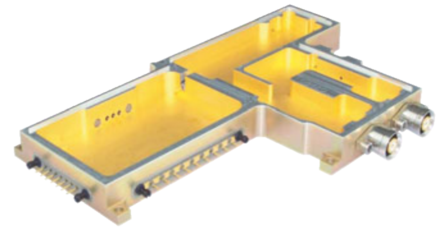
Hermetics For Extreme Environments

Integrated Packaging



Using technologies such as Kryoflex® and explosively bonded metals,SOURIAU PA&E designs and manufactures hermetic packaging for extreme environments — whether it's integrating components that protect satellites deep in space or connectors for oil-drilling tools that bore deep below the earth's surface. By pairing our Kryoflex and explosively bonded metal technologies, we can build hermetic packages using precision laser welding rather than solder joints, thus eliminating the two most common causes for hermetic package failure: solder joint fatigue and cracked glass.

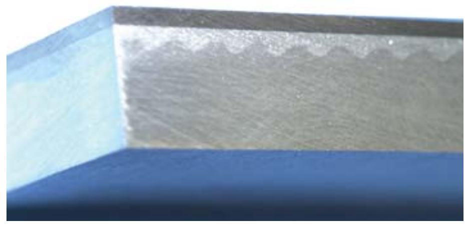
Rectangular DC Connectors

Our hermetically sealed rectangular DC connectors exceed most mil-spec requirements and are designed for use in military and commercial applications where environmental conditions require an extremely rugged and reliable hermetic seal. The uniquely controlled CTE characteristics, chemical bonding properties and polycrystalline structure of our Kryoflex^{O} allows SOURIAU PA&E to manufacture these hermetic connectors with 304L stainless steel shells and gold plated beryllium copper contacts to maintain excellent electrical performance and environmental characteristics.

RF/Microwave Connectors

Our 50 Ohm hermetic RF/Microwave connectors are designed for use in military and commercial applications where environmental conditions require an extremely rugged and reliable hermetic seal. Low-loss Corning 7070 glass is used for dependable electrical performance. SOURIAU PA&E manufactures these hermetic RF connectors from a variety of compatible shell and contact materials, in both laser weld and solder-in styles, which provide excellent electrical and environmental performance characteristics.

Bonded Metals



SOURIAU PA&E has been the innovative leader in the Explosive Metal Working field for over 30 years. We provide our customers access to some of the world's most exciting metal working technologies, such as: Explosive Metal Bonding, Explosive Metal Forming, Explosive Shock Hardening and Dynamic Powder Metal Compaction. These High Strain Rate technologies offer rare metal working advantages to help our customers achieve the "impossible."

SOURIAU PA&E
434 Olds Station Road Wenatchee, Washington 98801
TEL 509.664.8000 FAX 509.663.5039
www.pacaero.com

ISO 9001:2008/
AS9100

Esterline
Connection Technologies

WHITEPAPER: CERAMIC EMI FILTERS: A REVIEW

IVAN G. SARDA and WILLIAM H. PAYNE*

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.

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

Sources of continuous EMI can include, for example, automobile ignition systems, radio and TV transmitters, motors, computer clock oscillators, switching power supplies, ultrasonic equipment, and microwave devices. Intermittent EMI is produced by electrostatic discharges, lightning, switching on and off of inductive loads such as motors and welding machines, RF heating and soldering equipment, and a category that has recently come under intense study, the detonation of nuclear weapons in the atmosphere.

The EMI propagation modes are radiation, conduction, and any combination of the two. The various modes of propagation are illustrated in Fig. 1. In the combination modes, the wires connecting various pieces of equipment act like receiving or transmitting antennas.

Electromagnetic interference can be suppressed and controlled by two basic techniques: shielding and filtering. In the shielding technique, the entire piece of equipment is enclosed in a tightly sealed metal or metallized, plastic housing. This housing is then tied to ground by a solid, low resistance connection.

In filtering, at all points of conductor (input and output signal and power lines) entry to or egress from the shielded container, a filter is installed in the line at the point of penetration of the shield. Filtering and shielding are commonly used in combination to optimize circuit performance.

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 sensitivity of protected circuits to EMI and the nature of the interference.

Capacitors as EMI Filters

Reactance (the ac equivalent of resistance) of a capacitor can be expressed as:

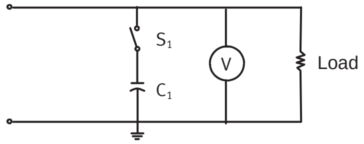


Fig 2. Capacitor as a filter

$$X_c = 1/2\pi f C \quad (1)$$

where X_c is capacitive reactance in ohms, f is the frequency of the ac signal in hertz, and C is the capacitance in farads.

It can be seen from the above relation-ship that as frequency and capacitance increase, X_c of the circuit decreases. In the circuit diagram of Fig. 2, as the frequency increases with switch S1 closed, the capacitor will present a lower and lower impedance path and, therefore, more of the signal will be shunted to ground through the capacitor.

If one measures the signal voltage with switch S1 open and again with S1 closed, the following relationship exists:

$$V1 > V2 \quad (2)$$

where $V1$ is measured with the capacitor not in the circuit and $V2$ is measured with the capacitor in the circuit.

