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OF MICROCHANNEL PLATE IMAGE-INTENSIFIERS"

AUTHOR(S): Arvid Lundy, Joseph R. Parker, James S. Lunsford,
and A. Don Martin

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Avalanche Transistor Pulser for Fast-Gated Operation of Microchannel Plate Image-Intensifiers

Arvid Lundy, Joseph R. Parker, James S. Lunsford, and A. Don Martin
Los Alamos Scientific Laboratory, University of California
Los Alamos, NM 87545

Summary

Transistors operated in the avalanche mode are employed to generate a 1000 volt 10 to 30 nsec wide pulse with < 4 nsec rise and fall times. This pulse is resistively attenuated to ~270 volts and drives the image intensifier tube which is a load of ~200 pf. To reduce stray inductance and capacitance, transistor chips were assembled on a thick-film hybrid substrate. Circuit parameters, operating conditions, and coupling to the microchannel plate image-intensifier (MCP1) tube are described.

To provide dc operating voltages and control of transient voltages on the MCP1 tube a resistance-capacitance network has been developed which (a) places the MCP1 output phosphor at ground, (b) provides programmable gains in "f-stop" steps, and (c) minimizes voltage transients on the MCP1 tube.

Introduction

Fast shuttering of 18 mm "Generation II" microchannel plate image-intensifiers (MCP1) tubes has been employed successfully for several years at Los Alamos. The larger photocathode-to-channel plate capacitance of the 40 mm MCP1 tubes concerned herein inherently lengthens the shutter time. The technique to be described allows gated operation of 40 mm diameter tubes with an "on-time" of 15 nsec or less, a delay of less than 8 nsec between trigger and tube turn-on, and a triggering jitter of less than 200 psec. Mixing techniques allow a single tube to be pulsed at 50 nsec intervals for up to ten consecutive pulses. Shorter "on-times" are possible with 18 mm diameter tubes which have lower photocathode to channel plate capacitance.

The MCP1 tube is a double proximity focusing microchannel plate tube whose gain can be in the thousands while retaining a resolution in excess of 20 line pairs/mm. It is comprised of three sections. The first of these is the photo cathode to channel plate gap, the first proximity focussed section (see Fig. 1). Next is the microchannel plate, a channeled electron multiplier (MCP). The last section is the proximity focussed MCP-to-output phosphor gap. Operation of the tube requires a low voltage across the photo-cathode to MCP gap (180 volts for the ITT Type F-4213 employed in the work described herein), a voltage across the MCP of a few hundred to 1000 volts, and an accelerating voltage of 5000 volts across the MCP to phosphor gap. The gain of the assembly is linearly related to the voltage across the output gap and exponentially related to the voltage across the MCP. In the operation described herein the tube is shuttered off by biasing the input gap with ~90 volts and turned on with an input pulse of ~270 volt. The output phosphor is required to be at ground potential.

Basic Pulsing Requirements

For the particular application (conventional high explosive detonation physics studies) the MCP1

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Fig. 1. Image intensifier tube.

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Fig. 2. Basic charge line pulser.
tube damage in case of pulser malfunction. The multiple pulsing requirement at pulse separations as low as 50 ns dictated multiple pulsers and a mixer. The 10 ns trigger to output jitter requirement, and rise and fall times commensurate with 10 ns wide pulses, suggested avalanche transistor switching. The tube capacitance ($C_1$ in Fig. 1) of 160 to 240 pF indicates that to achieve rise and fall times of less than 5 ns a pulser source impedance of < 10 ohms is required. It was decided to obtain this using resistive attenuation of high voltage pulses in a mixer box located next to the image intensifier tube.

**Avalanche Pulser**

Very little hard data is available on use of modern transistors in the avalanche mode. There are no economical transistors characterized for avalanche service available from United States manufacturers and avalanche switching designs are usually based on experimentation and "folklore". Most transistors will not usefully avalanche. LASL had used Motorola MPSU04 transistors extensively for higher voltage avalanche switching but just prior to this work a manufacturing process change by Motorola rendered the MPSU04's virtually unusable for avalanche mode work. A literature search located several references dealing with avalanche mode circuit design, two references dealing with parallel connection of avalanche transistors for increased current capability, one reference dealing with series connection for higher voltage operation, and three references discussing avalanche sweep and gate generators based on up to twenty 2N3700's connected in series. Numerous papers dealing primarily with low voltage applications of avalanche mode switching have been published by V. P. D'yakonov between 1966 and the present.

