CERAMIC EMI FILTERS

The discoidal feed-through capacitor, a unique configuration of a ceramic multilayer chip, is utilized as an EMI suppression device and as an element in EMI feed-through filter assemblies.

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COMPONENT SELECTION AND FILTER DESIGN CONSIDERATIONS

Feed-through filters can vary in complexity from a simple single element (a capacitor or inductor) to multi-element configurations containing three or more capacitors and inductors, depending on the sensitivity of protected circuits to EMI and the nature of the interference.

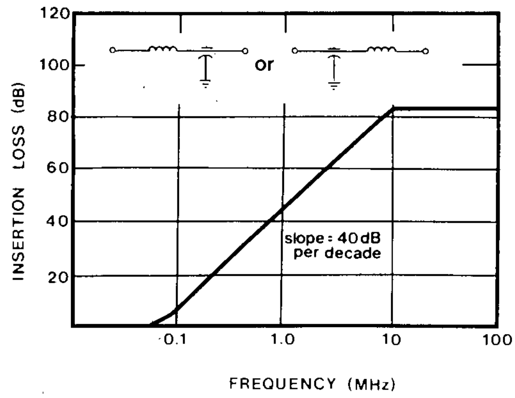


Figure 1. Attenuation of an L-section Filter.

Two-Component Filters. Two-component LC filters are used when a more effective filter is required. (Inductors are commonly referred to as "L's" and capacitors as "C's," hence LC circuits contain at least one of each.) These devices are called L-section filters with the schematic drawing showing a capacitor and an inductor connected at right angles, hence the reference to the letter "L." The L-section filter provides insertion loss values of approximately 40 dB/decade and, in the case of single component filters, the slope of the insertion loss versus frequency curve will remain constant, independent of the capacitor and inductor values. (See Figure 1 for the circuit diagram and insertion loss characteristics of L-section filters.)

The L-section filter can be used with either the capacitor or the inductor as the input terminal. The choice is usually dictated by circuit impedance considerations. In the case of mismatched systems, the capacitor should face the high impedance side of the circuit, with the inductor on the low impedance side. (See Table 1 for a summary of impedance matching considerations.)

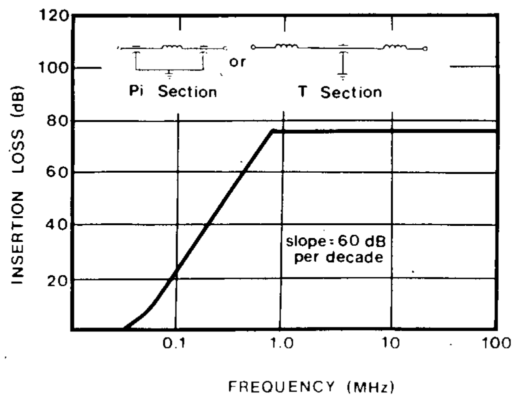


Figure 2. Attenuation of Three-component Filters.

Three-Component Filters. Three-component filters can be two types, and both are symmetrical in design. The "Pi" circuit (named for its schematic resemblance to the Greek letter) is shown in column 3 of Table 1. The "T" circuit is the second three-component filter and is also shown schematically in column 3 of Table 1. Both of these devices provide attenuation of approximately 60 dB/decade (3 components x 20 dB/decade = 60 dB/decade) and, as in the case of L-section filters, their selection is largely dictated by impedance matching and circuit application factors. (See Figure 2 for insertion loss performance and Table 1 for impedance matching considerations.)

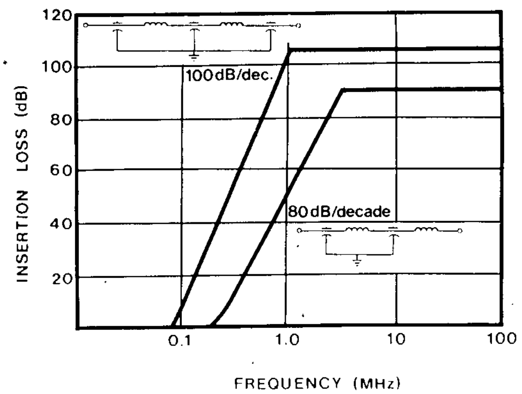


Figure 3. Attenuation of Multi-component Filters.

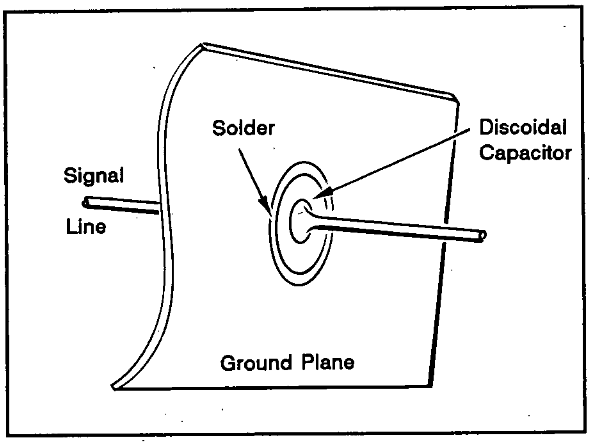


Figure 4. Feed-through in a Chassis.

Source Impedance	NUMBER OF FILTER ELEMENTS					Load Impedance
	1 20 dB/ Decade	2 40 dB/ Decade	3 60 dB/ Decade	4 80 dB/ Decade	5 100 dB/ Decade	
HIGH						HIGH
HIGH						LOW
LOW						HIGH
LOW						LOW

Table 1. Impedance Matching Considerations.

Multi-Element Filters. Schematic circuit drawings and typical insertion loss curves for four- and five-element filter devices are shown in Figure 3. The rough rule of thumb, that the slope increases by 20 dB/decade of frequency for each added element, holds for multi-element filters.

