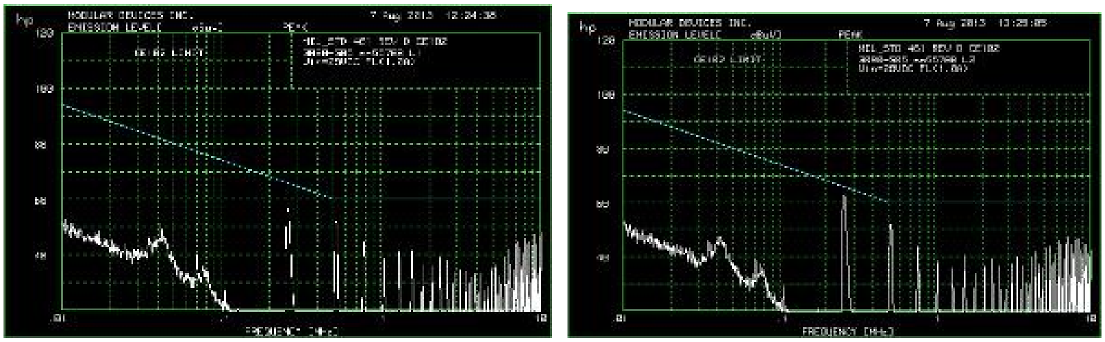
Introducing MDI's 3090, 3656 and 6681 series DC-DC Converters with advanced MIL-STD-461D, E and F EMI Filtering

MDI pioneered development and manufacture of an extensive range of hybrid DC-DC converters with internal filters that met widely used standard MIL-STD-461C for conducted emissions and susceptibility, power leads. Recently, many customers have also requested DC-DC converters featuring internal EMI filters that meet later revisions MIL-STD-461D, E and F.

These later revisions require more filter attenuation and a different filter topology than revision C, primarily because of different measurement techniques and limits. They present additional challenges of realizing more filter attenuation without increasing unwanted filter resonance effects within the interior volume limitations of MDI's existing case sizes.

After considerable analytical development, optimization of pin outs and packaging and advanced filter design, MDI introduced three advanced product families of hybrid DC-DC converters. The compact series 3090 produces 5 watts, the model series 6681 produces 30 watts and the series 3656 produces 80 watts. Models in these series are offered in single and dual outputs; all incorporate built-in EMI filters and meet MIL-STD-461D/E/F CE101, CE102, CS101, CS114, CS115 and CS116. They also meet DO-160C/ D/E/F/G CE section 21 and CS sections 20 and 22. These comprise state-of-the-art DC-DC converters that fulfill the latest Electro Magnetic Compatibility (EMC) requirements for aerospace, defense and civil aviation airborne electronics applications.



Conducted Emissions Scans, MIL-STD-461D CE102 Input Power Lead and Input Return Lead for 3090 5V Single Output Hybrid DC-DC Converter

Very compact and highly efficient, each model incorporates a completely self-contained input EMI filter that enables compliance with:

- MIL-STD-461D/E/F:
  - Conducted Emissions (CE)
    - CE101, power leads, 30Hz - 10kHz
    - CE102, power leads, 10kHz - 10MHz
  - Conducted Susceptibility (CS)
    - CS101, power leads, 30Hz - 150kHz
    - CS114, bulk cable injection, 10kHz - 200MHz
    - CS115, bulk cable injection, impulse excitation
    - CS116, cables and power leads, damped sinusoid transients, 10kHz - 100Mhz

- DO-160C/D/E/F/G:
  - Conducted Emissions (CE)
    - Section 21: power lines, emissions 15kHz - 30MHz, categories B, LMH, AZ
  - Conducted Susceptibility (CS)
    - Section 20: power lines, 10kHz - 400MHz
    - Section 22: lightning induced transients

The 3090 and 6681 designs are robust enough to operate through MIL-STD-704A 80V/100mS power line transients. The 3656 series, designed for MIL-STD-1275 vehicle electronics applications, survives 100V surge and 250V spike requirements of that specification.

The following application note describes the design considerations involved in producing these advanced parts.

What is EMI

EMI, or **E**lectro **M**agnetic **I**nterference is defined as the unwanted emission of signals from a device, such as a DC-DC converter. This unwanted emission of signals can cause upset to other devices within a system, or to other devices external to a system. It can also cause upset to circuits within a device, which is termed “self-EMI”.

