EMI Filter Characteristics and Measurement Techniques

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INTRODUCTION

Establishing EMI filter insertion loss characteristics requires the use of laboratory measurement techniques that simulate actual installation and operating conditions. It has been widely recognized that testing power line interference suppression filters in accordance with the procedures of specification MIL-STD-220A yields results that are not representative of filter performance in the actual circuit operating electromagnetic environment. The impedance encountered in power lines and equipment loads is considerably different from the 50-ohm measurement impedances of MIL-STD-220A.

The most important aspect of RFI/EMI filters is their insertion loss at full-rated load current when operating into their normal circuit impedance.

This article evaluates the present MIL-STD-220A filter measurement system and an RF current injection probe measurement procedure which simulates the measurement technique used in the present equipment interference test specifications. In addition, the insertion loss measurements of low leakage current filters, using both common- and differential-mode measurement methods, will be considered. However, before these measurement methods are discussed, the general characteristics of various interference suppression components will be reviewed.

SUPPRESSION COMPONENTS

Suppression components or filters may consist of a single capacitor or an assembly of capacitors and inductors arranged electrically to produce a specified loss of energy over a desired frequency range. Many questions must be answered before attempting to suppress the inherent interference in an equipment or system.

First, one must consider the frequency range over which suppression is required. This is important since it determines the type and degree of filtering necessary, and indirectly, the size and weight of the suppression device. In some cases, such as missile or aircraft installation, the problem of space and weight are severe, and preclude a brute force approach to EMI suppression

A second consideration is the effect of suppression components on circuit operation. A third consideration is the mechanical and environmental constraints imposed, such as shock, vibration, temperature range and maximum altitude.

CAPACITORS

Lead-type Capacitors

An ideal capacitor has an impedance characteristic that will show a linear decrease as the frequency is increased. However, in practice, a lead-type bypass capacitor consists of a capacitance in series, with an inductance with both series and shunt resistance. The inductance is composed of the capacitor winding inductance and the lead inductance. At some frequency, the capacitor will obviously become series-resonant. Therefore, at this resonant frequency, the impedance will be minimum and the insertion loss provided by the capacitor will be maximum. However, above the resonant frequency, the inductance predominates, and the capacitor ceases to be an effective suppression element. For a given capacitor winding, the internal inductance is fixed, but the external inductance will vary with the lead length. By varying the capacitor lead length, the resonant frequency can be shifted (Figure 1). Also, the lead-type capacitor is superior to the ideal capacitor at frequencies around the resonant point. Above the resonant frequency, the lead-type capacitor is

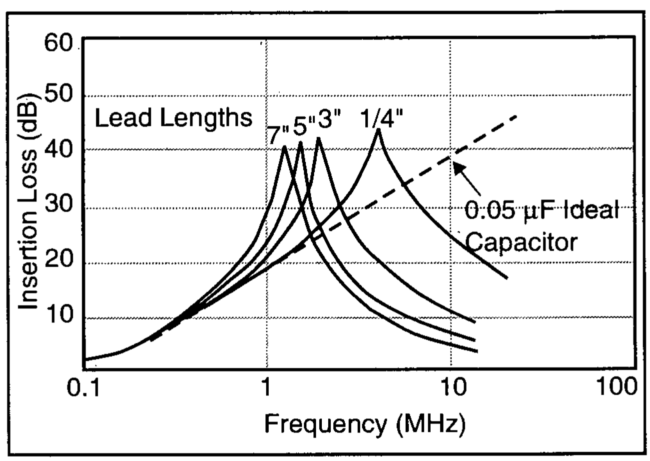

Figure 1. *Insertion Loss vs. Frequency for 0.05 µF (Lead-type) Capacitor.*

ineffective as an EMI suppression component. Even at minimal lead length, the lead-type capacitor has an upper frequency limit imposed on it by the winding inductance.

Feed-through Capacitors

In those cases where the suppression installation requires a broadband characteristic that the ordinary lead-type capacitor does not offer, a feed-through capacitor can be used. The feed-through capacitor design reduces the internal winding inductance and entirely eliminates the external inductance exhibited by the lead-type capacitor. Minimum capacitor winding inductance is achieved by maintaining the shortest internal connections within the capacitor. This requires that a good feed-through capacitor have soldered internal connections so that the inductance and resistance to any part of the capacitor foil (plate area), both the hot and ground side, be at absolute minimum levels. In practice, this is accomplished by connecting all the foil projections. In addition, the hot foil is connected directly to the feed-through wire, which is in series with the line to be suppressed. The capacitor ground foil is soldered or fastened to the capacitor case or filter assembly case. Thus, there is effectively zero lead length between the capacitor plates at both the line and ground points.

The response of a feed-through capacitor compared to both the lead type and the ideal capacitor is shown in Figure 2. As can be seen for the feed-through capacitor, a condition exists which causes the insertion loss characteristic to deviate from that of the ideal capacitor over part of the response. In practice, this phenomenon, known as the resonant dip of the feed-through, occurs at a frequency determined by the capacitance value, form factor and type of dielectric. It can be observed that for a given capacitance, the resonant dip frequency shifts as a function of the capacitance voltage rating and dielectric type. This frequency shift is due to the change in the capacitor size as the dielectric material thickness is increased or decreased to be consistent with the voltage rating of the capacitor. The insertion loss characteristic of a feed-through capacitor is similar to that of a lowpass filter.

RFI/EMI FILTERS

Filters are normally classified according to the position of the passband relative to the stopband in the frequency spectrum. There are four classes of filters: lowpass, highpass, bandpass, and band-reject. The control of EMI usually requires a filter of the lowpass type. Power line filters are lowpass types, since they pass dc and power frequency currents with minimum loss and reject signals above the specified passband. The following is a brief discussion of some basic filter configurations used for RFI/EMI suppression.

L-Circuit Filter

Improvement of the low frequency response of the previously discussed feed-through capacitor can be accomplished by the addition of an inductor in series with the current or signal carrying line. This additional element forms a circuit defined as an L-type filter. The single element feed-through capacitor has an insertion loss response that increases with frequency at 6 dB/ frequency octave (20 dB/decade). The two-element L-configuration filter response will increase at 12 dB/frequency octave, or 40 dB/decade (Figure 3). The physical size of an L-section filter depends on the required insertion loss, current and voltage rating, with the first two requirements predominating. High frequency response of this type filter is limited due to the distributed capacitance of the inductor and the existence of a single feed-through capacitor element.

