# Housings For Undersea Photonic Systems - 2010

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**Abstract:**

In repeatered systems, optical amplifiers are housed in hydrostatically sealed containers that must withstand demanding service conditions. Components for these housings are produced in relatively small quantities on irregular production schedules. Quality assurance measures are as rigorous as found in any industry often surpassing the requirements of aerospace, oil and gas, and power generation. These requirements must be met at as low a cost as possible. This paper describes the manufacturing and engineering challenges and offers suggestions for improvement.

## 1. INTRODUCTION

This paper discusses ways in which one supplier, namely our company, has approached the goal of meeting the complex demands of this industry with total reliability. Two points must be emphasized.

First, although we can only comment knowledgeably from the point of view of a single company, other suppliers worldwide must have closely similar approaches judging by the success that all have achieved. We know that these statements are true for us; the inference is that they are true for others who serve this industry.

Second, the technology of the undersea repeater housing is contained in the intricate detail of thousands of drawings, specifications, special engineering instructions and other documents that the cable companies have developed. These are, of course, highly proprietary to those companies. This explains, at least in part, the relatively small amount of published information available. Nevertheless, the comments of this paper are based on information learned from our experience and from publications in the open literature.

Specifically, these housings must:

- Remain leak tight for twenty five years or more,
- Resist corrosive environments and hydrostatic pressure in subsea service,
- Survive mechanical stresses from aggressive handling in deployment,
- Join and seal easily during manufacture and assembly by welding, brazing and soldering.
- Seal completely and reliably in threads and press fit joints,
- Bond well to polymers and elastomers,
- Contain high voltage without danger of arcing,
- Avoid galling or seizing during cable makeup,
- Maintain precise dimensional stability in manufacture and service, and

 

- Keep components cool by dissipating internally generated heat.

Figure 1 provides an example of the various components and illustrates the variety in size and shape.

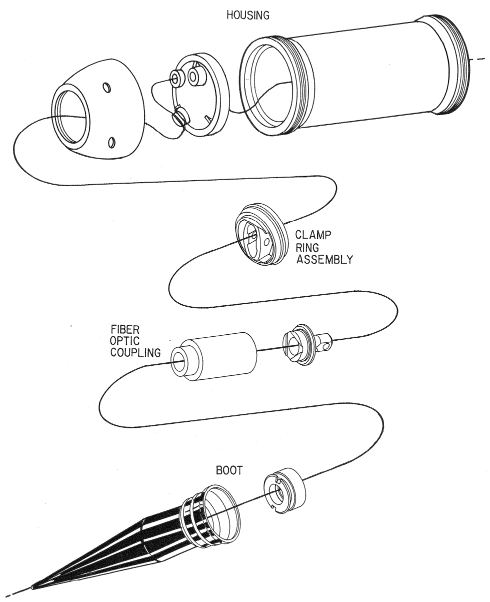


**Figure 1: Generalized Illustration of Repeater Housing Components**

## 2. OVERVIEW

From the undersea coaxial telephone cables of the 1960s to the advanced fiber optic cables of the 2000s, housing designs have remained essentially unchanged[1]. In the earliest coaxial systems, small diameter, articulated housings were used[2] since they simplified cable laying operations, but these proved impractical as electronic systems increased in capability. Advances in shipboard technology, achieved by the mid 1960s, enabled cable ships to handle larger housings while laying cable continuously. These advances permitted the use of housings which, with relatively minor upgrades[3,4,5], and in different configurations[6,7] have been used successfully through more than three decades. Housings for branching repeaters have similar requirements[8] but are larger and produced in still smaller quantities.

