P.O. Box 131748
Roseville, MN 55113

Plated Wire Memory Usage on the UNIVAC Minuteman Weapon System Computer

Larry Bolton was a component engineer assigned to the Minuteman program from 1969 to 1975. In support of the Minuteman program, we purchased a plated wire element and a raw tunnel structure. These were used by UNIVAC St. Paul to build the plated wire memory assembly. Larry Bolton's function on the Minuteman program was to monitor suppliers to ensure that the program received plated wire and tunnel structure materials that met the specification requirements.

Clint Crosby was an Applied Research engineer assigned to the Minuteman program and was part of a plated wire element analysis group from 1969 to 1980. Clint was involved with plated wire testing, plated wire manufacturing support at Bristol, and Minuteman memory module fabrication support at St. Paul.

Jim Howe was the lead engineer for the three generations of plated wire memories for the Minuteman WSC computer (the EDM, ADM, and production versions), and was the lead engineer for a company-sponsored wide-margin plated wire memory design that was done as a backup to the three Minuteman memories. Unfortunately, even though it was a great success, it wasn't needed (customer political implications).

PLATED WIRE PROGRAM

UNIVAC Commercial in Philadelphia, PA, had developed a continuous chemical plating process to put a Ni-Fe magnetic plating over a 5 mil beryllium-copper substrate wire. Manufacturing was located at Univac Commercial in Bristol, Tennessee. The finished product was used in the 9000 series and initial 1110 commercial computers as well as on the Minuteman program.

Plated Wire Substrate

The beryllium-copper wire substrate material was delivered to Bristol in the form of 20 mil wire spools. The 20 mil wire was drawn down to 5 mil wire through a machine having multiple dies. The 5 mil wire was loaded onto a spool at the end of the drawing process. The completed spool was stored in a sealed plastic bag to minimize the formation of beryllium oxide on the surface of the substrate. Beryllium oxide is a hard, glasslike material that could contaminate a wire die in the wire drawing process by causing a groove (gouge) in the substrate surface. Beryllium oxide could also cause poor adhesion in the Ni-Fe plating process.

Plating Process

A beryllium-copper substrate wire reel was installed on a wire plater, by threading the wire through plastic modules (cells). Each of the cells had a unique solution flowing through the cell that etched, plated, or flushed the substrate wire surface. A small current was passed down the wire from the substrate source reel to a test cell at the end of the manufacturing sequence. The current was used to "attract" material in the plating steps as well as create a small magnetic field to help magnetically orient Ni-Fe particles.

The first major step was an anodic cleaning to remove contaminants such as oil from the wire drawing process. Cleaning was followed by a rinse and an etching process to prepare the wire surface to remove any Beryllium oxide. After another rinse, a copper underplate was added to provide a uniform roughness to the surface. The Ni-Fe (Permalloy) plate was added between two more rinses. The plated wire characteristics were continuously evaluated at the end of the plating process by an online tester. When a failed spot was detected, a cutter was activated, and a new wire was initiated. The short piece was discarded. If 16 inches of the wire passed without a bad spot, the wire was cut and loaded into a plastic tray that had separate grooves for each wire. According to the plated wire procurement spec for Minuteman (Procurement Drawing #7903591), a surface protectant coating was finally added by dipping the finished plated wire trays in a benzotriazol solution. Figure 1 is a simplified block diagram of the plating process.

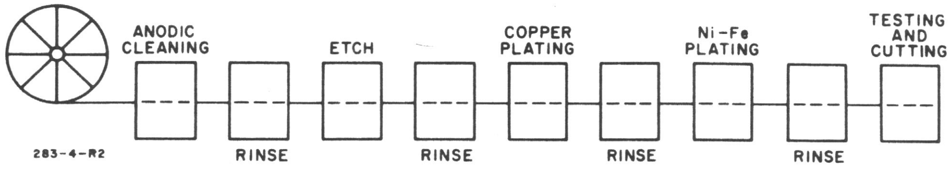

Figure 1. Simplified Diagram of Wire-Plating Apparatus

Univac Bristol had seven wire platers. Two were dedicated to the Minuteman program. Since all processes had to be under control of Minuteman, Larry Bolton made several trips to Bristol from 1971 to 1974 for the purposes of establishing a process baseline, ensuring processes were followed, and auditing changes. Even though the control systems (valves) on the plating machine were set within the limits defined by the process and plating solutions were monitored daily, there was no guarantee that the product would work in a Minuteman environment. Sample tests of each lot of plated wire (one day production from a plater) were completed using an offline tester called a UNIversal Magnetic Element Tester (UNIMET). Sample tests included basic magnetic tests and Long Term Disturb (LTD) tests. The LTD test evaluated test bit sensitivity to adjacent bit writes and reads (one million) on each side of the test bit to ensure that the plated wire element would tolerate long-term usage of the device. Clint Crosby provided UNIMET tester design changes to automate the LTD test function. Vince Korkowski designed support equipment to analyze the LTD test results.