However, the L-circuit filter can be changed to provide improved high frequency performance with the addition of another series inductor and shunt capacitor, to form a double L-filter type (Figure 4). This filter type will have

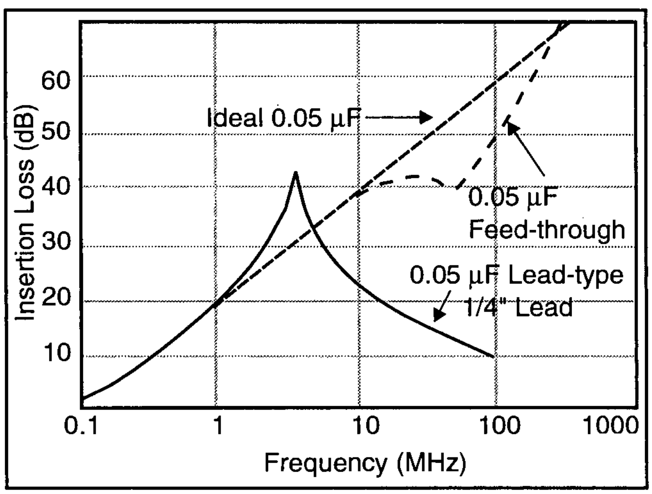

Figure 2. *Insertion Loss vs. Frequency for Typical Feed-through and Lead-type Capacitors.*

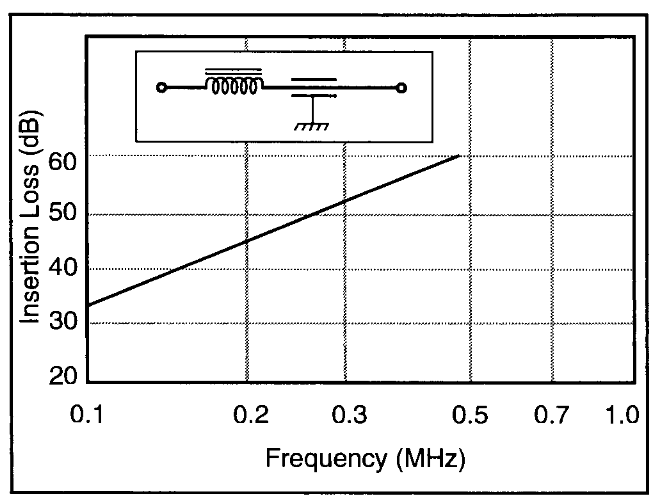

Figure 3. *Insertion Loss of an L Circuit.*

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an insertion loss response that will increase with frequency at 24 dB/octave (80 dB/decade). Although the distributed capacitance of the inductors is still a consideration, the overall high frequency response is improved due to the second feed-through capacitor element. However, one must be aware that this filter type exhibits a resonant dip in the response curve, which occurs at a frequency above the cutoff frequency. This frequency is calculated by using approximately ½ the total inductance and ¼ the total capacitance of the filter. Therefore, the use of a double-L filter must consider this resonant dip, and must be selected so that the dip frequency falls below the desired rejection frequency band.

The insertion loss of L and double-L filters is independent of the direction of inserting the filter in a circuit where the source and load impedances are equal. However, when the load and source impedance are not equal, the greatest signal rejection will usually be achieved when the capacitor element shunts the higher impedance. Suppression of ac and dc input power lines requires that the inductive element be at the input end of the filter, since the power line usually presents a low impedance, and is always the existing condition when performing interference measurements per MIL-STD-461. The placement of the capacitor element at the output or load end of the filter results in a very effective RFI/EMI suppression device when the filter sees a high impedance load. For the condition where the load impedance is low, a filter network that also presents an inductive output element would be more effective.

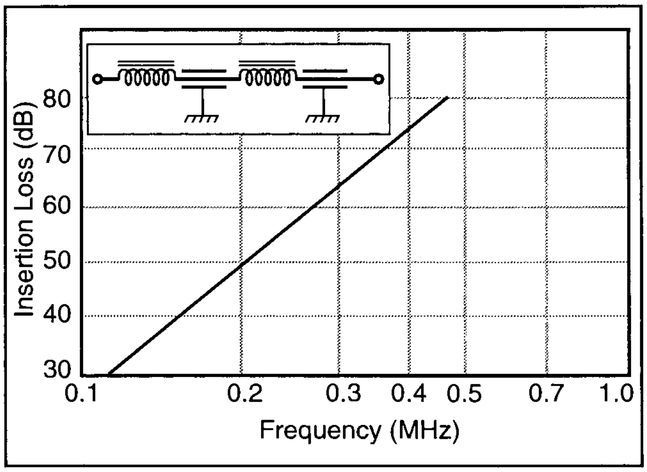

Figure 4. *Insertion Loss of a Double-L Circuit.*

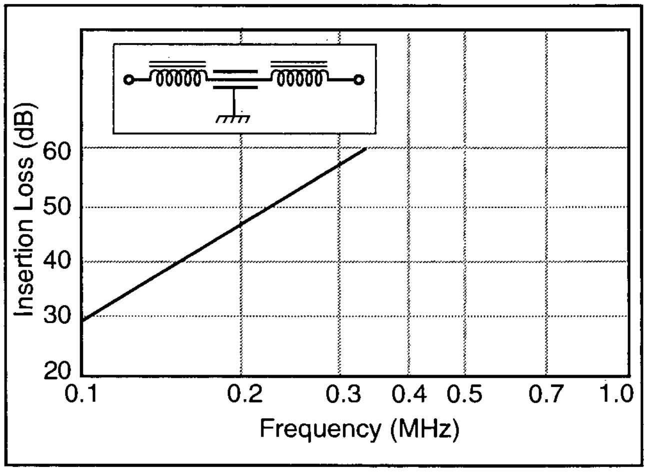

Figure 5. *Insertion Loss of a T Circuit.*

T-Circuit Filter

A filter having an inductive input and output is known as a T-circuit type. The T-circuit filter has two coils connected in series, and a shunt or capacitive element connected between the coil junction and the filter case or ground (Figure 5). As previously discussed, this filter will work effectively into a low impedance source and load. Also, this network will suppress interference signals equally well, whether they originate at the load or source end of the filter. It is also an effective network for the suppression of transient interference. Stopband insertion loss nominally increases at 18 dB/frequency octave (60 dB/decade). The T filter high frequency performance, similar to that of the L circuit, is also limited to 60 dB to 70 dB, since again it has only one feed-through element. Its major disadvantage is the requirement for two inductors, which under certain circumstances presents a size penalty, particularly when they are used to suppress power lines at high operating currents. T-circuit filters have been used in many low current applications, and where the use of an input capacitor would adversely affect circuit performance.

