FILTER CONTACT CONNECTORS

INTRODUCTION

The industry-accepted term "filter connector" is in essence a misnomer as it represents a "complex four terminal (i.e. per connector contact) system in a can" with the shape of the "can" being that of a "connnector" for packaging convenience. Its application involves considerations both for the traditional wire interconnection functions and electrical/circuit analysis related to the filtering functions desired. Means used to prevent radiation signals are essentially the same as those used to prevent external interference (considered both as EMI and transients with high frequency components) from getting into signal circuits:

1. Filters;
2. Shielded connectors used with shielded cables;
3. Shielded (individual) contacts used with shielded leads.

Assuming that system redesign is not practical, the only way to eliminate the unwanted EMI/RFI once it is in the *conducted* mode is filtering.

An effective way of filtering is to provide it where interference enters the system, and building it into the connector offers many advantages. Although filter contact connectors have been offered since the early 1960's, only recently has widespread concern and sensitivity towards the overall EMC environment focused attention on them and justified broad product line offerings.

When properly applied, the use of filter contact connectors can provide significant systemic cost savings, and improved reliability.

APPLICATION CONSIDERATIONS

Size: A connector with integral filter contacts typically is only .125/.250 inch longer than its standard counterpart. (See Figure 1.)

Volume: For one assembly involving 55 filters, notable weight and space savings are obtained by use of a single filter connector versus an array of discrete filters plus a connector all enclosed in an RFI-proof "dog box."

Space: Standard connector and discrete filters versus integral filter connector: 10.1 vs. 2.6 cubic inches
Weight: Standard connector and discrete filters versus integral filter connector: 495 vs. 189 grams

Packaging: The need for "dog boxes" or false panels to prevent the radiations of the wires from the connector to discrete filters from affecting equipment is eliminated. Special assembly checks to assure the low impedance grounding of the filters and this enclosure are eliminated.

Cost: The single charge for the filter connector is often-times an order of magnitude more expensive than the regular connector that it "replaces" --- but remember that actually it is a complete "system" and should be compared only to the filtering network starting with the standard connector, adding in the discrete filters, and ending with the RFI enclosure needed to assure that interference doesn't couple back in on the same or other line on the other side of the filter. Other "systemic" cost factors not required for the filter contact connector include:

- Stripping both ends of each wire required per terminal
- Termination to both the I/O connector and to both ends of the filter
- Mounting individual filters
- Designing the panel/box to enclose the filters
- Procurement, QC and stocking the various items.

Electrical: The *voltage drops*, due to the series connections of the connector, to/through the wire, to/through the filter, and to the final terminating wire, (detrimental to low level signals), are not present in filter contact connectors. Since the filter elements circumvent the central metal contact, only the high frequency functions to be attenuated "know" that it is a filter. Additionally, the integral filter contact connector should be received after complete testing by its manufacturer (ready for installation) versus having to perform as a minimum IR, DWV and attenuation tests on each line after termination is completed to the discrete filters.

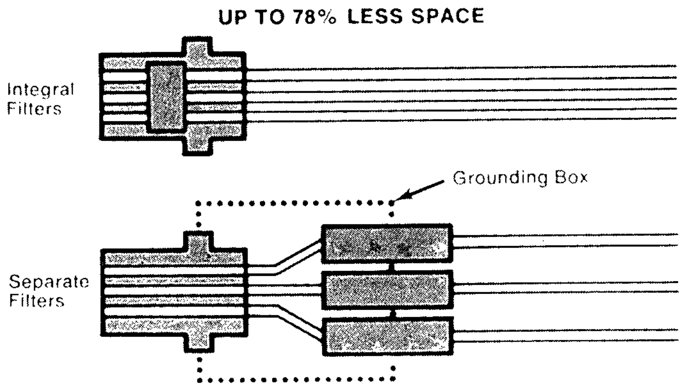

Figure 1,

CONNECTOR CONSTRUCTION

Ground Plane: This is the area of greatest difference between suppliers and several methods have been shown to have equally good performance. Thus, performance, not internal design, should be specified.

The most common forms seen use one of the following:

1. Conductive epoxy or soldering the filter to a solid metal ground plate. (Connector is epoxy potted.)
2. Multiple finger tines from photo-etched copper alloy material grasping the filter O.D. (contacts are rigidly held in place but may be removed for repairability.)

The first technique provides rugged construction and the epoxy must be very closely matched for thermal expansion to the metal shell.

