Fig. 1—The 500 MHz buncher cavity.

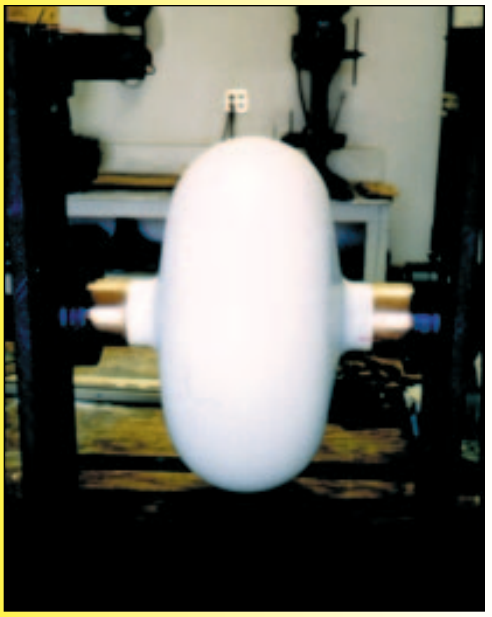

Fig. 2—Buncher cavity mandrel.

Fig. 3—Mandrel conductivized with silver paint.

Copper Electroforming Success Stories—Fabricating a 500 MHz Buncher Cavity

By Glenn Malone, CEF

This presentation from the 1997 AESF/NiDI Electroforming Course & Symposium describes the fabrication of a 500 MHz buncher cavity assembly using copper electroformed from the acid sulfate electrolyte. The buncher cavity is a high-power radio frequency (rf) device used in a modular component project at TRW Space & Electronics Group, Redondo Beach, CA. The device, shaped as an oblate spheroid, contained integral stainless steel vacuum ports with flanges, cavity inlets (for rf couplers, probes and other equipment to operate the device), stainless steel rings (for support and force reaction sites for tuning the cavity) and external cooling manifolds and tubes.

A high-power rf device—known as a 5000 MHz Buncher Cavity—to be electroformed consisted of a thin-wall copper shell with a precise internal shape that would present a resonant cavity to rf energy at 500.00 MHz. The inside required capability to be evacuated to high vacuum conditions of 1 x 10^{-9} Torr. Wall thickness of the copper cavity was 0.125 in. Various components, such as high vacuum flanges, rf, couples ports, probe ports, other instrumentation ports, water cooling system and means for mechanical adjustment of the cavity shape (reaction rings) were attached to the outside of the cavity by various means. The complexity of the device to be fabricated is shown in Fig. 1.

Mandrel Selection, Preparation & Fixturing

Selection of an epoxy-fiberglass mandrel over an NC machined mandrel was based on a shorter delivery time and lower cost (two epoxy mandrels were made for less cost than a metal mandrel).

The epoxy mandrel was source-inspected by the customer and found acceptable—particularly with regard to the polished finish. Figure 2 shows the fixtured mandrel with the polar end stainless steel vacuum flanges installed. All vacuum fittings were adapted by machining from commercial stock vacuum hardware. The nipple ends were tapered to make a smooth transition to the cavity wall during copper electroforming. Each was activated and plated with a thin layer of copper prior to mounting on the mandrel polar extensions. The flanges proper were not plated. The flange nipples were masked to protect them from paint contamination, while the epoxy mandrel was spray-coated with silver pigmented paint having a butyl acetate vehicle. Each coat was cured and hand polished before applying the second and third coat (Fig. 3).

The fixture was built from PVC to form a frame on which was mounted two vertical PVC plates with center holes for affixing the rotational shaft and drive system for the part during electroforming. The mandrel could be adapted to contain a metal drive shaft with electrical contacts to the vacuum flanges mounted on each polar extension of the mandrel. Plastic slip-rings on each end of the mandrel drive shaft, resting on dual plastic rollers built into the fixture, permitted heavy-load rotation of the mandrel, which filled with water and sealed to overcome buoyancy.

The drive shaft was keyed to permit attachment of a PVC pulley wheel for rotation. Attached to the wheel was a plastic composite drive belt driven by another pulley wheel mounted to a gear box shaft, and a variable speed drive motor. A PVC pipe threaded into a seal housing on the main rotator shaft of the cavity contained an electri-

cal lead and spring-loaded commutator to supply current to the part. The cavity mandrel mounted in the fixture is shown in Fig. 4.

