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.

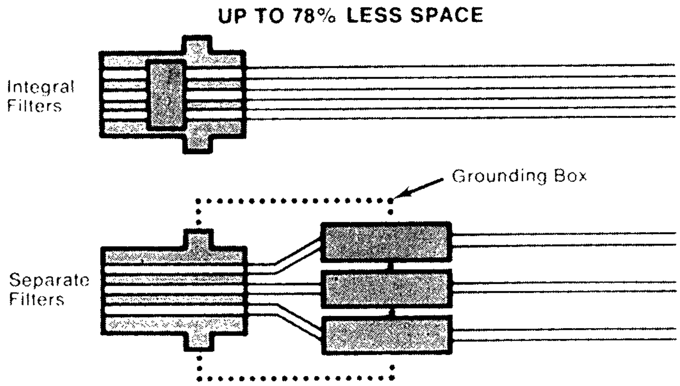

Figure 1,

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.

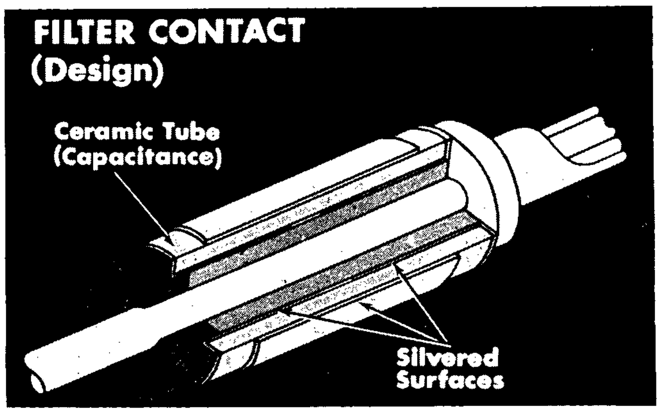

Figure 2,

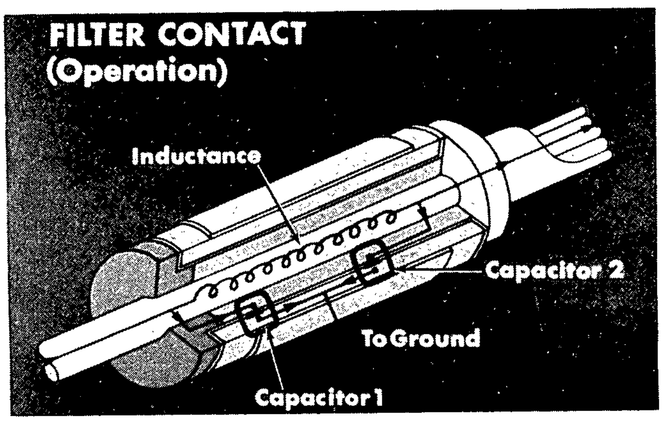

Figure 3,

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.

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:

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

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.

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.

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 tc 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.

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.

The above article is a condensation of the original article which appeared in ITEM 77. *The original text was prepared by David H. Shaff, Manager, Market Planning and Development, ITT Cannon Electric, Santa Ana, CA.*