References 9-11 and personal communication with L. Coleman led us to try using 2N3700 transistors manufactured by National Semiconductor Corporation. We have not evaluated 2N3700's manufactured by other vendors, but often it is found that avalanche characteristics vary greatly with vendor. Over 90% of the transistors received from National have exhibited satisfactory avalanche characteristics. Earlier experience with MPSU04's in series indicated that the avalanche leakage current may drop (i.e. transistor leakage current decreases), but there doesn't seem to be any effect on triggering stability. The trigger transformer is a transmission-line type made by wrapping 4 turns of 50 ohm #30 AWG wire-wrappable coax (N. L. Gere & Assoc., CN-1214) around a toroidal core (Ferroxcube 3E3A266CT125). The coax shield is used as the primary and the inner conductor as the secondary. The trigger transformer in the string is chosen to minimize voltage stress on the trigger transformer windings although they will withstand the full 3 kV power supply voltage. Reliable triggering is obtained with 4.5 volt pulses although normally 15 volt pulses are used. Delay and jitter are reduced with the higher voltage.

![Fig. 3. Charged line pulser with avalanche transistor switch.](image-url)
To reduce circuit inductance, simplify printed circuit card layout, and hopefully improve rise time the transistors were bought in chip form, epoxied in "lids", and mounted in groups of six on a thick film hybrid substrate. Figure 4 shows three of the hybrid assemblies with the center one unpotted, while the end units are potted with a silastic protective coating. The pin spacing on the units is the same as a standard 16 pin dual-in-line (DIP) IC package although pins are mounted on only one side. (The additional pins are brought out to allow flexibility in triggering and in using the hybrid string in other applications where fewer than six transistors are needed). On the printed circuit card a pin layout identical to that for a 16 pin DIP IC allows plugging in two of the hybrid assemblies to form a 12 transistor avalanche string. This is shown in Fig. 5. (Ten pulser cards are mounted in a single chassis so adjacent pulser cards show in the photo). The upper left-hand corner of the DIP is the pulse output and the upper right hand corner is the charge line connection. Approximately 1 meter of charge line is coiled inside the chassis, as shown, to provide a 10 ns minimum pulse width. The end of the charge line away from the avalanche string, attaches to a rear connector to allow additional charge line length to be attached externally. To minimize the source impedance a 31 ohm, 0.195" diameter coax (Amphenol #21-412) is used for the charge line and for output cables to the mixer box. (Since the impedance of the avalanche switch in the "on" state is approximately 22 ohms, a better match would be to use 50 ohm cable for the charge line. However, because of the need for low source impedance to drive the capacitance load, this mismatch is accepted).

With the parameters given one obtains an output pulse of approximately 1085 volts across a 31 ohm load, corresponding to a current of 33 amperes through the transistors and a voltage drop of 64 volts across each transistor during conduction vs 235 volts in the "off" state. Rise and fall times are approximately 3 ns.

On the pulser chassis an output indicator showing when a given pulser has been triggered is needed - both a front panel LED indicator and a remotely readable data bus indication. Initially we tried to achieve this using TTL Shottky flip-flops. Extreme problems were had with cross-talk between indicators and finally Fairchild F40175 CMOS flip-flops were tried and found to work well. The Fairchild F40175 "D" flip-flop clocks very reliably with 10 ns wide pulses, but 40175's from other vendors that were tried were not fast enough. The circuitry used is shown in the lower right-hand corner of Fig. 5. The coupling transformer used for the indicator circuit and monitor output is a Techtronic 118GA.

Figure 6 shows a bottom view of the chassis with five pulser cards and five charge lines visible. The top view is essentially identical with five additional pulser cards. Top and bottom circuits are separated by two 1/16" thick copper sheets which have a lip bent up at the rear of the chassis. The rear panel connector mounting holes line up with holes in the lips of the copper sheets to provide good connector ground reference. This lip proved absolutely essential to prevent cross talk between pulser cards. A ground plane was used on both sides of the pulser printed circuit cards. The indicator circuit printed circuit cards are mounted just behind the front panel and can be seen at the bottom of Fig. 6. The data bus interface card is visible in the upper right hand corner of Fig. 6. This card uses standard TTL-LS logic without any memory elements and interrogation of the unit are not done during pulsing. Once the
Fig. 7. Rear view of pulser chassis.

copper plates with lips were added, there have been no problems with the generated 1000 volt, 35 ampere pulses affecting the low voltage logic. Figure 7 shows the rear panel. Each pulser circuit has four associated connectors - trigger input (BNC), connector for additional charge line (SHV), pulse out (SHV), and a monitor output (BNC), used to drive an oscilloscope or time interval meter.