With the engineering and design parameters established, the technology became almost routine, but a careful program of continuous improvement was implemented and still exists today. Table 1 shows a timeline of some events that have led to today's state of art.

| | |
|---|---|
| 1953 | *"Corrosion Resistance of Beryllium Copper"* [9] |
| 1954 | *State-of-art Casting and Extrusion plant opened* |
| 1956 | First Transatlantic Telephone Cable - TAT-1 Articulated Repeater (Retired 1978) |
| 1958 | *Precision Cast housing and boot frame components* |
| 1959 | TAT-2 Articulated Repeater (Retired 1982) |
| 1961 | CANTAT-1 First Large Housing |
| 1961 | *First Pressure Cast End Covers* |
| 1963 | TAT-3 First Flexible Housing |
| 1964 | TPC-1 First Transpacific Cable |
| 1970 | Defense Systems - C17200 housings |
| 1972 | *First Precision Forged End Covers* |
| 1973 | *First Reverse Extruded Cylinders* |
| 1976 | TAT-6 First Buried Cable |
| 1983 | *Advanced Rod and Tube production High Productivity Heat Treating and Cleaning* |
| 1986 | First Southeast Asia Cable |
| 1988 | TAT-8 First Fiber Optic Cable – Regenerated |
| 1990 | *Advanced Fluorescent Dye Penetrant inspection system* |
| 1992 | TAT-9, 10, 11 TPC-3 Fiber Optic - Amplified |
| 1993 | *Streamlined Material Specifications* |
| 1997 | *Advanced Direct Chill Casting Facility* |
| 2001 | 187,000 route km installed – all time record |
| 2002 | *Extrusion Capability extended to 54" (1400 mm)* |
| 2005 | *Machining Process Advancements* |
| 2008 | *Corrosion analysis – eight modes – 22 year exposure* |
| 2009 | *Forging, NDE inspection, chemical analysis, inventory management developments.* |

**Table 1: Timeline – Undersea Communication – Long Haul Systems**

As electronic/photonic equipment has been downsized, housings have not become significantly smaller. One reason might be related to the tremendous increase in the capacity of the optical amplifier system. This requires more devices that make up for their smaller size with higher numbers and more volume. But another reason is possibly that reducing the size of the housing to the minimum volume for optical amplifiers would require extensive design work and reliability analysis. Shipboard and assembly plant handling systems might need modification. The costs of this would be amortized over a fairly small number of housings. Furthermore, the cost of a repeater housing is less dependent on size than on other factors especially the quantity produced, complexity of the manufacturing process, testing requirements, machining precision, and acceptance procedures.

Throughout nearly five decades of building repeatered systems, housings were designed initially by advanced research and development laboratories (Bell Laboratories and KDDI Laboratories for example)[10] and later improved by the cable laying companies. This was essentially in accordance with the "build-own-operate-maintain" philosophy that governed cable construction. In the process, small teams of engineers from the cable laying companies built a considerable reserve of test data and experience in this narrow field of material technology. Although possible to borrow from shipbuilding, marine military systems, and undersea exploration technologies, commercial telecommunication needs were special enough that they required their own unique developments. Cable alternatives and electronic packages often received the greatest attention because of their rapidly changing technologies and because of the sizable capital investment required in their production. Housing these electronics successfully was a detail left to relatively few specialists.

These specialized engineering teams produced intricate drawings of intermediate shapes, finish machined parts and parts assemblies. Most drawings contain detailed notes and references to a system of specifications covering the parts themselves as well as the materials and compounds used in their manufacture. Total reliability at reasonable cost was the central issue. Suppliers may have offered suggestions, but in general the rule was "make to print." The telecommunication engineers became involved in the manufacturing and spent significant time in the suppliers' plants to ensure that their designs were understood, that the test and inspection requirements were met, and that the products were successful in meeting all their expectations.

Although the internal contents of the containers changed dramatically with the advent of fiber optic systems in about 1988, the container design itself did not change noticeably. The cost of changing a handling system aboard ship or within an assembly plant apparently was so high as to make a major change prohibitive. In addition, there was little reason to change since the system reliability had been superb.

From these design and development efforts emerged a transoceanic cable system that has experienced virtually no failures caused by any of these housing members, at least in the experience of this manufacturer.

## 3. SYSTEM COMPONENTS

The basic housing elements include cylinder components and coupling parts. The cylinder parts make up the pressure-tight body of the housing and include the cylinder, end covers and end rings. The end covers accommodate sealing mechanisms where the fiber passes through. End rings protect the glands from damage during deployment and allow for tension transfer to the next cable section.