The attenuation of signal or insertion loss is defined as:

$$IL(\text{dB}) = 20 \log_{10} V1/V2 \quad (3)$$

where the insertion loss, IL, is expressed in decibels (dB).

If the attenuation is measured as a function of frequency and plotted on semilog paper, the slope of the curve will be ≈20dB/decade of frequency, as is shown in Fig. 3. If the capacitance value in the circuit is changed from $C1$ to $C2$, the slope will remain the same, but the insertion loss at any frequency will decrease (as shown in Fig. 2) when $C1 > C2$.

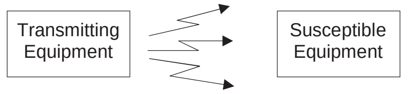
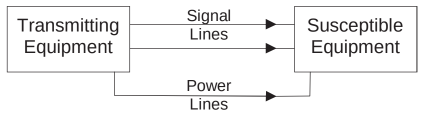
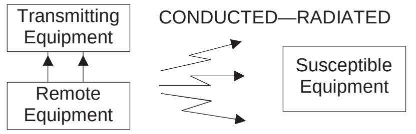
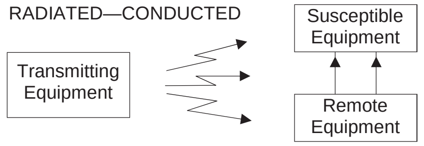
PROPAGATION MODE	SUPPRESSED BY:
RADIATED  	- Shield transmitting and susceptible equipment units
CONDUCTED  	- Shield both units - Filter entry and egress of signal lines at both units - Filter power lines at both units - Shield signal lines
CONDUCTED—RADIATED  	- Shield susceptible equipment - Filter entry and egress of signal lines at both remote and transmitting equipment - Shield signal lines
RADIATED—CONDUCTED  	- Shield transmitting equipment - Filter entry and egress of signal lines at both remote and transmitting equipment - Shield signal lines

Fig 1. Propagation modes for EMI

---

*Member, the American Ceramic Society

Reprinted from the CERAMIC BULLETIN, VOL. 67, NO. 4, 1988 (© ACerS)

SOURIAU PA&E

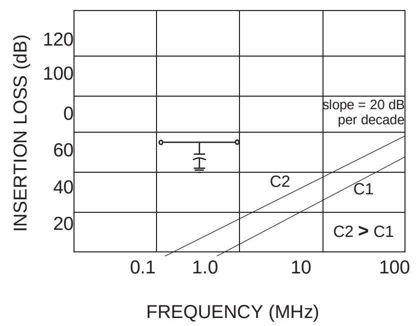


Fig 3. Attenuation of a capacitor.

Inductors as EMI Filters

The reactance of an inductor can be expressed as:

$$X_L = 2\pi f L$$
(4)

where X_L is the inductive reactance in ohms, f is the frequency in hertz, and L is the inductance in henries.

The inductive reactance is the ac analog of series resistance, and it can be seen that as the frequency and inductance increase, so does X_L.

In Fig. 4, $V1 > V2$ and the attenuation of the signal or insertion loss can be expressed as:

$$IL(\text{dB}) = 20 \log_{10} V1/V2$$
(5)

If a plot of attenuation vs frequency is made on semilog paper, then, just as in the case for the capacitor, the slope will be ≈ 20 dB/ decade of frequency, as is shown in Fig. 5. If the value of the inductor is changed, the insertion loss at any frequency will change; but the slope of the insertion loss vs frequency curve will remain constant at 20 dB/ decade.

It can be seen that a single capacitor or inductor can be used to attenuate EMI by ≈ 20 dB/decade of frequency. It also will be shown that capacitors and inductors can be used in combination to reduce EMI and that the attenuation or insertion loss of combinations of these elements is additive; that is, one capacitor and one inductor can be used to achieve 40 dB/ decade of attenuation. Three such components in the proper design can, therefore, result in 60 dB/decade attenuation. These relationships will hold up to an upper value of attenuation when the internal inductance and resistance of the capacitor and the series resistance and capacitance of the inductor produce a self-limiting effect. Depending on the complexity of the filter and the component values, this ceiling will be between 70 and 120 dB for the EMI filters discussed herein.

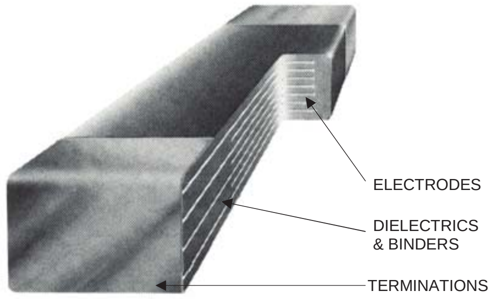


Fig 6. Cutaway view of a chip capacitor.
(Courtesy of E.I. du Pont de Nemours & Co., Inc.)

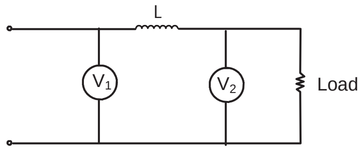


Fig 4. Inductor as a filter

Discoidal Multilayer Ceramic Capacitors

The multilayer ceramic capacitor has become the dominant capacitor in use by the electronics industry in the past decade. It is available as a radially or axially leaded device. Unencapsulated and without leads, this passive component is known as a chip capacitor. Chip capacitors are monolithic, cofired sandwiches of alternating ceramic and metal layers as is shown in Fig. 6. Each alternating conducting layer of metal is offset end-to-end, and layers of common polarity are connected with metallic terminations at each end of the capacitor, as is shown in Fig. 7. Since the capacitance of a dielectric is inversely proportional to thickness (Fig. 8) and capacitors sum in parallel (Fig. 9), it can be concluded that multilayer ceramic capacitors have great volumetric efficiency (large capacitance in a small package). This characteristic, coupled with the reliability of ceramics and the convenience of design for surface mounting applications, explains the popularity of the device.

