13.4: Design of a Microchannel Plate CRT for a General-Purpose Oscilloscope

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History and Background

For many years, microchannel plate electron multipliers (MCPs) have been used for amplifying photo-electron images in night vision devices and image intensifiers.[1] Several years ago the declassification of these devices lead to their use in amplifying the electron beam intensity of cathode ray tubes. Until recently the expense of the MCP and the complications of using the device in a CRT environment have limited its use to very high bandwidth, special-purpose oscilloscopes. Recent demands for both higher visual writing speed and improved resolution have pushed the conventional oscilloscope CRT to its fundamental limits. Placing an electron multiplier after deflection has opened the way to separating the deflection performance of the electron gun from the need for that gun also to produce high beam currents for transient-event detection.

Microchannel Plate Operation

The MCP is a large array of microscopic conductive glass channels fabricated by drawn-glass techniques in the same fashion as fiberoptic plates. With both sides of the plate metalized a potential can be applied and a field set up within the channels.

Secondary electrons are caused to be emitted by the input primary electrons hitting the walls. These secondary electrons are accelerated along the channel and collide with the wall, causing further secondaries to be emitted. Many collisions take place producing electron multiplications of many thousand times. MCP operation is shown in Figure 1.

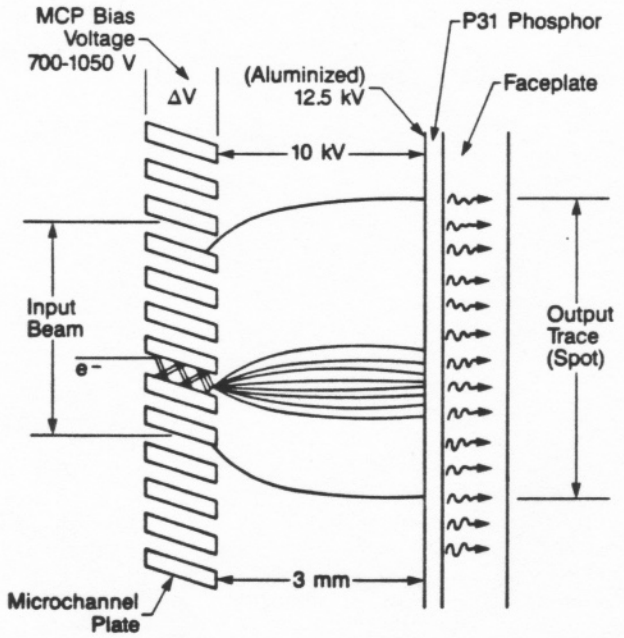

Figure 1. MCP operation.

Current gain in an MCP device is sufficiently high to detect the input of a single electron. At high input currents, channel saturation occurs causing a compression in the output brightness. This effect is utilized in the oscilloscope to detect an aberrant signal occurring amongst more frequent signals. Frequent events, by increasing average input currents, will saturate the channel, compressing the output brightness while there is still sufficient gain to make an infrequent event visible. Thus even if a fault occurs just once in a million normal operations, it is still visible.

Electron Gun Design

Integrated medium- to high-bandwidth deflection amplifiers need a CRT having low deflection factors. For 350-MHz operation these are typically 2.5 V/div vertical and 3.5 V/div horizontal. To achieve this sensitivity the CRT needs some form of expansion lens following the deflection system to amplify the scan angles. In a conventional CRT this lens is usually a mesh post-deflection acceleration (PDA) system,[2] where scan angles are expanded while the beam is accelerated to the phosphor. Other PDA systems are in use, such as the meshless system of Janko.[3]

If an MCP is used to amplify the beam current, it is desirable to have the MCP's input electrode at or near gun potential and a conventional style accelerating lens cannot be used.

In other high-frequency tube designs either the box lens of Odenthal[4] or a mono-accelerator gun design was used, making for very long tubes. The box lens is complicated and bulky, making it expensive to produce. For a general-purpose oscilloscope an inexpensive gun system is more suitable for high-volume production. For this reason, we examined several other types of lenses.

Full electrostatic quadrupole lenses can be used for expansion of the scan. We studied these extensively. Quadrupole lenses have a number of drawbacks, the most significant being the complicated quadruple optics needed to focus the beam to a round spot and the tight mechanical tolerances needed to maintain good geometry and linearity of scan. Therefore we considered a conventional mesh expansion system which, being rotationally symmetric, allows simple gun optics to be used.