The coupling parts consist of the gimbal assembly and the fiber optic coupling box with connecting hardware. The gimbal assembly acts as a universal joint to maintain cable to repeater alignment during deployment, and the coupling cylinder is the container in which the cable is spliced. Altogether there are over 40 individual parts that are assembled via threaded joints or welds to make up the complete housing. The estimated number deployed is charted in Figure 2.

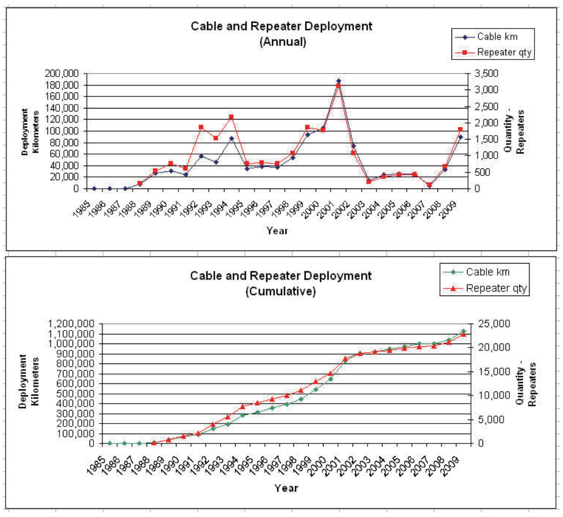


**Figure 2: Submarine Fiber Optic Cable Deployment with Estimated Repeater Usage, 1985 – 2009** [11]

## 4. METALWORKING

The components are made by a wide variety of metalworking processes. For example, in our process, cylinders are reverse extruded, covers are forged in a closed die system, and the major gimbal parts are machined from extrusions or forgings. Cones and some coupling parts are machined from castings. Cold drawn rod is used for pins, screws, and connecting rods. Strip or sheet is used for the retaining rings, shims, springs, and washers. Nearly all major product categories are represented in the finished repeater.

Scheduling these through the process equipment in small lots requires careful attention to detail. Full traceability is maintained with major parts serialized. All parts retain identification of the numerical code or "heat number" of the melting and casting operation prior to hot working by extrusion or forging operation. All processing is done according to the requirements of an ISO 9002 quality system. In our case the parts are manufactured in an AS9100/ISO9001 certified facility.

## 5. MACHINING

Some special requirements of the finish machining operations are worth noting.

End covers are usually joined to the ends of the cylinders by welding around the circumference of the cover. Welding is done as part of the repeater assembly process. Achieving a helium leak tight seal requires a high degree of precision in machining the outside diameter of the cover to fit closely inside the cylinder. The machined fit requires high precision; the clearance before welding is only slightly wider than the thickness of a human hair (or an optical fiber).

The cones are mated to the cylinder with matching threads. These threads require moderately high precision in machining, and because of their large diameter coarse pitch, special thread gauges are needed to facilitate machining and inspection. These gauges need regular calibration and other special precautions in order to be sure that the final assembly goes smoothly wherever it is done. The gimbal parts are fitted into the cone via moderately large diameter threads also, and the same considerations regarding gauges apply.

The components of the gimbal mechanism are assembled with opposing guide pins. Smooth operation of the gimbal requires that the diameter of these pins precisely match the diameter of the holes that contain them. Furthermore, the holes must be precisely located and perfectly aligned. Snap acting retaining rings keep the pins, and therefore the entire assembly, locked firmly in place. Machining of these components is not difficult, but the machine setup is time consuming when starting a new production run. Production runs are typically not very long.

## 6. NON-DESTRUCTIVE EVALUATION AND MECHANICAL PROPERTY TESTING

The critical parts of the repeater housing are subject to rigorous testing and evaluation prior to shipment. The chemical composition must comply with specifications covering major alloying elements and impurities. Heat treatment is confirmed by in-process hardness measurement, and the hardness of the finished parts are measured and certified. Some users require tensile tests on each cylinder and cover with a statistical sampling of other critical parts. Others require destructive testing periodically.