Acid Copper Sulfate Electrolyte & Deposit Mechanical Properties

The plating bath contained 936 liters of acid copper sulfate solution containing 187–225 gal/L of copper (as metal), 60–75 gal/L of sulfuric acid, and 0.5–0.8 gal/L of d^+ xylose (a pentose known to reduce oxides at the cathode surface during deposition). The bath was operated at a temperature of 30 °C (86 °F) and a current density of 2.15 A/dm^2 (20 A/ft^2). Use of periodic current reversal had been considered for this electroforming task to maintain smaller, more uniform grain sizes. Because brazing would be used to attach certain appendages to the cavity wall, however, annealing would occur, and grain growth would be expected. Therefore, conventional direct current plating was used.

Test specimens were deposited from this bath to a thickness of 3.81 mm (0.150 in.) for mechanical property evaluation. Two specimens were heat treated at 538 °C (1000 °F) and tested to determine brazing effects on the mechanical properties. The results were:

	As Deposited	Heat Treated
Ultimate Strength, ksi	25.3	30.2
Yield Strength, ksi	12.8	10.9
Elongation, % in 5.08 cm	16.2	41.4

Other testing included silver spray painting electroformed copper for exposure to the epoxy stripper to be used in removing the fiberglass-epoxy mandrel. The paint binder was removed with no attack on the copper. A cut-off of excess stock from the polar extension of one of the mandrels was soaked in epoxy stripper to confirm that the epoxy could be broken down for removal of the fiberglass material.

Copper Electroforming the Cavity Wall

The half-nipple vacuum flanges were masked for the first stage of electroforming to prevent weak copper bonds from forming over the copper-plated fittings. This would occur as a result of not activating for copper bonding—it was feared that the phosphoric acid and sulfuric acid deoxidation and activation system might degrade the silver paint on the mandrel. The mandrel fixture was attached to a hoist that permitted periodic inspection of the cavity during electroforming (Fig. 5). This allowed the part to be raised to expose surfaces during rotation so that all areas could be inspected prior to lowering back into the bath. Deposition was started at a very low current density and gradually raised to prevent burning of the silver pigmented paint. After a buildup of 1.27 mm (0.050 in.), the first electroforming stage was complete. Each cavity/vacuum fitting interface as reworked with jeweler's tools (after de-masking) to remove unbonded copper, then inspected for adequate joint profiles. The entire surface to receive further electroforming was now electrodeposited copper.

Preparation for bonding the second stage of copper electroform was achieved by treatment in 75% by volume phosphoric acid at 8–9 volts (electropolishing), rinsing, cathodic treatment in 25% by volume sulfuric acid and double rinsing. Voltage was applied to the cavity, which was placed in the copper electrolyte with low current during immersion. Current was slowly raised until the required current density was achieved. Electroforming was continued in additional stages until an expected thickness in excess of 3.175 mm (0.125 in.) was achieved. The excess thickness was for external surface machining purposes. Machining was performed on a large lathe (Fig. 6).

Adding Components

The next step involved growing the vacuum flange half nipples at positions 180 degrees apart on the equator of the cavity. The part was masked with areas exposed where the pedestals for the nipples would be mounted. PVC rings were manually sculptured to seat at the exposed locations. The objective was to fill these rings with electroformed copper bonded to the

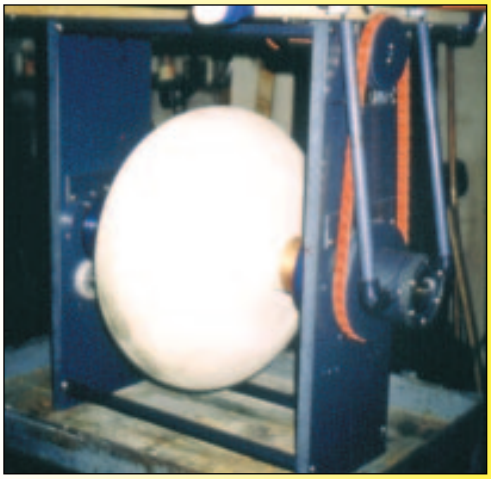

Fig. 4—Cavity mandrel in electroforming fixture.