Mixer & Attenuator Circuit

The mixer-attenuator circuit is shown in Fig. 8. In normal operation the pulser chassis is located about 8 meters from the image intensifier camera but the cable length is not critical. The mixer-attenuator must be very close to the image intensifier tube for proper performance - there is inherent cable impedance mismatch when driving the capacitive load of the tube and the cable inductance must be minimized to achieve fast rise and fall times. At present 30 cm of RG174/50 ohm, 1/8" diameter cable is used but this does limit the performance. We plan to try flat ribbon cable.

The attenuator is made up of the 20 ohm input resistors driving the four parallel 43 ohm resistors (10.75 ohms combined) through the series-parallel IN-3731 diodes. The voltage drop across the diode string during the 35 ampere pulse is approximately 20 volts. Selected IN3731's were used which had a reverse breakdown voltage in excess of 100 volts.

The output diodes allow coupling a 270 volt, 30 μs long pulse from a 50 ohm lumped line pulser for ambient light photography. These output diodes do adversely affect pulse shape and also drop about 10 volts during the pulse. The layout of the mixer-attenuator is shown in Figs. 9-10.

Pulser-Mixer-Attenuator Performance

Figure 11 shows the output of the mixer-attenuator with a 50 ohm resistive load. The scale factors are approximately 60 volts/division vertical and 5 ns/division horizontal. Figure 12 shows the output at the mixer-attenuator with the image intensifier connected through a 30 cm cable which is terminated with a 50 ohm resistor at the tube (R6 in Fig. 13). The pedestal on the output is due to charge-line to load impedance mismatch. The effective load impedance is the switch impedance, $R_{SW} = 220$ ohms plus the external load impedance - 31 ohms.

Since the photocathode-MCP input is back biased by 90 volts the pedestal is tolerable. Rise time on the pulse is clearly less than 4 ns at this point. The pulse at the tube electrodes is smoother with little ringing but with slower rise and fall times due to the inductance of the 30 cm coupling cable.

With this system, LASL Group M-3 has made image intensifier camera photographs with effective exposure time of 15 ns. The measured resolution is 17 to 19 line pairs/mm. Most of the 40 mm tubes received to date, however, will not perform well at this speed. There appears to be a photocathode resistance problem on many tubes which prevents one from turning-on the central portion of the tube with such a short pulse.

Electrical measurements were made with a Tektronix 7403 oscilloscope, a 7A19 50 ohm input preamplifier, and a P6057 probe. The P6057 probe provides 100x attenuation and 5000 ohms input impedance with the 7A19 preamplifier but is rated for only 50 volts. Rise time for the combination is 0.8 ns. With 10 ns pulse length, the life is increased to 30 ns the life drops to approximately 15,000 pulses. This is tolerable in our application but discouraging compared to the performance we had seen with Motorola MPSU01's, which had virtually unlimited life under similar conditions. The 2N3700's in contrast have much higher useable yield from each batch, and much lower trigger jitter and delay.

Measurements indicate the jitter between trigger signal and pulse out is less than 200 ps. The delay to the output of the pulser is about 8 ns with a total delay to the mixer output of about 50 ns when using 8 meter cables. Repetition rates of 1 kHz on each pulser can be run with the 10 ns charge lines but normal operation is to single pulse the units. The most disappointing aspect of the performance has been failure problems with the transistors when trying to generate longer pulses. There appears to be a cumulative damage problem with the transistor when they are operated at this current level (35 ampere) which results in sudden shorting of transistor. After a fixed number of pulses of a given length have been generated. With 10 ns pulse length, the life is several million pulses but when pulse length is increased to 30 ns the life drops to approximately 15,000 pulses. This is tolerable in our application but discouraging compared to the performance we had seen with Motorola MPSU01's, which had virtually unlimited life under similar conditions. The 2N3700's in contrast have much higher useable yield from each batch, and much lower trigger jitter and delay.

It was interesting to note in working with the pulser that while the 1000 volt, 10 ns pulses will create a visible and audible arc in air, no shock can be felt when applied to one's skin.
Fig. 9. Mixer-attenuator printed circuit card.

Fig. 10. Mixer-attenuator.

Fig. 11. Output of mixer with resistance load.