Pi-Circuit Filter

The pi-circuit filter is the most common type of RFI filter network. Advantages of this type filter are ease of manufacture, high insertion loss over a broad frequency spectrum, and moderate space requirements. Although voltage must be considered, current rating and insertion loss requirements are the most important factors in determining the size of the filter. A typical insertion loss curve for this type filter has a slope of approximately 18 dB/frequency octave, or 60 dB/decade (Figure 6). High frequency performance of the filter is improved over the L- and T-type by the addition of internal shielding and the use of two feed-through capacitor elements.

Insertion loss readings of 80 dB can be achieved with a pi filter over a wide frequency spectrum. However, a multiple pi-section filter (cascade pi sections) exhibits an insertion loss response that rises much faster than the single pi filter. For example, two cascade pi sections would increase at a rate of 30 dB/frequency octave (100 dB/decade), versus the 18 dB/octave (60 dB/decade) for the single pi filter (Figure 7). Extensive use is made of multi-stage networks for power-line filters in large instal-

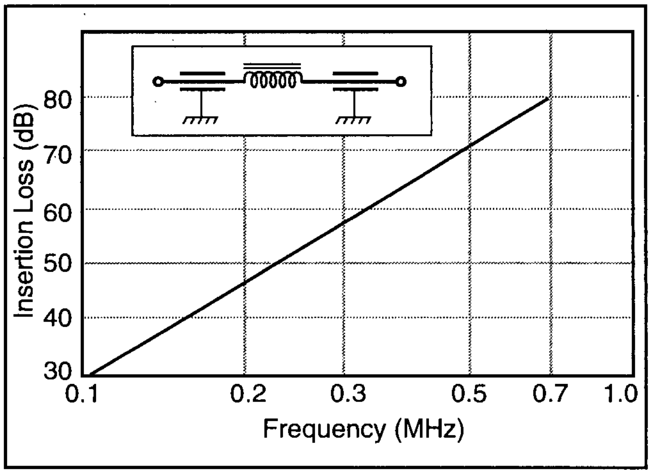

Figure 6. *Insertion Loss of a Pi Circuit.*

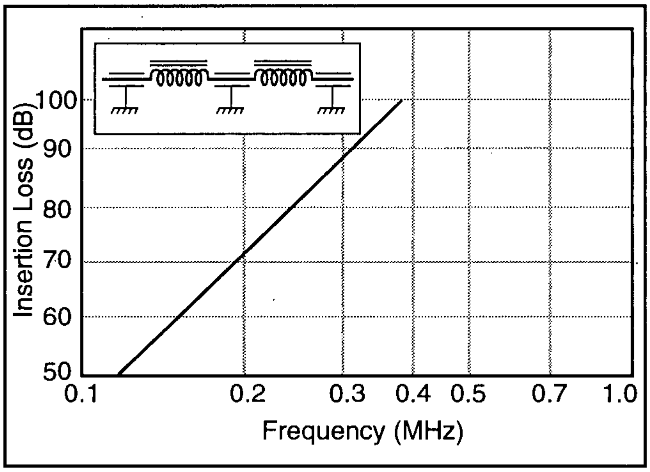

Figure 7. *Insertion Loss of a Double-pi Circuit.*

lations, shielded enclosures, and secure areas where high insertion loss is required.

Low-leakage Filters

The low-leakage, minimum capacitance-to-case filter designs required by MIL-STD-461 restrict line-to-ground capacitance to 0.1 µF for 60 Hz operation and 0.02 µF for 400 Hz operation. Most filters of the low-leakage type contain both common-mode and differential-mode circuitry (Figure 8). Common-mode or line-to-ground insertion loss is achieved through the use of a large-value common-mode inductor, normally wound on a high permeability core, and a low value line-to-case capacitance. Differential mode or line-to-line rejection is obtained with discrete inductors of relatively low value, as compared with the common-mode coil, and large-value line-to-line capacitors. The capacitor and inductor elements for both common- and differential-mode designs are selected to provide similar performance. However, if the known interference is predominately common-mode, then only a minimal differential-mode design is necessary.

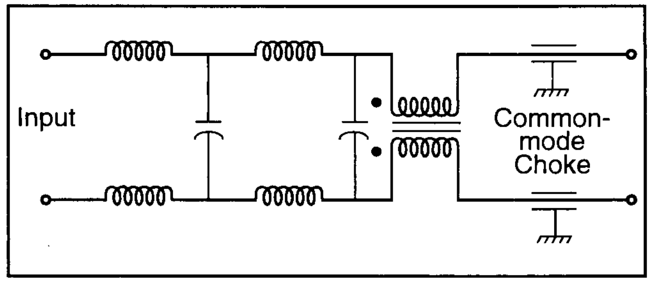

Figure 8. *Low-leakage Filter.*

Magnetic core saturation for the discrete inductors is based on core size, inductance and operating current, which is consistent with existing non-restricted leakage current filters. However, the common-mode inductor forward and return circuit currents flow through the coil windings in opposite directions and therefore the fields cancel and there is no core saturation or reduction of the common-mode inductance. It should be noted that the common-mode coil has little effect on the filter differential insertion loss since it presents negligible differential inductance. Also, the discrete inductors do not add significantly to the filter common-mode response, since their value of inductance is very small compared with that of the common-mode coil. This combination filter usually requires a larger package size to provide the same insertion loss response as a conventional high capacitance-to-case filter design.