Mesh PDA lenses, although used extensively in modern oscilloscope tubes, suffer from a series of faults, mainly:

- Secondary electrons causing a ghost image of the spot.
- Beam intercept by the mesh degrading brightness.
- Mesh lenslet aberration degrading resolution.
- Particle contamination on the fine mesh structure causing local spot degradation.

In addition, the use of mesh PDA lenses with an MCP causes intolerable halo around the beam due to the amplifying effect of the MCP on secondary electrons.

Use of a mesh lens in a decelerating mode, where the exit potential of the lens is lower than the gun potential, eliminates most of these mesh-use drawbacks. (This scheme is shown in Figure 2.) A drift tube at the gun's exit is held at gun potential, about 2 kV from cathode, and a mesh—shaped concave to the electron gun—is connected to the funnel wall coating and held at a potential of 1 kV. The expansion lens is formed in the field produced between the drift tube and the mesh. Figure 3 shows computer-generated potential plots and electron trajectories in such a lens.

In this reverse mode a potential ratio of 1:2 produces a stronger lens giving more expansion than the 8:1 of a conventional PDA lens. The secondary electrons produced at the mesh are accelerated

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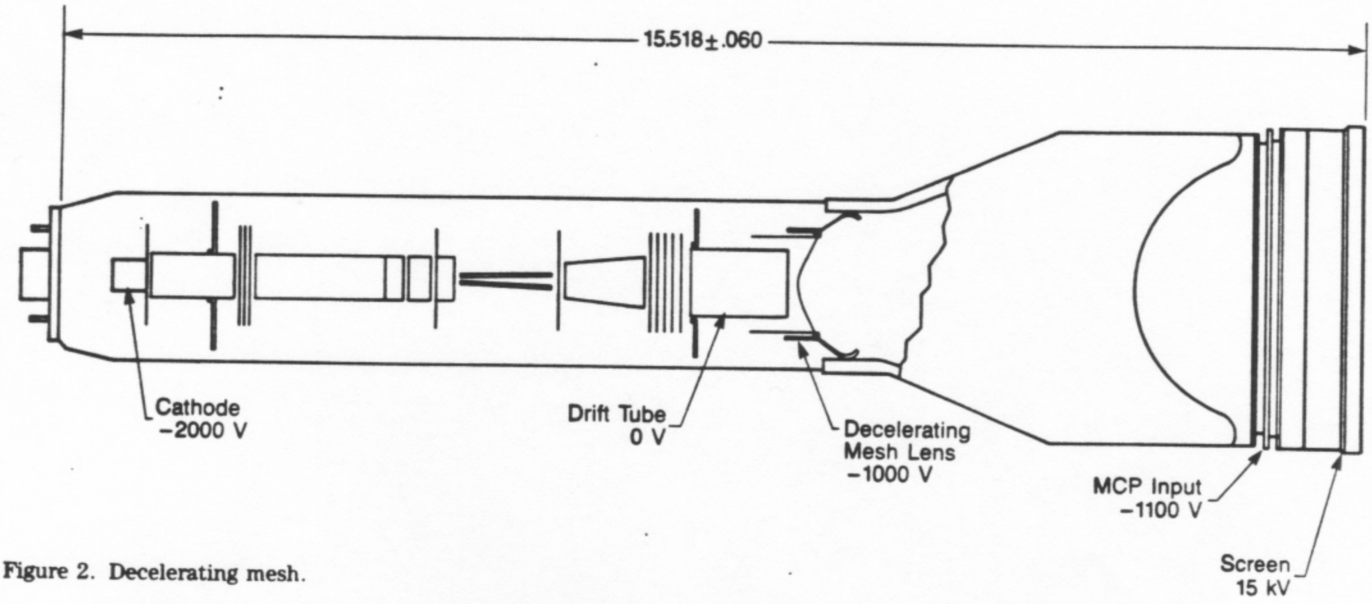

Figure 2. Decelerating mesh.

