit to locate the start of the microstrip, "b" shows the unterminated microstrip with the 50Ω , 6.8 Ω , and open circuit components. And "c" shows the microstrip terminated with distributed (ten parallel resistors) 6.8 Ω resistance.

a) entering MCPT

b) leaving MCPT

Fig. 4. Pulse dispersion from insertion of a stripline MCPT in the microstrip.

The shuttering characteristics of ITT stripline MCPT SN 14/498/1 were measured in two configurations. First, the MCPT was gated in our non-microstrip package normally used for standard Generation II MCPTS. The optical gate shutter sequence shown in Figure 5 is characterized by essentially iris-free shuttering throughout the sequence. As indicated in the figure, the total photocathode surface turns on in ~ 200 ps and turns off in ~ 100 ps. However, the total optical gate time is long, approximately 3.3 ns for this sequence. The TV scan lines in Figure 5 indicate the relative gain throughout the sequence. When normalized to the signal amplitude for the first "on" frame, t_0 , the signal peaks at $t_0 + 600$ ps as shown in Table 1.

Next, the same MCPT was gated in the microstrip circuit. That shutter sequence (Figure 6) shows the lateral propagation characteristic with the area adjacent to the gate input turning on first. The area next to the gate exit turns off last. This sequence was obtained using a 1.2 ns base width electrical pulse. The 1.3 ns total optical gate therefore indicates excellent correlation between the two.

Fig. 5. Shutter sequence for stripline MCPT in non-microstrip configuration. The outer circle is the vidicon target and the inner circle is the MCPT photocathode. The dashed lines indicate pedestal from which amplitudes are read. The titles are coded labels for convenience in reducing CPU file data.

Table 1. Gain vs Time for Optical Gate Sequence for ITT SN 14/498/1 Stripline MCPT.

$\Delta t(\text{ns})$	gain
t_0	x
0.2	12x
0.4	32x
0.6	34x
1.1	28x
2.0	24x
2.5	24x
3.0	11x
3.2	11x
3.3	0

Fig. 6. Shutter sequence for stripline MCPT in microstrip configuration. Here, the MCPT was intentionally coupled off-center with respect to the vidicon target for easier observation of MCPT performance.

The propagation time from gate input to the center of this MCPT is $\sim 100\text{ps}$. The longer time from center-to-gate exit ($< 300\text{ps}$) is attributed to standing wave rather than traveling wave character because of MCPT dimensions. The initial propagation time, however, is shorter than the time predicted by the radial model which is given by

$$t = T(R_0 C_1 a^2) \quad (2)$$

where R_0 is the photocathode substrate resistance per unit area, c is the capacitance per unit area of the photocathode to MCP gap, a is the radius of the gated surface, and is equal to the radius r of the photocathode when the gate voltage reaches the center of photocathode, t is the universal time parameter which describes the voltage amplitude V/V_{max} (as a fraction of the applied gate voltage V_{max}) vs the radius traversed a/r (as a fraction of the total radius r). For $T = \text{unity}$, the gate voltage at the center of the photocathode is equal to the applied gate voltage. For that case, using measured values of sheet resistance ($\sim 94\Omega/\text{sq}$ for 50% transmissive nickel, calculated gate capacitance of $\sim 4 \times 10^{-14} \text{ F/mm}^2$, and $a = 9 \text{ mm}$ for an 18-mm-diameter photocathode, we obtain predicted value of $t = 305\text{ps}$. This is in close agreement with the $\sim 300\text{ps}$ measured for t during turn-off, but is much slower than the observed speed during turn-on.

Fig. 7. 500ps shutter sequence for stripline MCPT showing resolution achieved at short gate times. The pattern was a standard Air Force pattern.

The shortest optical gate for ITT MCPT SN 14498/5 is shown in Figure 7. A 500ps basewidth pulse was used to gate the MCPT in microstrip configuration. The resolution for each time during the sequence is also shown. Analysis of the CTF obtained from scanning the resolution data show approximately 50% at 4 lp/mm and 10% at 8 lp/mm.

Similar shuttering patterns and gate times were measured for a total of six ITT and two RTC-Phillips stripline MCPTs. We believe that this design represents an economical modification to standard Generation II MCPTs which produces a reliable subnanosecond optical shutter.

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