INSERTION LOSS TEST METHODS

FILTER MEASUREMENTS

The most important aspects of an RFI/EMI filter are its insertion loss characteristics at full-rated load current when operating into its normal circuit impedance. As previously stated, filter insertion loss is dependent on the impedance of the circuit in which it must function. Most filter specifications express insertion loss performance in a 50-ohm system, which in the majority of cases is not the filter's normal operating circuit impedance. The predominant use of a 50-ohm measurement system is primarily due to two main factors. First, the available military filter specifications define measurement of insertion loss in a 50-ohm system. Secondly, signal generators and receivers are designed to operate in a 50-ohm input line impedance.

MIL-STD-220A MEASUREMENTS

To standardize the method of measurement for filter insertion loss, the armed services have adopted MIL-STD-220A as the prescribed procedure for these measurements. Filters are tested in a 50-ohm system, maintained by a 10 dB isolation network installed at both the filter input and output (Figure 9).

The 50-ohm matched condition is desirable for measurement of signal filters, which were designed for operation in a 50-ohm system. However, power-line filters are normally installed where power line and load impedances can vary from fractions of an ohm to hundreds of ohms. Therefore, testing of power-line filters in a 50-ohm system will not indicate realistic frequency versus magnitude characteristics.

A signal of known amplitude E1 is fed directly through a length of coaxial cable via the through position of the coaxial switches to the receiver. A reference level is established on the output meter of the receiver. The signal is then injected into the filter via the coax switches, and the amplitude of the signal generator is increased until the receiver output meter again reaches the reference level. This new signal generator output is designated E2. The filter insertion loss is then calculated as 20 times the log of the voltage ratio E1/E2. Note that the filter measurements are taken while the filter is drawing rated dc current or a dc current equivalent to the peak of the root mean square (RMS) current for ac-rated filters. This test condition will determine the effect of the filter inductor core saturation upon filter performance. The present version of MIL-STD-220A specifies full load measurements from 100 kHz to 20 MHz. Today, most systems require filter insertion loss performance down to at least 10 kHz, which is one order of magnitude lower than permitted by the measurement techniques in MIL-STD-220A. Measurement at frequencies down to 10 kHz under full load conditions requires the design of a new low-frequency buffer network. Buffer networks allow dc current to flow through the filter, while preventing the RF signal from being bypassed around the filter under test through the power supply. For the buffer network to perform satisfactorily, it must have a high impedance compared with the filter and must not vary the characteristics of the filter, thereby assuring that the insertion loss measurement is accurate. Use of extended-range buffer networks permits full load insertion loss measurements over the frequency range of 10 kHz to 20 MHz. Therefore, filter evaluation at peak load conditions can be accomplished over the frequency range where most filter inductive elements are effective. However, as previously stated, this measurement procedure, although it evaluates the filter at full load current, still provides the filter performance in a 50-ohm system and not in the actual circuit application.

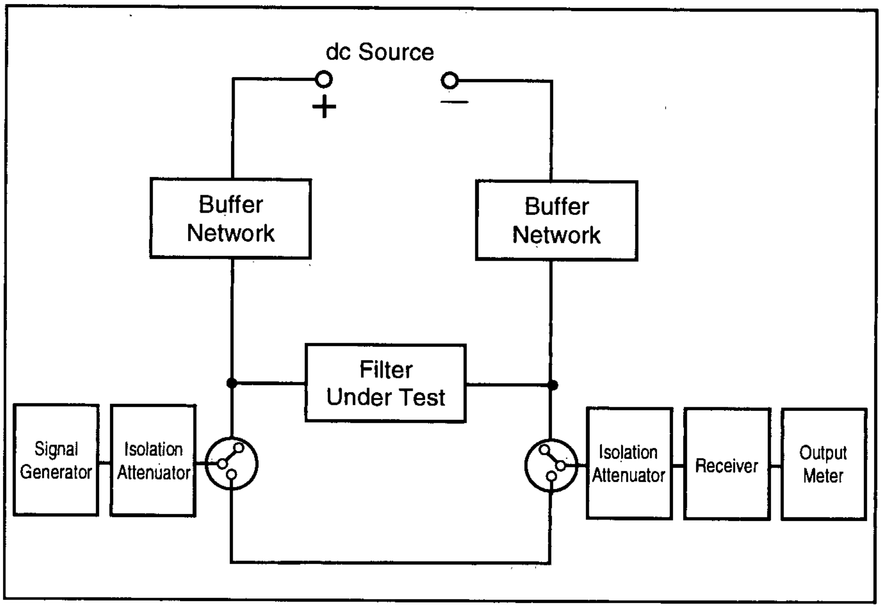

Figure 9. *MIL-STD-220A Test Setup.*

The MIL-STD-220A measurement procedure is still a useful production test system for evaluation and comparison of filters by the manufacturer and user, knowing the limitation and true meaning of the resulting data. Proper use of this procedure and resultant data will be discussed later.

CURRENT INJECTION PROBE MEASUREMENT

The following measurement procedure will more closely simulate the actual filter operating condition. An obvious way of eliminating the 50-ohm loading problems at the input and output of the filter is to use current probes for both the injection and reception of RF signals. This eliminates the hard wire connection between the signal generator and filter input and between the receiver and filter output. The test setup uses a current injection probe (CIP) to overcome the 50-ohm loading problems of MIL-STD-220A (Figure 10). Signals are injected into the measurement system by the CIP driven by a signal source. Measuring components of the test setup consist of two CIPs and a receiver. The CIPs measure the signal current input to the filter and the filter signal output current. The receiver and load impedance are isolated from the high-level signals emanating from the signal source and current injection probe by a shielded enclosure.

With the filter installed in the test circuit, rated line voltage is applied to the filter, and the load impedance is adjusted for the maximum rated current of the filter. The attenuation measurement at rated load conditions is made as follows:

- Raise the injection signal current (I1) until the load current (I2) is at least 6 dB above the receiver background level. Record both input signal (I1) and output signal (I2).
- Define the attenuation loss at a given frequency as 20 times the log of the ratio of the input current (I1) to the output current (I2).