A discoidal capacitor is recognized within the industry as a multilayer ceramic capacitor in the geometric configuration of a disk. Alternating conductor layers are offset and connected by the termination at the edge of the disk. The termination of opposite polarity is made at a center hole. This configuration retains the volumetric efficiency and reliability of the multilayer ceramic capacitor in a geometry which will be shown to be ideally suited to EMI filtering .

Choices of Materials

Multilayer ceramic capacitors are constructed of ceramic and metallic layers plus organic materials which are used solely to facilitate chip manufacture and are eliminated during subsequent processing. Platinum, palladium, gold, silver, nickel, and copper are being or have been used to manufacture multilayer ceramic capacitors as part of the alternated conductive layers (electrodes) or the terminations. Capacitors suitable for the most common applications have been fabricated using these metals with adequate electronic performance. The choice of metallurgy of the electrode is generally determined by the chemistry of the cofired ceramic dielectric, while the choice of termination metals is determined primarily by the processes dictated by the user for installation of the capacitor in the circuit.

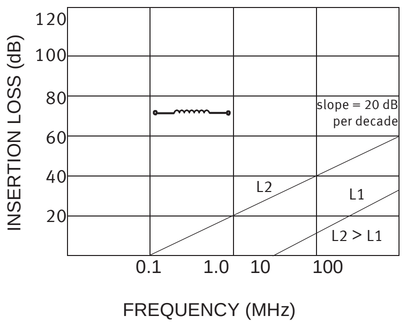


Fig 5. Attenuation of an inductor.

In specifying the electrical performance, then, the designer need only define the performance of the ceramic dielectric. In most cases, the user specifies the expected capacitance of the device and the tolerance of change in capacitance from capacitor to capacitor and over the operating temperature range of the circuit. Variance among capacitors is related primarily to the consistency of the manufacturing process. Change in capacitance over the expected operating temperature range of the device is determined by the dielectric. Multilayer ceramic capacitors are generally available in three dielectrics : NPO (same as COG), X7R, and Z5U (sometimes Y5V). (These three digit dielectric descriptions are specified by the Electronic Industries Assn.)

Temperature stability of ceramic dielectrics is generally related to their dielectric constant (K). Some low K dielectrics are exceedingly stable, exhibiting < 30 parts per million/°C change in capacitance over an operating temperature range from - 55° to 125°C, a maximum of ≈ 1% change over the entire temperature range. These dielectrics are specified as NPO ceramics and generally have a dielectric constant of ≤ 100.

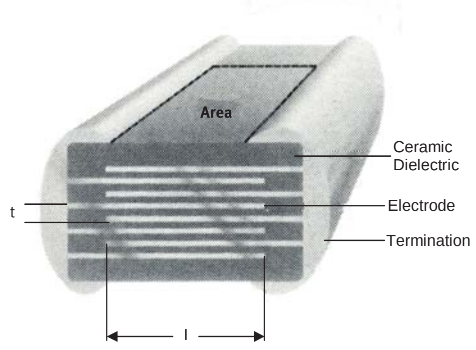


Fig 7. Cross-section of an MLC. (Courtesy of E.I. du Pont de Nemours & Co., Inc.)

Ivan G. Sarda founded Ceramic Devices, Inc. in 1982.

Mr. Sarda received his B.S. in geology at Rensselaer Polytechnic Institute, Troy, NY, in 1955 and continued his studies in geophysics in California Institute of Technology's graduate school.

Mr. Sarda has 25 years of experience in the development and manufacture of solid state electronic circuits and devices. He served as Manager of Device Development for the Microelectronics Division of Westinghouse Corp. in the early '60s and established a hybrid microcircuit facility for Radiant Energy Systems in the early '70s. He served as Chief Engineer for AVX filters prior to joining Viclan/Kyocera in 1977 to establish and manage their EMI filter division.