Fig. 12. Output of mixer of MCPI² tube load.

Fig. 13. Divider network circuit for MCPI² tube.
Divider Network For MCP17 Tube

The original network, with its associated capacitors, was designed to meet the following criteria:

- Place the output phosphor at ground potential.
- Provide a low impedance path for the gating signal.
- Provide a cut-off bias voltage across the photo-cathode to MCP gap.
- Stored energy available for tube damage when arc-overs occur shall be a minimum.

The network employed for the 40 mm tubes shown in Fig. 13 is essentially the same except for component types and values and the addition of zener diodes across the photo-cathode to MCP gap. The changes were made to accommodate the following additional criteria:

- Gain stability.
- Gain control in "f stop steps".
- Transient voltages at turn-on and turn-off to be within tube ratings.
- Total current from a -6 kV supply to be less than 0.5 mA.

Criteria a, d, and g conflict, therefore compromises will be involved in an acceptable design.

D.C. Analysis Of The Network

The gain $G$ of the MCP17 tube can be closely approximated by the relation

$$ G = K(V_{cp} - V_{th})^{mcp} \tag{1} $$

where $V_{cp}$ is the channel plate to phosphor voltage, $V_{th}$ a threshold voltage determined by phosphor backing and thickness, and $V_{mcp}$ the channel plate electron multiplier voltage. By varying $V_{mcp}$ from less than 500 volts to 800 volts the gains of typical tubes can be varied by 7 or 8 stops (120 to 256X). This is accomplished by changing $R_4$ in Fig. 13 in discrete steps according to the relation

$$ R_4 = \left[ \frac{A R_4 + B}{C R_4 + D} \right] \left[ \frac{E R_4 + F}{G R_4 + H} \right]^{mcp} \tag{2} $$

where $V_{mcp}$ is a unique function of gain for each MCP17 tube (derived from data supplied by the manufacturer for each tube), $R_4$ is the MCP resistance, and the coefficients $A, B, C, D, E, F$ are determined by the remaining network resistance values. Values for $R_4$ range from 7 to 120 megohms. To make $V_{mcp}$ relatively independent of $R_4$, the current through $R_4$ is made as large as permitted by the available power supply.

The gain is a strong function of $V_{mcp}$, therefore it is essential that the resistors which determine $V_{mcp}$ be very stable and precisely the values required. Adequate gain stability was obtained by changing to 1% low voltage coefficient and low temperature coefficient metal film and metal oxide resistors and operating these well below their maximum voltage rating wherever possible.

Transient Analysis Of The Network

The digital computer network analysis program, NET-2 was employed to analyze the turn-on and turn-off transients. These transients are shown for the original network and the modified network in Figs. 14 and 15. In Fig. 14 it may be noted that the turn-on transient across the photo-cathode to MCP gap exceeds 800 volts, far above the maximum rating for the tube of 160 volts. This transient is caused by the different time constants of the branch comprised of $R_5$, $R_7$, $C_3$, and $C_4$, and the branch comprised of $R_7$, $R_5$, and $C_3$ (Fig. 13). It was not possible to change $C_3$.

Fig. 14. Photo-cathode to MCP gap transients.

Fig. 15. MCP voltage transients voltage.
and \( C_{\text{g}} \) for it is essential that \( C_{3} \approx C_{4} \gg C_{5} \) to preserve a low impedance gate signal path. Therefore, \( C_{9} \) was added to slow the rise of voltage across \( R_{k} \) and \( R_{4} \). Reasonable values for \( C_{5} \) were still not adequate; therefore a string of Zener diodes were added across this gap to hold the transient to 180 volts. The Zener diode string was actually made a back-to-back string to also hold the gating voltage to a safe value. The presence of the Zener diodes did not appreciably affect the gating signal rise and fall times.

Figure 15 shows the transient voltage across the MCP - as high as +2700 and -1000 volts for a tube whose maximum rating was 800 volts! After modification of the time constants the transients were held within 800 volts. Therefore, though the addition of \( C \) adds to the energy available to destroy the tube if a tube arc-over should occur its presence does reduce the probability of arc-over considerably.

Physical Configuration of Network

A donut shape for the network nicely adapts to the MCP tube. The pc board carrying the network is shown in Fig. 16 with all components mounted. All external leads are brought out along one radius to reduce the probability of arc-over considerably.

The entire network assembly is potted in Epo-Cast 202 and installed concentric with the tube.

Fig. 16. Unpotted divider network for MCP tube.