The LTD test showed that plater settings were more an art than a science and involved combinations of settings to produce a product that met Minuteman requirements. An example was a case where the plated wire element characteristics changed as a result of a de-ionized water contamination. As a result of waning commercial plated wire production, de-ionized water usage had also waned. Stagnant de-ionized water resulted in algae growth that contaminated the NiFe plating process. The result was a porous plating having higher than normal output and higher sensitivity to LTD. The de-ionized water tanks were cleaned to remove the organic matter and the de-ionized water storage volume was reduced to solve the problem.

Near the end of the Minuteman contract, Univac Bristol facility stopped making plated wire. Two wire platers were moved from storage in Ilion, New York to the Shepard Road facility in St. Paul, MN, to complete plated wire element production.

TUNNEL STRUCTURE

For the Minuteman application, the raw tunnel structure was purchased from Duluth Scientific Incorporated (DSI) in Superior, Wisconsin, using drawing 7511623. The tunnel structure was made by pressing two opposing layers of 0.001 inch thick polyimide sheet with a 5 mil Teflon secondary over a stretched series of 0.0071 inch diameter steel tooling wires on 0.0125 inch centers. The tooling wires were stretched to limit wire snaking to 0.002 inch and were coated with a mold release agent to simplify tooling wire removal from the finished product. Pressure and temperature were used to fuse the layers together into a 0.010 inch thick by 4.35 inch wide by 14 inch long sheet containing 346 tunnels. Once finished, the tooling wires were cut approximately an inch longer than the finished tunnel structure. The tooling wire ends were etched to minimize burrs. The tooling wires were left in for shipment of the tunnels to Univac, St. Paul.

Near the end of the contract, DSI moved the fabrication location from Superior, Wisconsin, to San Diego, California, to Tijuana, Mexico, and back to San Diego, California. Clint Crosby and several other St. Paul personnel completed a one-day trip Tijuana, Mexico, to help DSI solve manufacturing problems. Approximately two weeks later, production was back online. After DSI moved back to San Diego, a decision was made to provide a second source capability at the Univac Shepard Road facility in St. Paul.

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MEMORY ASSEMBLY

The first steps at Univac required the lamination of copper word lines, magnetic keeper material, and ground plane on the raw tunnel structure. Word lines ran perpendicular to the tooling wires in the tunnel structure. Drawing 7511745 defines some of the first layers added to the tunnel structure. The tooling wires were still embedded in the tunnel structure. Finally, the tooling wires were pulled out leaving tunnels for plated wire installation. The wires were pulled from both ends of the tunnel structure. The tooling wires necked down and broke at the weakest point in the wire without leaving a burr on the end of the wire to scratch the tunnel.

A tunnel structure was bonded to the top and bottom of an aluminum frame. The final step was taken by the well-trained and talented people at the Shepard Road assembly plant. They took plated wire "hairpin" elements and fed one leg of the hairpin into the top tunnel and one into the bottom tunnel at the same time. The "hairpin" was manufactured by Electrocraft at its Montevideo, MN, facility. Clint Crosby supported the development of this capability. The hairpin connection completed an electrical interconnect between the top and bottom plated wires that allowed the wires to freely move within the tunnel structure. Free movement was needed to minimize the effect of magnetic plating sensitivity to physical stress (magnetostriction). Any contamination in tunnels could cause the plated wires to bind in the tunnels. Each end of the wire hairpin was soldered to copper pads completing the electrical circuit. Sense line noise was minimized by sensing on a plated wire and an adjacent copper (dummy) wire. This part is best explained by Jim Howe and the diagrams he probably has.

Minuteman used a unique, half-turn, word line geometry. Univac Commercial used a full-turn word line geometry, and a 'competitive' vendor used a two-turn word line geometry. The half-turn word line geometry reduced electrical noise in the system design and allowed for increased bit densities. Figure 2 shows the basic structure of the plated wire, full turn word lines, and resulting magnetic fields.

