An Alternate Approach to EMI/RFI Suppression With High Density Connectors

STEPHEN J. NORTH and MALCOLM E. MARSDEN
Oxley Developments Company Ltd., Ulverston, UK

INTRODUCTION

Operational experience of modern military and avionic equipment has highlighted the necessity of achieving electromagnetic compatibility among all parts of equipment and their environment; e.g., onboard radio systems should be compatible with automatic landing systems and should not become inoperative because of nearby aircraft. Equally critical are many industrial environments which can be hazardous; the control system of a guardless press should not malfunction due to electrical interference. Failures have shown that each electronic subsystem should be immune to spurious electrical signals from other subsystems and also not generate interference themselves.

The dramatic increase in the level of system complexity and integration over the past few decades has resulted in the increasingly extensive use of electronic equipment. The increase in system complexity has meant that the interfaces to the equipment have become more complex. The need for high density connectors and filter arrays has meant that new techniques have been essential in order to meet the EMI/RFI suppression requirement for equipment in both industrial and military systems.

EMC DIRECTIVES

Legislation such as the European Community Directive 89/336/EEC states that all electrical and electronic equipment must meet electromagnetic compatibility (EMC) standards, including those for electromagnetic interference, transient voltage and electrostatic discharge (ESD). This legislation has a wide scope; it includes consumer products and extends to all industrial equipment. The directive specifies the minimum level of interference that equipment can tolerate without malfunction (susceptibility) and also the maximum level of EM field that may be generated by the equipment itself (emissions). These problems are not new and have been addressed for many years in military, avionics and telecommunications equipment. However, as the scope of the Directive includes, with very few exceptions, all electrical and electronic equipment, there are many manufacturers who have previously not addressed EMC issues. From 1996 onwards, all products placed on sale in the EC must carry a CE mark to demonstrate compliance with the relevant standards.

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FUNCTION OF THE FILTER

All entrances to an enclosure must be screened. Screening involves the use of conductive gaskets, often silver-loaded or wire impregnated rubber, at the panel interfaces. In addition, the input and output wires to the enclosure, including signal sources and returns, power lines and ground connections must be prevented from transmitting interference into or out of the enclosure.

To protect against radiation interference sources, it is necessary to electrically screen the equipment. In screened enclosures the material choice will be governed by the minimum frequency of the radiated field which is likely to be encountered, generally high frequency sources (>1 MHz).

A number of techniques exist for diverting or reducing the interference currents. Included are the use of screened cables or sleeving, the addition of ferrite beads to increase wire self-inductance, and the use of feed-through or lead-through capacitor filters.

Feed-through capacitor filters are mounted directly to the wall of the screened enclosure or to a bulkhead behind the interface connector (Figure 1). Operation is by reduction of interference currents through series impedance, and by presenting a low impedance to ground for EMI via the capacitor.

Feed-through filters provide a flexible method of interference suppression. The cut-off frequencies may be

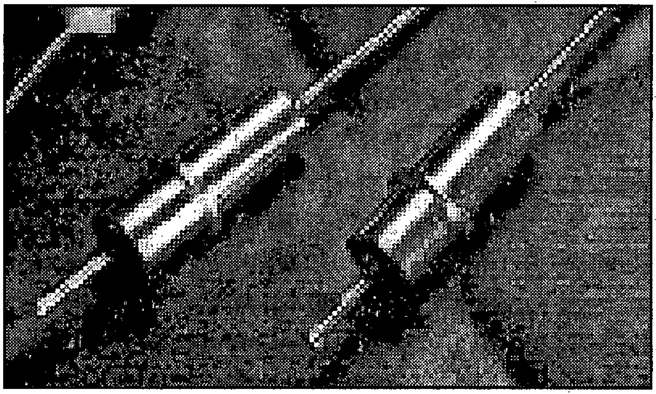

Figure 1. *Typical Tubular Feed-through Filters.*

tailored by variations in capacitance. Temperature coefficients may be varied by the adjustments to the basic ceramic materials.