Discoidal Capacitors - Utility in Design. The shunting to ground of unwanted EMI on input and output lines from functional electronic circuits in shielded metallic boxes is the most common use of filters. The discoidal capacitor is unique in its utilitarian design for this purpose. Figure 4 shows a discoidal capacitor in the simplest such design. Achieving such filtering with a rectangular chip capacitor is all but impossible. Surface-mounted components on a circuit board can, however, provide some filtering between circuit traces and ground. It is also possible to use a leaded component to filter incoming EMI by providing an interconnection between the input line and the shielding box or to suppress some existing EMI by locating the component close to the circuit board and shunting noise from the output line to ground on the board. Using surface-mounted components or leaded devices such as filters will often result in the input or output lead wire becoming an antenna for pickup or transmission of EMI, often negating the filtering accomplished with these components.

Tubular Ceramic Capacitors as Filters. A second type of ceramic feed-through capacitor not previously discussed is the cylindrical or tubular capacitor (Figure 5). These devices are generally formed on large presses which extrude a plastic mix of the selected ceramic powders and an organic binder plus solvents. After extrusion, the tubes are cut to convenient lengths (10-20 cm, depending on the diameter), dried to eliminate the solvents and some binders, and fired in a high temperature kiln at approximately 1300°C.

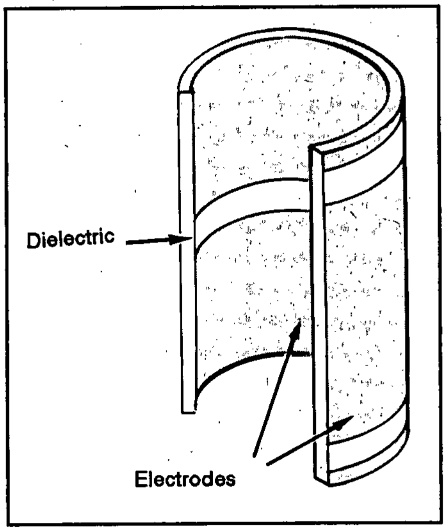


Figure 5. Cutaway View of a Tubular Capacitor.

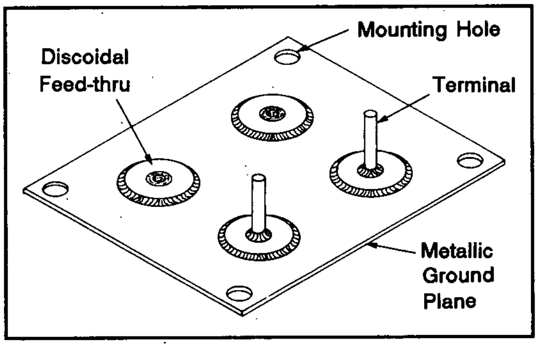


Figure 6. Feed-through Capacitor Array.

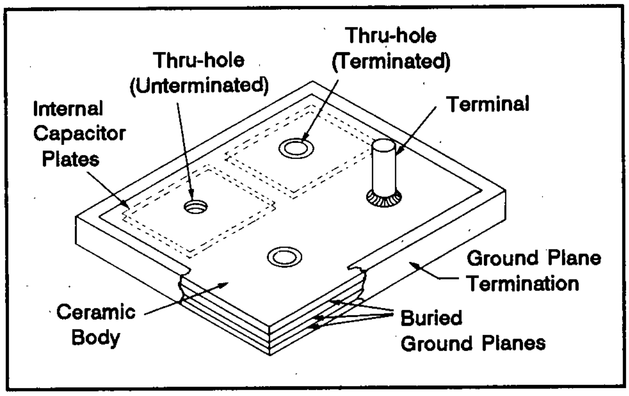


Figure 7. Monolithic Capacitor Array.

After firing, the tubes are cut to the desired length, generally 0.5 to 1 cm, with a high speed diamond saw. Electrodes are then applied on the OD and ID by either electroless metal deposition followed by electroplating or by mechanical application of a precious metal fired-on paste. Electrodes can be either continuous on both OD and ID or interrupted on the ID to provide two independent capacitors in the ceramic tube, which can be useful in the construction of PI filters.

The advantages of tubular capacitors are: (1) Due to their coaxial construction, tubular capacitors provide the same filtering efficiency as is discussed for discoidal capacitors above, where low values of capacitance are acceptable. The discoidal capacitors, however, due to their multilayer construction offer a much wider range of capacitance in a given application. (2) Tubular capacitors are economical to manufacture, costing as little as 5 percent of the cost of manufacturing a discoidal capacitor. (3) The geometric form of tubular ceramic capacitors is convenient for facilitating high volume, automated feed-through filter and capacitor assemblies.

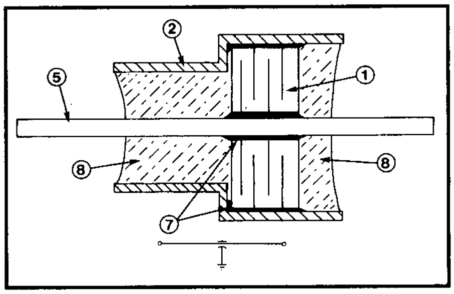
Tubular capacitors are used extensively in commercial electronic applications, such as home entertainment systems and portable audio systems. The major disadvantage, however, of tubular ceramic capacitors in filter applications is their mechanical fragility under handling and environmental stresses. This shortcoming has sharply limited their use in high reliability and military applications.

