INTRODUCTION

Filter connectors have been offered since the mid-1960's but have only recently "come of age." Increased concern (and product sensitivity) over EMI/RFI in medical electronics, rapid transit, commercial aircraft, industrial control systems, and military applications has resulted in broad product-line availability from several manufacturers. Most filter connectors intermate and intermount with their standard equivalents.

BENEFITS

The use of a filter connector has many significant advantages over the standard connector plus the use of separate filters. These include:

a. Weight and space savings of 75% and more are typical (Table 1).

TABLE 1 TYPICAL WEIGHT/SPACE SAVINGS

	Standard Connector With Separate Filters	Filter Connector	Savings Realized
Space (cu. in.)	10.1	2.6	78%
Weight (grams)	495	189	72%

b. Greater reliability. In the filter connector, a single termination is all that is required. The standard connector requires three wiring connections: one to the connector; and one to each end of the filter. These additional terminations, plus the U-shaped failure rate of the discrete filter add up to increased costs for inspection and increased failure rates for the discrete filters and connector combination, when compared to the filter-connector.

c. Filtering occurs at the point at which unwanted signals would otherwise enter or exit the system. As a result, maximum unit efficiency is obtained.

d. Crosstalk or terminal-to-terminal coupling is virtually eliminated in the filter circuit design.

e. 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.

f. Cost comparisons show that total systemic costs favor the filter connector when the majority of lines in higher density connectors need filtering. (For filtering just a few lines, discrete filters are less total expense). The additional systemic costs for wiring and mounting (filters-to-connector, filters-to-bulkhead and "dog box"-to-chassis), plus inspection, etc., must be considered in offsetting the initially apparent higher piece price of the filter connector (when improperly compared to just standard connectors by itself).

FILTER CONTACT DESIGN

Without altering the normal function of a standard connector contact, the filter contact provides attenuation at frequencies above a prescribed point (low pass). Through the use of special ceramic and ferrite compounds, shaped, plated and located appropriately, a network approximating a Pi-section low-pass filter is achieved on any or all contacts on a standard connector. "L" and multilayer capacitive "C" filters are also in use.

In the Pi-filters, a high-permeability ferrite tube surrounds the contact forming the equivalent series inductor (through of as a one-turn toroid). The shunt capacitor members appear as a result of selective plating of a high dielectric constant ceramic tube. Both ends of this ceramic tube which concentrically envelops the ferrite are attached to the contact to form an extremely compact circuit. The plated outside diameter of the ceramic tube is the common electrode and is attached to the shell through a ground plane. In addition to this interconnection of filter to shell, the ground plans forms an "electric wall" preventing alternate paths for radiated leakage, a frequent problem in discrete filter circuits at higher frequencies.

The "L" section filters usually consist of a multilayer capacitor concentric about the central pin (or socket) contact with a ferrite next to it. The ground plane connects to the capacitor. This type of filter increases RF resistance at high frequencies and compensates for resonances that may occur in

ELECTRICAL CHARACTERISTICS

Typical manufacturer electrical and filter capacities are as presented in Table 2. The attenuation values shown reflect "expected values in application" and assume less-than-perfect shell grounding-to-panel.

TABLE 2 ELECTRICAL CHARACTERISTICS

CONTACT SIZE		20, 16				
Available Filter		VLF	Low Freq	Mid Freq	Std Freq	High Freq
Symbol		V	L	M	T	H
Voltage rating (working)		50VDC	200V DC - 120 VAC rms - 400 Hz			
Current rating (amp DC)		7 5 amp. - Size #20, 20 amp. - Size #16				
Insulation resistance, 2 min. electrification time max at 25° C		700 meg-ohm min	5000 meg-ohm min.	10,000 megohms minimum		
DWV, sea level, with 500 microamps max. charge/discharge current		100 VDC	600 VDC			
Capacitance at 1 KHz, 0.1 V rms (picofarads except r/ufd)		.82ufd 1 22ufd	75,000 150,000	6,000 12,000	2,500 5,000	500 1,000
	Freq MHz	Attenuation (dB)				
Attenuation per MIL-STD-220 at 25°C with no applied voltage or current	0 01	2-5	—	—	—	—
	0 1	20 min	2-5	—	—	—
	1	40 min.	15 min	2-5	—	—
	2	40 min.	20 min.	5 min.	2-5	—
	5	45 min.	30 min.	15 min.	8 min.	—
	10	52 min.	35 min.	20 min.	12 min.	2-5
	100	56 min.	50 min.	55 min.	50 min.	30 min
	500 to 10,000	70 min.	50 min.	60 min	60 min.	50 min.

The 3 dB point is defined as the frequency at which the pass band ends and the attenuation per octave filter-capability really begins to take effect. This is also the frequency at which the filter has reduced the power by 50%, as shown by the following:

$$dB = [10 \log (\frac{P_2}{P_1})] = 10 \log (\frac{1}{2}) = 3 \text{ dB}$$

The relationship between attenuation and circuit parameters is shown in the following equation (for a simple first order low pass shunt capacitor filter):

The cut-off frequency (3 dB level) 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.

$$3 \text{ dB} = A = 20 \log_{10} \left| 1 + j\, \omega C \left(\frac{R_L R_S}{R_L + R_S}\right) \right|$$

where: A = attenuation at cut-off frequency

$j = 1\sqrt{-1}$

$\omega = 2\pi f$

C = filter capacitance

R_L = load resistance

R_S = source resistance

For systems with greater resistances (vendor data usually references a 50 ohm balanced system) significantly better filter effectiveness is seen, and the 3 dB point is found at lower frequencies.