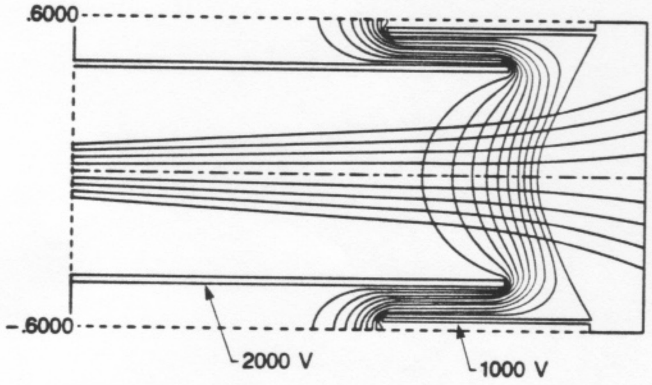

Figure 3. Computer plots of decelerating mesh.

towards the gun—away from the MCP—and thus cause no halo around the beam. Beam intercept in the mesh is no problem since with the high gain of the MCP the electron gun need produce only a few microamperes.

The mesh lenslet aberrations are a function of the field strength at the mesh. The field strength itself is a function of the ratio of potentials on either side of the mesh and, since this ratio is lower than in a conventional mesh lens, aberrations with the new lens are less.

Contamination problems are no more severe than with a conventional mesh tube. Manufacturing methods in this mature technology have been refined to make mesh contamination a minor cause of rejects.

The MCP input electrode is now no longer at ground potential, but is depressed below ground by 1100 V. It is held an additional 100 V below the funnel wallband to collect the secondary electrons produced on the lands between channels, thus reducing background scatter and improving contrast. The 1100 V isolation required for the exposed metal mounting structure of the MCP poses no real problem compared to the 10 kV or more required with a more conventional PDA lens system.

The rest of the electron gun is very conventional, with rotationally symmetric optics. The first anode is extended to gain resolution at the expense of beam current; an electrostatic stigmation lens is added to further improve resolution by correcting for manufacturing anomalies. The vertical deflector is a meanderline structure matched to the requirements of a 350-MHz amplifier.

MCP Mounting

In Figure 4(A&B), the front-end mounting structures of the previous MCP design, used in the 7104 oscilloscope, is compared to the current MCP design, used in the recent 2467 oscilloscope. In both designs a vacuum seal has to be made near the structure containing the MCP. This seal must be large to allow the MCP structure to be inserted into the tube and placed close to the phosphor screen. The large size of the 7104 design is dictated by the need to dissipate the heat generated in sealing the Sealmet flanges. This is done by heli-arc welding the two flanges together while clamping them in large copper heat sinks. Sealmet is used to match the expansion coefficient of the ceramic ring being used. These seals are prone to leaks both in the welded joint and the frit joints with the ceramic. The forming and preparation of these flanges is expensive and time consuming. A new method of mounting the MCP was therefore desired.

The expansion of titanium metal also matches well with ceramic and was thus considered as a replacement. No oxidation preparation is necessary as with Sealmet; it is light and easily drawn into the required shapes. To reduce the size of the sealing flanges, it was necessary to reduce the heating required to fuse the metal together. This was achieved by laser welding techniques. Both CO_2 and YAG lasers were evaluated. We choose the YAG because of power problems with the CO_2. The high power of the CO_2 necessitated high weld speeds and material handling was difficult. The YAG laser system needed lower power to melt the titanium and had better material handling systems. The resultant design is compact and inexpensive, allowing for a shorter tube that is produceable in volume.

Performance

The primary reason to use an MCP electron multiplier in a CRT is to make single-shot or low-repetition-rate signals clearly visible in normal room lighting. An additional advantage is that the saturation effects of the MCP limit the brightness of high-duty factor signals with no trace blooming effects. This means that anomalous signals occurring infrequently in a stream of repetitive signals can be readily observed.

This ability to observe anomalous signals is extremely important in diagnosis of digital-signal errors. Modern digital oscilloscopes

