Honeywell (formerly AlliedSignal, Inc.)

# Metallic Glass to Improve Electric Energy Efficiency

*Over the last several decades, many industries have sought ways to reduce energy consumption as well as harmful emissions. A less familiar method is to reduce the loss of electricity that occurs during the distribution and consumption of electric power (hereafter referred to as power loss). In response, AlliedSignal, Inc., proposed to improve the efficiency of the magnetic core materials used for electric-power transformers and motors. The company believed that its proposed technology, thick ductile metallic glass for electric-power applications, could aid the United States' energy-saving efforts. However, because of technical failures in this area by other companies, AlliedSignal was reluctant to fund the research. In 1992, the company applied for funding from the Advanced Technology Program (ATP) to assist in its three-year research and development project. The project began in 1993 and by the end of the project, AlliedSignal had developed thick metallic-glass ribbons for use in electric-power transformers and motors. They were able to demonstrate a 60-percent reduction in core power loss as compared to conventional grain-oriented silicon steel that was commonly used. Moreover, AlliedSignal's technology has been successfully incorporated into anti-theft devices.*

**COMPOSITE PERFORMANCE SCORE**
(based on a four star rating)
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**Research and data for Status Report 92-01-0116 were collected during September 2001 - January 2003.**

## Energy-Efficient Transmission of High Voltage Proves Problematic

For decades, the electric-energy industry understood that inefficiencies exist in all phases of the electric-power cycle (power-generation, transmission, conversion, and consumption). A primary inefficiency results from magnetic and ductile materials (that is, materials that are easily molded or shaped) that lack the ability to transmit high currents.

Typically, stacked grain-oriented steel wires or plates were used to make the cores of electric-power transformers and motors. Researchers sought alternative materials that had the following specific characteristics: high ductility, superior magnetic qualities, and a high degree of fabrication (cutting and stacking) adaptability. Metallic glass was considered a viable alternative because of its superior characteristics. Additionally, metallic glass was efficient in low-power transformers and motors. However, scientists had not been able to develop metallic-glass ribbon with the thickness needed in high-power electric transformers and motors. The challenge was to create a thick (greater than 75 micrometers [µm]) metallic-glass ribbon capable of carrying high-voltage electricity. Previous attempts consistently delivered brittle materials incapable of being incorporated into functional motors or transformers. These development failures worried AlliedSignal's management, who hesitated to fully fund such a high-risk project. Consequently, in 1992 AlliedSignal turned to ATP for cost-shared funding for the development of its proposed technology. With ATP providing approximately 50 percent of the financing and affirming the technical merits underlying the proposal, AlliedSignal's top management was willing to pursue research and development (R&D) efforts.

## AlliedSignal Seeks To Develop Manufacturing Process

AlliedSignal's broad objective was to develop a manufacturing process for producing 75-µm ductile metallic-glass ribbon required for high-power (greater than 100 kilowatts [kW]) stacked-core transformers. To achieve this objective, AlliedSignal had to meet several milestones over the course of the three-year project, including the following:

- Design and fabricate a new casting system
- Define the requirements and demonstrate an air-side cooling system concept
- Cast a 5-cm-wide ribbon with a thickness up to 75 µm
- Produce a 50-µm- to 75-µm-thick, 14.2-cm-wide ribbon
- Produce a 75-µm-thick, greater than 7-cm-wide ribbon with good magnetics

Additional milestones included improving the annealing (i.e., the heating and slow cooling of glass or metal in order to toughen and reduce brittleness and to strengthen or harden the material) and ductility/cuttability processes. Achieving these milestones was essential to the success of the project and its anticipated broad-based economic benefits. Because of the magnitude of AlliedSignal's objectives, the company subcontracted with the Division of Engineering and Applied Sciences at Harvard University and ABB Transmission Technology Institute (ABB) to develop and test specific components.

## Subcontractors Assist in Achieving Project Objectives

At the project's completion, AlliedSignal, with the support of Harvard and ABB, successfully achieved the following objectives: (1) developed a casting system that provided significantly higher cooling rates than were previously possible; (2) established conditions for casting metallic-glass ribbon up to 80 µm thick; (3) gained an improved understanding of the correlation between casting conditions and ribbon properties; (4) developed a 53-µm-thick, 14.2-cm-wide ribbon with high-quality magnetic properties; (5) developed a 75-µm-thick, 7.6-cm-wide ribbon with high-quality magnetic properties; (6) constructed equipment and processes for cutting thick ribbon; and (7) incorporated a process for annealing spooled ribbon.

***The challenge was to create a thick metallic-glass ribbon capable of carrying high-voltage electricity.***

Harvard conducted a fundamental characterization task that revealed that ductility-controlling solidification events occurred near the glass-transition temperature. This analysis was critical in determining optimum conditions for producing metallic glass that would retain quality ductile characteristics. While Harvard's role in the project was to maintain a theoretical perspective, ABB's functional contribution was to improve the cuttability of the metallic ribbons. It was essential that the ribbons be cut properly before they were incorporated into the transformers. If the ribbons were improperly cut, they would cause technical inefficiencies in the transformers, thereby reducing the benefit provided by the thick ribbons. Both ABB and Harvard overcame the challenges they faced, which allowed AlliedSignal to meet its milestones and achieve the overall objectives of this ATP project. AlliedSignal's successful technology resulted in a 60-percent reduction in core losses, a significant achievement for AlliedSignal, Harvard, and ABB.