Dielectric Comparisons. The coaxial capacitor configuration is available in a wide variety of dielectric materials commonly used in the manufacture of discrete devices, such as plastic films (mylar and polycarbonate), electrolytics (aluminum), and many ceramic compositions. The major advantage of ceramic discoidal capacitors over the other available dielectrics is the very high volumetric efficiency and extreme ruggedness of devices manufactured from ceramic dielectrics.

In summary, the unique disk design with ID and OD terminals coupled with the volumetric efficiency of a multilayer design and the durability of ceramics has resulted in extensive use of the ceramic discoidal capacitor in applications in which weight and volume are of prime importance, and where operations in hostile environments (high shock and vibration levels, wide temperature extremes, high altitude, moisture, humidity, and salt spray) is critical. In short, discoidal capacitors are admirably suited to all military, airborne, and space applications.

FORM FACTORS IN FILTER ASSEMBLIES

Discoidal Arrays. It is frequently necessary to filter a number of parallel electrical input and output lines. The feed-through capacitor array, illustrated in Figure 6, is a very efficient assembly for achieving this objective. This device consists of a conductive ground plane with holes punched at feed-through locations. Discrete discoidal capacitors are soldered into the holes, wire terminals are soldered into the center holes



Key to cross sections depicted in Figures 8-18:
1. capacitor
2. plated metal case
3. inductor (toroid or ferrite)
4. glass-to-metal seal
5. center terminal
6. wire
7. solder
8. potting epoxy

Figure 8. Potted Eyelet.

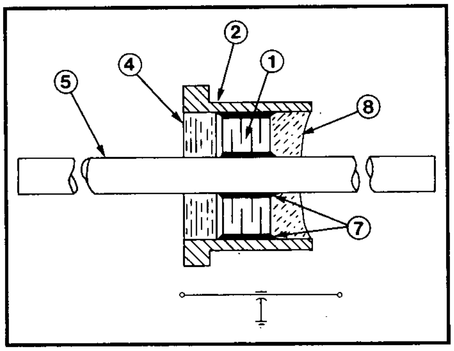


Figure 9. Hermetic Eyelet.

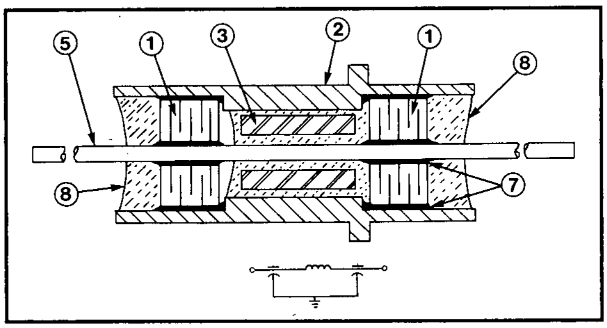


Figure 10. Potted Discoidal Pi Filter Pin.

(ID) of the capacitors, and the entire assembly is soldered or bolted into the shielded enclosure of the electronic equipment.

Figure 7 illustrates a more complex solution to the same problem. In this design, a ceramic block is printed and laminated as previously described but alternative conductive layers are continuous throughout the entire bar. After drilling, instead of punching out individual devices, multiple capacitor sections are cut from the larger bar. This produces a multi-hole block with every other layer exiting from all edges. Opposite polarity plates terminate at the holes in the bar. This block is then fired as a unit and terminated in the usual manner. After testing, the block is soldered into a ground plane in the electrical system along all four edges of the block, and the multiple parallel input and output feedthrough wires are soldered into all the holes. This monolithic capacitor array can be very cost-effective in high volume applications; however, the special tooling requirements make short runs prohibitively expensive.

Discoidal capacitor arrays and monolithic capacitor arrays are the simplest applications of discoidal capacitor technology in filtering multiple input and output lines. However, considerable expertise is required on the part of the user during the installation of these ceramic devices in electronic equipment. For user convenience, it is more customary to enclose the capacitor in a protective housing. The common packaging methods will be discussed in the remainder of this section.

Eyelets. Eyelet assemblies are available in two configurations with both ends potted, and with one end potted and the other hermetically sealed. Figure 8 is a cross section of an assembly with both ends sealed with an organic potting compound. In use, the eyelet is inserted in a hole in a ground plane with solder around the circumference. Signal or power line wires are then soldered to each end of the center terminal. These devices are used extensively in commercial applications and lend themselves to automatic loading and soldering.

For applications requiring a greater degree of system protection from hostile environments, hermetically sealed eyelets are commonly used. Figure 9 is a cross section of such a device. These units are available in capacitor or L-section configurations with the hermetic seal provided by a glass-to-metal seal on one end of the case. This feature allows the user maximum convenience in protection from hostile environments.

Filter Pins. These solder-in units are more complex than the feedthrough eyelet. They have been used traditionally to package Pi configuration filter assemblies but are also available as L section circuits.

As an example, Figure 10 shows a design for rugged military applications. This Pi section filter employs discoidal capacitors in a plated metal cylinder which acts as a protective housing for the assembly. The discoidal capacitors are soldered into cavities near each end. A ferrite bead is located between the capacitors, and the through-terminal is soldered to both capacitors. The entire unit, including the ferrite bead, is epoxy potted in the case to provide environmental protection and to immobilize the ferrite, thus preventing damage under high shock and vibration conditions.

Bolt-Style Filters. Both the eyelet and filter-pin types of filter assemblies described above are designed for solder-in applications. In many cases it is not possible to use solder techniques to attach filters to the circuit assembly due to local temperatures or materials limitations. The preferred high frequency device for these applications is the bolt-style filter. It is, as the name implies, essentially a hollow bolt which acts as a case (or package or housing) for any number of filter circuit types from simple capacitor filters to complex multi-component filters. It was originally designed as a potted unit (epoxy sealed on both ends), but recent military versions have been developed with hermetic sealing on both ends. Thread sizes range from 4-40 to 5/16-24 with capacitance ranging from 10 pF to greater than 2 μF. The smaller thread sizes usually employ tubular ceramic capacitors in their construction, and the larger sizes use discoidals; but for military or high volumetric efficiency applications, discoidal capacitors are used throughout the entire family.

