Ceramic Dielectric Surface-mount and Coaxial EMI Filters

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Coaxial electromagnetic interference filters and filter elements have been evolving since the early 1950s. Today's product offerings reflect ongoing miniaturization and reliability improvements in these basic technologies.

Coaxial Capacitor Evolution, 1950-1998

The need for electromagnetic interference (EMI) filters as part of the arsenal of solutions for electromagnetic compatibility (EMC) has been well documented, and it is not the purpose of this article to discuss and justify this need. The purpose of this article is to provide some insight into the evolution of coaxial discoidal capacitor elements utilized in EMI filters, discuss the performance and improvements of EMI filters utilizing the discoidal and finally, discuss the newer surface-mountable (SMT) three-terminal EMI filters. Suffice to say that low-pass coaxial feed-through and three-terminal EMI filters are well established in applications requiring shielding, isolation and suppression of conducted electromagnetic interference for both emissions and susceptibility.

Electromagnetic interference is defined as any electrical signal radiated or conducted into or out of the electronic equipment, disrupting the normal operation of the equipment. EMI includes the frequency range of the entire electromagnetic spectrum, from direct current to the visible frequencies, and can be either continuous or intermittent in occurrence.

Many of today's miniature EMI filters utilize a unique coaxial multilayered ceramic element, commonly termed a discoidal capacitor element. In the simple one-element EMI filter, which provides 20 decibels (db) per decade attenuation, the discoidal is simply used as a feed-through coaxial capacitor. An inductive element may be added to provide an "L" circuit (improving attenuation to 40 db per decade), then another discoidal capacitor can be added to provide a 3-element or "Pi" configuration (further improving attenuation to 60 db per decade) and so on.

The invention of the discoidal element began at Erie Resistor Corporation (ERIE) in Erie, Pennsylvania in the early 1950s when ERIE invented and patented a coaxial high-frequency button mica capacitor for use in telephone systems and microwave links pioneered by Bell Telephone Laboratories and Western Electric Company. In order to have two sources of supply, Sangamo Electric in Springfield, Illinois was licensed by ERIE to manufacture the button mica capacitor product offering. This discoidal transmission line device was made up of a stack of mica dielectric washers, printed with a gold or silver electrode coaxial transmission line pattern, that made each washer a "stackable" capacitor element.

Typically, about 30 electroded mica washers are stacked in electrical parallel to form a coaxial high-frequency capacitor, with typical values up to about 1,500 pF. The button mica capacitors exhibit outstanding low loss performance through several gigahertz. One of the limitations for utilizing the coaxial button mica for EMI filtering, where some brute force filters need 3 or 4 μF, is the low dielectric constant of naturally occurring Muscovite mica, which is about 7.

As the need to miniaturize electronic circuits and packages evolved, it was a natural evolutionary step to develop a process to fabricate coaxial capacitors utilizing higher dielectric constant barium titanate ceramic formulations in multilayered discoidal forms (Figure 1). Barium titanate ceramic formulations, with dielectric constants ranging from about 20 to more than 15,000, enables the manufacture of high-performance discoidal capacitor elements with capacitance values to several μF in a miniature package. In the 1960s, this work simulta-

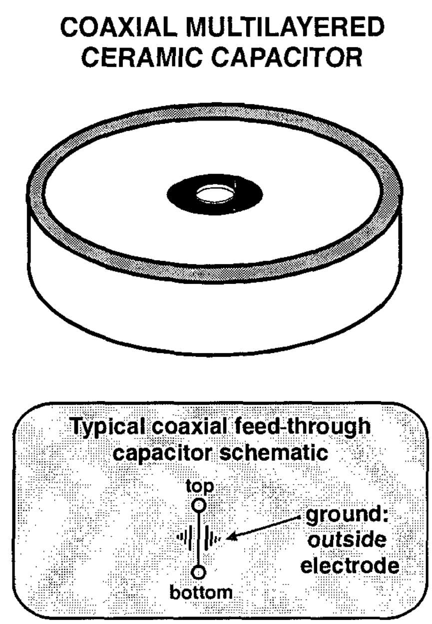

Figure 1. *Multilayered Discoidal Ceramic Capacitor, Formed by Building Up Offset Alternating Electrodes and Connecting Them in Electrical Parallel to the Outside Diameter and Inside Diameter.*

