Molypermalloy sends clear signals

One of the most important innovations in communications history occurred when telegraph cable designers incorporated loops of wire wound around iron cores into their cables. This "simple" innovation evolved into inductors wound around Molypermalloy Powder cores, which are omnipresent in electronic devices on earth and in space.

The Law of Unintended Consequences states that: "actions sometimes produce unexpected outcomes." While the "law" is usually cited for unexpected negative outcomes, it also applies to unexpected positive outcomes. A good example is the invention and development of the loading coil for electronic circuits. The loading coil owes its existence to a mathematical analysis aimed at understanding why telegraph signals became unintelligible after traveling long distances. Years of research and development in communications theory, circuit design and materials science drove the evolution of loading coils. One result was Molypermalloy Powder (MPP) cores for the coils. Today MPP cores play irreplaceable roles in myriad devices in automobiles, trains, wristwatches, cell phones, computers, and electronic-equipment chargers.

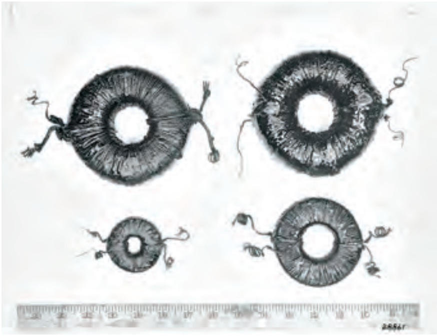
The Queen illustrates the problem

The first successful (and short-lived) transatlantic telegraph cable began operation in 1858. Soon after its commissioning, the UK's Queen Victoria used it to send US President James Buchanan a 98-word message that took 16 hours to complete. The long transmission time was necessary because the cable distorted the signal when the telegrapher sent more than a few words per hour.

Heaviside paves the way

When the telephone came on the scene in the mid to late 1800s, communication cables had to carry a spectrum of frequencies instead of just the telegraph's "dahs" and "dits". This made transmission fidelity even more important. In 1887, English electrical genius Oliver Heaviside developed a mathematical expression known as the "Heaviside Condition". He showed how to greatly increase the clarity of messages transmitted over long cables by coiling each wire pair in the cable around a circular magnetic core at regular intervals. This innovation eliminated time delays and distortions in the signal, permitting much higher transmission rates. The loading coil (so named because the coil "loaded" the circuit with inductance) was born!

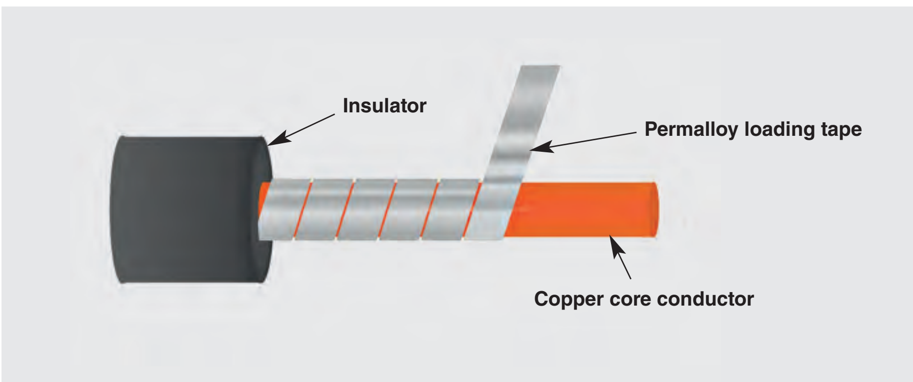
In 1899 AT&T engineer George Campbell tested his own mathematical analysis of loading coils. He demonstrated that a telephone transmission line loaded with coils could transmit clear voice signals twice as far as unloaded telephone transmission lines. This led to considerable cost savings over the iron-clad copper wire technology of the day. Around the same time, Columbia University professor Mihajlo (Michael) Pupin received a patent for a similar concept in priority to Campbell's application. As a result, loading coils became known as "Pupin coils", and adding coils to transmission lines was called "Pupinizing" the lines. Ironically, Campbell lost the patent priority battle because he waited to file until after completing his experiments. Pupin himself had neither built coils nor demonstrated the concept as Campbell did.



Loading Coils from 1900 (upper right) to 1927 (lower left). © AT&T Archives and History Center CC BY-NC-SA 3.0 (www.ethw.org/Telephone_Transmission)

Permalloy cable

Other people were also working on improving transmission quality at that ❯



Permalloy-wrapped cable for undersea telecommunications. © SpinningSpark CC BY-SA 3.0 (https.en.wikipedia.org/wiki/permalloy) time. Danish engineer Carl Emil Krarup had the idea to wrap copper cable wire tightly with iron wire (inventing the "Krarup cable") in order to meet the Heaviside condition. Unfortunately, his design still required loading coils in long transmission lines. AT&T therefore searched for a material with higher magnetic permeability than iron. In 1914, Gustav Elmen discovered Permalloy, a magnetic 80% Ni - 20% Fe alloy. Around 1915, Elman and Bell Laboratories scientists Oliver E. Buckley and H. D. Arnold greatly improved the transmission speed of wrapped submarine cable.