The performance of a feed-through filter system can vary substantially depending on the type of filter and input/output impedance of the system. The insertion loss is the ratio of the voltages across a load with and without the filter in the circuit and is normally expressed as a logarithmic ratio in decibels (dB). The formula below enables insertion loss to be calculated assuming both source and load have impedance of 50 ohms.

$$\text{Insertion Loss (dB)} = 20 \log \frac{V_1}{V_2}$$

where
V_1 = voltage measured without the filter
V_2 = voltage measured with the filter

Manufacturers specify the performance in terms of insertion loss (dB) at given frequencies in a 50-ohm source and load impedance circuit. Although actual filter performance in a real circuit may vary from the predicted levels due to different source and load impedances, the convention of using 50-ohm measurements allows useful comparisons to be made between different types of filters. The filter construction dictates the performance level and this depends on the number of capacitive and inductive elements within it. A capacitive or inductive element alone should theoretically give insertion loss increases by 20 dB per decade and a three-stage pi section filter (capacitor-inductor-capacitor) should give 60 dB per decade. In actual practice there are some parasitic elements of resistance, capacitance and inductance which result in the capacitance leveling off at approximately 60-80 dB (Figure 2).

FILTERED CONNECTORS AND ARRAYS

Filter connectors and filter arrays typically comprise several component parts. The components primarily responsible for any EMI suppression are the capacitive and inductive elements of the connector. These components are assembled within a connector shell or ground plane with the signal/power lead-throughs passing through the connector. One electrode of the capacitor is connected to the signal/power line while the other electrode of the capacitor is connected to the connector shell. Low frequency signals have a low impedance path through the conductor and a high impedance path to ground. However, high frequency signals have a low impedance path to ground due to the frequency dependent effects of the capacitor.

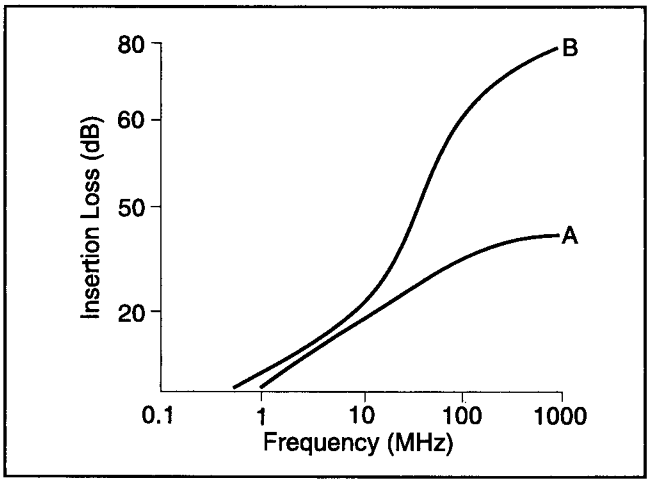

Figure 2. *Typical Insertion Loss Curves for (A) 5000-pF Capacitor Filter and (B) 5000-pF Pi-section Filter.*

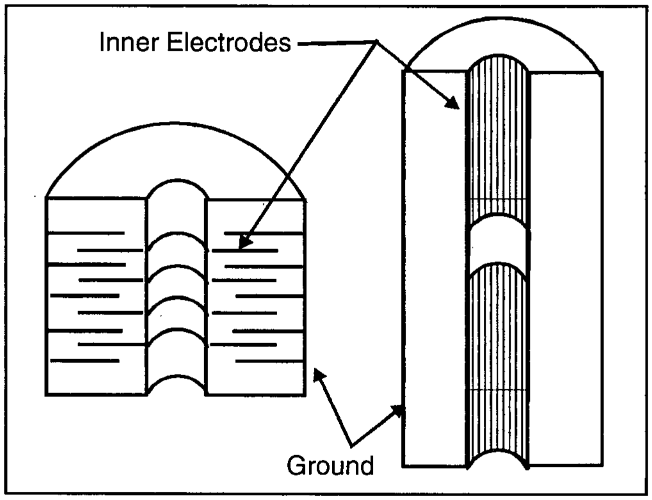

Figure 3. *Electrode Configurations within Discoidal and Tubular Feed-through Filters.*

Feed-through filters used within connectors are mainly constructed from either tubular or multilayer discoidal capacitors. Figure 3 shows the cross section and electrode configuration within these types of devices. The discoidal capacitor may have many layers of interleaved electrodes which enable high capacitance values per unit volume, while tubular types are difficult to manufacture with buried electrodes, and offer increased densities

