VISHAY PRECISION GROUP

# 50 Years at a Glance

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## The Invention and Evolution of The World's Most Precise Resistor, The Legacy of Dr. Felix Zandman

This year, Vishay Foil Resistors (VFR) celebrates 50 years of leadership in precision resistors, starting with the invention by Dr. Felix Zandman of the Bulk Metal® Foil resistor in 1962.

Dr. Zandman, Founder of Vishay Intertechnology, Inc. (VSH), died on June 4, 2011, at age 84. The Vishay Foil Resistors (VFR) products of Vishay Precision Group, which spun off from VSH in 2010, are a key part of his legacy and heritage, which we continue to develop towards the goal of fostering technologies that make our world a better place to live in.

In this article we share a number of behind-the-scenes stories about the invention, development, and evolution of Bulk Metal Foil resistors.

### 1962-1972

In 1962, the physicist and Grodno, Poland (now Belarus)-born Holocaust survivor Dr. Felix Zandman, world-renowned for his work in stress analysis, took his ideas for uniquely isolated strain gages and applied them to the electronics industry with the introduction of the most precise and stable resistor ever developed. By that time, Dr. Zandman had been awarded science and engineering degrees by the University Of Nancy (France) and a doctorate degree from the University of Paris (Sorbonne). Later many prestigious awards would be added to these accolades, including The French Legion of Honor, The French Order of Merit for Research and Invention, The Franklin Institute's Medal for Science, and The University of Nancy's Student Of The Century Award.

Having already developed the means of isolating strain gages from all influences except the strain on the structures being analyzed, Dr. Zandman applied these same principles to electronic resistors for new breakthroughs in resistor precision, stability over temperature excursions, and long-term operation. With these principles he founded Vishay Intertechnology Inc. to develop and produce unique resistor products.

The first Bulk Metal Foil products were not discrete resistors but unique applications of resistive technologies to solve specific unique problems. For example, at that time, one of the first geo-stationary orbiting satellites was being built, but the technology was new and issues surfaced after the satellite was designed and partially built. It was found that every one of the solar cells in the entire array of solar cells required a shunt resistor to work properly. But there was no allowance in the satellite design for the additional space and weight traditional resistors would require. To overcome this daunting challenge, the developers turned to Dr. Zandman for his unique but untried Bulk Metal Foil technology. They gave Dr. Zandman the fold-out wings of the satellite on which the solar cells would be mounted and asked if he could mount one resistor for every solar cell and fit them on the wings within the available space without adding significant weight. Vishay then produced a large array of resistors etched from thin electrically-resistive foil and attached these with thin layers of insulating bonding adhesive along the satellite's aluminum wings which were then wired to connect every resistor to every solar cell. Challenges met; satellite saved!

By 1964, Bulk Metal Foil was available as fixed, packaged discrete resistors. But in another unorthodox move, Vishay packaged this technology in a square configuration with both leads coming out the bottom side so that the resistors could be plugged into standard printed circuit boards, to minimize the resistor footprint and maximize board utilization. At that time the all other resistor manufacturers considered this evolution to be a wrong idea. Soon, however, every resistor manufacturer, even those who had been in the business for decades, began copying the foil configurations in an effort to retain their business, as Bulk Metal Foil resistors were quickly expanding into the most advanced applications in the most sophisticated electronic equipment.

The geo-stationary orbiting satellite experience illustrated one of the most important advances in precision resistor technology in the century. For the first time it was shown that high-precision resistors could be built without the bulk and weight of the common wirewound resistors which, until that time, were the most precise resistors available. The lesson was not lost on the industry and soon every leader in military and aerospace electronics was investigating and investing in Bulk Metal Foil technology. One of the earliest votes of confidence came from the company developing the first communication satellite. Again, unproven technologies needed all the help they could get to assure success. Under the developer's contract, his company would not begin to get paid for the satellite until it was in full operation for three years. After the first three years of operation, the company would be paid so as to recover its investment if the satellite continued to work from year 3 to year 5. If the satellite continued to operate after year 5, the payments would continue and only then would the developer begin to make a profit. The unsecured investment was enormous but the developer turned to the new Bulk Metal Foil technology to boost its probability of success. And it was a success: the satellite functioned flawlessly for about 15 years before it was replaced by newer satellites and then by the whole series of satellites we've seen from many manufacturers in many countries over the past 40 years.

By the late 1960s, the leading suppliers of military and aerospace equipment were actively designing with foil resistors. Industry leaders under the supervision of NASA, JPL and Defense Electronics were designing Vishay's foil resistors into their most critical circuits. Soon European and Asian space agencies joined in.

In 1969 Vishay opened its first foreign manufacturing plant in Israel to help handle the international demand for its resistors.

