Excerpt from

A Brief History of Bendix Red Bank Tubes

Author Charles Hansen offers a unique perspective of the Bendix tube-manufacturing facility in his recent book.

. . . Bendix no longer exists. The plant at Eatontown closed in 1999 and was torn down in 2001. As of this writing, the land hosts a Lowes home improvement center.

The Bendix tube business ceased operation only about 45 years ago, but detailed information is extremely difficult to find. It was mainly through the remaining retired employees, the local Bendix retired employees associations, and old Eatontown documents that I could piece together this puzzle. Some of it is anecdotal and may not be entirely accurate. Keep in mind that by the time I started at Bendix in 1966, there was hardly even a mention of the tube business at Eatontown. Here we are in the midst of the greatest information age of all time, and we have difficulty keeping track of events that happened barely half a century ago.

MILITARY VACUUM TUBE HISTORY

When the US armed services first started using vacuum tubes just before WWI, they devised a method for tube identification that would meet the needs of the individual services. In 1916, the Army started assigning a series of "VT-" numbers to commercial off-the-shelf (COTS) equivalents of standard production tubes. The Navy system used "C" designations for each manufacturer: CG was GE, CRC was RCA, CW was Westinghouse, and so on. The Associated Radio Manufacturers (ARM) was formed in 1924, and was renamed Radio Manufacturers Association (RMA) that same year. They endeavored to standardize the peacetime radio industry.

As the US was dragged into WWII, vital materials were required for the war effort. A lot of firms in early 1941 began seeking war contracts and even started to manufacture some wartime items. The US manufacturing industry was converted by Government order to full war production in early 1942.

The different vacuum tube numbering systems used by the Navy and Army (and the Army Air Forces) was a chaotic mess, with a huge number of obsolete tube types. The War Department instituted a Joint Army-Navy (JAN) part numbering system that, for the most part, used standard industry tube numbers.

The extreme shock and vibration environments required that some of these tubes be improved mechanically (ruggedization) to ensure the operability of critical electronic equipment. The suffix "W" was added to the tube designation for identification of rugged tubes, i.e., a ruggedized 5Y3GT became a 5Y3WGT. A short time later, the numbering system was modified to use the four-digit RMA/EIA (Radio Manufacturers Association/Electronic Industries Association) numbering system. The 5Y3 became the 6106.

As a result of the rapid industrial conversion toward the war effort, the government found that quality varied widely across what were previously industrial products. After the war, the military decided it needed better control over the quality of all materials and components that went into critical military equipment. It instituted a series of Military Specifications (Mil Specs) that defined the parameters, performance, test and quality requirements for military items.

All military contracts required that the contractor have in place a Quality Assurance program. It also prohibited the re-marking of tubes or any other attempts at third-party manufacturing. All military tubes had to be manufactured, tested, and qualified at the same facility.

The very first Mil Spec was for electron tubes, called MIL-E-1. It consisted of 77 pages of specifications, tests, and quality requirements for electron tubes. Each unique tube type was given a MIL-E-1 "slash number," and this same specification is still in use today.

While the identity of the MIL-E-1/1 tube type is lost in obscurity, MIL-E-1/2 was issued for the 6SK7WA remote cutoff pentode. Other electronic components covered by that first group of Mil Specs were:

MIL-C-5	capacitor, fixed, mica dielectric; type CM
MIL-R-11	resistor, fixed, composition (insulated); type RC
MIL-R-19	resistor, variable, wirewound (low temperature); type RA
MIL-C-20	capacitor, fixed, ceramic, temperature compensated; type CC
MIL-R-22	resistor, variable, wirewound (power type); type RP
MIL-C-25	capacitor, fixed, paper dielectric, DC; type CH
MIL-R-26	resistor, fixed, wirewound (power type); type RW
MIL-T-27	transformers and inductors (audio, power and pulse)
MIL-C-62	capacitor, fixed, electrolytic (dry electrolytic); type CE
MIL-W-76	wire, hookup, electrical, insulated
MIL-C-81	capacitor, variable, ceramic dielectric; type CV
MIL-C-92	capacitor, variable, air dielectric (trimmer); type CA
MIL-R-93	resistor, fixed, wirewound (accurate); type RB
MIL-R-94	resistor, variable, composition; type RV

