ELECTRON TUBES FOR SUBMARINE CABLE SYSTEMS

The electron tubes developed for submarine telephone cable systems were probably the most reliable tubes ever made. Because of the use of electron tubes in costly to access sea-bottom repeaters, the first transatlantic cable system, TAT-1, was recognized as a very ambitious project. As former Bell Laboratories president W. O. Baker stated in the *Bell Labs News* of January 29, 1979, "TAT-1, for its time, ranked in engineering difficulty with the later feat of putting an earth satellite into orbit."[50]

While all components of the system were required to be highly reliable, the tubes, with a known wear-out mechanism, were the key to the success of the project. Reliability was designed and built into the tubes. At Bell Laboratories, work on tubes for use in a proposed transatlantic system was started in 1933.[51] A short field trial cable from Key West, Florida to Havana, Cuba was laid in 1950, and the first major system was put into commercial operation across the Atlantic in 1956.

The suggested objective for submerged repeaters was that the tubes should not be responsible for a system failure for many (possibly 20) years. At that time, an average operating life of a few thousand hours (perhaps three to four months) was satisfactory for tubes in the home entertainment field. In land-based telephone equipment, an average life of a few years was considered reasonable. To meet the 20-year objective, no new or untried technologies were introduced; the emphasis was on conservative design and careful manufacture.

In design, three basic assumptions were made: (1) operation at the lowest practical cathode temperature would result in the longest thermionic life, (2) operating anode and screen grid voltages for the tubes should be kept low, and (3) the cathode current density should be kept as low as practicable.

In manufacture, care would be exercised in the selection and processing of materials, in fabrication procedures, and in detailed testing; long-term aging of all tubes would be carried out. Records of these items would be reviewed as part of the final selection of individual tubes for use in the repeaters. This selection concept was unique at that time.

The tube developed and manufactured by Bell Laboratories was the 175HQ shown in Fig. 3-36. The operating characteristics were cathode temperature, 670 degrees C (true); anode and screen voltages, 32 to 51 V; and cathode current density 0.7 mA/cm^2.

The cathode operating temperature was derived empirically. Life tests were run for many years, even during World War II when testing had to be squeezed in, and while the bulk of the work was done at about 710 degrees C, the results at 670 degrees C and 615 degrees C indicated that 670 degrees C would be appropriate. Normal cathode temperatures were approximately 750 degrees C.

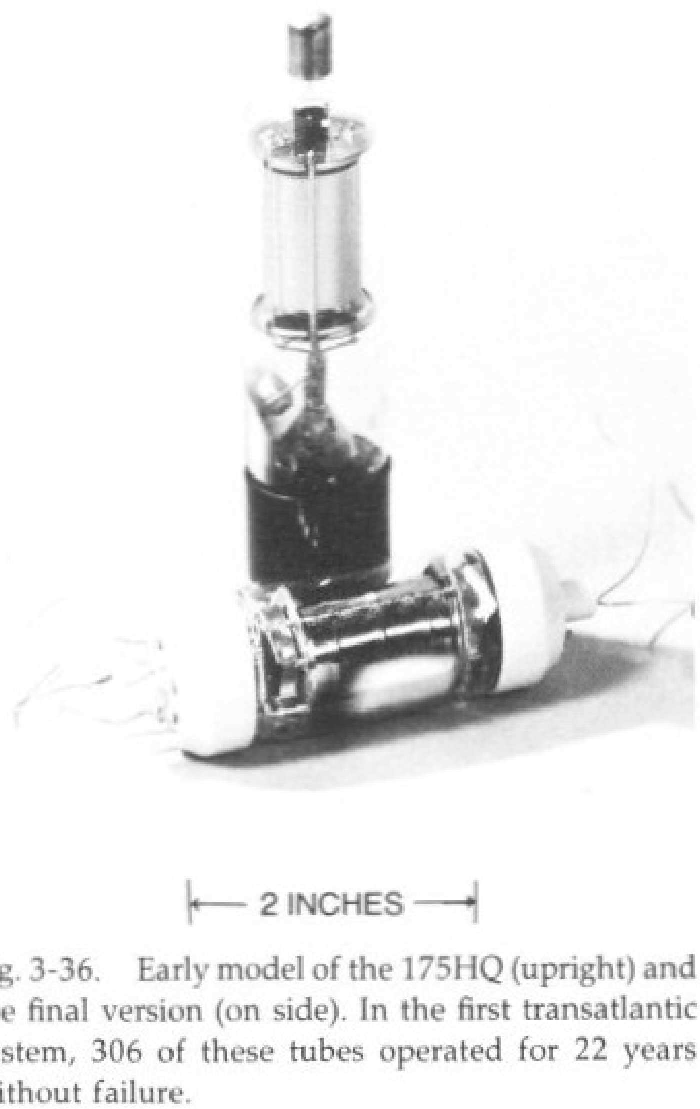

Fig. 3-36. Early model of the 175HQ (upright) and the final version (on side). In the first transatlantic system, 306 of these tubes operated for 22 years without failure.

