Applications at a Glance

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Seismic Instruments for Oil Exploration, Earthquake and Tsunami Detection Need Precision Resistors in Their Analog Circuits

Seismographic systems – the most widely used method in exploring for oil and gas and detecting earthquakes and tsunamis – utilize a surface shock energy source such as explosives, weight dropping, or gas guns to introduce a shock-wave front into the earth. The effect is similar to creating a small, controlled earthquake.

Although geologists do not know exactly where oil may be found, they do know it is more likely to be found in certain types of rock formations. It often collects in porous rocks between layers of non-porous rocks. These layers are usually tilted or folded upward in what are known as synclines, or in downward folds known as anticlines.

Each discontinuity in the earth's composite structure, such as interfaces between limestone, shale, or salt, results in reflected energy. This small energy is reflected back to the surface where it is detected by geophones – with very sensitive pickup – spaced out over a very large area. As the rapid series of reverberations from each layered interface reaches the surface, it is amplified and recorded. The recording equipment attenuates the initial high-energy returns and then switches through a series of increasing amplifications so as to maintain appropriate sensitivity levels to record all layers from the most shallow high-energy signals to the weakest signals from the deepest layers of the earth. The measurement equipment must sequentially switch sensitivity extremely fast to avoid loss of data from any layer during the transitions, and the equipment must be noise-free to prevent the weakest signals from being lost in the noise.

By timing and measuring these signals – after correcting for weathering and elevation of the surface layer, normal move-out, time of first arrival, etc. – it becomes possible to produce a plot that represents a cross section of the earth for about the first few miles of depth. These cross sections show anticlines, synclines, stratigraphic traps, and other structures where oil or gas may be pooled.

The digital seismic equipment that amplifies and records reflected seismic signals on a wideband receiver and tape drive in the field utilizes matched and discrete surface-mount foil resistors.

The new Z1-Foil Bulk Metal® Foil resistors from Vishay Foil Resistors (VFR) assure virtually noise-free operation. They offer predictable responses and very precise tracking of amplifiers within an individual seismic system or among several interrelated systems — whether operating in the high-humidity heat of the jungle or in the dry cold of the Arctic. When signals are later reconstructed during analysis, the precision-built amplifiers guarantee that geologists can base their analyses on precise, accurate data.

A seismic system requires the attenuating resistors to have fast-response precision to prevent missed pulses. The resistors used in such systems must not be sensitive to temperature changes and must track each other exactly so that the gain settings and ratios are predictable and reproducible over time. The resistors must also exhibit very low current noise to avoid masking the reflected signals. Amplifier modules must track with each other since there may be many signal input channels in operation, thus the phase shift between all amplifiers must be extremely tight. These requirements, particularly tracking, are absolute if the information collected from various parts of the world is to be later compared meaningfully.

The heart of the seismic system is its amplifier module. The high-gain amplifier is frequency selective and requires a very large automatic gain control (AGC) range. Demands put upon the unit are stringent. As the first precise measured energy burst is sent into the ground, the amplifier must throttle down the signal and then increase amplification as the signal reflecting seismic energy diminishes.

The amplifier logic used in the equipment consists of gain stages and attenuators. A resistive divider network permits signal attenuation in various steps that attenuate or pass the signals to the first amplifier, depending upon the amplifiers input range. Gain switches automatically sequence through their ranges to control the amount of attenuation.

The signal then goes to another resistive attenuator which can provide full signal or similar attenuation. This attenuator connects to a second amplifier stage. Each of the succeeding amplifier stages also contains a resistive attenuator which can provide precise attenuation or the full signal.

Earthquake monitors and tsunami trackers are essentially the same as oil well logging equipment, but the initial impetus shock is caused by nature rather than being manmade.