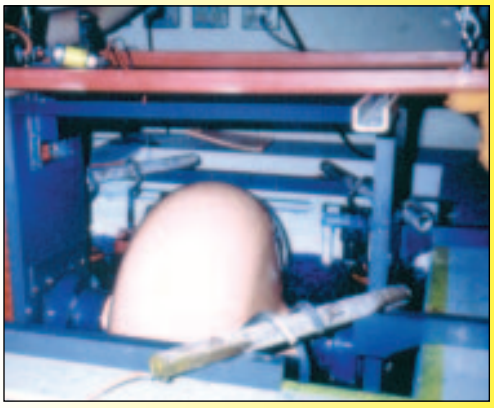

Fig. 5—Cavity inspection during electroforming

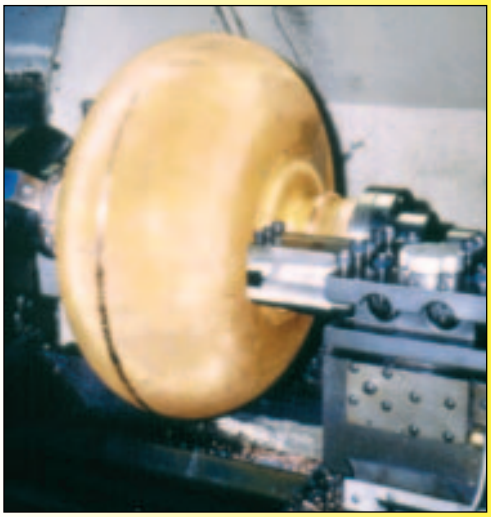

Fig. 6—Cavity outside profile machining.

Fig. 7—Electroforming pedestal for equator flange grow-ons.

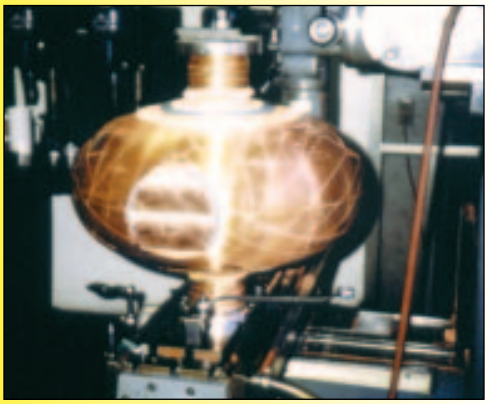

Fig. 8—Milled pedestals for flange nipple mounting.

Fig. 9—Equator flange electroform joint.

cavity wall (Fig. 7). At the same time, additional plating was applied to areas near the polar flanges that did not clean up during initial machining. One of the pedestals is shown in Fig. 8, after machining on an end mill. Holes were drilled into the pedestals for mounting the half nipples with cover plates and threaded rods. The half nipples were pre-plated with bonded copper. After activation, a copper electroformed "weld" was made at each pedestal/nipple interface. Manual dressing and rotary filing were required periodically during the "grow-on" operations. Figure 9 shows a vacuum flange electroformed in place at the cavity equator.

At this point, the mandrel required removal to accommodate the brazing operations. A rotating fixture was built (Fig. 10), and all openings were sealed with metal plates to contain the epoxy stripping solution. The cavity was rotated for a 24-hour period to allow the solution to attack the epoxy. The large polar ports were opened and the stripper drained. Fiberglass could be removed manually through these ports. The cavity was well rinsed and re-mounted on the rotation fixture. Ceramic polishing cones were poured into the cavity and the ports resealed. The part was then tumbled for several hours to remove all traces of the silver paint, and to polish the interior of the cavity.

The stainless steel reaction rings were next brazed into place around the polar vacuum flange nipples (Fig. 11). Other tubes for probes and instrumentation were added in separate brazing operations. Progressively lower temperature braze alloys were used in each subsequent operation. The cavity was purged with argon burning in all brazing steps. Machined copper-water coolant manifolds were spot welded in place circumferential to the reaction rings. Water coolant tubes were bent to a shape conformal to the cavity and assembled into openings in the copper manifolds. Attachment of these parts was made by silver soldering. The final buncher cavity assemble is shown in Fig. 12.

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About the Author

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Fig. 10—Rotation device for mandrel removal and internal polishing.

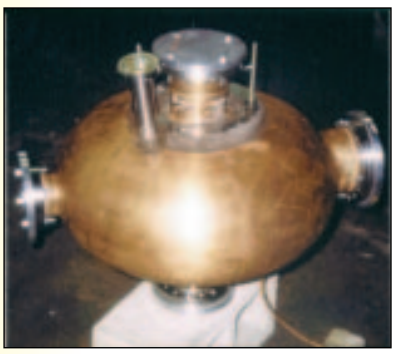

Fig. 11—Buncher cavity with brazed components.

Fig. 12—Buncher cavity with silver soldered cooling system.