Ultrasonic inspection and x-ray examination are required for some parts, but there is a trend away from these techniques because of the time required and cost involved compared to the benefit attained. These tests would seem to be especially useful when finish machining is performed by the end user and the metal supplier provides rough blanks. In this case the non-destructive evaluation is performed on the blank which should be designed as a "sonic shape" (the term referring to the design of the blank in a way that facilitates testing).

By far the most important test is Fluorescent Penetrant Inspection. This technique is used to inspect finish machined components for surface connected indications, the type that could be most damaging to undersea service. Modern methods have automated the penetrant application, material handling, and visual reading in this process. The cost is modest, and the degree of safety that is gained makes the test highly worthwhile.

## 7. SERVICE PERFORMANCE

To this point our comments have been applicable to virtually any metal, alloy or composite that could be considered for service as a repeater housing. From here our observations are directed to the performance of the copper beryllium alloys that have been used in undersea service for as long as the program has been in existence.

Most components require wrought products made from the alloy designated UNS C17000. This alloy contains nominally 1.70 -1.85 weight percent (w/o) beryllium, 0.3 w/o cobalt with the balance (nominally 97.8 w/o copper). Cast components specify use of the alloy C82400. The nominal composition for this alloy is 1.7 w/o beryllium, 0.3 w/o cobalt, with the balance (at least 98 w/o) being copper. The trend since the mid 1990s is toward use of the more standard UNS C17200 for coupling parts since this alloy offers potentially shorter lead time.

The undersea telephone cable program began more than 40 years ago. We estimate that well over 20,000 units (see Figure 2) have been placed in service under the ocean in all types of undersea environments. Some are buried under mud, others are half submerged. Some lie exposed in deep ocean water, others are wholly or partially exposed at shallow depths. Some are in polluted water containing sulfides and oxygen as well as the chlorides and other cations typical of seawater. Others see clean seawater conditions. Microorganisms are present in many environments. Yet all continue to accumulate service hours unless retired by the primes.

There have been no service failures reported to us and we are told that many of the cables put down in the early years are still functioning. Others were decommissioned because of technical obsolescence after 20 or more years, but in all likelihood their housings would still be performing today. These facts tell us that the alloy and its manufacturing processes are fundamentally sound. It also tells us something about the mechanical and corrosion performance of the alloys. Specifically the record of successful service shows that general corrosion, pitting corrosion, crevice corrosion, and stress corrosion including the areas around welds are negligible under any of these undersea conditions. Similar service experiences are encountered in other fields where the alloys serve in contact with chlorides and salt spray such as are found in oil and gas drilling equipment and in aircraft landing gear components.

## 8. SAFE HANDLING

Handling copper beryllium in solid form poses no special health risk. Like many industrial materials, beryllium-containing materials may pose a health risk if recommended safe handling practices are not followed. Inhalation of airborne beryllium may cause a serious lung disorder in susceptible individuals. The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational respiratory exposures. Read and follow the guidance in the Material Safety Data Sheet (MSDS) before working with this material. For additional information on safe handling practices or technical data on copper beryllium, contact Brush Wellman Inc., 1-800-375-4205.

## 9. CONCLUSIONS

The demands on the undersea repeater housing are severe. The demands on the supplier are also harsh. The housing is expected to perform for 25 or more years and yet be made by processes that undergo continual cost pressures in spite of low and unpredictable production volume.

Our conclusions and recommendations are listed in the following points.

- Allow for realistic lead time in the supply chain.
- Provide forecasts that are as accurate and complete as possible. Startup and shutdown costs are high as is the cost of in-process and finished parts inventory.
- Consider standardization, perhaps beginning with coupling components and associated hardware.
- Examine reduced testing requirements, relaxed dimensional tolerances, and reduced inspection where appropriate to reduce cost.
- Consider a careful review of the major repeater housing components in conjunction with the material supplier to improve overall manufacturing efficiencies.

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