The second method is patented by ITT Cannon Electric, US Patents 3,569,915 and 3,670,292.

Other ground plane approaches include the use of conductive elastomer materials (usually filled silicone rubber). These would be good for crimp filters except for their shrinkage, abrasive and setting characteristics. Resistances and, thence, RF transfer impedance may vary with thermal aging.

Termination: Termination types are typically solder pot, printed circuit, or crimp contacts (the latter having the filter on the removable contact). Solder termination can result in a shorter connector since the contact retention areas are not required. "Piggy-back crimp" is new.

Crimp inserted filter contacts may still be considered developmental as evidenced by user-reported problems, including the following: inadvertant use of damaged filters; reduced attenuation due to ground plane "yields" (they must give and permit multiple insertion-extraction); lack of contact availability for field replacement; etc. They are usually rear insertion and front release in design. This is sometimes awkward due to limited behind-panel space required for connector mounting.

Good solder joints can be inspected by conventional means. Crimp filter contacts must be checked for all parameters once installed in the connector and the costs involved are often bypassed in product selection. A poor ground plane-to-filter engage ment may provide a satisfactory capacitance reading but *not* provide desired attenuation.

"Piggy-back" contacts combine the features of crimp termination with protection offered by non-removable filters. The filter contact assembly is double-ended: one end engages the mating connector while the other extends backward into the connector body whereby it mates with a rear insertion, rear release *crimp* contact. (If it is a smaller crimp socket contact for a high density layout, it should have a steel hood to prevent damage and be inserted through a closed entry insulator, to mate with the filter-on-contact portion.) In this manner, standard (often MIL-specification) contacts can be used along with wire sealing rear grommets and accessories equivalent to the non-filtered connectors. However, crimp "piggy-back" is finding limited applications due to cost (additional components --- grommets, endbells) and increased length (about .750 longer than solder pot versions). If offers the advantage for retrofit programs of potentially using already wired contact/harness assemblies and can be installed in the field.

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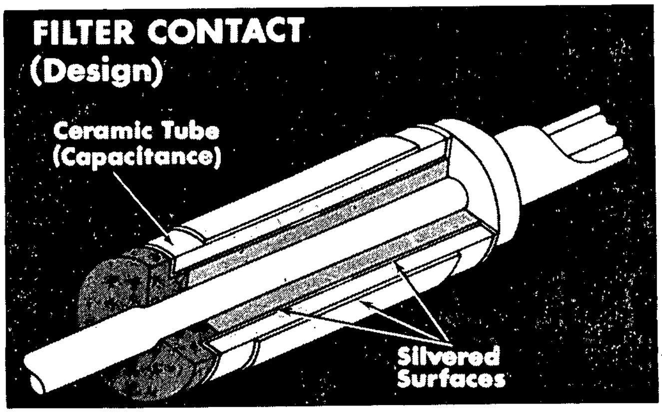

Figure 2,

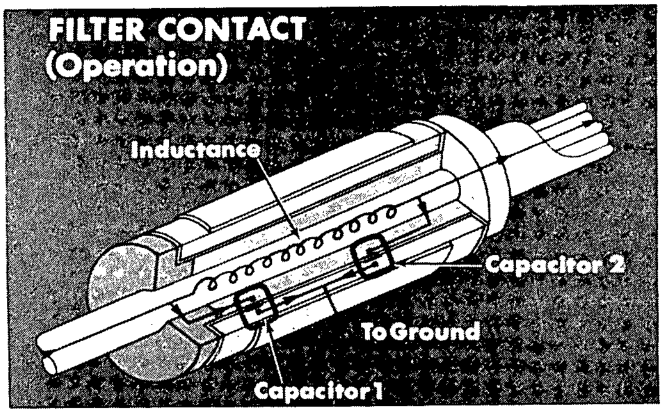

Figure 3,

continued from page 56

FILTER CONTACT CONSTRUCTION

Although multilayer capacitive types and L-sections are used, per figure 2, the more common Pi section design will be reviewed. The central contact is gold plated to meet standard connector requirements. The ferrite core is covered by a high K ceramic sleeve having two separate conductively plated sections on the inside and a single wide coating on the outside which connects to the ground plate. Each of the inside coatings is connected to the pin contact to form the two capacitors of the Pi section. Being in parallel, they are additive and are usually within ± 5% of each other in capacitance. (Differences up to ± 20% have been noted to not result in any noticeable attenuation changes.)