This technique is desirable since it allows the filter source and load

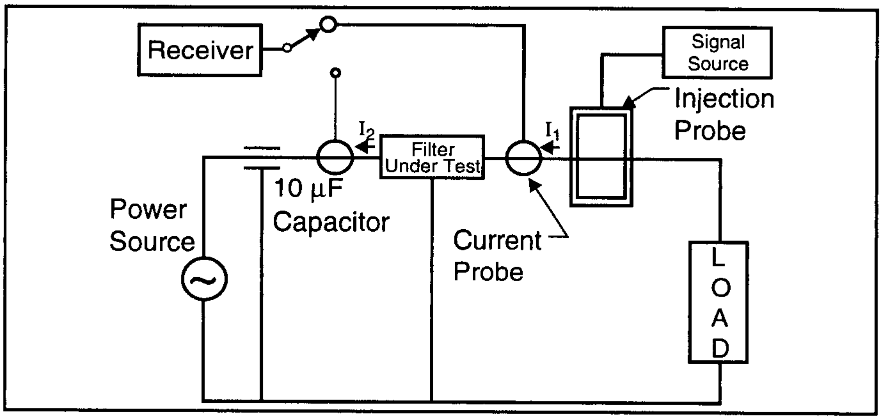

Figure 10. *Current Injection Test Setup per MIL-STD-461.*

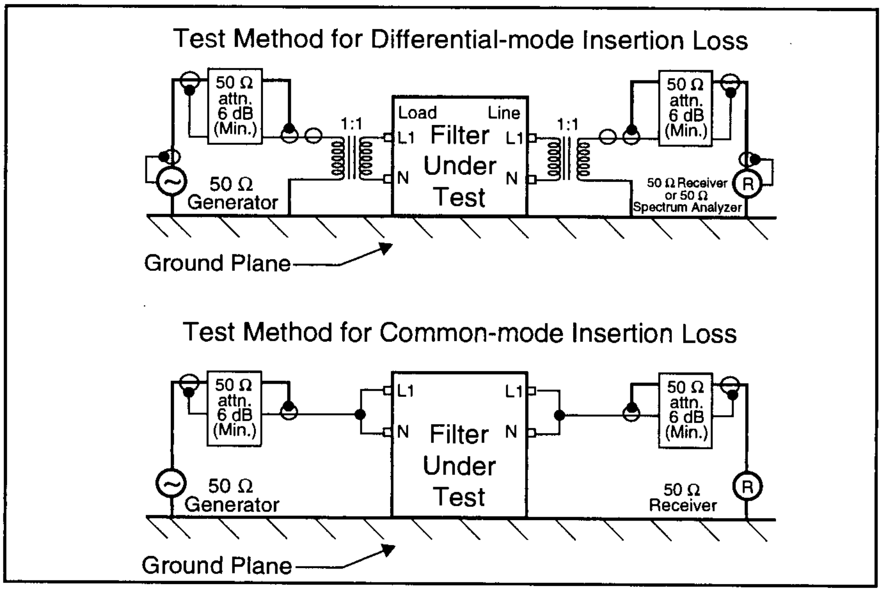

Figure 11. *Test Methods for Differential- and Common-mode Insertion Loss.*

impedance to be varied, so that actual operating conditions can be simulated. In addition, this method also approximates the conducted interference measurement procedure required by specification MIL-STD-461C, to which most military systems must comply.

This measurement system has several disadvantages that must be considered. One major problem is obtaining high dynamic range over the complete frequency spectrum. To achieve at least 100 dB of dynamic range, the current injection probe must be capable of transferring appreciable amounts of power from the signal source to the test circuit. This requires the use of power amplifiers that drive the current injection probe. This high signal level creates the second problem area, due to signal radiation within the test setup. Therefore, a well-shielded test setup is very important to assure that high level signals radiated from the injection probe are not coupled to the filter input. This technique demands that a shielded enclosure be used to isolate the filter load and source. The filter must be mounted to the test setup enclosure to ensure no leakage of RF signals through the mounting interface.

Experience has shown that this method is satisfactory up to a frequency of approximately 10 MHz. Above this frequency, the test setup shielding and signal power levels make the current injection method difficult to execute consistently. It should also be noted that the RF CIP causes impedance, ranging from less than 0.1 ohms at 10 kHz to approximately 6 ohms at 10 MHz, to be added to the test circuit. This impedance can reduce the effective Q of the circuit, and thus damp resonances that may occur and cause the measured result to be less than the actual operating response. This condition is more prevalent as the test frequency is increased, and is therefore another reason for the limit in the frequency range of current injection testing. The CIP measurement system is not as easily utilized for production testing of filters as is the MIL-STD-220A procedure.

COMMON/DIFFERENTIAL-MODE MEASUREMENTS

Low-leakage filters require a test procedure that will evaluate both interference transmission conditions. Two test methods used for production evaluation of low leakage filters are discussed here (Figure 11). One method is for common-mode measurement and the second is for differential-mode insertion loss measurement.

The common-mode test is similar to the MIL-STD-220A procedure, except both input and both output terminals are connected and measurements are performed at no load. Measurements at no load are consistent with common-mode coil operation, since the core saturation fields cancel, and the resultant data is similar to that obtained under normal filter operation. Connection of both input and output terminals minimizes the variation of the filter response due to the differential line-to-line components. If testing was performed at full load per MIL-STD-220A, the resultant data would not reflect the actual filter performance, since the dc load current would saturate the common-mode core.

Differential testing is performed using unbalanced-to-balanced RF transformers for the input and output

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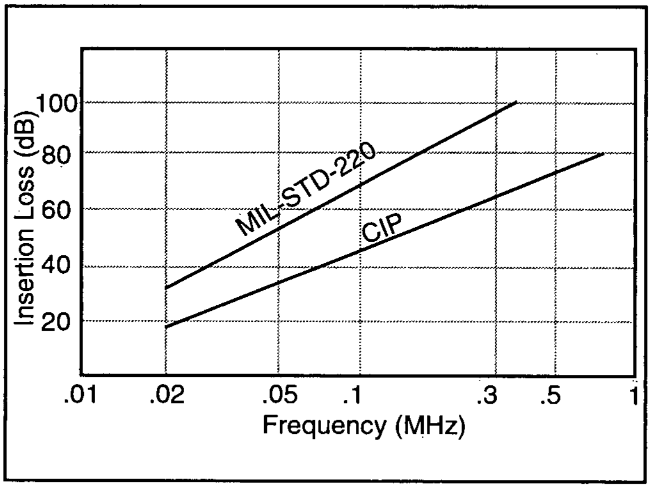

Figure 12. *Insertion Loss of a Pi Filter.*

termination of the filter. As with the MIL-STD-220A tests, a 50-ohm attenuator pad is used to establish the 50-ohm input and output impedance. The insertion loss data is a result of the line-to-line capacitance and discrete inductors. Again, this measurement is made under no load conditions. This procedure should only be used as a production testing method. Loaded inductance measurement of the discrete coils should be performed in conjunction with the no-load insertion loss measurement, to assure that the coil winding and core are according to the specified design. Other methods of differential measurement have been proposed, but were considered ineffective as a production test method.