Figure 11 is a cross section of a typical bolt-style Pi filter employing a tubular ceramic capacitor. Figure 12 is the equivalent device built with a discoidal capacitor. Figure 13 is a cross section of a hermetically sealed Pi section filter with discoidal capacitors in a bolt-style configuration.

Broadband Filters. These feed-through filters are the most versatile and varied filters in the family. Their distinguishing characteristics are a cylindrical housing with one end reduced in diameter and threaded for installation in bulkheads or printed circuit boards with a nut and washer. A typical outline drawing is shown in Figure 14. Body diameters range from 0.5 to 2.0 cm with corresponding thread sizes of 8-32 to 5/16-24. Circuit requirements range from simple feed-through capacitors to five- and six-element circuits.

General Information. Normally available voltage ratings for feed-through filters range from 50 to 1000 V dc and 125 to 240 V ac. Current ratings range from 0.1 to 50 A. In the lower current ranges (less than 10 A) toroidal (and occasionally solenoid) wound inductors are normally used, while in the higher current ranges, ferrite beads are used as

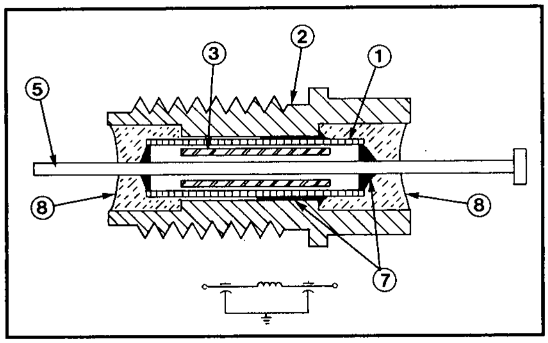


Figure 11. Potted Tubular Bolt Pi Filter.

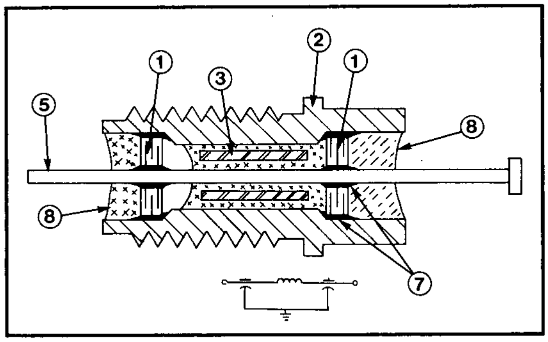


Figure 12. Potted Discoidal Bolt Pi Filter.

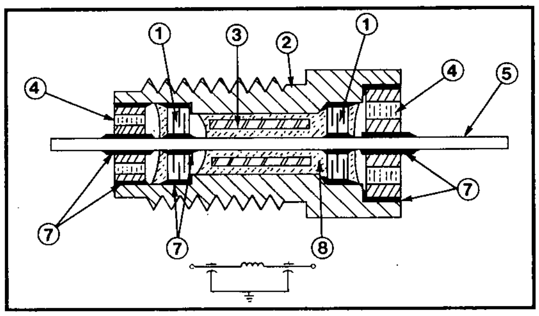


Figure 13. Hermetic Discoidal Bolt Pi Filter.

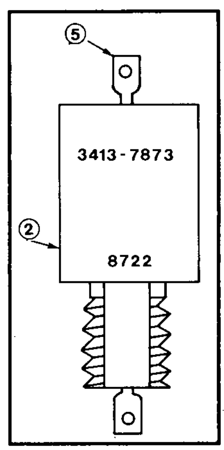


Figure 14. Typical Broadband Filter.

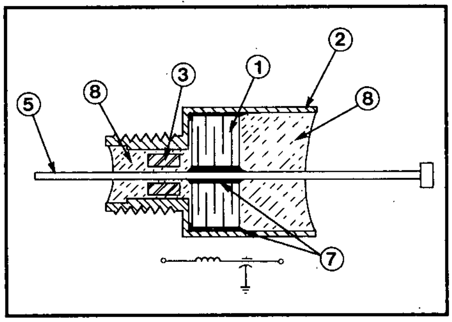


Figure 15. Potted High Current L-section Broadband Filter.

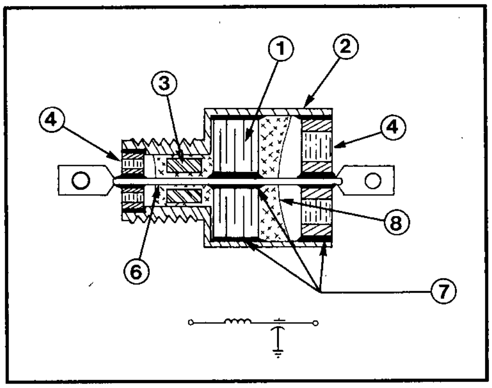


Figure 16. Hermetic High Current L-section Broadband Filter.

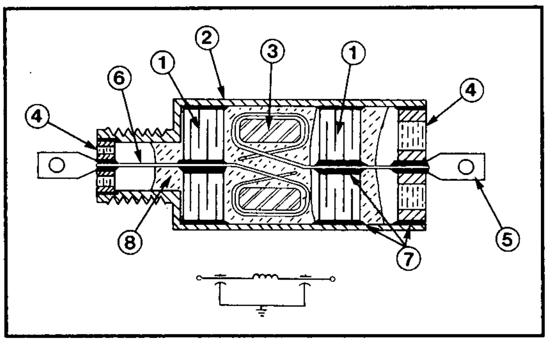


Figure 17. Hermetic Low Current Pi Filter.