Life tests were also used to study the effects of anode and screen grid voltages over the range of 40 to 60 V. No essential differences in performance were noted after eight years of operation, so the voltages listed above reflected the needs of the system. Voltages used in other vacuum tube amplifiers were typically 150 to 200 V.

The effect of cathode current density on thermionic life was also studied by life tests. After about 14 years, there was practically no difference over a 12-to-1 range of densities, i.e., 2.5 mA/cm^2 and 0.2 mA/cm^2. The final choice was to operate at 0.7 mA/cm^2, in contrast to normal current density of 50 mA/cm^2.

One common cause of tube deterioration with life is the formation of an interface layer on the surface of the cathode sleeve. As mentioned above, this depends in a complex way on the chemical composition of the cathode core material and, in effect, introduces a resistance in series with the cathode. This results in negative feedback and reduces the effective transconductance of the tube. The low transconductance of the 175HQ tube (1000 mS), the low cathode temperature, and the large cathode area were favorable factors to minimize the effects of this interface resistance. Again, as a result of life testing, one batch of nickel (melt 84) was selected for use in the production.

The tungsten heater for maintaining the cathode at the proper temperature was critical, since the heaters of all tubes in the system were connected in series. One open heater would disrupt the cable. Protection of the heaters from power surges was provided by a bypass gas tube across the three heaters of each repeater. Careful selection and control of the tungsten wire was instituted. The heaters were run at 1100 degrees C, which is well below that used in conventional tubes.

All 175HQ tubes used in submarine cables were made at Bell Laboratories, under the close supervision of many of the original development engineers. Fabrication was carried out with extreme care by operators specially selected for the job. Nylon smocks, acetate rubber gloves, and restricted areas were early steps toward modern ultraclean facilities. Thorough mechanical and electrical inspections over a 5000-hour aging period provided information for selection of individual tubes for cable use. By normal commercial test limits, the yield would have been about 98 percent. With the criteria used, only one tube in seven was accepted.

The original objective of a 20-year life was met by the first transatlantic cable, where 306 tubes operated for 22 years without a tube-related failure. This cable was retired in November 1978, for economic reasons. At that time, the 1608 175HQ tubes on sea bottom in seven cable systems had given 287 million tube-hours of trouble-free service.

The development of a new tube for the SD (1-MHz) cable system was started in 1955. The resulting 455A-F tubes[52] were designed by Bell Laboratories and manufactured by Western Electric in Allentown, Pennsylvania