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neously evolved at Sprague Electric in North Adams, Massachusetts and at Erie Resistor/Erie Technological Products in Erie, Pennsylvania. (Erie Technological Products, in the United States, was later acquired by Murata Manufacturing Company of Japan). Erie began producing coaxial multilayered ceramic discoidal EMI filter elements in 1966 for applications in ballistic missiles, airborne electronics and the NASA Space Program.

These discoidal ceramic capacitors were fabricated utilizing a "dry green ceramic tape" stacking and cutting process and were prone to exhibit serious reliability problems associated with misregistration, delamination and voids in the ceramic layers. In the 1980s, these inherent processing flaws were solved through the invention and use of a "wet process" build-up system for fabricating the dielectric and electrode layers. This state-of-the-art process is still in use today. The unique process is a fully automated and computer-controlled deposition process enabling build-up of the discoidal by sequentially depositing ceramic slurry and electrode paste layers. The process insures accurate registration and eliminates in-process handling. The total process is carried out under clean room conditions. The wet process eliminates the risk of delamination and voids when compared to the dry tape stacking process. The entire process is monitored and controlled using statistical process control. The wet process also improves the performance of all multilayered ceramics at higher voltages, as corona threshold detection is inherently higher due to the lack of dielectric voids. This performance improvement is especially noticeable when the system is required to meet UL, VDE and CSA transient testing requirements.

Simple Single-element EMI Filters

The best cost value, when selecting a ceramic element EMI filter, is to choose the simple single-element solder-in or bulkhead-mounted bolt style (Figure 2). New versions of the bolt style are now available in significantly higher voltage ratings—up 2,000 volts DC in several cases.

Cost-effective production of micro-discoidals, smaller than 3 millimeters in diameter, now allow their use in product applications formerly satisfied by tubular capacitor elements (Figure 3). The solder-ins shown in Figure 3 utilize a gold over nickel termination system to overcome the inherent problems and issues of solder leaching that have been a troublesome mounting issue for several years.

Discoidal Planar Arrays

The design and construction of a multiple-hole discoidal array is essentially the same as a single discoidal. Basically, the dielectric and electrode layers are built up in two or more offsets. The through holes are located in the proper place and the holes are metalized to provide contact to one electrode set. Normally, a common ground connection is terminated along the edges of rectangular arrays and around the periphery of circular arrays. A variety of configurations that are available for circular and rectangular connectors and/or assemblies (Figure 4). The ground, or common, can also be brought to a pin or pins for an additional ground point.

EMI filtered connector manufacturers usually assemble the planar arrays in pi or "c" filters inside the connector. This insures sharp cut-offs, very low impedances to ground, excellent shielding, reduced cross-talk, and higher band attenuation. The planar array solution to EMI issues affords the user weight and volumetric efficiencies, as well as performance and reliability advantages when compared to other capacitor technologies.

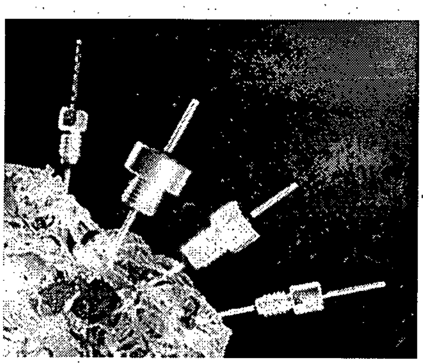

Figure 2. Coaxial Filters with Discoidal Multilayered Ceramic Capacitor as the Primary Filtering Device.