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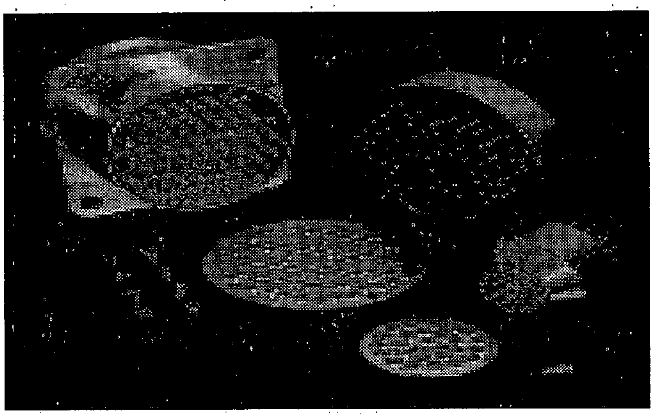

Figure 4. *Typical Multiway Planar Capacitor Arrays.*

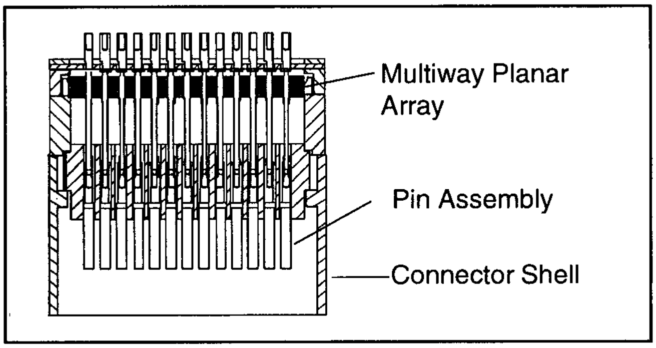

Figure 5. *Filtered Connector Showing an Integral Multiway Planar Array.*

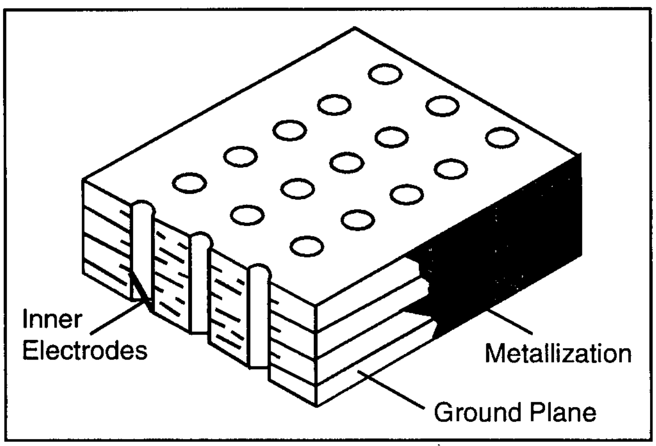

Figure 6. *Typical Multiway Capacitor Array, Showing the Internal Electrodes.*

within connectors. Both devices have a common factor, the dielectric ceramic medium used between the electrodes. A high relative permittivity can be achieved using doped barium titanate. Permittivities of greater than 15,000 can be achieved. The primary problem with these materials is the dramatic change in permittivity and, therefore, capacitance with changes in temperature. The more temperature stable materials may have a permittivity of several thousand and yet maintain capacitance variations within ±15% over a temperature range of -55°C to +125°C.

MULTIWAY PLANAR CAPACITOR ARRAYS

Capacitor feed-through technology has existed for many years. Input /output lines, using both individual discrete filters and complex connectors, have been filtered using the same basic ceramic capacitive elements, whether a discoidal multilayer capacitor (MLC) or tubular capacitor, for many years. A novel fabrication technology for multilayer ceramic multiway capacitor arrays (Figure 4) has been investigated and developed to meet the increasing demand for increased volumetric efficiency. This technology combines the current MLC processing with unique design, production and assembly techniques. In addition, this technology significantly reduces the assembly costs associated with the integration of capacitors into connectors and lead-through components.

The development of the multiway planar array offers a considerable advantage over existing technologies with increased pin densities and simplified assembly techniques. Figure 5 shows how a planar array can be incorporated into a connector.

One of the major limitations of filtered connectors has been the amount of space taken by the individual capacitor components. The pitch between adjacent pins within a connector can cause many problems, both in the manufacture of the individual ceramic capacitor components, and the subsequent assembly of the capacitor into the connector. This complex assembly problem can be reduced with the use of a single monolithic body of ceramic with holes to match the connector configuration. The design of the planar array incorporates capacitive electrode elements at each of the pin locations. The planar capacitor arrays can be tailored to suit many different applications.