**1972-1982**

By the 1970s Vishay's military and aerospace business had become so extensive that the proliferation of individual specifications for every customer, with their required approvals, presented a considerable workload for customers and DSCC (today known as DLA) alike. However, the existing standard military specifications were based on earlier lesser-performing technologies and could not be used for a foil technology that provided levels of accuracy and performance too advanced to be governed by existing standard specifications. So it became obvious that the mil specs had to be updated to cover the foil technology and its more precise and stable performance levels. In 1974, the new advanced amendments were added to the established reliability Mil-R-55182 as Mil-R-55182/9, a model known as the RNC90Y, to cover TCRs down to 5 ppm/°C. The new life and environmental stabilities now brought the better performance of the Bulk Metal Foil resistors to more mil/aerospace markets as standard products without the necessity for individual non-standard specifications for every new application. Similarly, Mil-R-83401 standardized foil resistor networks for military applications after Vishay introduced the first hybrid resistor using the Bulk Metal Foil technology.

Soon, Vishay's RNC90Y or its more-extensively screened version, model S555, were being used in military programs such as the latest advanced torpedo, the Viking Mars Lander, the Peacekeeper Missile, and many others. At the same time, Vishay developed its first dual element resistor on a single substrate with TCR tracking of only 0.5 ppm/°C. This dual device used all the exact same materials and processes as the RNC90Y, the only difference being a different pattern etched into the foil. This product, known as model 300144, was quickly accepted by the electronics industry with such applications as the 6-barrel rotary cannon that is still the principal armament for nearly all US military fixed wing aircraft. 1977 saw the launch of the foil-resistor-laden Voyager 1 and 2 deep space probes with 5-year life expectancies. Still operating after 35 years and 11.5 billion miles from Earth, Voyager 1, ahead of Voyager 2, is just now approaching the farthest reaches of our sun's magnetosphere. Within the next few months, having probed the atmospheres of all the planets in between, Voyager 1 is expected to signal that it has encountered a shift in magnetic direction indicating that it has passed into the interstellar space beyond the heliosphere, beyond the influence of our own sun.

In the late 1970s, Vishay formed its Precision Resistor Networks Division (PRND), based on the flexibility of chip and wire construction, to produce any unique schematic with any set of resistance values in standard hermetic packages with no NRE (non-recurring engineering) charges. This technique also made it possible to ship the most precise networks for prototype development in as few as five working days. For the first time, customers could get the best available network performance with no up-front expense for even the smallest projects and have the exact same performance in both the prototypes and the production units.

It was about this time that engineers in commercial industries began to realize that foil resistors, while more costly than other technologies, could actually save money in the overall system when considering total cost and not just purchase price. One instrument manufacturer, for example, made equipment that used a balance of two trimming potentiometers (coarse and fine adjust) that had to be set during assembly and then re-set again after assembly. The limitations of the trimmers to hold their setting through shock and vibration, after the difficulty of getting a precise setting, was ameliorated by placing a set of resistors around the trimmers to de-sensitize their adjustment positions for minimal change in setting. Soon, the manufacturer found

that using the foil trimmers allowed them to eliminate the surrounding de-sensitizing resistors with better settability and greater resistance to shock and vibration. Trimmers could be set faster during assembly and did not require re-adjustment afterwards. The cost savings in technician time alone more than paid for the foil trimmers but there were also savings in piece-part count, ordering, stocking, assembly, board space, etc.
Also, companies making oil exploration equipment found that using foil resistors in gain-switching networks in seismic oil exploration systems allowed them to search for oil deposits deeper into the earth without switching delays that would cause them to miss complete layers of strata where oil might be found.

During this time semiconductor manufacturers used the high speed and accuracy of foil in their automatic test equipment on their production lines. There, 300 measurements were made on every semiconductor in a production line that moved so fast that semiconductors could not be allowed to fall off the end of the conveyers because they did not fall fast enough—they had to be blown down with a stream of high pressure air! Again, the cost of the resistors was compared with the cost of the additional equipment that would be needed to keep up the production rate. Obviously, the resistors were cheap by comparison.

During the 1970s Vishay developed the world’s first thermotropic resistor. Vishay foil resistors already had the lowest TCRs in the world at ±2.5 ppm/°C over the entire military temperature range, but this resistor was so advanced that new terminology had to be developed to describe it. As the temperature increased or decreased, and the resistance value began to change in one direction, the resistor automatically corrected itself and reversed the direction of change—keeping the resistance value in a very narrow band over the entire operating temperature range. This hermetically sealed resistor, model VHP100, kept the resistance within a window of 15 ppm (0.0015%) total change from 15°C through 45°C, and within 60 ppm (0.006%) total resistance change from −55°C through +125°C. No other resistor could hold such an extraordinary level of thermal stability as the VHP100.

**1982-1992**

The 1980s saw the development of new products such as current sense resistors, power resistors, and surface-mount chip resistors all with the same Bulk Metal Foil performance. During this period, engineers with metrological, industrial, and commercial applications began appreciating the benefits of foil resistors in non-military systems. This decade saw the development of electronic scales capable of discerning one part out of ten thousand, a big step forward in accuracy over strain gage scales. These relied on the foil technology in extremely accurate current sense resistors to restore the force-balance equilibrium of a weighing pan floating in an electromagnetic field. Such companies designed Bulk Metal Foil resistors into critically sensitive applications such as the weighing of precious gems and pharmaceuticals. Although for vastly different purposes, the same basic circuit operation was also used by manufacturers of guidance and control systems in electrostatic gyro control systems for the guidance of ICBMs. Instead of using one sense resistor to increase an electromagnetic field to return a weight to a force-balance set point for weight measurement, the electrostatic gyro used three sense resistors (one for each degree of freedom) to force gyro alignment with the host missile—the output of the sense resistors recording and driving every required course adjustment to keep the missile on its pre-programmed path.