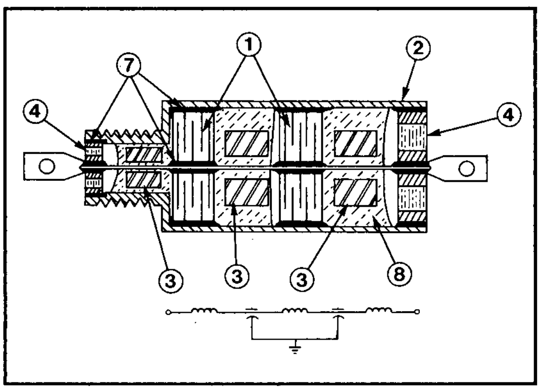


Figure 18. Hermetic Five-element Filter.

inductors. These units can be epoxy encapsulated but more frequently are hermetically sealed on both ends. Because of their higher voltage and current-handling characteristics, these devices are frequently used on both ac power lines and on the output of dc power supplies. They also are extensively used on signal lines in a wide variety of electronic equipment.

Figure 15 is a cross section of a 10-A, L-section, epoxy-encapsulated filter which can be compared to a similar hermetically sealed device shown in Figure 16. Figure 17 is a cross-sectional view of a low current Pi-section, hermetically sealed filter. Figure 18 is a section of a high current, five-element, double-T-section filter.

MANUFACTURING PROCESS FOR MULTILAYER CERAMIC CAPACITORS

Several competitive methods of manufacturing multilayer ceramic capacitors are used to fabricate very high volumes of units by large producers in several countries. Discoidal capacitors are made by only a few manufacturers and in relatively low volume. The process steps can be identical until the final configuration of the units is determined. The processes described herein were selected for the ease of explanation and do not necessarily describe any single process. The manufacturing steps used to build a chip capacitor will be shown and the deviations from this process necessary to produce a discoidal capacitor will be described.

Ceramic powders necessary to produce NPO, X7R, and Z5U capacitors can be purchased from formulators or can be manufactured with in-house expertise from chemicals, such as barium titanate. Electrode and termination metallic ingredients can, likewise, be manufactured in-house or can be purchased from quality suppliers. These metallic ingredients are used in the manufacturing processes as mixtures of metal powders

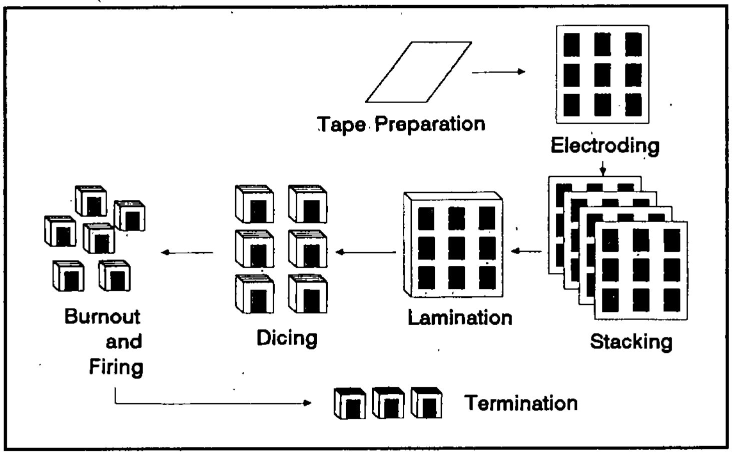


Figure 19. Process Steps for Making MLCs.

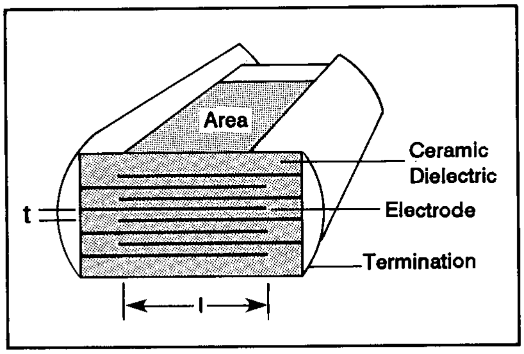


Figure 20. Cross-section of an MLC.

and organics in high viscosity pastes. Organic polymers and solvents are also combined with the ceramic powders to form a slurry used to produce the thin layers of ceramic. Ready-made polymer solutions designed for the ceramic powders are also available from commercial suppliers. The process described herein[1] and shown schematically in Figure 19 assumes that the tailored materials described above are available without describing techniques for making each.

Tape Preparation. A film of ceramic powders in an organic matrix is formed from a slurry of powder dispersed in an organic solution. A common method for forming this film or tape is known as tape casting.[2] This tape is produced with thickness carefully controlled at 25 μm, as an example, in widths greater than or equal to 10 cm and in great lengths, depending on the need of the manufacturer.

Electroding. Individual sheets of dielectric film can then be cut from this tape, and electrode paste is applied to each sheet by a silk-screening process that produces one layer for a multitude of capacitors (nine capacitors in Figure 19). Many such sheets are screen printed, half with the electrode located in one polarity position and the other half with electrodes offset very slightly but precisely in the second polarity position.

Stacking. These sheets are then stacked by alternating the first and second polarity sheets. Suitable blank sheets (no electrodes) are included at the top and bottom of the stack.

Laminator. These sheets are then laminated into a block at elevated temperature and pressure (50°C, 10 MPa).

Dicing. A heated blade is then used to cut the block into individual unfired capacitors.