The basic structure of a planar array is very similar to the multiway discoidal capacitor. In this component, multiple layers of ceramic dielectric are built up with overlapping electrodes between each layer. The electrodes are screen printed onto individual sheets of ceramic tape (70 microns thick) using a palladium or palladium/silver metallization material. The individual layers of ceramic tape are then stacked and the multilayer ceramic formed to its "green" (un-fired) final shape. Firing of the components takes place at temperatures up to 1400°C, when the metal electrodes and ceramic structure fuse to form a single co-fired monolithic structure. The finished ceramic monolithic planar capacitor array is manufactured so the capacitor positions coincide with the pins of the multiway connector. The common ground electrodes extend to the periphery of the planar array where a ground will be made to the body of the connector and hence the panel (Figure 6). The whole assembly can then capacitively decouple each line individually with a great reduction in assembly time compared with discrete capacitor components.

This integration of the capacitive elements into the multiway planar array gives connector designers and

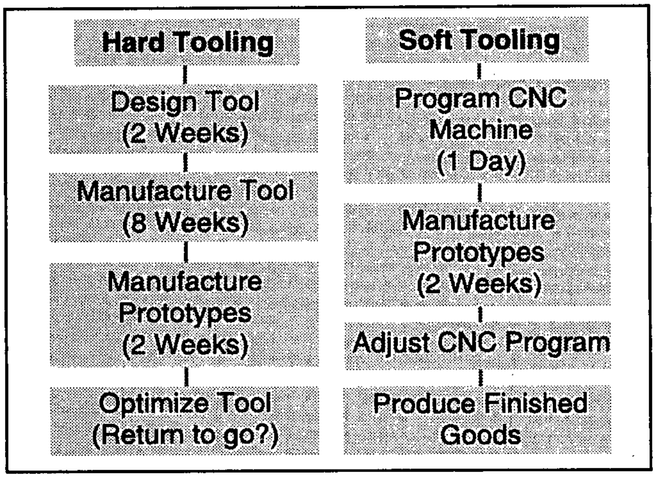

***Figure 7.** Advantages of Soft versus Hard Tooling.*

manufacturers the ability to reduce connector complexity, improve performance and reduce the cost of the assembly operation.

The planar capacitor array can be applied to connectors in which lines have differing filtering requirements. The designer can arrange for specific lines to have different capacitance values by altering the electrode configuration within the body of the planar array. In addition to varying the capacitance on individual lines (pins), the technology also enables lines to be grounded or left free of electrodes, thus removing any filtering. The planar array can be specifically designed for an individual customer's requirements. In addition to the advantages of producing custom-configured capacitive elements, the tolerance between individual lines is much tighter than can be achieved by randomly selecting individual discoidal or tubular capacitors. This is a particular advantage in applications that require balanced lines.

PLANAR ARRAY MANUFACTURING PROCESSING

A manufacturing technology for the planar arrays has been developed to enable custom configurations to be manufactured with a short lead time and minimal tooling costs. Manufacturing or forming green, un-fired ceramic to produce discoidal capacitors has traditionally been carried out using punch tools. The manufacture of "hard" tooling produces long lead times during initial component production. This limitation has been overcome with the use of flexible design and manufacturing techniques. CAD design tools and CNC machine tools allow reduced lead times for production and prototype components.

The processing of a planar capacitor array is similar to that of MLC chips. The process begins by blending the ceramic powder with an organic binder. This blend is milled to ensure that the ceramic is evenly distributed within the organic binder system. The ceramic/binder blend (liquid) is then accurately deposited or cast onto a continuous polymer film. This process forms a very even film of ceramic/binder (tape) on the film. The tape, when dry, has the electrodes screen printed onto the surface of the tape. To ensure accurate registration of the electrode layers, computer-aided video alignment is used during processing. The conventional route would typically be to laminate and punch out the components using a press tool before the organic binders are removed. The ceramic is then fired at 1400°C.

CNC PROTOTYPING

The use of CNC machine tools to form the holes and shape of the component has considerably reduced the lead time required to produce components. The elimination of hard tooling has enabled changes to be easily made to the component configuration without the major expense of retooling. A typical conventional manufacturing route for a planar array is shown and contrasted with the route for a soft tooled (CNC) manufactured component Figure 7.