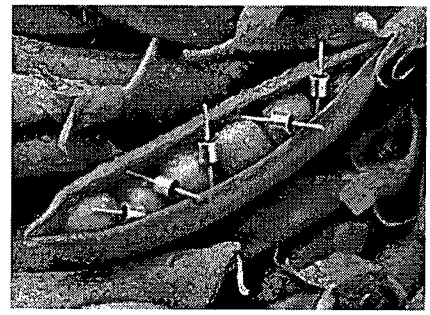

Figure 3. Brushing-style Microminiature Discoidals, with Gold over Nickel Termination.

A Discoidal Application Case Study: Telecommunications Power Filtering

Telecommunications and data communications markets continue to converge on new technologies, such as wireless and broadband cable, and equipment makers are looking for new, compact, and more cost-effective power supply options. Cramming more power into less space without undermining power efficiency or reliability has always been the name of the game for DC/DC converter designers. One popular way of saving space is to shrink the control electronics through the utilization of more functionality and smaller footprints of the ICs. Densities of 80 watts per cubic inch to 120 watts per cubic inch are emerging along with the need for smaller and more efficient EMI filter assemblies.

An example of this need for smaller, cheaper and more efficient

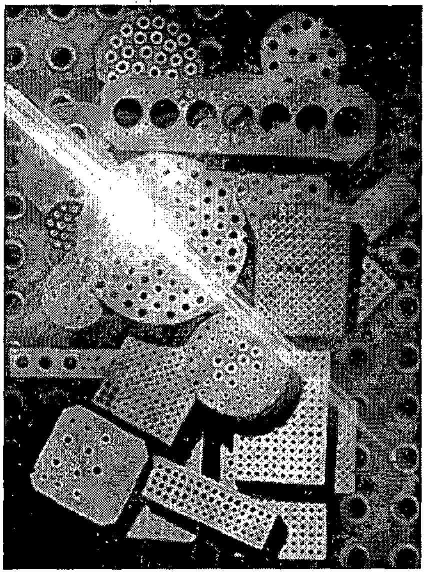

Figure 4. *Wet Processed Planar Multilayered Discoidal Arrays.*

EMI filters is the injection-molded, EMI-filtered terminal block (Figure 5). This same type of EMI-filtered terminal block, in a 60-amp 3-section EMI filter, can be assembled in a telecommunication power supply submodule (Figure 6). These injection-molded EMI-filtered terminal blocks and power supply subassemblies are required to meet the stringent transient withstanding voltages of Underwriters Laboratories and the EURO transients specifications. The combination of high frequency insertion loss, high voltage transient protection, and ruggedized but compact assembly, is a case study in this new world of cost-effective, multilayered ceramic capacitor design, manufacturing and processing abilities.

PCB EMI Filters

When there is no suitable bulkhead on which to mount a coaxial filter, and when cost-effective production is a priority, good performance can be achieved by through-hole mounting on a printed circuit board of a printed circuit EMI filter (Figure 7).

Naturally, you can not expect the same insertion loss performance, but good attenuation continues through 100 MHz, with a softening to about 40 decibels over the range to 1 GHz. Experimental results which have indicated improved performance can be obtained by providing a "floating" shielded ground plane in close proximity with the EMI filter.