Interestingly, the early germanium and silicon diodes were also listed in

MIL-E-1, starting with MIL-E-1C ("electron tubes and crystal rectifiers") in 1955. The first Mil-Spec diode I could find was the JAN-1N253, which was officially designated MIL-E-1/1024 with the oxymoron title of "Electron Tube, Silicon Power Rectifier" in 1956. Once solid-state diodes and transistors began to supplant vacuum tubes in military designs, the Department of Defense (DOD) recognized the need to produce a Mil Spec that was dedicated to semiconductors. The first device in this new Mil Spec was the 2N220 germanium PNP transistor, designated MIL-S-19500/1 June 14, 1957.

On Sept. 12, 1961, the 1N253 was made inactive on MIL-E-1 and moved to MIL-S-19500/194, soon followed by all the other semiconductor diodes in MIL-E-1. The title for MIL-E-1 then reverted to just "electron tubes." Over 1500 unique tube types were eventually listed in MIL-E-1. As far as I can determine, the last number used was MIL-E-1/1772, a ku-band magnetron.

ECLIPSE-PIONEER AND BENDIX RADIO HISTORY

The Fleming "valve" and DeForest "audion" were just beginning to have an impact in radio in 1909. About this time, the Bijur Motor Appliance Company of New York City formulated the idea of cranking a car engine with a battery-powered electric motor. In 1910, Vincent Bendix patented what later became known as the "Bendix drive" for electric starters. Instead of having the starter motor continuously engaged like the starter Delco designed for the 1911 Cadillac, it used a solenoid and sliding gear to engage teeth around the outside of the flywheel only during engine start. It did not require the Delco reduction gear.

The Bendix starter soon became standard on all cars produced in the US. Bijur went on to design the electric starter used on the famous Liberty aircraft engine used in WWI.

In 1923, Vincent Bendix started the Bendix Brake Company in South Bend, Ind., to market the Perrot four-wheel braking system. The Eclipse Machine Company of Elmira, N.Y., acquired the Bijur Company, also in 1923. Bendix went public in 1924 and issued shares to finance the brake business. In 1928 Bendix, with $6.8 million in notes granted by General Motors, acquired control of Eclipse, which had been producing the Bendix automotive starter since 1914.

Three former employees of Sperry Gyroscope had formed the Pioneer Instrument Corporation in Brooklyn, N.Y., in 1919. Bendix bought the Pioneer Instrument Corp. in 1929, and introduced the earth induction compass that Charles Lindbergh used for his epic flight across the Atlantic.

In 1929, a subsidiary of Eclipse, in East Orange, N.J., began building starters and generators for aircraft. Vincent Bendix changed the name of his company to Bendix Aviation, purchased Scintilla Magnetos, originally a Swiss firm; and set up manufacturing facilities in Sidney, N.Y. Then he bought the manufacturing rights to Stromberg carburetors.

At the start of the Depression in 1929, Bendix developed power brakes and power steering for cars and trucks. By 1937 he had successfully developed the pressure carburetor for aircraft engines. Bendix built a large plant in Teterboro, N.J., across from Teterboro Airport, in 1938, moving Eclipse Aviation and Pioneer Instruments into the new building. Bendix built a casting foundry and extensive engineering and test facilities.

Vincent Bendix acquired an interest in the Radio Research Company in Washington, D.C., in 1936. They licensed their home radio designs from RCA and Hazeltine Industries (a label on the radios listed the licensing notices). In 1937 all radio operations were consolidated in Baltimore, Md.

When the US entered WWII in 1941, another plant was opened in nearby Towson, Md. Bendix Radio made aircraft communications sets as well as the first automatic direction finder and radio detection systems. By 1938, Bendix had a complete line of navigation and communications systems.

In 1942, Vincent Bendix resigned as president and chairman of the board of his company (he died in 1945). Meanwhile, back in Teterboro, on May 4, 1943, Eclipse and Pioneer were combined into the Eclipse-Pioneer Division of Bendix Aviation Corp.

TALOS MISSILE PROGRAM

Like many companies of the era, Bendix's production philosophy determined that it be vertically integrated; that is, they kept as much of their production capability in-house as possible. What we today call "outsourcing" was a dirty word, because you were taking work out of the factory by buying outside material and services. Each Bendix division was also fully autonomous. The sales and service staffs were located in the same plant where the engineering and manufacturing took place. This philosophy propelled the Eclipse-Pioneer division of Bendix into the vacuum tube business.