Having one filter insertion loss measurement technique that would cover the complete frequency spectrum of interest would be ideal. However, the prior discussion suggests that having a single meaningful test procedure covering the broad frequency range from 10 kHz to 10 GHz is not practical. For installation-type filter evaluation, the CIP measurement technique will give meaningful results provided the test method limitations are correctly interpreted. Measurements above 10 MHz can be accomplished using the MIL-STD-220A procedure.

FILTER CHARACTERISTICS VS. TEST METHODS

As previously discussed, evaluating the performance of a filter under its intended operating conditions would be advantageous. This cannot always be accomplished. However, the CIP test method will simulate actual operation and measure filter performance using a measurement method similar to that used during conducted interference tests according to specification MIL-STD-461. The following paragraphs will look at various filter types, pi, L, T, and double L, measured according to MIL-STD-220A and a simplified current injection procedure. MIL-STD-220A data was determined in a 50-ohm system at a dc load current equivalent to the peak of the filter RMS current rating. Current injection probe data was obtained using the test setup previously shown, at rated line voltage and load current. The filter load current was established using a resistive load, which could also be made reactive and more closely simulate the filter operating load.

First let us consider the most frequently used filter, the pi type. Measurements were performed on a pi filter using both MIL-STD-220A and CIP test methods. The results are shown in Figure 12. As can be seen, insertion loss recorded per the MIL-STD-220A procedure increased at the rate of approximately 18 dB/frequency octave (60 dB/decade). This is the expected response of a three-element network. CIP insertion loss response of the pi filter increased at a rate of approximately 12 dB/octave. This is the response one would expect to obtain for a two-element L-type filter. It can be concluded from this data that the input capacitor of the pi filter would be relatively ineffective as a suppression element when making conducted interference measurements per MIL-STD-461. To be effective, the input capacitor would have to be an order of magnitude larger than the 10-μF source capacitance of the MIL-STD-461 test setup. By using a pi filter as a suppression element under these test conditions, one would pay a penalty in size, weight, and cost. The same performance could be achieved by using an L-type filter. If the filter selection was based only on the MIL-STD-220A response, the real-world performance would be inadequate from the standpoint of interference rejection and would prevent compliance with the required system interference specification.

Let us now consider the two-element L-filter networks. Measurements were performed on an L filter rated at 1 A, 115 V ac (Figure 13). As expected, the MIL-STD-220A insertion loss data increased at a rate of 12 dB/frequency octave (40 dB/decade). Since the L filter is not symmetrical, current injection measurements were performed for two conditions, first with the filter inductive element toward the input power source, and then with the inductive element toward the load or interference source. Current insertion loss measured under the first condition provided signal rejection similar to that obtained from MIL-STD-220A measurements. This insertion loss data also increased at approximately 12 dB/frequency octave. However, insertion loss data was much less when the filter was reversed, with the capacitor toward the power source (10-μF capacitor), again showing that the filter capacitive element is less effective working directly into a low impedance or the 10-μF source capacitance of the MIL-STD-461 test setup. This type network is an effective suppression component when the equipment under test presents a high impedance load. Then the L filter will perform effectively whether the interference signal originates internal or external to the equipment under test. If the equipment presents a low impedance load, then the L filter installed with the inductive element toward the power source would