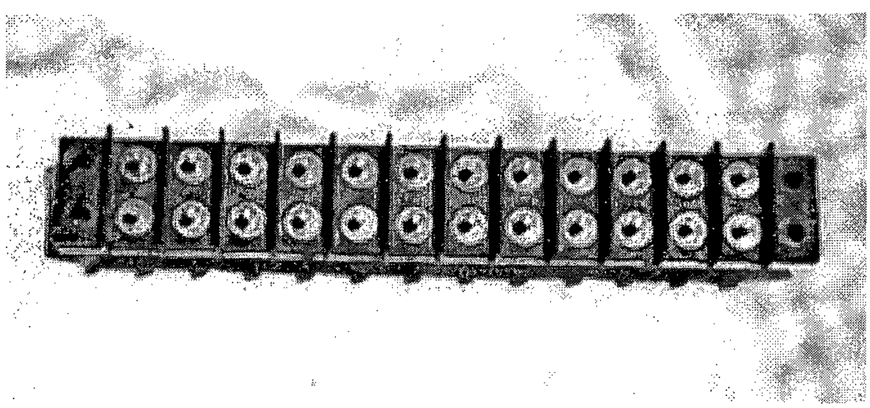

Figure 5. *Injection-molded 24-section EMI Filtered Terminal Block Utilizing Multilayered Ceramic Filter Elements for Telecommunications Applications.*

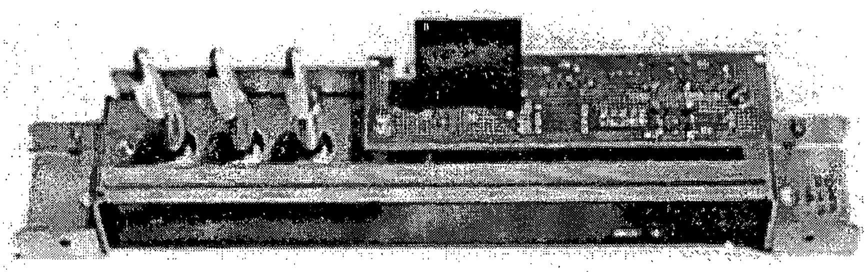

Figure 6. *Power Distribution Subassembly, EMI Filtered by 3-element High-current Injection Molded Terminal Block.*

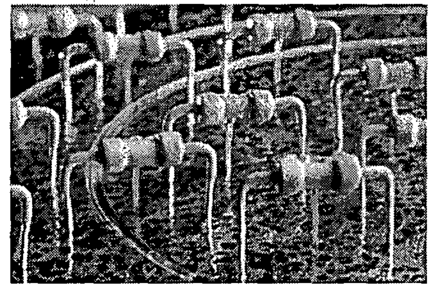

Figure 7. *PCB EMI Filters.*

Surface-Mount EMI Filters

It is obvious that today's modern electronic assemblies are, or have transitioned to, the cost-effective surface mounting of just about all types of electronic components—including EMI filters. The best place to position an EMI filter is in the wall of a Faraday cage and feed-through filters are designed to be mounted directly onto the conductive boxes surrounding the circuit. This best practice has to be tempered with cost and the reality of placing EMI filters directly onto printed circuit boards or other hybrid substrates. Bear in mind that the high frequency response will be compromised and not be as good as bulkhead mounting.

A range of multilayered ceramic products are now available to meet this demand. The simplest is a multilayered ceramic chip capacitor with an integral internal structure which allows improved decoupling of high frequency noise. This is achieved by increasing the resonant frequency of the components. These components are generally referred to as three-terminal chips, and they are quite inexpensive (Figure 8). These EMI chip filters are offered in standard EIA packages, i.e., 1206 and 1806, and are supplied bulk, tape and reel or cassette by several manufacturers. Typical performance values range from 22 pF in an NPO temperature coefficient of capacitance on up to 22 nF. Insertion loss for this family of devices is specified as 20 dB per