Burnout and Firing. The capacitors are then dried at temperatures sufficient to eliminate the organic components of the electrode paste and the binder and solvents used in the tape casting operation. The capacitors are then fired at 900° to 1300°C, depending on the maturing temperature of the ceramic.

Termination. In a subsequent process, termination paste is applied to either end of the chip and is fired at a temperature near 850°C. The terminations provide electrical continuity among electrodes of like polarity exposed at either end of the chip. (See Figure 20.)

This, then, briefly describes the process for manufacturing a chip capacitor.

MANUFACTURING VARIATIONS TO PRODUCE DISCOIDAL CAPACITORS

The production steps necessary to fabricate discoidal capacitors are identical to those for chips through the lamination step. Unlike the chip process, however, the electrode patterns for discoidals are circular with holes in the center, as shown in Figure 21.

Drilling. After the lamination step, a hole is drilled in the center of each electrode pattern in the laminated bar with a high speed carbide drill. This hole will provide access to those alternate metallic conductors (electrodes) which will later be terminated to provide electrical continuity for one polarity of the capacitor.

Punching. The individual capacitors are then cut from the laminated bar using a punching process.

Turning. The individual discoidal capacitors are then loaded on a mandrel using the center hole produced in the drilling step and turned on a special lathe (with a diamond tool bit) to accurately machine the

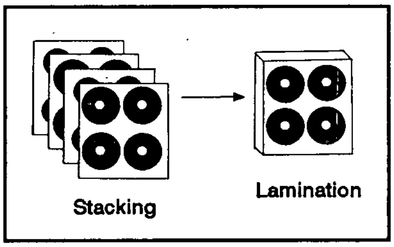


Figure 21. Electrode Patterns for Discoidals.

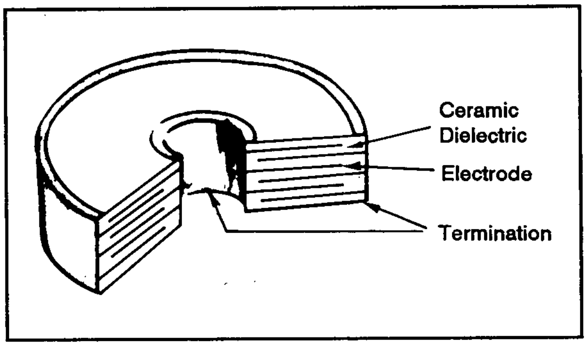


Figure 23. Cross-section of a Discoidal.

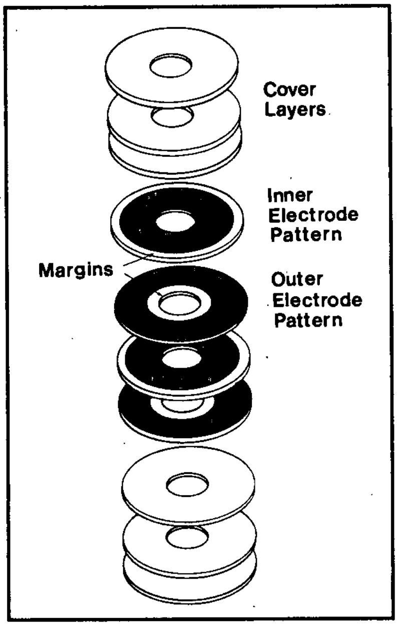


Figure 22. Exploded View of a Discoidal.

outside diameter of each capacitor within precise tolerances. An exploded view of a drilled, punched, and turned discoidal capacitor is shown in Figure 22.

Burnout and Firing. The burnout and firing steps are identical to those for chip capacitors.

Termination. The termination paste is then applied to the ID of the center hole and the OD of each discoidal capacitor and fired in a subsequent step at approximately 850°C. Since alternate electrodes are exposed to the ID and OD in this manufacturing process, the termination process links electrodes of identical polarity creating multiple parallel capacitors with one terminal at the center of the disk and the other terminal at the OD. A cross section of a terminated discoidal capacitor is shown in Figure 23, which can be compared to that of the chip capacitor in Figure 20.

MANUFACTURING TECHNOLOGY FOR THE ASSEMBLY OF FILTER CIRCUITS

To utilize ceramic (tubular or discoidal) capacitors in filter applications, these devices must be packaged in such a manner to ensure efficient handling by the users. The general principles and manufacturing techniques for all these assemblies are quite similar. As a case study, the various process steps will be demonstrated for a resin-sealed, bolt-style filter.

Filter housings are invariably made of metal to provide a solid conductive path to ground, as well as for mechanical protection. The most common materials used are steel, kovar, and brass. The basic case is plated with a metal to provide good conductivity, solderability, and protection from corrosive and hostile environments. Most commonly used platings are nickel, copper, tin, silver, and gold.

Electrical interconnections are made using solder assembly techniques. It is possible to use conductive polymers as alternatives to solder, but devices assembled by these techniques exhibit poor performance at high frequencies due to the increase in resistivity of conductive polymers at frequencies greater than 100 MHz.

Two major principles dominate solder assembly of ceramic capacitors: (1) Any assembly system must have provisions for minimizing thermal shock to the ceramic elements during solder reflow operations. This is normally accomplished by the use of assembly fixtures of high thermal mass. Units are preassembled and placed in the fixture. The fixture is then slowly heated to an equilibrium temperature of 30° to 50°C below the reflow temperature of the solder of choice. Individual units are then heated to the solder melting temperature but only long enough to ensure a good solder wetting of the capacitor termination and the case. The unit is then allowed to cool to the "idling" temperature, and when all units are complete, the entire fixture is slowly cooled to room temperature. (2) During the assembly of filter devices, each step must utilize a solder whose melting temperature is higher than that of any solder to be used in subsequent steps.