All DC-DC Converters Produce EMI

Just like there’s never been “a baby with no crying”, there’s never been a switching converter with no EMI. The EMI spectrum preceding the filter (which the filter must attenuate) depends on the type of switching waveform, whether simple pulse width modulation or a zero voltage/ zero current switch technique. The power level also has a direct influence. PWM modulation usually (but not always) has a fixed frequency spectrum, whereas the zero current or voltage schemes can vary widely with frequency.

Even though the zero switching methods produce less pre-filter EMI, the noise comes in “packets”, and at light loads appears at a relatively low frequency. This low frequency spectrum makes filtering more complicated and more comparable in size and weight to fixed frequency filters.

Based on the relatively low power level delivered by hybrid DC-DC converters, MDI usually uses the fixed frequency PWM method.

EMI Emissions Specifications

Because engineering requirements are quantitative, the degree of allowable signal emissions is normally defined by an allowable spectrum limit, shown in terms of log amplitude (decibels) versus log frequency. Some representative EMI specifications are:

- MIL-STD-461C*
- MIL-STD-461D and up
- DO-160
- FCC/VDE
- SSP30237*

Allowable EMI emissions may be specified in terms of a current or of a voltage. The specifications above with an asterisk use a current measurement. The others use a voltage measurement. Each of these specifications contains one or more *limit lines*, above which EMI is not permitted.

With the current measurement requirement, the leads to be tested for EMI (usually both input power leads) are connected through a very low inductance 10 microfarad feedthrough capacitor. The capacitor is an RF ground. The measurement is made by clamping a current probe around each lead to be tested. The current probe then generates a voltage signal which is fed into the spectrum analyzer or EMI receiver. The EMI specification limits for current measurement requirements are in terms of dBuA, which means dB above a microampere.

In specifications with a voltage measurement requirement, the leads to be tested for EMI (usually both input power leads) are connected through a LISN (**L**ine **I**mpedance **S**tabilization **N**etwork). A LISN is a high pass filter which allows power to be applied without attenuating the EMI signal, and the EMI voltage is made to appear across a 50 ohm termination. This signal may then be applied directly into the spectrum analyzer or EMI receiver. The specification limits are in terms of dBuV, which means dB above a microvolt.

When testing high power units (or high input current units), a special LISN may be needed to prevent the unit under test from malfunctioning or oscillating because of the LISN's high impedance.

The design of a DC-DC converter EMI filter should consider the specified method of EMI measurement.

Because EMI specifications using current probe measurement feed the power leads through a large capacitor, it is advantageous for EMI filters to have an inductor as its first input element. No attenuation improvement would be gained unless the input capacitor is much larger than 10 microfarads.

On the other hand, it is advantageous for EMI specifications using voltage measurement with a LISN to have a capacitor as its first input element. No attenuation improvement would be gained unless the input inductor has an impedance much larger than the 50 ohms presented by the LISN.

The degree of EMI filtering required when comparing a current measurement EMI specification and a voltage measurement EMI specification can generally be equated by increasing the current limit lines by 34 dB, which is 20 Log 50 ohms.

EMC Conducted Susceptibility

In addition to limits on a DC-DC converter's emissions, EMI specifications include externally imposed input power line effects (such as spikes and audio modulation) that a DC-DC converter must withstand. These input line effects can derive from the power source, such as a generator, or from the combined effect caused by other loads on the power system.

The imposed effects on the DC power lines are not uniform, but vary by the particular specification imposed. These perturbations superimposed on the input power lines <u>always</u> have some effect on the DC-DC converter's output voltage. When large scale perturbations are imposed by specification, the specific allowable effect on the DC-DC converter's output should be explicitly specified and understood.

Synthesizing an EMI filter

EMI filters for DC-DC converters pass the DC power, but block the high frequency emissions. Therefore they are Low Pass Filters.

In synthesizing the EMI filter, the designer estimates the difference between the un-filtered spectrum and the EMI specification limit lines (and also adding margin).

There are infinite combinations L, C and R that can achieve the required attenuation. It is not trivial to select a combination that is satisfactory for all constraints. The DC-DC converter designer is constrained by at least six factors:

- Filter resonance that does not unduly amplify input power conducted susceptibility and adversely affect DC-DC converter output voltage.
- Filter resonance that causes AC power loss and heating.
- Filter output impedance that can cause the DC-DC converter to become unstable.
- Filter DC power loss that causes loss of efficiency.
- Filter parasitic and layout effects that spoil the attenuation.
- Filter components that can physically fit inside the DC-DC converter.

Coping with Audio Susceptibility

EMI filters are low pass filters whose cut off frequency must lie in the audio frequency range since the switching frequency is well above the audio range. LC filters will have one or more resonant peaks near the filter cut off frequency. Depending on filter damping, LC ratios, etc., the EMI filter can amplify both audio frequency conducted susceptibility as well as input spikes. This unwanted effect can be minimized by controlling filter damping and by staggering filter resonance frequencies.