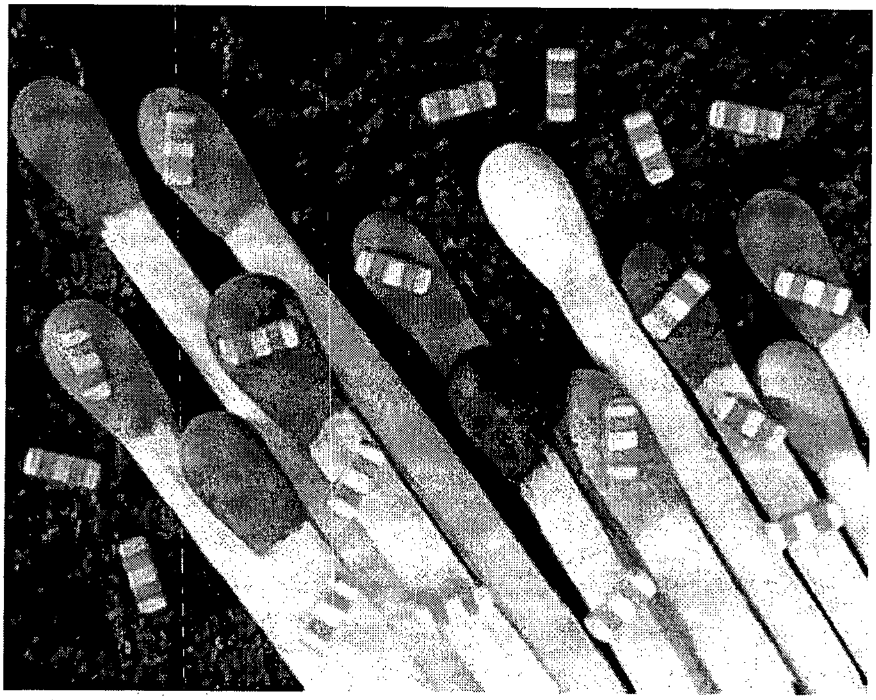

Figure 8. Low-inductance Surface-mount Filters.

decade above the cutoff frequency and rises to about 60 dB at 100 MHz before beginning a gradual fall-off.

Where enhanced performance is needed—60 db per decade—a high-current, Pi section, surface-mountable EMI filter is being offered by a number of suppliers. This product, which is in fact a chip capacitor with the internal configuration of pi filter inside, allows the designer to have a cost-effective robotic assembly method and the performance of a feed-through filter. Figure 9 shows a pi section filter rated at 10 amps with more than 40 dB insertion loss at 1 MHz, increasing to 60 dB per decade. These surface-mount EMI filters are all designed for robotic pick-and-place systems for economical assembly.

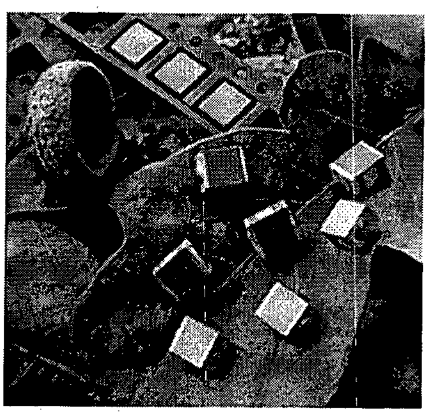

Figure 9. Surface-mount Filters Rated at 10 Amps or 20 Amps Depending on Configuration.

Summary

Since their humble beginnings in the 1960s, multilayered capacitor elements have evolved and are now being utilized across a range of standard discrete filters, planar arrays and surface-mount EMI filters. They offer the user more stable EMI filter performance over temperature, voltage, time and environmental conditions.

Higher and higher circuit densities and miniaturization will continue to create more demand for denser planar arrays and the worldwide trend toward surface mounting of all electronic components will continue to drive a need for multilayered surface-mount EMI components.

THOMAS L. VENABLE, *an industry pioneer, is President of Synergistic Technology Group, Inc., Tucson, Arizona. Synergistic Technology Group develops value-added strategic alliances and licenses among synergistic groups, while providing R&D and product marketing, sales and product distribution. Research and development is focused on dielectric film processing and the creation of polymer multilayered structures. Venable was General Manager of Erie Technological Products (now Murata-Erie) and then formed Spectrum Control, Inc., where he served as Chairman of the Board and President for more than 22 years. He is a member of the IEEE EMC Society, Society of Automotive Engineers and International Microelectronics and Packaging Society. (520)760-0291.email: tvenable@dakotacom.net.*