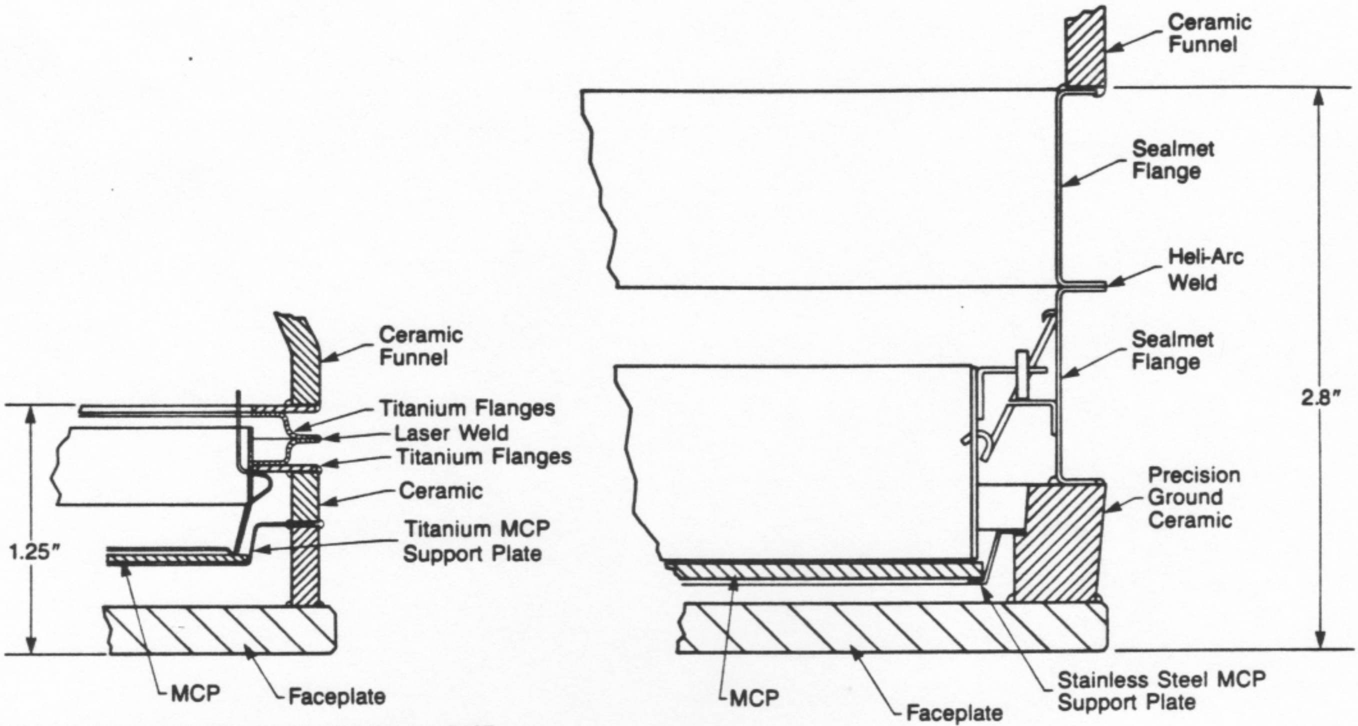

Figure 4. Mounting structures, 7104 versus 2467.

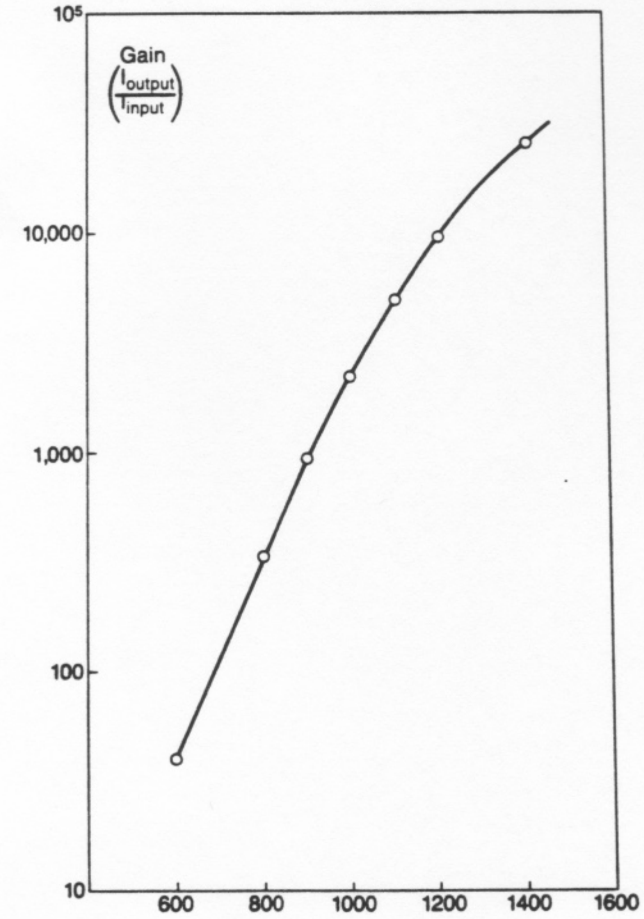

Figure 5. Unsaturated gain versus bias voltage.