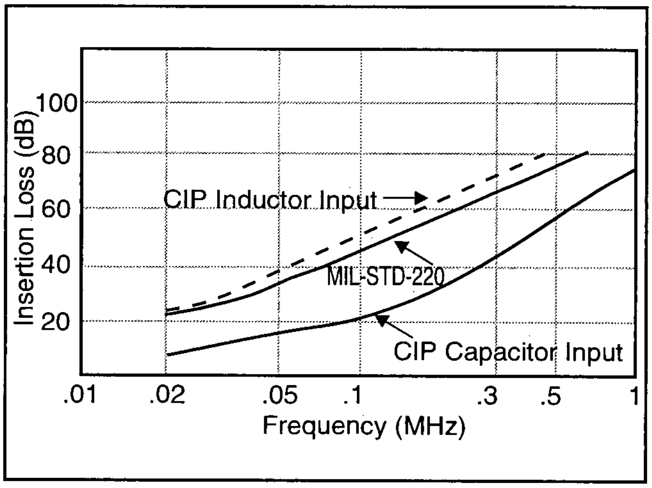

Figure 13. *Insertion Loss of an L Filter.*

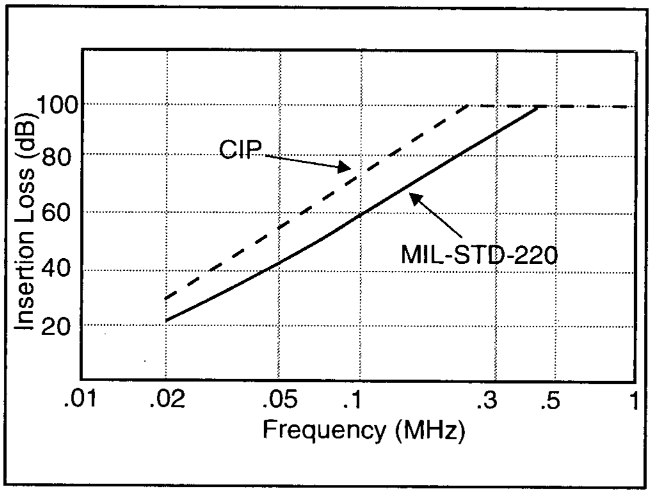

Figure 14. *Insertion Loss of a T Filter.*

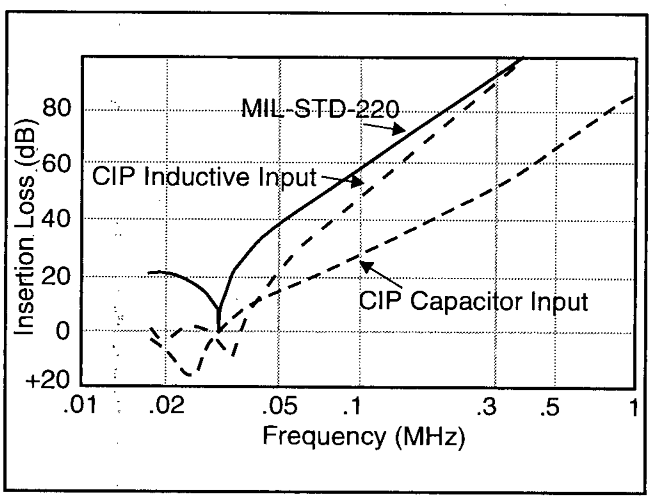

Figure 15. *Insertion Loss of a Double-L Filter.*

not effectively reject interference signals from external sources.

When both the load and source impedances are low, the T-circuit filter would be a more effective filtering network. The inductive input and output elements of the filter provide the necessary impedance isolation to make the capacitive shunt element effective. Figure 14 shows the CIP and MIL-STD-220A data for a T filter rated at 3 A, 250 V ac. As can be seen, the CIP data is approximately 10 dB better than the MIL-STD-220A results. However, this will not always be the case, as the resultant data will vary based on the inductance-to-capacitance ratio of the filter components and the characteristics of the source and load impedance.

Finally, consider the double-L filter that has similar characteristics to that of the single-L filter, but its insertion loss increases at a rate of 24 dB/frequency octave (80 dB/decade). Data for a double-L filter, rated at 30 A and 100 V dc is shown in Figure 15. The MIL-STD-220A insertion loss, measured in a 50-ohm input and output system, increased at a rate of approximately 24 dB/frequency octave above the 32-kHz resonant frequency. Again, this response is what one would expect for a simple double-L filter under these test conditions. As with the single-L filter, the double-L filter type CIP measurements were performed under two filter installation conditions. When the filter was installed with the inductive element toward the input power source (10 µF capacitor source impedance) and the interference signal originated at the load end of the filter, the low frequency insertion loss data was slightly less than the MIL-STD-220A results. At higher frequencies, above 300 kHz, the MIL-STD-220A and CIP results were similar. The high frequency results of both measurement procedures are limited by the isolation provided by the test setup and filter internal shielding. Concerning the low frequency response, it should be noted that there is a gain of approximately 10 dB in the measured CIP response at one of the filter resonant frequencies. This gain was not observed in the 50-ohm data, although there is a dip in the filter response. In a real world filter installation, this gain condition could present a serious problem if an undesired signal exists at the resonant frequency. Resonant frequencies are established by the filter inductive and capacitive elements and can be shifted due to the effects of load or source impedance.

When the filter installation was reversed, with the capacitor toward the input power source, the filter insertion loss response, like that of the single-L filter, was considerably reduced from that of the inductive input installation. This response is similar to that of a three-element network, approximately 18 dB/frequency octave. Again, the input capacitor is not an effective suppression component when looking into the low source impedance of the test setup 10-µF capacitor. Also, note that there is a gain of approximately 15 dB at the low frequency resonant frequency. It can be observed that the resonant frequency shifted lower in frequency from the previous inductive input condition. This is due to the added 10-µF capacitive reactance in parallel with the filter input capacitance, and therefore an increase in the total effective capacitance. If the filter requirements are only specified based on MIL-STD-220A response, the filter would provide inadequate performance under actual operating conditions, especially if interference signals exist at the resonant frequency.

The filter responses shown for the various filter types under different testing conditions suggest the necessity for establishing filtering requirements under actual operating conditions, rather than using only the 50-ohm MIL-STD-220A test data. Filter design requirements can be determined by breadboard tests or measurement of the interference spectrum of the equipment to be suppressed. This is not always feasible due to the unavailability of the equipment or system. Another approach is to do a mathematical interference prediction analysis using a model of the equipment and the interference measurement system. After establishing the predicted interference levels, a filter specification requirement can be determined based on the rejection required to comply with an applicable specification. A filter specification must consider the real-world requirements to assure that the supplied suppression device will be effective from the standpoint of interference reduction, size and cost. The following section will review the main items of consideration when preparing a filter specification.

FILTER SPECIFICATION REQUIREMENTS

When specifying a filter requirement to the filter designer, several details should be given to assure compliance with all applicable circuit and environmental requirements.

MAXIMUM CURRENT AND VOLTAGE RATING

The current rating should include any transients, their duty cycle, and the continuous filter current rating. Most filter inductor cores are saturable, and proper design requires consideration of this saturation effect at peak current. The voltage rating should be the maximum voltage to which the filter will be subjected during operation. Power line frequency must also be specified as this directly relates to the filter heating effects.

INSERTION LOSS VERSUS FREQUENCY

The required filter insertion loss is determined based on the unfiltered interference characteristics of the equipment to be suppressed. Complex circuit analysis coupled with experience in similar systems can often provide a general estimate of the required insertion loss levels. If the filter circuit has been established and circuit values are known, they should be provided along with the type of circuit. In addition, the inductor saturation level at rated current and core type should also be included. If adequate filter circuit definition is provided and controlled, the filter insertion loss response can be specified in a 50-ohm system. Then the MIL-STD-220A test method can be used for checking and comparing the response of the manufactured filters. Additional measurements should be made to check circuit configuration, and core saturation characteristics under load should be included and tested on a sample basis.

If the filter circuit cannot be defined, then the specification must include, as a minimum, a detailed description of the conditions under which the filter must operate, such as source and load impedance and the frequency versus amplitude response. Insertion loss requirements that are only specified per MIL-STD-220A, with a fixed 50-ohm source and load impedance, will not guarantee that the same response will occur in a real system having varying impedances. Therefore, it is very important that the insertion loss characteristics given as part of the overall filter specification accurately define the response required in the operating system.

ENVIRONMENTAL

Environmental requirements such as operating temperature range, shock, vibration, altitude, and salt spray must be identified. These will determine the type capacitor, fill material, case material, method of construction, terminal "creepage" distance and other design characteristics.