The steps involved in building a bolt-style, epoxy-encapsulated Pi filter are: (1) A tin- or gold-plated copper lead is soldered through the ID hole of a discoidal capacitor using a solder with a melting point of 309°C. (2) The subassembly is then soldered into a case using a solder with a melting point of 221°C. (3)

The device is thoroughly cleaned to remove all solder flux residue from the surfaces of the capacitor and the inside diameter of the case. (4) A ferrite bead is installed in the unit and immobilized with a thermosetting epoxy (cure: 4 h at 125°C). (5) The second discoidal capacitor is installed using two different solders. The ID solder melts at 221°C, and the OD solder at 167°C. (6) The device is cleaned as in step (3) above. (7) Both ends are potted with a thermosetting epoxy and marked by offset printing techniques using a durable epoxy ink. Then the epoxies are cured for 4 h at 125° C. (8) The units are electrically tested and subjected to any screening and environmental testing required by the user. The units are then packaged for shipment.

TESTING AND QUALITY CONTROL

The testing of filters can be divided into three major categories: (1) functional electrical testing, (2) environmental testing, and (3) screening, which includes elements of both electrical and environmental testing.

Electrical testing is routinely conducted at intervals during assembly (in-process inspection) and upon completion of the device (final inspection). In-process inspection is usually limited to measurement of capacitance and dissipation factors, inductance, insulation resistance, and dielectric withstanding voltage. In-process inspection also assures conformance to the design configuration. All in-process testing is performed in accordance with MIL-STD-202.

Final inspection usually includes those tests described as in-process tests, plus, in most cases, measurement of insertion loss on a sample quantity of the lot. Devices purchased to comply with military specifications require 100-percent testing for insertion loss. This test for filters is defined and governed by MIL-STD-202 and can be performed both with and without full-rated current flowing through the filter.

Inspection	Test Method Paragraph
Group I	
Thermal shock and voltage conditioning	4.6.2
Dielectric withstanding voltage	4.6.3
Insulation resistance (at +25°C)	4.6.13
Capacitance to ground	4.6.4
Insertion loss	4.6.5
dc resistance*	4.6.7
dc voltage drop*	4.6.6.2
Radiographic inspection	4.6.8
Seal (when applicable)	4.6.9
Visual and mechanical inspection	4.6.1.1
Group II	
Voltage and temperature limits of capacitance (when applicable)	4.6.10
Insertion loss (at temperature)	4.6.5.1
ac voltage drop (when applicable)	4.6.6.1
Temperature rise	4.6.11
Barometric pressure (reduced)	4.6.12
Insulation resistance	4.6.13
Current overload	4.6.14
Resistance to solvents	4.6.15
Group III	
Vibration (high frequency)	4.6.16
Thermal shock and immersion	4.6.17
Seal (when applicable)	4.6.9
Resistance to soldering heat	4.6.18
Salt spray (corrosion)	4.6.19
Radiographic inspection	4.6.8
Destructive physical analysis (2 sample units only)	4.6.20
Group IV	
Shock (specified pulse)	4.6.21
Terminal strength	4.6.22
Moisture resistance	4.6.23
Seal (when applicable)	4.6.9
Radiographic inspection	4.6.8
Destructive physical analysis (2 sample units only)	4.6.20
Group V	
Solderability (5 samples only)	4.6.24
Life	4.6.25

* The contractor has the option of performing either the dc voltage drop or dc resistance test.

Table 2. Sequence of Qualification Inspection Requirements for MIL-F-28861.

Most filter specifications define insertion loss requirements as a function of the frequency over a specified frequency range, e.g., 30 kHz to 1 GHz. While it is possible to perform these measurements in a point-by-point manner using a signal generator and RF voltmeter, it is faster and considerably more accurate to use a spectrum analyzer and a tracking generator to provide a continuous display of the signal strength versus frequency plot on the display of the spectrum analyzer. At the higher frequencies, fixturing and interface circuitry between the filter, the signal

Inspection	Test Method Paragraph
Group I	
ac voltage drop (when applicable)	4.6.6.1
Voltage and temperature limits of capacitance	4.6.10
Insertion loss (at temperature)	4.6.5.1
Barometric pressure (reduced)	4.6.12
Temperature rise	4.6.11
Current overload	4.6.14
Terminal strength	4.6.22
Thermal shock and immersion	4.6.17
Destructive physical analysis (2 samples only)	4.6.20
Group II	
Subgroup 1	
Solderability (5 samples only)	4.6.24
Life	4.6.25
Subgroup 2	
Resistance to soldering heat	4.6.18
Resistance to solvents	4.6.15
Salt spray (corrosion)	4.6.19
Radiographic inspection	4.6.8
Destructive physical analysis (2 samples only)	4.6.20
Group III	
Shock (specified pulse)	4.6.21
Vibration (high frequency)	4.6.16
Moisture resistance	4.6.23
Seal (when applicable)	4.6.9
Radiographic inspection	4.6.8
Destructive physical analysis (2 samples only)	4.6.20

Table 3. Sequence of Periodic Inspection per MIL-F-28861.

Inspection	Test Method Paragraph
Subgroup 1	
Thermal shock and voltage conditioning	4.6.2
Insulation resistance (at 125°C)	
Dielectric withstanding voltage	4.6.3
Insulation resistance (at 25° C)	4.6.13
Capacitance to ground and DF	4.6.4
Insertion loss	4.6.5
dc resistance*	4.6.7
dc voltage drop*	4.6.6.2
Radiographic inspection	4.6.8
Seal (when applicable)	4.6.9
Subgroup 2	
Visual and mechanical inspection	4.6.1.1

* The contractor has the option of performing either the dc voltage drop test or dc resistance test.