Commercial applications continued to flourish in such applications as high-end audiophile equipment. Experts in sound analysis found that no other resistor gave such pure noise-free sound over such wide frequency ranges and over such large swings in signal strength as the foil resistors. Further evaluation showed that modifications made just for that industry yielded even better performance than the standard foil resistors and new resistor models were developed for that industry alone.

In the energy and oil exploration industries, the 1980s saw rapid growth of foil resistors in the field of oil-well data logging. Instruments sent down-hole to make critical measurements had to withstand high levels of radiation and temperatures above 200°C. Again, foil resistors were able to withstand multiple journeys down and back up better than any other technology and with greater accuracy as well. As a result, companies in this industry around world came to rely on foil resistors.

The 1980s also saw the expansion of a unique Vishay concept that enabled customers to complete Bulk Metal Foil devices right inside their own facilities. All of the physics and technology that make the foil resistor what it is are inherent to the chip itself. Trimming to any specific value, even to tolerances as tight as 0.001%, can be performed anywhere with minimal equipment with no degradation in the foil performance. This system, known as an in-plant station, was provided to a number of companies that could benefit from completing high-precision resistors during their own product assembly. One of the best uses was in a portable back-pack military radio. During product assembly, the manufacturer determined a unique set of seven critical resistors for each radio. A computer print-out containing the seven optimum resistors for each radio was given to the night shift. By the following morning each set had been trimmed and made ready for insertion into equipment. In this manner, and because of the automatic TCR tracking of Bulk Metal Foil resistors, production yields increased from unsatisfactory to nearly 100%.

At the same time, this company looked for extraordinary resistor performance in extremely small packages for airborne radar systems. For this application Vishay developed a number of multiple binary resistor arrays on a single substrate to be wirebonded into hybrid circuits. These networks contained 14 to 16 precision resistors on a single quarter-inch chip, all matched to 0.01% and all tracking within 0.1 ppm/°C. Those network chips are still being produced for this application after more than 25 years.

**1992-2002**

Through the 1990s and into the 2010s, Vishay continued development of Bulk Metal Foil resistors. With every advance, customers found new applications and new levels of precision, but our creative customer engineers always foresaw more design opportunities if better resistors could be built. The pressure was always for smaller resistors, with lower TCR, lower thermal EMF, higher power, higher temperatures, and new configurations. New foils were developed as the original S102C resistor progressed through the “K-foil” and the S102K series, then the “Z-Foil” and the “Z1-Foil” and FRSM series, etc. Temperature coefficients improved from ±2.5 ppm/°C down to ±0.2 ppm/°C over the entire military temperature range. Temperature ranges increased from +125°C up to +240°C. Similar improvements were also made in long-term stability and reliability. New specifications for space applications came with new Vishay models qualified for them. In 1994, by special agreement with the US government, Vishay Israel became a DESC-qualified producer of the RNC90Y resistor—a special vote of confidence since Qualified-Producer (QPL) status had been allowed only in NATO countries. In 2000, Vishay—already having the most precise military-qualified resistor available—extended the precision of Mil-R-55182 resistors with a new product, the RNC90Z, having a maximum TCR of only 2.5 ppm/°C over the entire military temperature range.

**2002-2012**

In 2010 Vishay Intertechnology spun off its precision foil resistor operations and other notably precision operations into a new independent company, Vishay Precision Group (NYSE:VPG), in which Vishay Foil Resistors (VFR) plays a major part.

**In Retrospect**

The history of Bulk Metal Foil resistors is a history of constant development and continuous advances. Bulk Metal Foil resistors have been in nearly every military system, every orbiting satellite and space station, every deep-space probe, and every extra-planetary landing. They are used in deep-water communication repeaters, wind-solar-petroleum energy development, and in highly advanced medical, ATE, automotive, and metrology solutions and products, among others.

In 1962, Dr. Zandman, a quiet unassuming man with a great mind, conceived of a resistor unlike any other. He proposed specifications that exceeded what could be accomplished with any traditional resistor technology. To test his ideas he contracted two marketing research firms, one in England and one in the US, to find where the electronics industry might use such a device. Both marketing firms returned reports asserting that there would be no market for such a device because no one needed resistors with that level of precision. However, Dr. Zandman persisted under the driving imperative of advancing science wherever there was the potential to do so. Through his courage to proceed in spite of enormous skepticism, he helped enable US security through the Cold War and beyond, he helped in the exploration of outer space, he enabled companies around the world to develop new products for their own financial security and for the betterment of mankind, and he inspired tens of thousands of people to realize their dreams. We are all grateful for the time we spent with this towering legend in the electronics industry. With his inspiration we proudly carry on.

Dr. Zandman's biography is available from Amazon (direct link here).

Further information about Vishay Foil Resistors products is available at: **www.vishayfoilresistors.com**

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