Z1-Foil resistors excel over all previous stability standards for precision resistors with an order of magnitude improvement in temperature stability, load-life stability, and moisture resistance, all of which become more critical in our unpredictable global climate. These new benchmark levels of performance provide design engineers with the tools to build analog circuits not previously achievable, while reducing costs in the most critical circuits by eliminating the need for corrective circuitry used only for the purpose of stabilizing or iterating accuracy in previous stages of the circuit path.

Before Z1-Foil technology, high-frequency precision applications were only served by precision thin film resistors, but these are not as accurate or as stable as wirewound resistors, which do not have good high-frequency response. The new Z1-Foil technology presents designers with resistive components that are even higher precision than wirewounds, but are also well-suited for high-frequency and high-temperature applications. This fourth generation of VFR’s foil technology produces small surface-mount resistors not achievable with wirewound technology, while offering greater accuracy and stability than thin film resistors. Now, Bulk Metal® Foil resistors in sizes as small as 0603 can serve as on-board secondary standards going anywhere the equipment goes — even into deep space. The new Z1-Foil FRSM series and SMR3P of surface-mount chip resistors exemplify this innovative new technology.

In the past, resistive component engineers attempted to improve resistor performance by reducing innate stresses in the components. For example, in precision wirewound resistors, they tried several methods to wind wire with enough winding tension to hold the wire in place while reducing the stresses on the wire once it has been formed onto a bobbin. This was tricky enough to accomplish at the time of manufacture, but the process was unable to prevent the stresses from changing the resistance value after heating and cycling through actual in-circuit applications. Thin film resistors didn’t have this option because thin film must be sputtered or deposited directly onto the substrate to form a new resistive agglomeration. So engineers using thin film technology had to concentrate on protecting the film with coatings and encapsulants. Foil resistor technology actually manages stresses to counterbalance forces with opposing effects, thus utilizing those stresses to produce an extremely stable resistor.

In other technologies, manufacturers strive to achieve the lowest possible temperature coefficient of resistance (TCR) in their resistive material for the most thermally-stable components and are limited to what can be achieved by that one-dimensional consideration. Foil technology concentrates on achieving a foil with not the lowest TCR, but with the most linear TCR over the widest temperature range and ensuring that it is reproducible within extremely tight tolerances. This TCR is achieved in a relatively thick, cold-rolled foil that maintains the same molecular structure as the raw alloy from which it is built. This is the basis of the foil resistor because the foil must act as a monolithic structure with a fixed and known linear coefficient of expansion over any temperature range the resistor might experience throughout its design life.

The next most important element in the construction is the adhesive that holds the foil to the unique flat substrate. It must withstand high temperatures, pulsing power, moisture incursions, shock and vibration, low-temperature exposure, electrostatic discharge (ESD) etc., and still hold the foil element securely to the substrate. With these characteristics, the basic technology for foil resistors combines the essential stress compensation that defines foil technology.

The Bulk Metal® Foil alloy is developed using a known positive TCR with a known linear coefficient of expansion (LCE). The foil is bonded to a flat ceramic substrate that also has a known LCE, chosen to induce a pre-planned stress in the foil. In this structure, two opposing influences are imposed on the foil. The first is the foil’s inherent increase in resistance with an increase in temperature; a positive TCR. The second is the bonding of the foil to the substrate so that the foil is constrained to follow the substrate, which is chosen to have a specific LCE that is less than the LCE of the foil. Thus, when the composite structure experiences an increase in temperature, the resistive layer which is made from foil attempts to expand in accordance with its inherent LCE, but is constrained to the substrate’s lesser expansion characteristic.

The effect is that the foil, in trying to expand against the substrate’s constraining force, experiences a compressive force that drives its resistance down. In this perfect balance of forces, the decrease in resistance due to an increase in temperature exactly offsets the foil’s inherent increase in resistance due to that same increase in temperature. The net result is a resistor with a near-zero TCR of 0.2 ppm/°C from -55°C to over +225°C. The structure is designed so that the pre-planned stresses do not exceed Hook’s constant for the materials and, therefore, maintains the balance and resistance stability throughout the load-life and application of the resistor—holding total resistance change to less than 0.05 % throughout the planned life of the equipment.