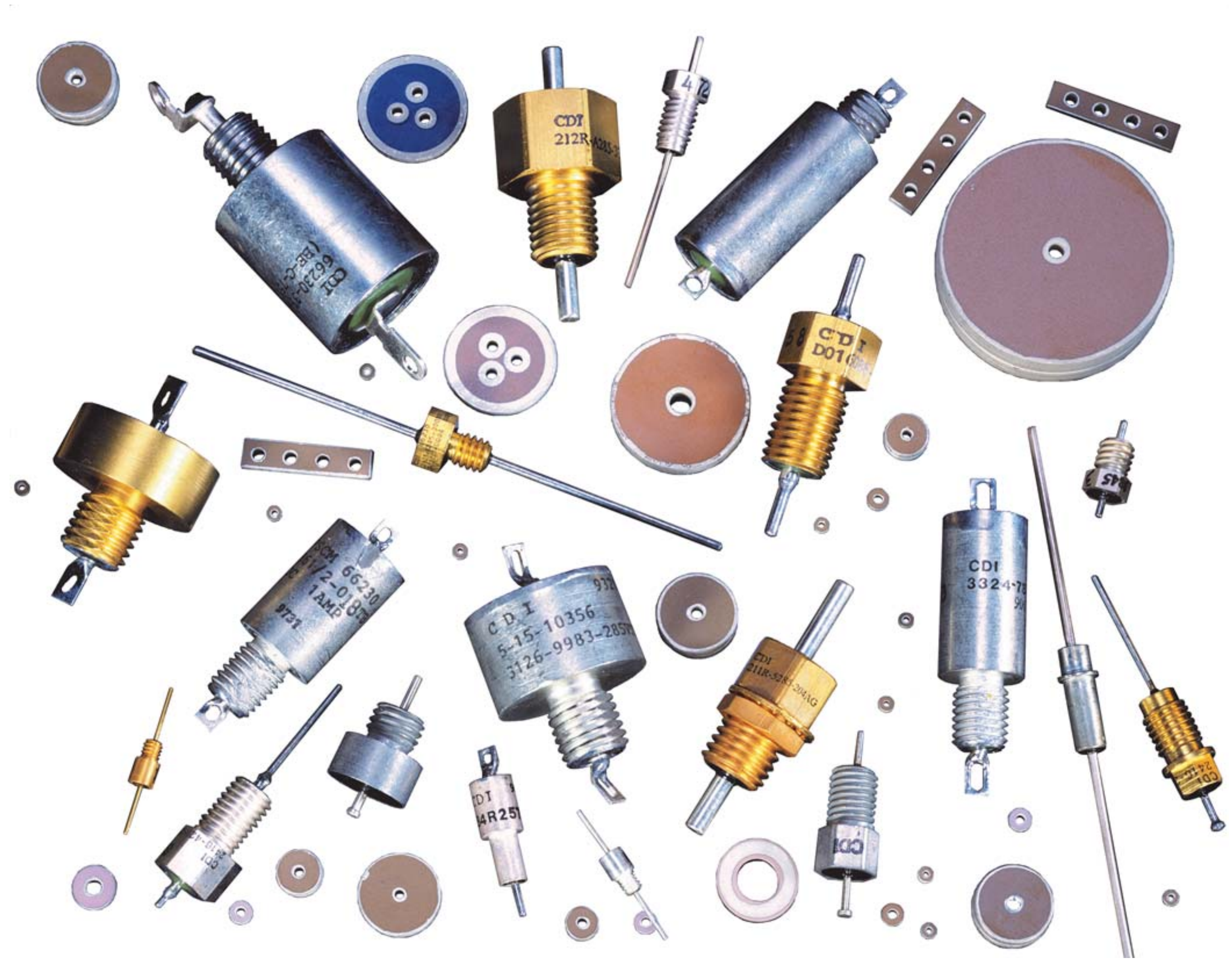
California Microcircuits, Inc., a successful start-up by Mr. Sarda, was sold in 1971.

William H. Payne

Mr. Payne received his B.S. in 1963 and his M.S. in 1964 both in ceramic engineering from the University of Illinois. He held positions with Interpace Corp. and Hughes Aircraft Co. before joining Solid State Dielectrics, Inc. in 1972, where he rose to the position of president. After Solid State Dielectrics was purchased by DuPont in 1982, he managed the merged business and sought new opportunities for DuPont in advanced ceramics until he left the firm in 1986.

Mr. Payne served as president of the United States Advanced Ceramics Association, Washington, DC, in 1986. He is a member of the Advisory Board, Ceramic Engineering Department at the University of Illinois. He is a member of the President's Council at the University of Illinois and the President's Club at the University of Washington.

A past president of the National Institute of Ceramic Engineers, he is a Fellow and president-elect of the American Ceramic Society and is affiliated with the Electronics Division and the Ceramic Education Council. He previously served the Society as treasurer and vice president and as past chair and counselor of the Southern California Section. In 1978 he was presented the Schwartzwalder-PACE Award and gold medal.



feed-through package that was inserted in the bulkhead of the existing housing. This device has a cut-off frequency of 20 kHz (vs 1 MHz for the previous design) and provided 60 dB of attenuation at 10 MHz (vs 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 cross-talk 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 yr, 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. Maler. 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.

SOURIAU PA&E
FILTER DIVISION

Originally founded as Ceramic Devices, Inc. (CDI), in San Diego, CA in 1982 to provide filtering solutions to electromagnetic interference (EMI) problems which plague manufactures of high performance, high reliability electronic systems. EMI is an intermittent or continuous noise which is radiated or conducted into or out of electronic equipment, disrupting the normal operation of electronic systems. Sources of EMI include broadcast transmitters, motors, power supplies, and microwave devices. High frequency EMI is often catastrophically disruptive to sensitive electronic circuits and the characteristics of this noise seldom can be predicted for the system's operating environment. Elimination of these undesirable signals is usually accomplished during field testing of the system, and hence, solutions require creativity under extreme time constraints. Designing EMI-free circuit housings, including access and egress for "pure" signal and power lines in military and aerospace electronic systems, is usually accomplished using combinations of discoidal multilayer ceramic capacitors and ferrite inductors in a filter assembly. SOURIAU PA&E Filter division is adept at designing EMI filters for electronic circuits operating in hostile EMI environments. The company is a military qualified business whose growth has been accomplished by quickly providing innovative solutions to EMI problems encountered by military, aerospace, and telecommunications users. A fully integrated filter manufacture, SOURIAU PA&E Filter division fabricates the highest quality discoidal multilayer capacitors. High volume manufacturing of complex multi-component filters to meet specification and subjecting these assemblies to testing and burn-in requirements are routine at SOURIAU PA&E Filter division.