The trigger event was the Talos missile program. The Talos (along with Terrier and Tartar, the "3-T" missile systems) Naval missile program was an outgrowth of the Naval Ordnance Bureau's Bumblebee program, which sought to provide medium- and long-range surface-to-air (SAM) missile protection for the Navy's surface ships in the face of increasingly faster jet aircraft. Jet aircraft were essentially immune to conventionally aimed antiaircraft artillery (AAA). Bumblebee was initiated at Johns Hopkins University's Applied Physics Lab (JHU-APL) in 1945.

Bell Labs had begun work on radar systems in 1937 at the request of the Navy. At this time radar waves were generated with conventional power triodes and were limited to relatively low frequencies. That same year the Varian Brothers in the US designed the klystron, and the British developed the reflex klystron in 1939. One year later British physicists invented the magnetron.

In August of 1940 the Battle of Britain began. The Germans destroyed the town of Coventry in the fall of 1940, where virtually all British aircraft radios were made. Winston Churchill dispatched a team to the US to find a company that could build radios for the British. Bendix was the only company that had any experience with VHF (very high frequency) radios, and, as a result, the company's production suddenly increased to 20 times its pre-war level, using RCA versions of the British tubes.

The British also needed to find a safer location to continue developing the "Home Chain" ground radar systems being used to detect German bombers, and smaller high-frequency radars for use aboard fighter interceptors. Bell Labs and the MIT Radiation Lab in the US took on the development of these high-power devices. Thus, by the end of WWII, Western Electric had gained extensive experience in high power radio and radar transmitting tubes.

Near the end of WWII, Western Electric was awarded the Army Nike long-range antiaircraft missile defense program, and developed both the ground-based tracking and targeting radar and the Nike missile guidance system. Convair was awarded the Terrier and Tartar missile programs. APL/Philco and Motorola were assigned the guidance system design tasks, and Bendix Aviation won the Talos project with the Naval Ordnance Test Center (NOTC).

The Talos, along with the Nike and Terrier, were to be the first guided rockets. The earlier rockets were all ballistic types with no guidance system. The "WAC" Corporal (designed after the supply of captured WWII German V-2s ran out) stood for "Without Any Control."

The Talos program presented a bit of a logistics problem because Bendix was neither in the missile nor the rocket engine business. After the war, Bendix Radio in Towson turned to home radios and TV sets, and then automobile radios. The military navigation and communications product lines were moved to Eclipse-Pioneer in Teterboro. About this time, Eclipse-Pioneer developed the first electric starter for jet engines.

JHU-APL had developed a ram jet engine that eventually became the final propulsion stage of the Talos. Bendix acted as the prime contractor. The missile airframe and ram jet engine were built by McDonnell, the solid rocket first stage was developed by Allegheny Ballistics Laboratory, and the automatic missile loading and launcher system program went to GE. The Guidance Systems group at Bendix in Teterboro teamed with Sperry Gyroscope to develop the missile guidance system (the shipboard tracking and guidance radar was probably a version of the Western Electric system). R&D work on the Talos program began in earnest in 1948.

The Talos team built a supersonic test vehicle (STV) to evaluate the guidance system at high speeds, but the high acceleration forces developed by the solid rocket booster were destroying even the ruggedized "W" tubes that were available at the time from GE, Tung-Sol, and Sylvania. All the previous guided "missiles" were basically unmanned subsonic winged aircraft—high g forces were never imposed on the guidance system vacuum tubes.

During WWII, British and American scientists had co-developed the top-secret variable-timing (VT) radio proximity fuse[1] used in 75mm and larger antiaircraft shells. The five subminiature metal tubes developed for the fusing circuits could tolerate 20,000 axial g's and a 30,000 rpm spin rate, and then trigger an explosion within 30′ of the target. But these tiny devices did not have the power needed to direct the course of a 3.5 ton, mach 2.5 missile fired against a fast, maneuverable target.