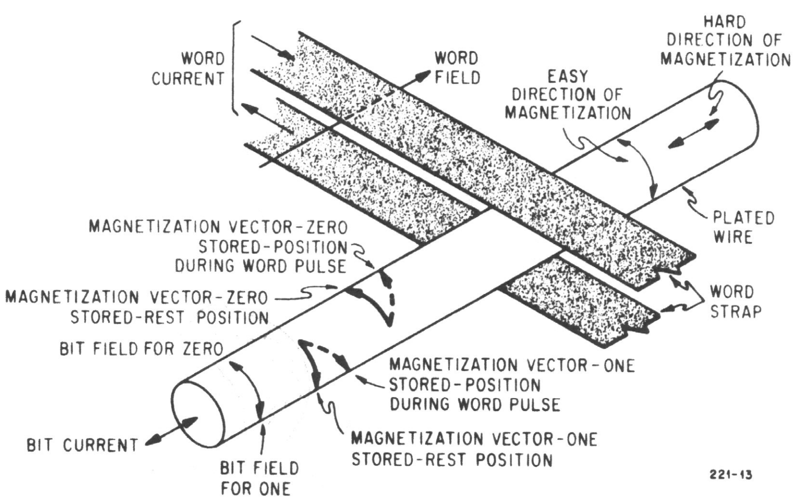

Figure 2. Information Storage on Plated Wire

The Minuteman application used 30 mil wide word lines on a 50 mil pitch. Each word line spanned four words of 36 bits plus two parity bits each. Tunnels in each plane were filled with alternated plated wires and dummy wires. Each tunnel structure had 256 word lines divided into eight 32 word blocks, so each plane had 1K words of NDRO (non-destructive read-out) storage. Planes were laminated to the top and bottom of an aluminum frame. This made a 2K word module. The Minuteman memory drawers had varying numbers of these modules depending on final application, probably no more than 32K words total of NDRO memory.

Figure 3 shows the electrical process of reading and writing to the plated wire memory.

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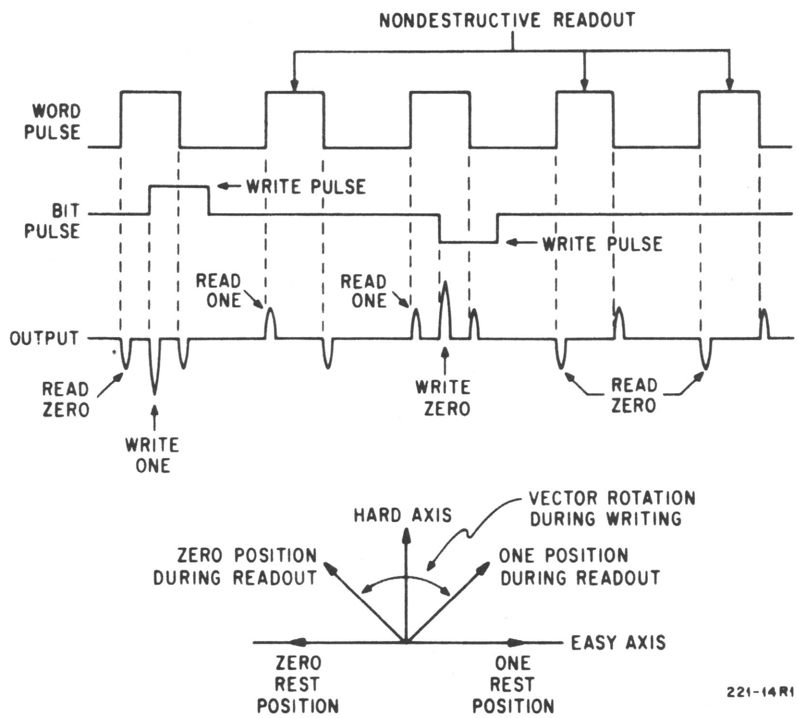

Figure 3. Simplified Diagram of Read and Write Cycles

APPLICATIONS

The Minuteman Weapon System Control (WSC) computer had a government nomenclature AN/UYK-11 and shows up on the Univac computer genealogy charts as an 18 bit computer. In reality, the AN/UYK-11 used the 18-bit Instruction Set Architecture (ISA) mapped onto a 36-bit memory and arithmetic structure. The NDRO plated wire was used instead of core memory because plated wire did not have to be re-written each time it was accessed. The shorter cycle time and NDRO capability resulted in a lower susceptibility to radiation effects, i.e. had a better chance of surviving near-by A-bomb blasts. This 18-bit ISA began in the late 50's as a Computer Unit Tester which evolved into the UNIVAC defense systems 1218 series and the UNIVAC commercial 418 computer series.

The UYK-11 was used in the ground-based part of the Minuteman III system and was in the underground LCF (Launch Control Facility) as well as in each silo. The UYK-11 was well known within the Air Force for its reliability. The computer ran 24 hours a day, 7 days a week continually testing the Minuteman launch readiness. Most of them ran for over five years without any downtime!! An actual Mean-Time-Between-Failure (MTBF) in excess of 45,000 hours for the 100 plus systems that were deployed was observed.

Other non-Univac applications for plated wire memory included the Mars Viking Lander and Hubble Space Telescope. Honeywell also used plated wire in the Minuteman missile. The Univac wire was 5 mils in diameter. Later developments at Univac led to a 2 ½ -mil plated wire mass memory for Rome Air Development Center applications.

Reference Material:

Plated Wire Procurement Specification: 7903591.pdf
Tunnel Structure Procurement Specification: 7511623.pdf
Tunnel Structure – Word Line Assembly: 7511767.pdf
Tunnel Assembly: 7511745.pdf