END TERMINATION

Once the planar array has been fired, the ceramic body effectively becomes a single structure. The electrodes within the body of the ceramic are terminated at the outer edge of the ceramic body. An end termination metalliza-

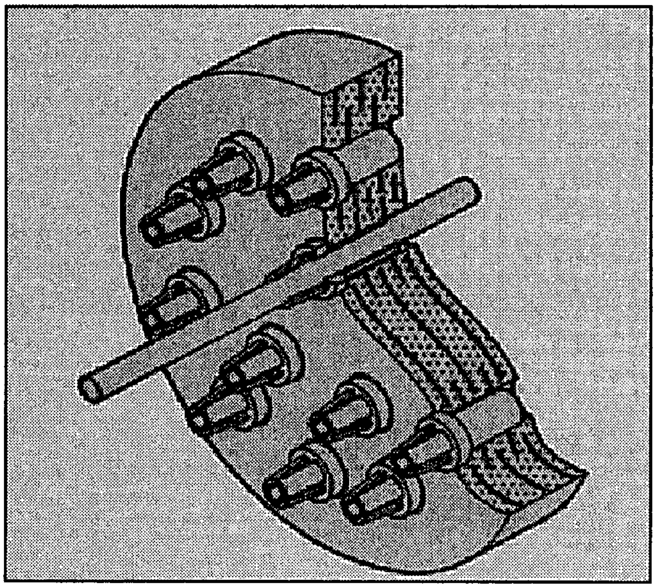

***Figure 8**. Planar Array Showing a Spring Contact onto a Connector Pin.*

tion paste is applied to the edge of the component. These end termination materials are typically palladium/silver compositions designed to have good solder leach resistance. In applications where increased soldering times are required, and thus increased leach resistance is required, palladium/silver/platinum materials are used. The platinum content, a small percentage (2%) of the total metal content, leads to a significant improvement in solderability. The end termination materials are fired to the surface of the ceramic at a temperature of 850°C.

The end termination of the component completes the manufacturing process. Components are then subjected to final electrical, mechanical and visual inspection procedures.

FILTERED CONNECTOR ASSEMBLY TECHNIQUES

Reliability of an assembled filter connector has largely dictated the design of the filter array. Typical assembly techniques will involve the assembly of capacitors, pi-filters, earth terminals, unfiltered feed-throughs and inductive elements into a connector housing. The capacitive element in the system must have one electrode terminated to the pin while the other electrode must be connected to a ground plane. Traditionally, this is carried out by soldering individual capacitors into a metal ground plane. The assembly procedures have to be accurately controlled, and the use of assembly jigs is essential in the relative positioning of the filters. Considerable care must be taken when soldering the ceramic components into the connector. Excessive thermal gradients can cause components to be mechanically shocked, which can cause cracking in the component.

The multiway planar array enables the assembly procedures involved in the manufacture of a filtered connector to be simplified. In complex filter arrays, where there is a combination of different capacitor values, grounded lines and non-filtered feedthrough lines, the planar capacitor array simplifies the assembly procedure dramatically.

SPRING CONTACTS

The use of compliant spring contacts and earth strips enables the planar array to be tested prior to assembly in the connector. This is considered to be a major advantage, as the components can be tested prior to assembly and also reworked easily. In many instances, the use of spring contacts enables the planar array to be inserted into the connector without the use of solder (Figure 8).

SUMMARY

Planar capacitor arrays offer a means of combining multiple capacitor locations within one ceramic body. The integration of these planar arrays into a connector application enables high density pin configurations to be realized. Advanced processing techniques have been developed in order to manufacture these components. The use of CAD design and manufacturing techniques has enabled conventional costly tooling techniques to be bypassed, thus reducing component lead times.

REFERENCES

1. J. Chambers, "High Density Filtering for Military Equipment," Capacitor and Resistor Technology Symposium, March 1984.
2. C.J., Noade and J. Chambers, "EMI Filtering for Digital Equipment."
3. M. Marsden, "Ceramic Capacitor Arrays," Ceramic Technology International, 1994.

***STEPHEN J. NORTH** is currently responsible for business development and marketing within Oxley Developments Company Ltd. He has over 8 years experience in advanced ceramic materials and component technologies. Previously, he worked as the technical manager in the development of high frequency interconnection and packaging, multichip module packaging design and multilayer capacitor manufacturing techniques. (01229)582621.*

***MALCOLM E. MARSDEN** is currently responsible for EMI/RFI component and process development within the EMC division of Oxley Developments. He has over 5 years experience in the design, development and application of multilayer ceramic components. He has recently become responsible for the development and manufacturing techniques for ceramic planar capacitor arrays. (01229)582621.*