Bendix had no choice (because of its vertical integration philosophy) but to develop expertise in the vacuum tube business, and do it fast! The Eclipse-Pioneer group at Teterboro was tasked to develop the vacuum tubes required for the Talos program. Bendix received vacuum tube production code ID number 125 from the Electronics Industries (EIA) in 1948.

The task was certainly easier than the proximity fuse program, whose tubes needed to withstand much higher g-forces along with the high spin rate imparted by the rifled barrels of the artillery.

The guidance system selected for these early missiles is known as a guidance radar *beam rider*. The Talos was to be launched into a capture beam that steered it to the guidance beam. Using conical radar scan techniques, the Talos needed to keep itself inside the guidance beam all the way to the target.

This type of external control guidance required only one radar that tracked both the target and the missile, and sent steering commands to the Talos that directed it into a collision course with the target. The system minimized the electronics that the missile carried, but accuracy tended to decrease with range. The tubes in the early test missiles, which must operate for only a few minutes in flight, would tend to fail at launch or soon after.

TUBE DESIGN ENHANCEMENTS

Bendix Aviation and Eclipse-Pioneer threw all its expertise into the tube durability problem. It used its best metallurgists, chemists, electrical and materials engineers, along with whatever tube experts it could hire (especially from the nearby RCA and Tung-Sol factories). Tube designer John Wyman headed up the division.

Rather than the Bakelite or phenolic used in commercial octal tube bases, they first tried a material called Micanol, a mica-filled phenolic. After further experiments with some new materials, they settled on a tough brown mineral-filled melamine formaldehyde resin. For further insurance, they filled the base with a polyester potting compound while the tube envelope was connected to the base. (Eatontown developed a proprietary high-temperature silica-filled brown epoxy called RB-159 in 1962 to encapsulate generator and transformer windings, but it came along too late to ever be used for octal tube bases.)

They used Corning Nonex[2] envelope glass, with higher amounts of silica and boron oxide than the soda lime glasses used in commercial tubes. This borosilicate glass withstood much higher temperatures, and is known as a "hard" glass. This necessitated the use of platinum or tungsten lead-in wires, and tungsten or kovar alloy pins on the miniature tubes, because Nonex had half the expansion rate of "soft" commercial glass. Commercial glass tubes used either dumet alloy or nickel for the stem wires and pins.

A rugged support system for the tube elements was absolutely critical in order to withstand the high g-forces imposed on the missile guidance system tubes. Standard mica was inert and could tolerate the high internal envelope temperatures, but it was too weak for guided missile applications. The Eclipse-Pioneer engineers turned to ceramic materials. One readily available material was alumina (aluminum oxide).

Champion Spark Plug had developed the aluminum oxide insulator in the 1930s for aircraft spark plugs. Drawings were made to procure press-molded alumina equivalents of the mica wafers then in use. Metal eyelets were added wherever the nickel support rods passed through the alumina, to lock the entire support structure together and maintain the critical inter-electrode spacings (these metal eyelets were also fitted to Bendix tubes with mica spacers). There were some early problems with the different expansion rates between alumina and the metal tube elements.

The coiled tungsten heater was threaded through an extruded alumina heater insulator block, and this heater-insulator assembly was then inserted into the cathode. Covering the legs of the heater wire below the alumina insulator block with nickel sleeves provided a strong swaged weld, and heavy heater bus wires provided firm anchoring to the base.

In addition to the inherent ruggedness of this structure, it provided two other advantages. The heater-cathode breakdown voltage was much higher than that allowed by the standard alumina-coated heater. And the heatsinking capability of the alumina insulator helped prevent local hot spots in the heater that might shorten tube life during the turn-on surge, but this also lengthened the warm-up time.

The cathodes were larger than commercial tubes of the same types to increase the cathode area and accommodate the alumina heater blocks. Two large cathode tabs were used on each alumina spacer to hold the cathode in place despite the high vibration and shock.

The getters were way overdesigned. The thinking seemed to be that if *some* getter surface area is good, *more* is better, and *too much* is just right! Some tubes included as many as four getter loops, one on each of the support posts. An extra ceramic spacer was used at the top of the tube as a getter shield to ensure that the flashed metallic vapor did not splash against the stem or the insulated lead-in wires. It was also anchored in place with metal eyelets.