In February 1995 SOURIAU PA&E Filter division was acquired by Pacific Aerospace and Electronics and in April of 1996 moved from San Diego to the parent company location in Wenatchee, WA. The name has been changed to Pacific Aerospace and Electronics, U.S. Electronics Group, Filter Division.

DEFINITION OF CAPACITANCE: The capacitance (C) of a device with one active (dielectric) layer is determined by

$C = \frac{KA}{t}$ coulombs/volt (Farads)

Where K = the inherent dielectric constant of the insulating dielectric
A= the area of electrode overlap (l x w)
t = the dielectric's thickness

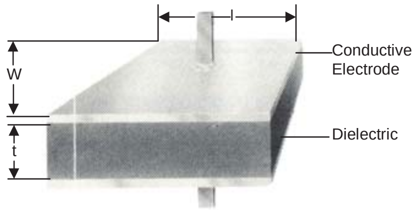


Fig 8. Definition of capacitance. (Courtesy of E.I. du Pont de Nemours & Co., Inc.

X7R capacitors are designed for performance over the same temperature range as are those constructed of NPO dielectrics. However, this specification allows change in capacitance of ± 15% from nominal (a maximum of 30% change over the specified temperature range). The dielectric constant of X7R dielectrics can be as high as 3000.

Since the capacitance of a multilayer ceramic capacitor is directly proportional to the dielectric constant (Fig. 8), it is apparent that the user can purchase ≈ 30 times as much capacitance in an X7R ceramic capacitor but may sacrifice as much as 30 times the stability with changes in temperature.

The third dielectric, Z5U or sometimes Y5V, is designed solely for use at room temperature. Capacitance of these dielectrics can change as much as ≥ 50% as the operating temperature rises to 85°C. However, the dielectric constant of Z5U dielectrics can be ≥ 10 000, allowing the user to specify as much as 100 times the capacitance in Z5U as NPO in the same package.

From the users' view, then, the choice of materials is based primarily on a tradeoff of capacitance volume efficiency and the variation in capacitance with the range of operating temperature of the device installed in a circuit.

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.

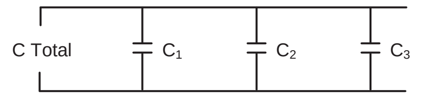
Ceramic powders necessary to produce NPO, X7R, and Z5U capacitors can be purchased from formulators or can be manufactured with in-house expertise from chemicals, such as barium titanate. Electrode and termination metallic ingredients can, likewise, be manufactured in-house or can be purchased from quality suppliers. These metallic ingredients are used in the manufacturing process as mixtures of metal powders 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. Readymade polymer solutions designed for the ceramic powders are also available from commercial suppliers. The process described herein' and shown schematically in Fig. 10 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 of ≥ 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 silkscreening process that produces one layer for a multitude of capacitors (nine capacitors in Fig. 10). 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.

THE CAPACITANCE OF CAPACITORS IN PARALLEL IS ADDITIVE



$C\ Total = C_1 + C_2 + C_3 + \ldots$

Fig 9. Summing capacitors.

Lamination 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 Fig. 7).

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 is shown in Fig. 11.

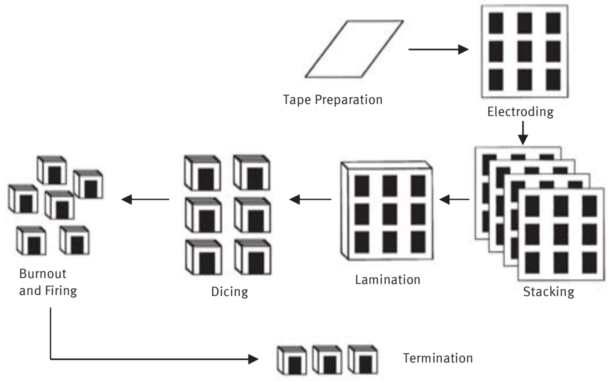


Fig 10. Process steps for making MLCs.

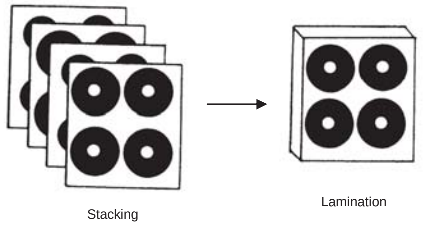


Fig 11. Electrode patterns for discoidals.