By controlling filter resonance, we also minimize the possibility of large circulating currents driven by audio susceptibility, which can cause filter heating.

Avoiding "Middlebrook" oscillation

Most regulating DC-DC converters have a negative impedance characteristic to some extent. In other words, with a constant output load, as the input voltage is increased, the input current is reduced.

A paper written by Dr. Middlebrook described how the combination of an input filter's positive impedance can interact with a DC-DC converter's negative impedance to create an input side oscillation. Because we want the DC-DC converter to be efficient, we want it to have its negative impedance characteristic, and therefore we need to prevent the "Middlebrook" oscillation by keeping the EMI filter impedance as low as possible.

(This “Middlebrook” effect is the same phenomenon that creates an oscillation when EMI testing is done with a high impedance LISN.)

Parasitic LC effects bring us to reality

When we synthesize an EMI filter design, we start with pure L and C elements. However, in the real world, all passive components have “parasitic” effects that spoil the “purity” of the L’s and C’s. In inductors, shunt capacitance allows high frequency to pass. Winding resistance can cause power loss, but we can also appreciate the added damping that winding resistance offers. Inductance can vary with current and temperature.

Capacitors have ESR (equivalent series resistance) and ESL (equivalent series inductance). Capacitance can vary with applied voltage, temperature and frequency.

Capacitors and inductors can have stray capacitance to the mounting surface and to the case. Finally, EMI can bypass the filter entirely if the layout of the filter is not optimized and if component-to-component proximity is ignored.

In a large, discrete power supply, the mechanical aid of a shield or an EMI plenum can be used to prevent parasitic EMI leakage around an EMI filter. However, in a small hybrid microcircuit, components are in close proximity and there is no room for a physical shield. This makes implementing such a design more art than science.

Why an external filter for one or more converter not ideal

All power sources have an impedance. As well, all EMI filters have an impedance, and this impedance is typically much higher than the power source impedance.

When hybrid DC-DC converters were introduced many years ago, none had built in EMI filters. Then, in response to customer demand, some manufacturers produced stand alone EMI filters that were intended to filter one or more DC-DC converters. This approach has several drawbacks:

- The extra cost, size and weight of the additional hermetic hybrid package.
- The wiring between the filter output and DC-DC converters are “hot” and can radiate EMI.
- Because of the common filter impedance, the loading on one converter can influence the input to other converters using the same filter. This can cause output cross regulation or added ripple.

Why one filter per converter is best

Here are some reasons why the MDI concept of one filter per converter is best:

- Only one package minimizes size, weight, cost and engineering risk.
- EMI filter is optimized for the converter, no cross regulation between converters
- No exposed “hot” wires between filter and converter
- Output Common Mode filters keep EMI “bottled up” in the can.

What about Radiated emissions and susceptibility?

As part of most EMI specifications, in addition to the requirements for controlling *conducted* emissions and for withstanding *conducted* susceptibility, similar requirements apply for *radiated* emissions and *radiated* susceptibility.

MDI DC-DC converters are packaged in completely enclosed metal packages, which act as a shield for radiated emissions and radiated susceptibility. Therefore, only the input output and control leads are a factor for radiated effects.

The first available hybrid DC-DC converters from other manufacturers did not contain integral EMI filters and gave little consideration for meeting EMI requirements. Many of these early converters established industry standard pin outs which were not optimum for controlling radiated effects.

In particular, these early pin outs separated the power inputs by the width of the case. Also, output pins were in close proximity to the input pins. This is poor practice for minimizing radiated effects. Wide spacing of input power pins not only affects external radiation, but increases radiated noise inside the hybrid converter.

Input power leads can serve as antennas if they form a big loop. Optimum practice is to locate input power plus and return close to each other. To reduce the radiated loop, power wires can be twisted. If power wires are run through a printed wiring board, the traces can be co-planar, top and bottom.

All MDI DC-DC converters contain output common mode filters, which reduce high frequency noise. Output high frequency noise is typically generated by output rectifiers and is in the range of 10 mHz. to 30 mHz. The output common mode filters provide high attenuation of this output noise.

Nevertheless, DC-DC outputs should be wired properly to minimize any possible radiated EMI. In particular, large wiring loops should be avoided and outputs should not be routed close to input leads.

In general, if these practices (which are facilitated by proper pin out selection of the hybrid DC-DC converter) are followed, radiated emission and susceptibility requirements should be readily met.