Various exothermic and nitrogen-doped alkaline and rare-earth metals and compounds were tried in order to remove all traces of nitrogen, hydrogen, and especially oxygen following initial pump-out, as well as throughout the life of the tube. The chemists experimented with barium, barium-aluminum, barium-magnesium, cesium chromate, calcium, hafnium, magnesium, rubidium chromate, strontium, zirconium, zirconium-iron, and mischmetall (an alloy of cerium, lanthanum, and other rare-earth elements). While some of the more exotic getter materials were probably used in microwave, high power, and gas tubes, the electron tubes (TE) used conventional barium flash getters.

The grid lathes were modified to use smaller diameter wire, with a finer winding pitch than standard tubes. The copper grid side rods were also heavier than usual. Bendix engineers developed a winder that automatically swaged the rods so the grid wire was embedded into them. Heavy radiators connected the grids to their through-supports with multiple welds. Extra spacing was added between the cathode and control grid to prevent voltage breakdown.

Using custom tooling developed at Eclipse-Pioneer, workers assembled the tube elements, supports, and other parts inside a set of alumina (or sometimes mica) spacers. The entire assembly was then crimped and spot-welded to the tube base. The glass envelope for each particular tube (with an integral exhaust tube) was installed over the assembly and sealed to the base disk using a natural gas flame.

Next the tube/envelope assembly was sent from the clean assembly area to Sealex rotary workstations. A vacuum line was connected to a glass exhaust tube at the top (miniature tubes) or bottom (octals) of the tube envelope. The air was pumped out with a multi-stage vacuum pump, and the metal parts of the assembly were heated with an induction coil. The pump removed most of the gases inside the envelope and the heat activated the cathode coating.

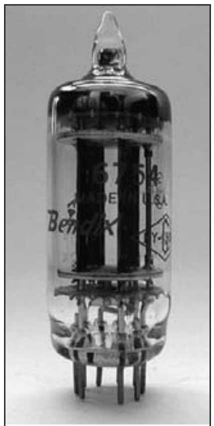

PHOTO 1: 6754 TE-36 miniature tube tip-off.

Next, the exhaust tube was heated in another gas flame and automatically sealed (tipped-off). If you look at the Bendix miniature tube in **Photo 1** (a 6754 TE-36 with the HY-G-300 marking and gold-plated pins), you can see that the tip-off is larger than commercial tubes, because of the heavier hard-glass envelopes.

Next, the Sealex turntable rotated the tube to the getter-flash RF induction coils, where the barium getters were heated white hot to absorb the last vestiges of oxygen, nitrogen, and hydrogen. After the Sealex machine, the tubes went to inspection and test.

Missiles were always on hot standby (powered up), so, to ensure there were no infant mortalities (early failures), Bendix gave each tube a 45-hour run-in under various overload, vibration, and shock conditions to eliminate any tubes with defects that might lead to failure under operational use. Vacuum tubes and gas regulator tubes were also used in some of the Eclipse-Pioneer generator voltage regulators and supervisory panels (the black boxes with the generating system control and protection circuitry), but I was unable to find out whether those tubes were ever made in Teterboro. aX

ABOUT THE AUTHOR

Charles Hansen is an Engineering Consultant and holds five patents in his field of electrical engineering. He began building vacuum tube audio equipment in high school. He plays jazz guitar and enjoys modifying guitar amplifiers and effects to reduce noise and distortion, as well as building and restoring audio test equipment. He has another book to his credit, The Joy of Audio Electronics, and over 200 magazine articles on electronics and audio. He joined the Bendix Red Bank Division in 1966, and retired in 1998 as Supervisor of the Systems and Controls engineering group.

REFERENCES

1. "Deadly Accuracy," *Inventions and Technology*, Spring 2001, D. Colley.
2. Nonex was a slightly different borosilicate formulation than the Corning Pyrex or Kimble Kimax glasses that were used for laboratory test tubes and flasks.

A Brief History of Bendix Red Bank Tubes is available for $24.95 from Old Colony Sound Lab (PO Box 876, Peterborough, NH 03458, 888-924-9465, custserv@audioXpress.com). The book, which contain over 80 pages, clearly details the role this N.J.-based company played in the history of tube manufacturing. Includes photos of the Red Bank tubes manufactured, a list of key Bendix personnel, and dozens of pages of valuable datasheet information about these tubes.