The ferrite presents the effect of a single turn toroid inductor, thus multiplying the initially low inductance of the filter pin by the permeability of the ferrite for effective low frequency attenuation, while at high frequencies it presents series resistance with very little reactance (reducing chance for resonances). Filter contact operation is illustrated in Figure 3.

Parameters for the filter contact assembly are based upon mechanical size limitations since usually the connectors must mate with standard or MIL-Spec connectors with fixed, minimized contact center to center spacing. Wall thickness (between contact cavities) reaches a physical minimum and then the filter O.D. is maximized and the various parameters are derived based upon these limitations. The ceramic tubular capacitor material is usually varied (see values in Table 1) based upon the following:

$$C = \frac{K\,(.614)\,(B)}{\log_{10}\left(\frac{OD}{ID}\right)}$$

Where:

OD = tube outside diameter B = electrode length
ID = tube inside diameter K = dielectric constant

(The above sometimes may be an oversimplification since it omits considerations for fringe capacitance.)

Table 1

Contact Size		20, 16					22	
Filter "Terminology"		Very Low Frequency	Low Frequency	Mid Frequency	Standard Frequency	High Frequency	Low Frequency	Standard Frequency
Working Voltage		50 V DC	200 V DC - 120 V AC rms 400 Hz				100 V DC	200 V DC
Current rating (amp. D.C.)		7.5 amp. - Size #20; 13 amp - Size #16					5 amp	
Insulation Resistance, 2 min. electrification time max at 25°C		700 megohms min	5000 megohms min	10,000 megohms minimum			500 megohms min	10,000 megohms minimum
DWV, sea level with 500 microamps max. charge/discharge current		100 V DC	600 V DC				300 V DC	600 V DC
Capacitance at 1 KHz 0.1 V rms picofarads (Very low is microfarads)		.82 mfd 1.22 mfd	75,000 150,000	6,000 12,000	2,500 5,000	500 1,000	75,000 150,000	1,500 min.
	Freq. MHz	Attenuation (dB)						
Attenuation per MIL-STD-220 at 25°C with no applied voltage or current	.01	2-5						
	0.1	20 min.	2-5				2-5	
	1	40 min.	15 min.	2-5			12 min.	
	2	40 min.	20 min.	5 min.	2-5		18 min.	2-5
	10	52 min.	35 min.	20 min.	12 min.	2-5	32 min.	10 min.
	100	56 min.	50 min.	55 min.	50 min.	30 min.	45 min.	45 min.
	500 to 10,000	70 min.	50 min.	60 min.	60 min.	50 min.	45 min.	50 min

ATTENUATION CONSIDERATIONS

Measurements are usually made in accordance with MIL-STD-220A "Method of Insertion-Loss Measurement." This presupposes that both signal source impedance and load impedance are 50 ohms and that only RF current is present. Attenuation values recorded will depend upon changes in actual application and proper grounding of the connector shell. Representative data is per Table 1.

Impedance: Greater values of source and load impedance will show greater filtering as the resultant attenuation curve shifts based upon cut-off frequency change.

The cut-off frequency can be seen in relationship to the load and source resistances (R_L and R_S) by the following equation for a simple first order low pass shunt capacitor filter:

$$A = 20 \log_{10} \left| 1 + j\omega C \left(\frac{R_L\, R_S}{R_L + R_S} \right) \right|$$

Where:

A = Attenuation at cut-off frequency
ω = $2\pi f$
C = Filter capacitance
R_L = Load resistance
R_S = Source resistance

Cut-off Frequency: The frequency at which 3 dB insertion loss occurs in known as the cut-off frequency (i.e. RF currents above this frequency will have greater than 3 dB losses and those below this frequency have 3 dB loss or less, with practically no attenuation apparent at frequencies one-fourth or less below cut-off). This is the frequency when the pass band ends and, notably, when 50% of the RF power (or 30% of the voltage) is rejected, as shown by the following:

$$dB = \left| 10 \log \left(\frac{P_2}{P_1} \right) \right| = 10 \log \left(\frac{1}{2} \right) = 3$$

Pi Section Filters: Filter design is well covered by other articles in ITEM, but it should be noted that most filter contact connectors utilize Pi-section filters. The ferrite becomes increasingly lossy at higher frequencies and prevents resonances (with resultant attenuation dips) potentially inherent in purely capacitive filters.