Table 4. Screening Sequence per MIL-F-22861.

source, and the load power supply become critical and difficult to design.

Compliance is normally assured on a sample of the lot to the requirements of MIL-STD-202 for thermal shock and immersion, resistance to soldering heat, resistance to solvents, high frequency vibration, moisture resistance, barometric pressure reduction, temperature rise, terminal strength, solderability, life, salt spray, and mechanical shock.

Environmental testing of filters can be specified by the user in two ways: (1) The manufacturer can be asked to demonstrate compliance with the environmental specifications as part of a qualification inspection during which a filter manufacturer demonstrates the capability to manufacture the device for the first time, and/or (2) as part of a continuing testing program for each lot produced, or on a regular basis, such as quarterly, or semiannually. Tables 2 and 3 show testing sequences for these alternatives according to MIL-F-28861.

Screening is generally required by and defined for most military applications. Table 4 shows typical requirements of MIL-F-28861. Thermal shock and power conditioning (at twice rated voltage at 125°C for 168 h) are common tests for most screening requirements. Destructive physical analysis (DPA) is usually required on 5 to 10 percent of lots manufactured for military applications.

APPLICATION OF FILTERS: TWO CASE HISTORIES

Electronic filters are required in a wide variety of systems and are used in electronic applications for many industries. The one factor common to most such uses is that the performance characteristics for the filters cannot be (or are not) determined until the system has been designed, built, and field tested. The need for filtering is very difficult to predict from a theoretical analysis of system performance during the design phase. Furthermore, comprehensive EMI susceptibility testing is difficult and very expensive to perform at the system level. Electronic filters are normally retrofitted to prototype systems to resolve interference problems demonstrated in the field. The need for close cooperation between the user and the filter manufacturer and the time pressure on quickly resolving these system problems is obvious. The following two hypothetical case histories (based on actual problems) will demonstrate the typical applications of filters to the elimination of EMI.

Case History No. 1. During the mid-1970's, several major truck manufacturers implemented an anti-skid braking system program for their large truck and bus product lines. These advanced braking systems were to be similar to those in use for many years on aircraft. Anti-skid brakes consist of rotation sensors in each wheel which report rate of rotation to a central computer located under the truck chassis. The computer compares and analyzes the data from the wheels and controls hydraulic fluid pressure to the individual wheel cylinders.

When the first trucks equipped with these systems had been on the road for several months, drivers began to experience unusual temporary brake system failures, including no brakes when pressure was applied to the foot pedal, spontaneous lockup of one or more wheels without applying pressure to the foot pedal, or lockup of one or more wheels during braking.

It was noted that the second failure listed above frequently occurred on steel-grid roadbed bridges. Further investigations determined that the on-board computer was susceptible to EMI, and that some of the steel roadbeds were not well grounded and were acting as collectors and radiating antennas. Re-radiated local broadcast and TV frequencies were being received by the on-board computers as the vehicles passed over these bridges.

The solution consisted of providing a solid electrical ground connection between the computer and its cover (shielding) and then filtering each of the input and output lines at their entrance or egress points to and from the computer enclosure. Since space was at a premium in this system, an array of discoidal capacitors in a metal ground frame was incorporated into each input/output connector on the computer.

The result was that since the first engineering samples were installed in the field units, there have been no reported EMI-induced brake system failures.

Case History No. 2. During the early 1980's, a secure airborne communications system was developed. Since space and weight were at a premium, the number of individual printed circuit boards in the system was minimized. This required that unencoded (raw) and encoded electronic data exist on the same board. The initial system utilized a metal housing and ground plane attached to the board to isolate and secure raw data. Bolt-style feedthrough filters employing tubular capacitors were used to filter three of the seven dc power lines shared by the encoded and raw data circuitry.

During initial field trials, it was determined that filtering of the three lines was inadequate (not enough attenuation) and that all seven lines required filtering. These changes would have required a complete redesign of the circuit board (at a cost of $300,000), delaying the program by 6 to 8 months.

The solution consisted of packaging seven high capacitance Pi filters in a custom feed-through package that was inserted in the bulkhead of the existing housing. This device has a cut-off frequency of 20 kHz (versus 1 MHz for the previous design) and provided 60 dB of attenuation at 10 MHz (versus 25 dB in the earlier system). Furthermore, the seven filters fit into the same area required by the three filters used in the original design.

As a result, all units built to date have utilized the custom high performance device, and no problems with EMI or crosstalk between the two sections of the system have been encountered.

SUMMARY

Ceramic EMI filters provide a superior solution to the problem of controlling EMI in advanced, high reliability, high performance electronic systems. The manufacturing technology for multilayer chip capacitors, which has evolved over the past 25 years, has been applied to the manufacture of discoidal multilayer ceramic capacitors. These unique capacitors provide the filter manufacturer with a spectrum of design capabilities and the ruggedness necessary to perform in a variety of hostile environments. ■

REFERENCES

1. J. H. Adair, D. A. Anderson, G. O. Dayton, and T. R. Shrout, "A Review of the Processing of Electronic Ceramics with an Emphasis on Multilayer Capacitor Fabrication," *J. Mater. Educ.*, 9[1-2] 71-118 (1987).
2. R. E. Mostler, D. J. Shanefield, and R. B. Runk, "Take Casting of Ceramics," pp. 411-88 in Ceramic Processing Before Firing. Edited by L. L. Hench and G. Y. Onoda, Jr., Wiley, New York, 1978.

This article was adapted from the article, "Ceramic EMI Filters - A Review," Ivan G. Sarda and William H. Payne; Ceramic Bulletin Vol. 67, No. 4; pp. 737-739; 1988. Reprinted with the permission of the American Ceramic Society.