The flat planar structure of the foil resistor, with the resistance element at the surface (before encapsulation), lends itself to a unique process for trimming resistors to value. Tolerances as tight as 0.001% can be achieved in hermetically-sealed packages such as the radial lead VHP100 or the many other package configurations. The resistor element is photo-etched with a grid that incorporates geometrically proportioned successive links that can be removed while incrementally increasing resistance in successively smaller amounts without introducing current noise or hot spots. The grid is further designed with opposing currents in adjacent paths so as to minimize both inductance and capacitance for high-speed performance. Using these basic technology innovations, the resistor can be completed in many different configurations, including power resistors, current sense resistors, hermetically sealed metrology resistors, surface-mount chip resistors with stress-isolating flexible terminations, and many more for applications in space and aviation, medical equipment, process controls, or wherever high-precision resistors, networks, and trimming potentiometers are required.

In addition to providing circuit design engineers with the most precise and stable resistive components available in the world today, the FRSM surface-mount chip resistors utilizing the Z1-Technology of the Bulk Metal® Foil resistor technology shrink circuits and reduce power consumption by achieving all of the performance advances in resistors as small as the 0603 chip resistor. But reducing circuit area introduces new design challenges associated with thermal management and its unintended consequences, and in some cases more sensitivity to ESD. One such problem is the thermal electromotive force (TEMF) that introduces error voltages wherever temperature differentials exists between two junctions of two dissimilar metals, such as where internal resistive elements are joined to the external terminations of a resistor. Temperature differentials are developed across a resistor by uneven internal power dissipation, terminations heated by heat-radiating components, and from thermal dissipation paths running along the circuit board in both the conductive paths and the base board material itself. Foil devised for its innate TCR and its LCE also has a very low TEMF of only 0.05 µV/°C.

This extraordinary technology did not arrive as a result of searching for a new more-accurate resistor; it grew out of the stress analysis physics of strain gage applications. Dr. Felix Zandman, inventor and developer of foil technology, had already established world-wide recognition in the field of stress analysis when he developed a means of accurately measuring strain on structures by isolating all extraneous influences from the intended strain measurements on a specific structure. These same isolation principles were then applied to resistor applications to produce a new resistor far more accurate and stable than any resistor developed through historic resistor technologies. The details of these unique processes are described above with new refinements in foil and adhesives extending performance to higher temperatures than ever before. Surface-mount resistors with flexible terminations and operation temperature up to +240°C are also available.

Although the basic principles of counterbalancing stresses to produce stable resistors were well understood, there were very few metallurgical companies with the capabilities to cold-roll the metal alloy as thin as necessary without also containing micro-voids that would interfere with the resistance grid once it had been etched. Thicker foils could be produced, but they limited the resistance range and didn't possess the correct LCE to balance the foil's TCR. At first, glass substrates suited the physical requirements, but they soon proved to involve a reliability risk when used in a moisture-laden atmosphere; free ions from the glass would combine with the micro-particles brought in by moisture penetration through the encapsulants to form a low-activity acidic etching of the foil, resulting in occasional failures. Further research showed flat ceramic substrates would eliminate that problem but then new alloys for the correct balance of TCR versus LCE had to be developed, in addition to the capability for cold-rolling of defect-free alloys.

At the same time, skeptics predicted that there would be no market for such a device because —no one needed anything of such extraordinary accuracy. Dr. Zandman, however, intrigued by intellectual imperative as well as the challenge, forged ahead with developments in the belief that the availability of better components would instigate the development of more precise circuitry for better end equipment. Today, these resistors are used in the most exacting applications, including space and aviation, with the latest development of the Z1 Bulk Metal Foil FRSM surface-mount precision chip resistor now extending improved levels of performance for higher temperature applications, greater resistance stability through temperature changes, and near-zero change due to moisture exposure.

For more information about this product group, please contact us at: **Foil@vishaypg.com**

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