SOURIAU PA&E

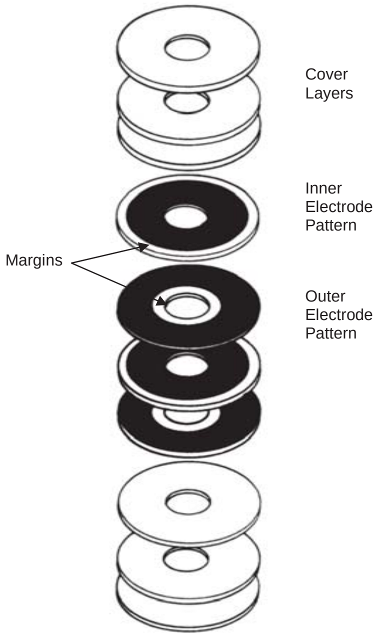


Fig 12. Exploded view of a discoidal.

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 outside diameter of each capacitor within precise tolerances. An exploded view of a drilled, punched, and turned discoidal capacitor is shown in Fig. 12.

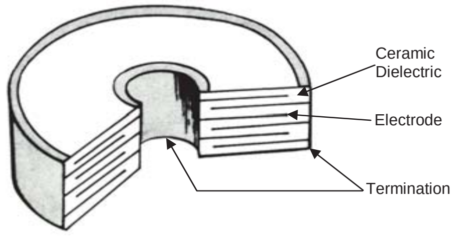


Fig 13. Cross-section of a discoidal.

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 ≈ 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 Fig. 13, which can be compared to that of the chip capacitor in Fig. 7.

Component Selection and Filter Design Considerations

Single-Component Filters

Capacitors and inductors as single component filters have been discussed earlier in the present paper.

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 ≈ 40 dB/decade and, in the case of single component filters, the slope of the attenuation vs frequency curve will remain constant, independent of the capacitor and inductor values. (See Fig. 14 for the circuit diagram and insertion loss characteristics of L-section filters.)

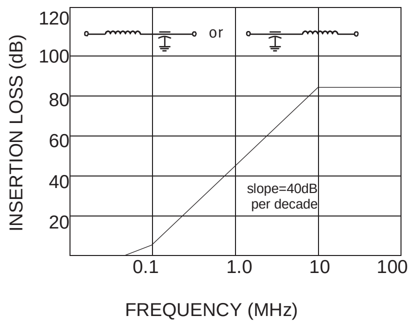
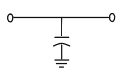
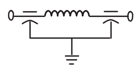
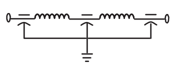
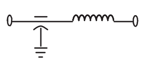
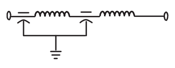
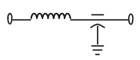
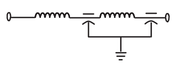
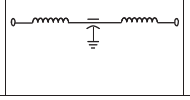
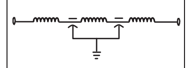


Fig 14. Attenuation of an L-section filter.

Table I. Impedance Matching Considerations

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

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 I for a summary of impedance matching considerations.)

Three-Component Filters

Three-component filters can be of 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 I. The "T" circuit is the second three-component filter and is also shown schematically in column 3 of Table I. Both of these devices provide attenuation of ≈ 60 dB/decade (3 components x20 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 Fig. 15 for insertion loss performance and Table I for impedance matching considerations.)

Multi-Element Filters

Schematic circuit drawings and typical insertion loss curves for four- and five-element filter devices are shown in Fig. 16. The rough rule of thumb, that the slope increases by 20 dB/decade of frequency for each added element, holds for multi-element filters.

defined for most military applications. Table IV 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% of lots manufactured for military applications.

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

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 IV. Screening Sequence per MIL-F-28861

Subgroup I	
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.

Applications 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 are 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 antiskid 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. Antiskid 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 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. Reradiated 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 existed on the same board. The initial systems 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 6-8 months.

The solution consisted of packaging seven high capacitance Pi filters in a custom

Table II. Sequence of Qualification Inspection Requirements per MIL-F-28861

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	
Solderablility (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.

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 > 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 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 factor, 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% 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.

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 vs frequency plot on the display of the spectrum analyzer. At the higher frequencies, fixturing and interface circuitry between the filter, the signal 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 reduced, 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 semi-annually. Tables II and III show testing sequences for these alternatives according to MIL-F-28861.

Screening is generally required by and

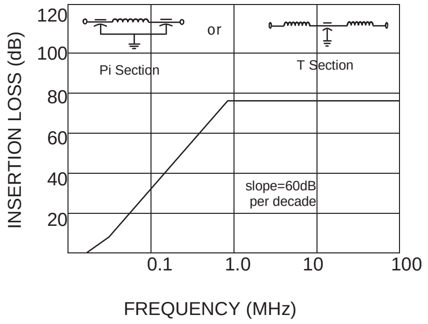


Fig 15. Attenuation of three-component filters.

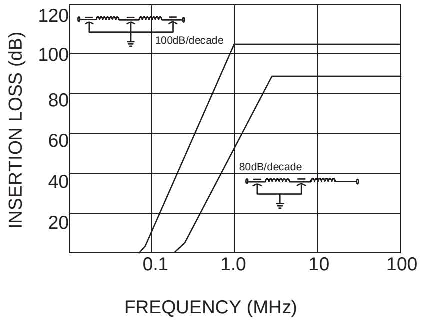


Fig 16. Attenuation of multi-component filters.