## Several Factors Stall Widespread Technology Integration

Although the electric-power industry agreed that existing technologies needed to be replaced with improved alternatives, the associated replacement costs were significant. Therefore, several studies and analyses have been conducted to determine whether the current technology should be replaced immediately or should be phased out as existing transformers become inoperable or obsolete. These studies and analyses have concluded that replacing worn-out transformers over time is the commercially viable alternative.

In the electric-power industry, thick metallic-glass ribbons are now being used in power transformers. While electric-power motors and generators are expected to incorporate this technology, the adoption cycle will be longer because generators and motors have longer service lives and are more expensive. Once the transformer sector has fully adopted metallic-glass ribbons, efforts will focus on integrating the technology into other areas.

### Technology Spills Over into Anti-Theft Devices

Anti-theft devices used primarily in retail stores use a metallic-glass material that is similar to the material used in the improved electric-power transformers. The anti-theft devices use the magnetostrictive properties of the metallic glass; that is, properties that couple the magnetic properties to the mechanical vibration modes of the material. Each device consists of a strip of metallic glass enclosed by a capsule that is attached to the retail item. Sensors at the store's exit door sound an alarm when a magnetostrictive device, commonly called a resonator tag, passes through the exit before a clerk deactivates it.

*AlliedSignal's successful technology resulted in a 60-percent reduction in core losses.*

The technology AlliedSignal developed during this ATP project has been incorporated into the commercial production of resonator tags. The technology has also opened the possibility of new product designs for anti-theft devices, with a potential market of more than 20 billion resonator tags per year. In addition, the thicker ribbons enable a product extension to magnets for these new resonator systems.

### Further R&D Essential for New Product Development

While the electric-energy and the anti-theft-device industries are currently experiencing large-scale benefits from this technology, AlliedSignal, which later merged with Honeywell, is continuing its R&D in the metallic glass technology in order to penetrate additional industrial sectors. The technology is still limited by the following factors: cutting this product is difficult; the magnetic properties need to be improved; and the annealing characteristics are only useful in certain applications. As these problems are overcome, widespread utilization across other industries may be possible.

*The technology AlliedSignal developed during this ATP project has been incorporated into the commercial production of resonator tags.*

Revenues from the technology have ranged upwards of $100 million since the project's conclusion in 1996 from products that include power transformers and anti-theft devices. AlliedSignal expects its market share in the transformer arena to increase as more transformers become obsolete and are subsequently replaced. In addition, the company expects to incorporate a metallic-glass spin-off technology into electric generators and motors.

### Conclusion

ATP's support helped AlliedSignal develop a 53-micrometer (μm)-thick metallic-glass ribbon that demonstrated a 60-percent reduction in core loss over conventional grain-oriented silicon steel. AlliedSignal's management team was initially hesitant to invest fully in the technology because of the high possibility of failure and because of previous failed attempts by other scientists and corporations to create thick metallic-glass ribbons. However, with ATP's support, the company's management moved forward, and the project was successful. Furthermore, the company achieved its ambitious goal of discovering improved annealing and magnetic qualities for its ribbons. The spillover of this technology into the anti-theft device industry is an indication of its broad-based benefits. Without ATP's funding assistance, this technology and its associated benefits would have taken five to seven years longer to achieve.

# PROJECT HIGHLIGHTS
## Honeywell (formerly AlliedSignal, Inc.)

**Project Title:** Metallic Glass To Improve Electric Energy Efficiency (Thick Ductile Metallic Glass for Electric Power Applications)

**Project:** To develop a manufacturing process to produce 75-micrometer (μm)-thick ductile metallic-glass ribbon required for higher power (greater than 100 kilowatts [kW]) stacked-core transformers and generators to reduce wasteful power losses from electricity distribution and consumption in the electric utility industry.

**Duration:** 4/1/1993-3/31/1996
**ATP Number:** 92-01-0116

**Funding** (in thousands):**

| | | |
|---|---|---|
| ATP Final Cost | $1,967 | 47% |
| Participant Final Cost | 2,253 | 53% |
| Total | $4,220 | |

**Accomplishments:** AlliedSignal developed a 53-μm-thick metallic-glass ribbon that demonstrated a 60-percent reduction in core loss over conventional grain-oriented silicon steel. In addition, the company met the following objectives: (1) successfully developed a casting system that provides significantly higher cooling rates than were previously possible; (2) established conditions for casting metallic-glass ribbon up to 80 μm thick; (3) gained an improved understanding of the correlation between casting conditions and ribbon properties; (4) manufactured a 14.2-cm-wide, 53-μm-thick ribbon with high-quality magnetic properties; (5) crafted a 7.6-cm-wide, 75-μm-thick ribbon with high-quality magnetic properties; (6) constructed equipment and processes for cutting thick ribbon; and (7) incorporated a process for annealing spooled ribbon.

**Commercialization Status:** Metallic-glass ribbons are currently incorporated into many products that are sold worldwide. In the United States, revenues from the technology have ranged upwards of $100 million since 1996 from products that include power transformers and anti-theft devices.

**Outlook:** Honeywell anticipates that demand for this new technology in electric-power transformers will increase in the future. The company also expects that the technology will be incorporated into electric motors and generators, as old and obsolete units are replaced. At this time, the company continues to conduct research and development to increase the technology's capabilities.

**Composite Performance Score:** * * *

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**Subcontractors:**

- The Division of Engineering and Applied Sciences, Harvard University
- ABB Transmission Technology Institute, Raleigh, NC

** As of December 9, 1997, large single applicant firms are required to pay 60% of all ATP project costs. Prior to this date, single applicant firms, regardless of size, were required to pay indirect costs.

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