Temperature: Most filter contacts can take 150°C or higher without damage, but the user must keep in mind the shift in capacitance just after the Currie Point is passed (typically around 130°C) and the fact that at higher temperatures you are operating at lower values of the attenuation curve.

ATTENUATION TEST METHODS

The standard method of testing is per MIL-STD-220A, "Method of Insertion-Loss Measurement." To obtain smoother test curves, some suppliers add 50 ohm resistance between the filter and the test terminals. 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 should not affect accuracy.

INTERNAL CONSTRUCTION

Filter contacts: The filters are attached by various means to the central metal contact around the circumference. Manufacturers are limited by the fact that these hybrid filter connectors must mate with standard, often MIL-specification mates and therefore have fixed center-to-center contact spacing. Wall thickness reaches a mechanical/physical minimum and then the filter O.D. is maximized.

Ferrite materials can be selected for their permeability and thermal stability. The ceramic capacitor material is usually varied (see capacitance values in Table 2) based upon the following:

$$C = \frac{K\,(.614)\,(B)}{\log_{10}\left(\frac{O.D.}{I.D.}\right)}$$

O.D. = tube outside diameter
I.D. = tube inside diameter
B = electrode length
K = dielectric constant

The above sometimes may be an over simplification since it does not include fringe capacitance.

Ground Plans: 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 grasp 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. They have found that the number of tines is critical to attenuation and that with less than 6 tines per contract, the $\lambda/4$ wave can couple through the ground plane, drastically reducing attenuation. Their current designs use a minimum of 8 tines.

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

APPLICATION CONSIDERATIONS

Attenuation: The user should be careful not to over-specify the level of attenuation needed. For example, shifting from a "Pi" filter of typically 8000 picofarads with a 3 dB point at 1 MH_Z, to a multilayer "C" filter of 100,000 picofarads will often double the price.

A.C. Voltages: A filter that has a 200 volt DC working voltage typically has a 125 AC rms working voltage. Thus, D.C. is not equivalent to A.C. rms. De-rating for altitude is typical of connectors. A good rule-of-thumb to follow is that the D.C. voltage value for 70,000 feet is one-third that of sea level.

Transients: Filter connectors are available to meet the DC requirements of MIL-STD-704A, but not always the AC spike levels. Thus, protection must be provided in those instances.

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, 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 used. 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).

Contact Size, Capacitance and Voltage: Due to historical usage and market demand, most filter contacts have been in Sizes 20 and 16. Size 22 are new and use physically smaller filter elements with reduced ratings. Capacitance is inversely related to working and hi-pot voltages; for example, the "very low" filter of Table 2 has 1.0 ufd nominal capacitance with a 50 V DC working level while the others have 200 V DC. What may be available in one series may not be available in another, even if contact sizes are the same, due to contact-spacings, construction, etc., so always check with the manufacturer. Size 12 filters of the MIL-C-5015 variety are limited to 20 amps.

Combination Layouts: A high percentage of filter connectors are supplied with combinations of filters and unfiltered contacts installed. The proper/selective use of feed-thru/unfiltered contacts and/or grounding contacts (i.e., the contact is conductive to the ground plane) can reduce price. Different filters can also be supplied in the same connector to best meet the needs of each application. In these cases, the user must be sure to identify each cavity requirements to the manufacturer.

Mounting: The filter connector and the panel must have conductive surfaces. If flange-mounted, usually the four screws will provide sufficient surface pressure and EMI gasketing is not needed. Integral filtering in cable-connecting plugs is *not* recommended due to the rugged physical abuse usually given cables and plugs. The use of grounding fingers between bayonet type connectors and plugs is required in order to duplicate the filter's wall mounted performance. Possible poor conductivity from the plug to the receptacle, and then to the panel is another problem.

MIL-C-83736 UNDER PREPARATION

The Defense Electronics Supply Center (DESC), in Dayton, Ohio, is preparing MIL-C-83736 (USAF) "Military Specification, Connector, Electric, EMI Filter, General Specification for". Its broad scope is to provide "electric connectors having individual electromagnetic interference filtered contacts.....operating within the temperature range of -55°C (-67° F) and +125°C (+257° F) and shall mate with existing connectors as specified".

It's good to note that new contact arrangements and/or mates are *not* to be created by this specification and/or for its mates. Preliminary reports are that five different filters will be defined, and that there will be eight product series ranging from circular connectors per MIL-C-27599/38999 and MIL-C-5015, to rectangulars per MIL-C-24308 and MIL-C-83733, etc.

The "Classes" will be determined by the types of *contacts* used in the connectors:

E - Environmental resisting with provisions for backend hardware - with *fixed filter element* - termination to accept *crimp removable* contact.

S - solder cup termination and fixed filter elements.

R - Entire contact with exposed filter element crimp-removable.

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