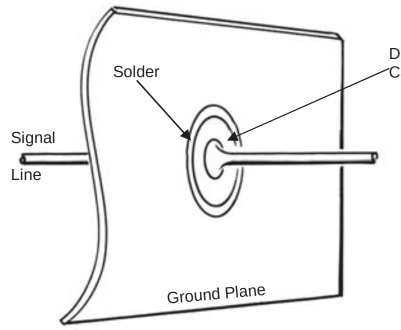


Fig 17. Feed-through in a chassis.

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 17 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 as filters will often result in the input or output lead wire becoming an antenna for pickup or transmission of EMI, negating in many instances 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 (Fig. 18). 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 ≈ 1300°C.

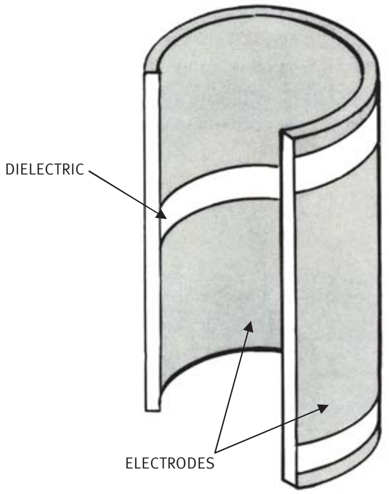


Fig 18. Cutaway view of a tubular capacitor.

After firing, the tubes are cut to the desired length, generally 0.5-1 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 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 same ceramic tube, which can be useful in the construction of PI filters.

The advantages of tubular capacitors are: (I) 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% 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, to 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 operation 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 Fig. 19, 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 (ID) of the capacitors, and the entire assembly is soldered or bolted into the shielded enclosure of the electronic equipment.

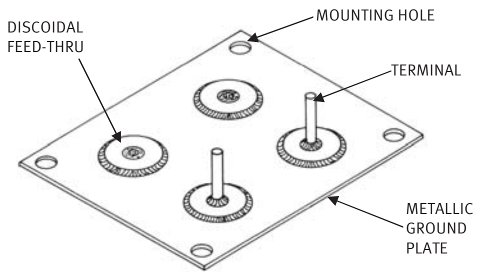


Fig 19. Feed-through capacitor array.

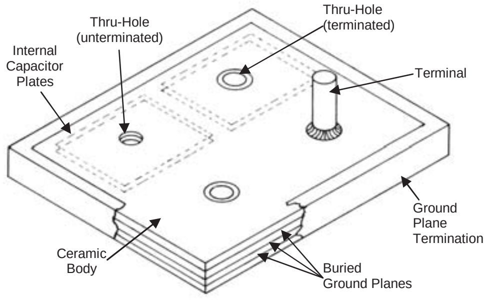


Fig 20. Monolithic capacitor array

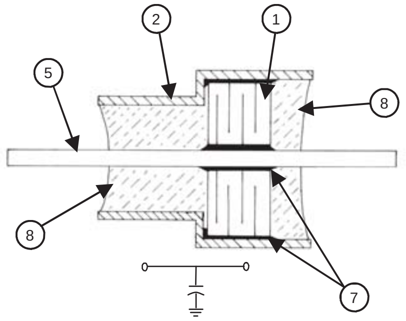


Fig 21. Potted eyelet

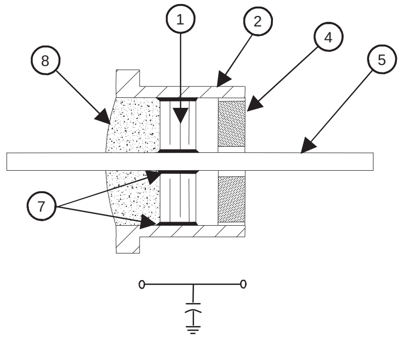


Fig 22. Hermetic eyelet.

Figure 20 illustrates a more complex solution to the same problem. In this design, a ceramic block is printed and laminated as previously described but alternate 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 feed-through 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 chassis. 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 21 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 22 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 feed-through eyelet. They have been used traditionally to package Pi configuration filter assemblies but are also available as L-section circuits.

As an example, Fig. 23 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 temperature 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 ≥2 mF. 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.

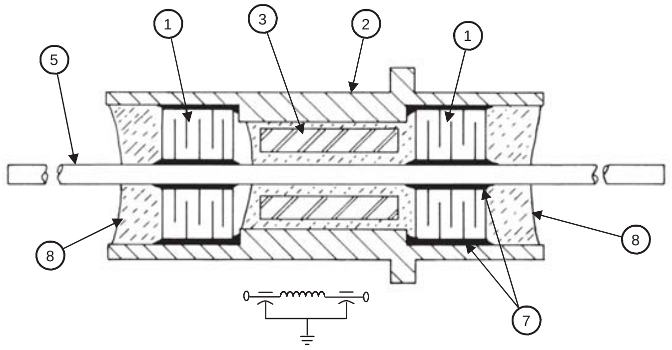


Fig 23. Potted discoidal Pi filter pin.