Temperature: Generally insertion loss diminishes as temperature is increased and typically a 15% drop can be expected at 125°C versus 25°C results. Most filter contacts can take 150°C or higher without mechanical damage, but it must be kept in mind that capacitance will shift notably just after the Currie Point is passed (typically around 130°C).

Current: Under most circumstances when DC or low frequency alternating current carried by the filter contact begins to exceed .5 ampere, insertion loss is reduced. The amount of loss depends upon the frequency of the signal to be attenuated. For proper results for specific applications, currents, and source/load impedances, it is usually necessary to test filter connectors in the actual circuits.

Low Frequency and DC Currents: Integral filter contacts used in these "connectors" have virtually no affect in transmission of DC currents, low frequency currents, or audio frequency currents. If the filter contact is assumed to be at most one-half inch longer than the standard contact, its resistance would be greater by this length or approximately 1.08 milliohm, which is equivalent to one inch of No. 20 AWG copper wire. The losses to low frequency alternating current will of course depend upon the circuit impedances and can be expected to be negligible at audio frequencies; for example, using a Pi filter with 2500 pFd typical, in a 50 ohm circuit, the loss at 100 kHz has been tested to show just .14 dB rising to 3 dB at 2 MHz.

Test Circuits: Although not used by ITT Cannon, some suppliers add 50 ohm resistance between the filter and the test terminals to obtain smoother test curves. The user can check for this by seeing if the attenuation curve crosses the zero dB line or *starts* at 6-8 dB. The resistor shifts the results curve up approximately 6 dB but otherwise reportedly does not affect test accuracy.

Logic Circuitry: Recent filter contact developments have taken advantage of newer ferrite materials to produce low capacitance types that will not attenuate out the fast rise-time components of TTL and similar solid state components, but still provide 50 dB or better attenuation at higher frequencies.

RELIABILITY

The use of fewer series components and their ensuing terminations alone results in greater systemic reliability for the filter contact connector when compared to multi-circuit arrays using discrete filters. The singular connector ground plane assures consistency of attenuation. References to MFBF and the U-shaped failure rate for discrete capacitors/filters do not apply to the filter connectors since the filter elements are not conductively in-line to the power/current and are not affected by voltage drops (through the two terminations to each discrete filter) and other system parameters. In effect, if a filter connector is applied within its specified limits, it should remain indefinitely in a static functional mode.

CROSS-TALK

Cross-talk may be defined as the relative level of a signal carried in one conductor compared to the level of the same signal induced in a second conductor by virtue of the proximity or coupling to the second conductor. Reduction of cross-talk pick-up is one of the foremost application usages of filter contact connectors.

When using an array of separate individual filters in conjunction with a standard connector (for input/output power), additional coupling between conductors potentially may exist because of:

1. Imperfect shielding between filters,
2. Coupling between conductors that lay between the filter and the connector, and
3. Inductive coupling between poorly shielded filter coils.

In the integral filter design, each individual filter is normally housed in a shielded cylindrical compartment of solid aluminum. Thus the filters are electrostatically and electromagnetically shielded from each other (i.e. no capacitive or inductive coupling exists). In addition, most of the electromagnetic field is confined to the toroidal cores which inherently have a very small external magnetic field.

Most filter connector contacts are designed with a low inductance and comparatively high capacitance. Because of this, less cross-talk is generated by a given amount of capacity coupling. The integral filter connector contact uses peripheral grounding of the capacitor plate, resulting in a ground return with extremely low inductance. This increases the effectiveness of the filter in UHF and microwave regions and prevents dips in the attenuation curve due to internal resonances as the frequency increases.

Testing for EMP is not equivalent to testing for lightning susceptibility, due to the vastly different rise/fall time factors. Energy from lightning presents a greater problem sometimes as its longer duration can result in filters heating which can lead to mechanical breakdown.

Moreover, the "final" ground return plane for all the integral filter contacts in the connector is confined to a small common area for all the filters which is usually located on the outside surface of the equipment chassis. The high frequency noise components return to ground through this external surface of the chassis and its mounting and can not penetrate through to the inside surface. Noise interference is thereby prevented from coupling into the equipment circuitry through common ground paths or by induction.

An array of separate filters, depending upon layout, may have the disadvantage of having longer ground returns spread out over a much larger area. This sometimes could lend to possibilities for radiating/coupling external noise into equipment circuitry.

While filter contact connectors can serve as one of several options towards reduction of cross-talk problems, oftentimes proper initial design (compartmentizing, selective wire routing, etc.) will preclude the need for filtering of any type.