The design was tested in Bermuda in 1923, and the first Permalloy-wrapped telegraph cable was placed in service connecting New York City and Horta (Azores) in 1924. Permalloy wrapping increased the cable's transmission speed from 40 to 400 words per minute.

Molypermalloy and the MPP core

During the early 20th century, loading coils found new applications in power supplies and filters to eliminate current spikes and circuit noise. Designers soon needed new magnetic core materials to optimize the coils' properties for specific applications.

In the 1940s, researchers discovered that adding 2% molybdenum to Permalloy yielded a material with the lowest signal losses available at the time. Over the years it evolved to include alloy variants with as much as 5% Mo. Coils with cores made from "Molypermalloy Powder" (MPP) were higher quality, smaller, lighter, and more tolerant of temperature extremes than coils made with unmodified Permalloy. MPP set the standard for high-quality powder cores, a standard that stands today.

MPP cores have several advantages: They have high stability and high electrical resistance. They have low magnetic hysteresis (i.e. they demagnetize readily when the magnetic field changes), thereby minimizing heating and energy loss. They strongly resist current fluctuations after magnetization, especially when exposed to high currents. They excel in high-precision applications that must operate under a wide temperature range with minimal loss in properties. They can store large amounts of energy, making them ideal for applications such as chokes that block higher-frequency AC currents in DC circuits and power inductors that maintain a steady current in a circuit that experiences voltage or current fluctuations.

Today MPP is made by both the traditional ingot casting/hot rolling/grinding/screening process and by powder atomization. Cores are compacted from MPP using high pressure. They are then annealed, covered with insulation, and wound with wire to form finished coils. MPP cores are produced in many shapes and sizes dictated by the requirements of specific applications. Toroidal (donut-shaped) cores are the most common; they are available with outside diameters that range from only a few mm to over 160 mm.

The versatility of coils with MPP cores justifies their higher price; they are found in microelectronic components, inductors, power supplies, transformers and electronic filters. They serve industrial, aerospace, commercial, governmental, and renewable energy/green technology markets.

MPP cores in space

Filters with toroidal cores played an important role in the early stages of space exploration, and still do today. MPP cores replaced much heavier cores in satellite and rocket communications components, reducing both size and weight. These reductions translated to increases in payload capacity and significant cost savings. MPP cores reduced the total core weight in one vehicle from 2.1 kilogram to 0.009 kilogram with an attendant increase in fidelity of communications and data transmission. One early telemetry system employed 23 filters and auxiliary equipment weighing a total of 94 kilogram. Similar equipment using sub-miniature and micro-miniature components, some with MPP cores, reduced the system weight by 99.7% to 315 grams.

Today, NASA engineers trust the well-established reliability and stability of MPP cores for designs that have traveled throughout the solar system. MPP cores have been used on over 40 missions, including those to Jupiter, Saturn and Mars.

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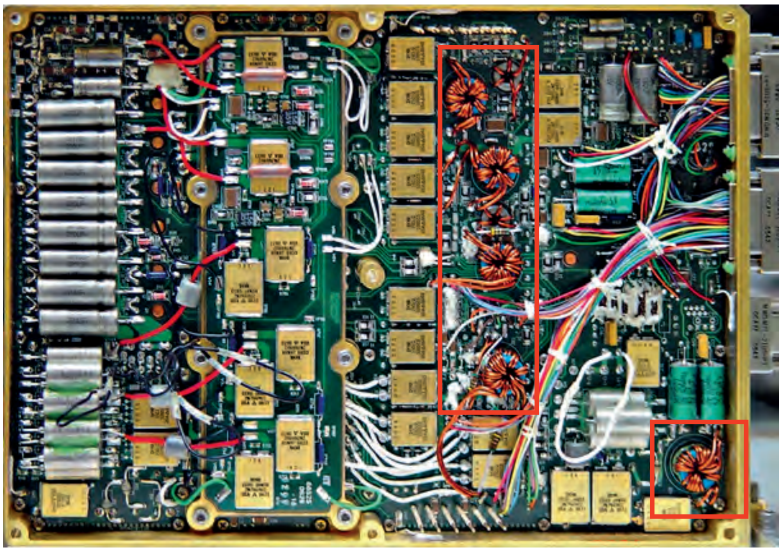

Bottom view of the 275 watt power converter developed by Battel Engineering for the SAM instrument on the Mars Curiosity rover. The converter has 15 isolated power outputs for operating the three scientific sensors comprising the instrument. Seven of the seventeen MPP cores used in the power supply are visible on the right half of the picture (boxed). © Battel Engineering

A rendering of the Cassini-Huygens spacecraft as it flies by Saturn.
© NASA/JPL-Caltech/Space Science Institute

A spacecraft with superhuman senses!