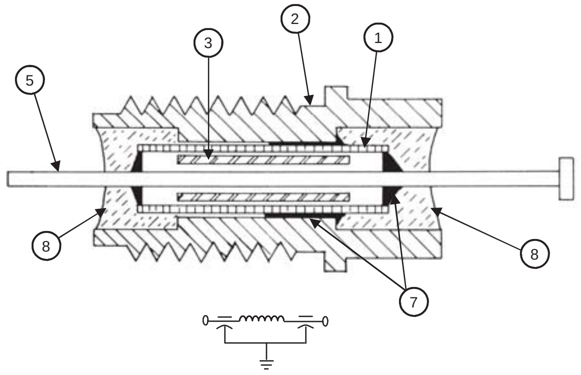


Fig 24. Potted tubular bolt Pi filter

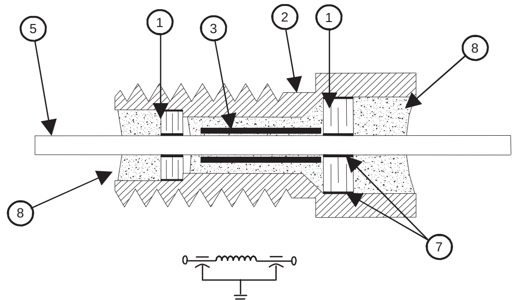


Fig 25. Potted discoidal bolt Pi filter.

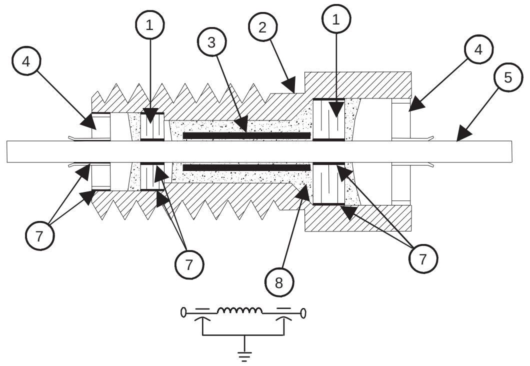


Fig 26. Hermetic discoidal bolt Pi filter.

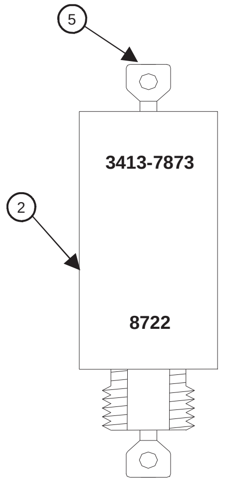


Fig 27. Typical broadband filter.

Figure 24 is a cross section of a typical bolt-style Pi filter employing a tubular ceramic capacitor. Figure 25 is the equivalent device built with a discoidal capacitor. Figure 26 is a cross section of a hermetically sealed Pi section filter with discoidal capacitors in a bolt-style configuration.

Broad Band 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 Fig. 27. 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, < 10 A, toroidal (and occasionally solenoid) wound inductors are normally used, while in the higher current ranges, ferrite beads are used as 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 28 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 Fig. 29. Figure 30 is a cross-sectional view of a low current Pi-section, hermetically sealed filter. Figure 31 is a section of a high current, five-element, double-T-section filter.

Manufacturing Technology for 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. Details of the various types of designs and housings are discussed earlier in the present paper. 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.

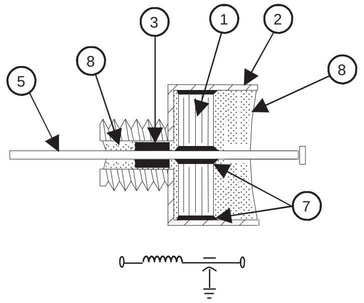


Fig 28. Potted high current L-section broadband filter

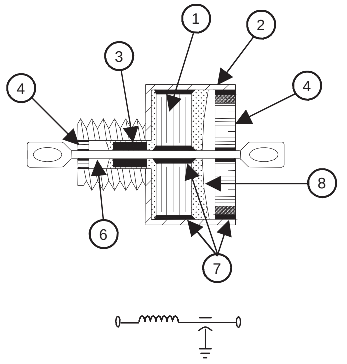


Fig 29. Hermetic high current L-section broadband filter.

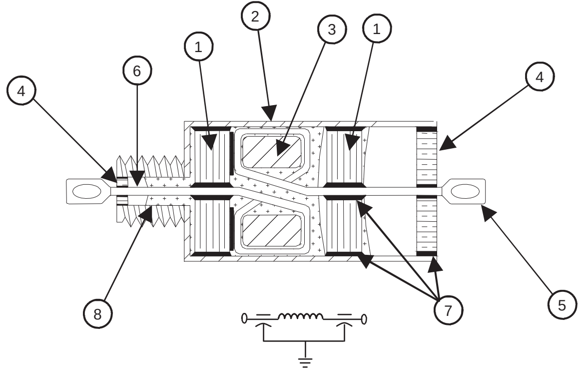


Fig 30. Hermetic low current Pi filter

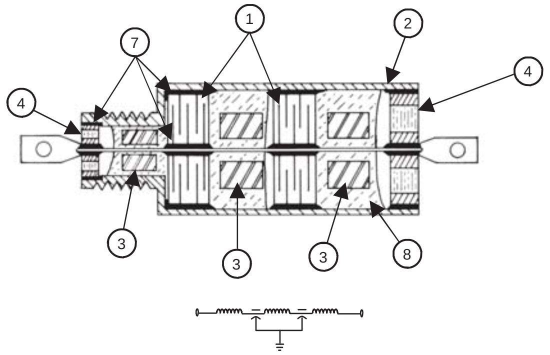


Fig 31. Hermetic five-element filter

---

*Key to cross sections depicted in Figs. 21-31: 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.