EMP CAPABILITY

The treat of EMP upset to electronic equipment is somewhat similar to that for other transient-type signals, except its magnitude and speed are more severe. The use of filters is a useful technique for reducing energy levels in some cases, but some form of additional signal amplitude-limiting (such as Zener diodes at control-functions or surge arrestors forward in the system) may be required as well for higher levels.

Pulse testing in the 0.1 to 10.0 microsecond range has been performed on ITT Cannon filter contact connectors. Preliminary results indicate that, perhaps due to packaging and other considerations, filter contacts successfully withstood levels significantly above specifications. For example, the Very Low Frequency filters (with 10 kHz cut-off frequency) withstood source voltage of 2024 volts at 1 MHz. Many levels of classified testing were performed during initial design work for the Cruise Missile Program by the Vaught Corp., which indicate that high amplitude repeated pulses, when in the nanosecond range will be slightly attenuated without damage.

System benefits are obtained by the metal cross-sectional grounding plate which closes the window normally appearing in standard connectors. By protecting at the location closest to upset susceptibility, the possible pick-up by additional wire runs is eliminated and rise times can be reduced by inherent line inductances, shielding, etc.

These and other tests indicate that integral filter contact connectors are useful for EMP suppression but that further analysis is needed to define characteristics at levels normally encountered in an EMP environment. In all cases, the best approach currently is to test samples under simulated conditions.

DO'S AND DON'TS

Attenuation Requirements: Overspecification of Insertion Loss can result in a more expensive product and perhaps a filter connector with reuced electrical capabilities. If the supplier is forced to change from Pi section construction to a multilayer capacitive filter (using noble metal between ceramic layers) the price could double.

AC Voltages: (Remembering that AC rms is not equivalent to DC) Alternating currents/voltages produce stress on the ceramic capacitor material and since the filters are voltage sensitive, they are usually derated. For example, a filter connector with a 200 VDC *working* voltage typically has an AC working level of 125 VAC rms.

Altitude: Derating for filter connectors follows guidelines for standard connectors. Voltage values for 70,000 feet are presented as one-third that for sea level.

Capacitance Versus Voltage: Capacitance is inversely related to hi-pot and working voltages, as illustrated by data of Table 1. Users should always check manufacturer's data as filter and electrical specifications available for a particular contact size may not be available from one connector series to another due to spacing, construction, etc, which affect DWV capability.

Transients: Filter connectors are available to meet the DC requirements of MIL-STD-704A, but not always the AC spike levels. Thus, protection may be needed in some instances. However, transients with fast rise times are "seen" as "noise" and often are attenuated out before they can damage the filter.

Repairability: Considering the cost of filter connectors, repairability is a desirable feature. This should be performed by the manufacturer who should be expected to re-issue it with a full warranty. However, under certain failure modes (such as shorting to ground) repairability is not possible, whether the connector is of crimp or solder termination design.

Termination: For solder pots use controlled temperature irons limiting tip temperature to 500°F. Performance is equivalent to non-filter type connectors as long as reasonable care is ued. MIL-STD-454 is often referenced. For crimp, be sure correct special tools are provided and check the surface conditions and cleanliness of filter O.D. before and after crimping. Use design wherein each contact has its own retention mechanism wherever possible to avoid mislocation with respect to ground plane. (Be sure to evaluate "piggy-back" crimp, if your space permits the additional behind-panel length required.) Additionally, remember that it is a *filter* contact and special post-assembly electrical checkouts should be performed on each contact after installation.

Mounting: Normally filter contact connectors take the same mounting as their non-filtered counterparts with respect to panel cutouts and screws, jam nuts, and the like, except that the panel must have a conductive surface (to carry off the filtered RF energy from the connector shell). If flange-mounted, usually the mounting screws will provide sufficient surface pressure for conductivity. Should the need arise to remove the filter connector after it has been in service awhile, it often is necessary to re-surface the mounting area before it is re-installed.

TROUBLE-SHOOTING

The most common application problems occur when: (1) the connector shell is not grounded properly; (2) the wrong filter attenuation was specified; (3) the filter was damaged by inadvertant dielectric (hi-pot) testing at standard connector levels above filter capability; or (4) mis-assembly and related probelms associated with crimp filter contacts.

In trouble shooting, always first check the capacitance and the insulation resistance. Damaged parts so located often can be repaired by factory. If the filter has shorted to ground, then normally, it has suffered from excessive voltage and the ground plane around it may have also been damaged.