In one of the most ambitious missions yet to deep space, the NASA/ESA/Italian Space Agency consortium launched the Cassini-Huygens spacecraft in October of 1997. The probe travelled more than 1.6 billion kilometers over a six-year period to study Saturn. Its array of powerful instruments continues to beam accurate scientific data and detailed images to scientists on earth today. The following are two examples of the instrumentation on Cassini.

The Composite Infrared Spectrometer (CIRS) plays a major data-gathering role in the mission. CIRS incorporates MPP cores into the complex electronics of instrumentation that measures Saturn's infrared energy, thermal structure, and composition. The spectrometer performs the same functions for Saturn's moons and rings.

Components with MPP cores also help to power NASA's Ion and Neutral Mass Spectrometer (INMS). INMS measures the density and composition of neutral and ionized gases in the atmospheres of the bodies it passes near. It was built to study the atmospheric composition and structure of Saturn's moon Titan, Titan's atmosphere interaction with Saturn's magnetosphere plasma, and the neutral and plasma environment of Saturn's rings and icy moons. It has already returned groundbreaking information about both Titan and Saturn's icy moon Enceladus. Scientists hope that the INMS will identify molecular hydrogen present in plumes of Enceladus, which are 90% water vapor. With Cassini's mission extended to 2017, multiple fly-bys of both Titan and Enceladus will occur and even more data will stream back to Earth.

Consortium scientists are now analyzing Cassini's trove of data. So much data is available that many more years will pass before they finish their work. If molecular hydrogen and other complex organic molecules are identified, it might mean life is present on a neighboring planet!

It is a testament to the creativity and perseverance of generations of engineers and technologists that a discovery intended to enhance the quality of telegraph and telephone cable transmissions has helped to take humankind to the far reaches of our solar system. Coils with MPP cores helped to enable this progress because of their unique and versatile combination of properties. MPP cores already touch our lives here on Earth in a multitude of ways, and may help to find life on other planets.
(Robert Bukk, John Shields)

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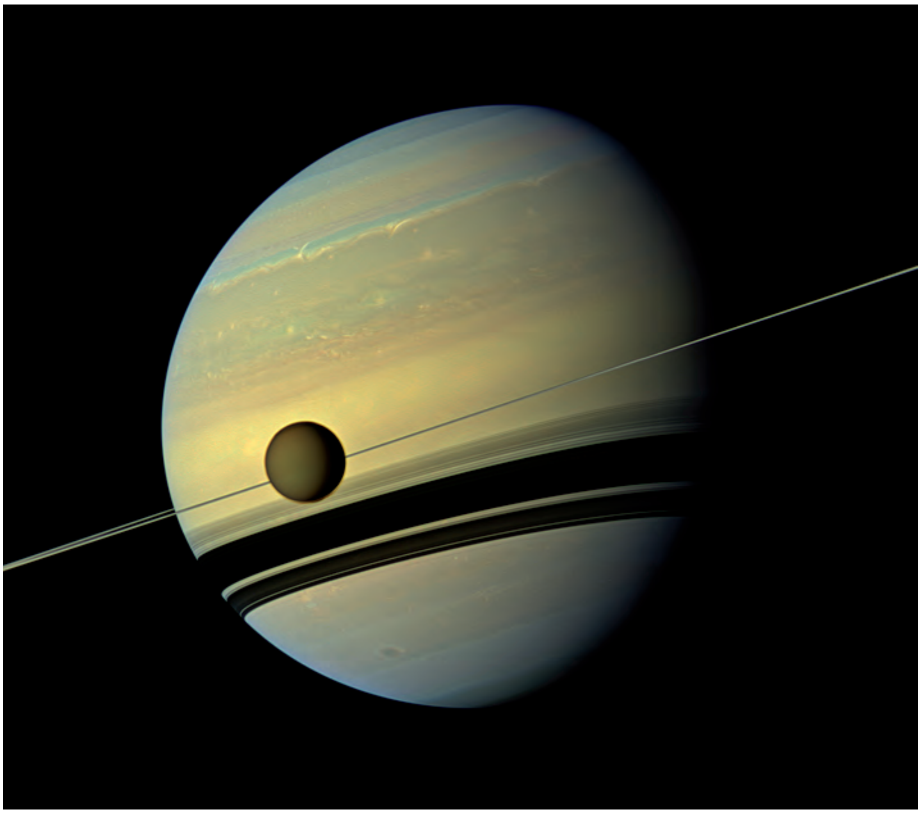

This photograph taken by the Cassini-Huygens spacecraft on August 29, 2012 shows one of Saturn's moons, Titan, aligning with its rings, which cast a dark shadow on Saturn. © NASA/JPL-Caltech/SSI.