CRITICAL CIRCUIT REQUIREMENTS

Normal operation of circuits requiring suppression is often affected by excessive capacitance, series resistance, ac leakage current, etc. Where these circuit limitations exist, they should be specified as part of the overall filter requirement.

MECHANICAL

The mechanical requirements should include such details as the maximum case size, type of mounting, terminal type (solder lug, screw type, connector, shielded lead) and similar design characteristics. The following items should be considered when developing the package configuration of the subject filter:

- To realize the high frequency response of the filter, the input and output terminals must be mechanically and electrically isolated from each other. Lack of isolation will degrade the filter effectiveness by permitting signals to be coupled from input to output.
- Isolation is most easily accomplished by using a filter design that mounts through bulkheads or chassis. A radio frequency tight barrier or bulkhead may be constructed to isolate input from output (Figure 16). This can be accomplished more effectively by incorporating the input connector into the filter package as shown. The latter arrangement will require less volume than the separate input compartment. In cases where bulkhead mounting is not possible, a shielded wire can be used to interconnect the filter and the input connector.
- Radio frequency impedance of the filter case to ground must be as low as possible. If the filter grounding

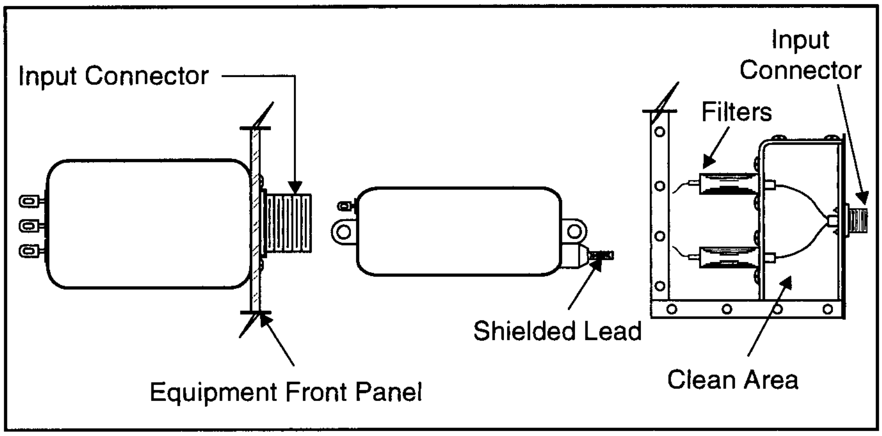

Figure 16. *Typical Filter Installation.*

impedance becomes sufficiently large in value, then RF voltages will be developed across this impedance. This reduces the effectiveness of the filter. It is important that the surface on which the filter mounts and the filter mounting surface be provided with a low-impedance conductive finish. Also, the type of mounting ears or studs must insure firm and positive contact over the entire area of the mounting interface. All the above requirements form the basis for a complete and viable filter procurement specification.

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FLAT FERRITE RF ABSORBERS *. . . Continued from page 121*

Experimental results are shown in Figure 17. While the uncovered cell has two big resonances at 300 MHz and 320 MHz (the inside field is multiplied by 12 and 18 respectively), the modified cell is usable up to 400 MHz (it retains a small resonance at 320 MHz with a factor 2.3 in place of 18).

The GTEM cell is the second application of flat absorbers in TEM structures. Standard GTEMs are manufactured with foam pyramid absorbers to overcome the degradation of matching to 50-ohm resistors at the end of the line. This decreases the useful test volume under the septum (or increases the overall size of the cell) by a large amount.

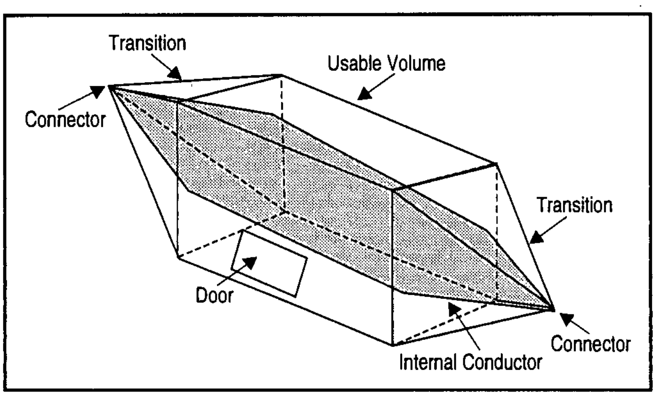

Figure 16. *TEM Cell Schematic Representation.*

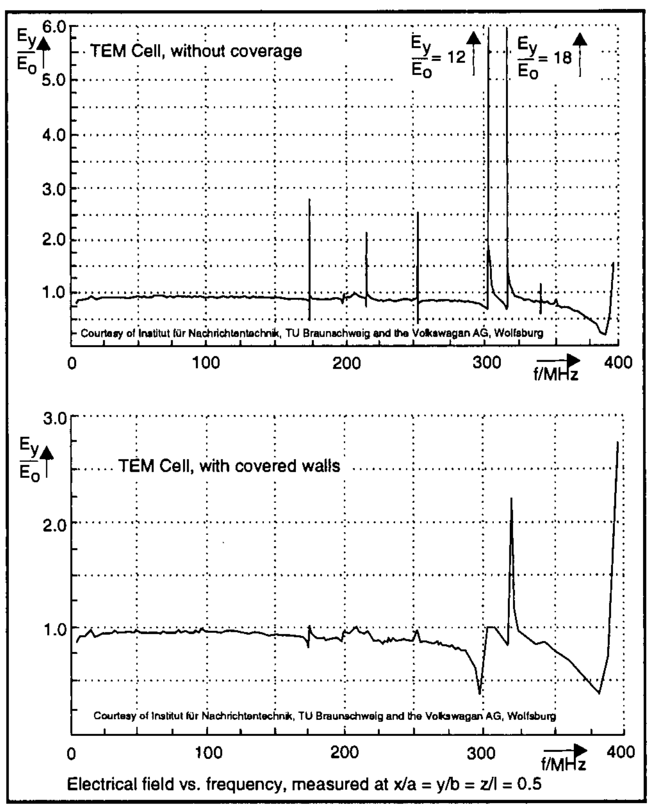

Figure 17. *TEM Cell Field Level Before and After Modification.*

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