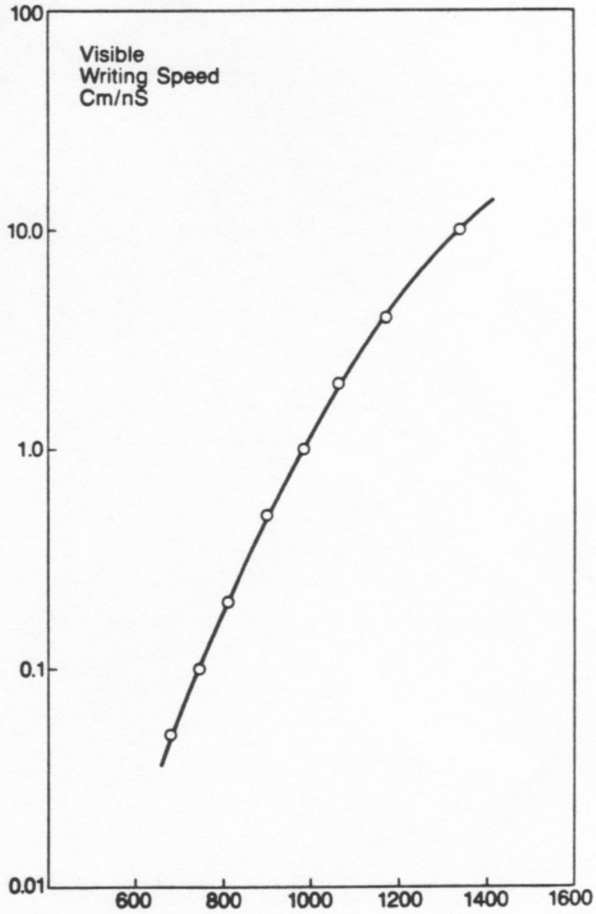

Figure 6. Writing speed versus bias voltage.

ususally have modes to detect these kinds of anomalous signals, but the frame rate of their system is usually so low that very infrequent signals cannot be detected. An MCP-based real-time oscilloscope display has sufficient visual writing speed to detect the anomaly.

The gain of the MCP is adjusted by changing the bias voltage across the plate. Initially, the unsaturated gains of an MCP are extremely high, but unfortunately an aging phenomenon quickly degrades this performance. If used unaged, differential patterns would be discernible on the screen. In practice the plate is aged to a more stable level before use. Figure 5 shows how the unsaturated gain changes with the bias voltage after aging. Figure 6 shows how the detectable writing speed is affected by MCP bias, with an input current of 3 microamperes.

A conventional oscilloscope display designed for high-writing speed exhibits large changes in trace width from low-drive to high-drive conditions. This change is due to the demands on the electron gun to provide all the electrons necessary to produce a visual image on the phosphor. Because an MCP is used for electron multiplication, the electron gun need supply only relatively few electrons. Thus the gun can be designed to produce a more constant spot size versus drive characteristic. The 2467 CRT provides such a constant spot-size display.

Because in a portable oscilloscope ruggedness is essential, there were fears of using the fragile glass honeycomb. These fears were negated by careful MCP-mounting design. In all three axes, the CRT structure withstands greater than 100 g shock.

Conclusion

Novel use of a mesh electron lens and innovative use of laser-welded titanium mounting-hardware for the MCP has produced a CRT design that is relatively inexpensive to build and that provides unexcelled performance for a general-purpose oscilloscope. The high visual writing speed of the CRT needed for glitch detection in digital circuits is readily obtained and extends the usefulness of the real-time CRT for many years.

Acknowledgments

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References

1. "Advances in Electronics and Electron Physics," vol. 64B, pp. 299–365, Academic Press Inc.

2. J.D. Hawes and G.A. Nelson, "Mesh PDA Lenses in Cathode-Ray Tubes," *Proceedings SID*, vol. 19/1, 1978.

3. B. Janko, N. Franzen, J.H. Sonneborn, "CRT Architecture with Meshless Scan Expansion," *SID Dig. Tech. Papers*, pp. 118–119, 1983.

4. C.J. Odenthal, "A Box-Shaped Scan-Expansion Lens for an Oscilloscope CRT," *SID Dig. Tech. Papers*, pp. 134, 1977.