MILITARY SPECIFICATIONS

To date, no general military specification exists for filter contact connectors. These products are employed in systems meeting MIL-STD-461, but are tested installed as part of the overall assembly. Unlike discrete filters, MIL-F-15733 does not apply to filter connectors due to common/group grounding and other basic packaging differences.

The Defense Electronics Supply Center (DESC) in Dayton, Ohio had a project underway to prepare a single military specification, MIL-C-83736 to cover all types of filter contact connectors. This project was closed in 1976 and, instead, the various agencies are planning to add individual "slash sheets" and/or ms drawings for specific filter connectors as required according to usage. These sheets would be appended onto existing military specifications so that both the filtered and non-filtered versions of each type of connector would be covered together. Industry is awaiting preliminary DoD inputs.

The long awaited revision B to MIL-STD-220 is currently underway by the Army Electronics Command in Fort Monmouth, under the direction of B. DeNardi. (See Government Directory on page 169.)

UL recognition is not a common occurance, with most filter connectors receiving indirect approval as part of the approved final system.

AVAILABILITY AND OPTIONS

Contact Size: Due to historical control-circuit usage and market demand most filter contacts are in sizes 20 and 16. Filters for Size 22 are available, but are of higher cost due to material tolerances and special handling/assembly required. Recently, larger contacts up to Size 12 have become available but they are often derated (e.g. 20 amps in lieu of connector potential rating for over 70 amps per contact.)

Mixed/Combination Assemblies: To reduce cost (by eliminating filters) and/or to optimize for specific applications (by using different filters), most suppliers offer mixed/combination layouts as desired. These can involve use of different filters and/or grounding contacts (contact itself grounds to the metal ground plate) and/or unfiltered/feed-thru contacts (wherein an insulating tube mechanically isolates the contact body from the ground plane). The user need only tell the manufacturer his requirements on a per-cavity basis. Elimination of unnecessary filters should always be kept in mind for cost reduction in high volume production runs (provided that analysis confirms that cross-talk or other interference will not be reintroduced through unfiltered/feed thru contacts, in which case grounding contacts should be used). Contact types are illustrated in Figure 4.

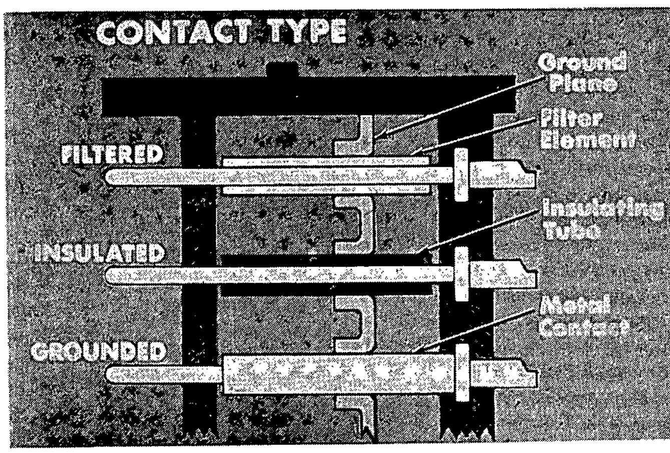

Figure 4

Cable Connecting Plugs: Usually not recommended for filtering due to physical abuse given cables and plugs. The use of plugs with peripheral engaging grounding fingers is required to duplicate the filter's wall mounted performance for bayonet-coupled connectors. ARINC style filter connectors are available with grounding fingers on plug shells. However, due to excellent shell-to-shell mating and standard use of conductive jackscrew coupling, using *filtered* D-Subminiature MIL-C-24308 style connectors as *plugs* is considered acceptable.

Configuration: Broad families of filter connectors are available as equivalents (intermate and intermount) to the following types:

Rectangular	Circular
MIL-C-24308	MIL-C-26482/0026482
MIL-C-81659	MIL-C-38999
MIL-C-83733	MIL-C-5015/005015
ARINC 404	MIL-C-83723

Additionally, in-line filtered adapters have both pin and socket opposing engaging ends and are available for some styles (require that one end mate with conductively-plated receptacle mounted to conductive panel). Compression glass sealed hermetic filter connectors are also available in some styles.

The above article was prepared by David H. Shaff, Manager, Market Planning and Development, ITT Cannon Electric, Santa Ana, CA.