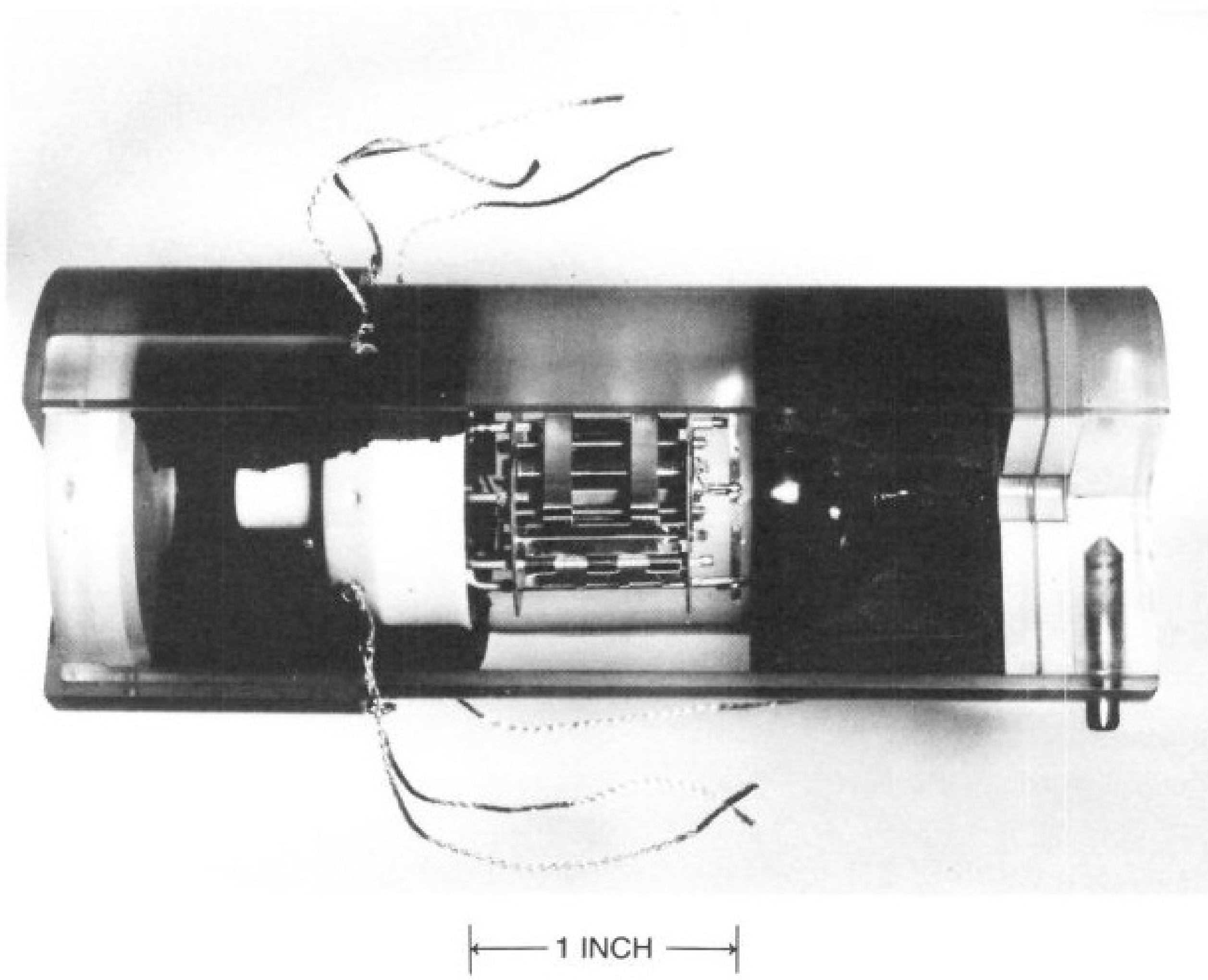

Fig. 3-37. The 455A tube cushioned in a methacrylate housing, used in the 1-MHz SD submarine cable system. As of November 1978, 5874 such tubes in 10 cable systems had accumulated 738 million tube-hours of service.

with the close surveillance and cooperation of a resident group of Bell Laboratories engineering personnel. This tube is shown in Fig. 3-37.

To meet the same 20-year system reliability objective, developers of the new tube used an extension of the 175HQ design philosophy, updated in those areas where significant progress in basic knowledge had been made. For the broadband system, a higher-transconductance tube was needed, and a much closer grid-to-cathode spacing was required. The spacing for the 175HQ tube was 0.024 inch, compared to 0.0055 inch for the 455A-F. The use of frame-type grids aided in maintaining the closer spacing. Table 3-3 compares the two tubes.

Table 3-3. Comparison of Submarine Cable Tubes

	175HQ	**455A-F**
Cathode temperature (true)	670°C	670°C
Cathode current density	0.7 mA/cm^2	10 mA/cm^2
Grid-cathode spacing	0.024 in.	0.0055 in.
Maximum element voltage	51 V	45 V
Transconductance	1000 μs	6000 μs

With the closer spacing, concern for small particles of debris in the tube structure was increased. To improve microscopic inspection for such unwanted particles, development engineers designed the tube with an open structure. Minimization of particle generation was effected by assembling the tubes under laminar flow hoods located in segregated clean rooms and by other advances in environmental control. This was the showplace clean room of its day.

As seen in Table 3-3, the cathode temperature was kept at 670 degrees C (true) but the current density was increased from 0.7 to 10 mA/cm^2. This was necessary to achieve higher transconductance but was considered reasonable in the light of long-time life tests. The choice of cathode material was again of prime importance. By this time, work by physical chemists had advanced the knowledge of cathode emission phenomena to the point where the use of specific materials could be recommended. Thus cathodes were made from selected melts of high-purity nickel to which had been added 2 percent of magnesium.

Once more, close attention was paid to the tungsten used for heaters, since the heaters, protected in a more refined way by gas tubes, would again be connected in series for the entire system. Control of materials, assembly, processing, aging, testing, and inspection were pursued to a high degree, and again all information was scrutinized in selecting individual tubes for system use.

The performance record of the 455A-F tubes was most impressive. As of November 1978, 5874 tubes in 10 cable systems had accumulated 738 million tube-hours of service. Two tubes were considered "probable failures," although no service interruption could be directly attributed to either tube.

The gas-tube surge protectors were made with the same conservative care. While they were not actively part of the repeaters, they provided standby protection and were required to perform over the same time period in the same remote locations.

Gas-filled bypass tubes were needed in each repeater as a part of the fault-locating arrangement. They were designed to break down in the event of an open circuit within the repeater, thereby restoring circuit continuity so that the remainder of the repeaters could continue operating. The tubes were also necessary to protect against transient surges that might propagate down the cable in the event of external damage to the cable sheath. Requirements for the bypass tubes were (1) the breakdown voltage must be safely above the normal operating voltage drop across the repeater; (2) when breakdown occurs as a result of an open circuit within the repeater, the tube must be able to carry the full cable current of 0.25 A with a sustaining voltage less than 20 V to minimize heat generation in the repeater; and (3) for surge protection, the tube must safely carry short-duration current pulses of either polarity measured in hundreds of amperes. An argon-filled tube containing a cold cathode heated to emitting temperatures by ionic bombardment successfully met these requirements.