Design Notes

Brief Introduction to EMC

The concern of designers to produce electromagnetic compatibility issue has dramatically increased in recent years. Many different standards have been developed and released, and all electrical and electronics engineers are aware of different compatibility tests. Unfortunately, there are still a lot of designers that encounter difficulties when dealing with EMC, either with understanding the issue, or in solving the related problems.

So, what is EMC?

Electro-magnetic Compatibility (EMC) is defined as the ability of a device or system to satisfactorily function (without errors) in the target electromagnetic environmental conditions.
Nowadays, various EMC standards define the permissible electromagnetic interaction between every system and its immediate environment. All electronic systems must be compatible to all other systems in the affected environment, in terms of EMC. This system compatibility must be proven by tests to be certified by the applicable EMC standard.

All these developments has led to the emergence of a new engineering branch - EMC engineering.
EMC engineering uses analytical methods, design practices, test procedures, and solution hardware and components both to enable the system to function without errors in its target electromagnetic environment, and to prevent it from inflicting errors to any adjacent system. It also enables the system to meet the EMC control specification limits.

EMC deals with 3 major components:

- **The source of interference (noisy system or power supply), also called EMI source.**
- **The victim of interference. (sensitive circuitry), also called EMI victim.**
- **The coupling path.**

EMI (Electromagnetic Interference) is defined as the electromagnetic emissions discharged by a device or a system that interfere with the normal operation of other devices or systems.

Electromagnetic compatibility problems are generally solved by identifying at least two of the above-mentioned components and eliminating one of them.

Potential sources of electromagnetic compatibility problems include radio transmitters, power lines, electronic circuits, lightnings, lamp dimmers, electric motors, arc welders, solar flares and just about everything that utilizes or creates electromagnetic energy. Potential receptors include radio receivers, electronic circuits, appliances, people, and just about everything that utilizes or can detect electromagnetic energy. The way this electromagnetic energy is transferred from a source to a receptor falls into one of the following four categories.

1. **Conductance (electric current)**
2. **Inductive coupling (magnetic field)**
3. **Capacitive coupling (electric field)**
4. **Radiation (electromagnetic field).**

The coupling paths are often comprised of a complex combination of these routes, making the path difficult to be identified, even when the source and/or receptor are known. There may be multiple coupling paths, and steps taken to attenuation one may enhance another.

- **Conducted noise is coupled between components through interconnecting wires such as power supply and ground lines. Common impedance coupling is caused when currents from two or more circuits flow through the same impedance such as power supply and ground lines.**
- **Radiated electromagnetic field coupling can be handled in one of the following ways: in the near field, E and H field couplings are handled separately. In the far field, the coupling is handled as a plane wave coupling**
- **Electric field coupling is caused by the voltage difference between conductors. The coupling mechanism can be modeled by a capacitor.**
- **Magnetic field coupling is caused by the current flow in conductors. The coupling mechanism can be modeled by a transformer.**

The most common method used for noise reduction include proper circuit design, shielding, grounding, filtering isolation, separation and orientation, circuit impedance match control, cable design, and other noise cancelation techniques.

Corry Micronics gained extensive experience in developing and producing filter and transient protection connectors. We have a variety off-the-shelf connectors similar in size to standard connectors, and we have the capacity to develop custom-made filtering products that are fully compatible with the customer specifications and enable the customer system to be approved by compatibility tests.

Design Notes

EMI Standards

The requirements for control of EMI characteristics of systems and equipment are defined by specifications and standards. The specifications and standards define the permissible interaction between the electromagnetic environment on the one hand, and systems and equipment on the other hand. Different standards are applied in different countries. U.S., European, British, Australian, Japanese and many other standards are in use in the corresponding countries, but they all fall into 2 major groups of EMI standards:

1. **Military**
2. **Commercial/Industrial**

Each group is divided into sub-groups, each of which deals with different types of equipment and environment: avionic, ground, navy, communications, etc.

The standard tests relate to 1 or both of the following major categories: conducted and radiated.

These 2 categories deal with emission and susceptibility interferences; it is presented as CE - for conducted emission, RE - for radiated emission, CS - conducted susceptibility, and RS - for radiated susceptibility. Each section deals with different levels of interference as well as different frequency range.

Herein are the details of a few well-known standards:

- **A variety of commercial and industrial standards are in use, and in general, they are applicable to certain types of equipment. Few of these standards are listed in the following table.**

Equipment	Standard	Description	Test
Household Appliances, Electric tools and Similar Apparatus	EN 55014-1	EMC: Emission	CE, RE
	EN 55014-2	EMC: Immunity	CS, RS
Information technology Equipment	EN 55022	Radio Disturbance Characteristics - Limits and Methods of Measurement	CE, RE
	EN 55024	Immunity Characteristics - Limits and Methods of Measurement	CS, RS
Testing and Measurement Techniques	EN 61000-4-2	Electrostatic Discharge Requirements	ESD
	EN 61000-4-3	Radiated, RF, Electromagnetic Field Immunity	RS
	EN 61000-4-4	Electrical Fast Transient/Burst Immunity Test	Transient
	EN 61000-4-5	Surge Immunity Tests	Lightning
	EN 61000-4-6	Immunity to Conducted Disturbances, Induced by RF Fields	CS

- **EUROCAE ED-14D/RTCA-DO-160D**
  ENVIRONMENTAL CONDITIONS AND TEST PROCEDURES FOR AIRBORNE EQUIPMENT

EUROCAE ED-14D/RTCA-DO-160D ENVIRONMENTAL CONDITIONS AND TEST PROCEDURES FOR AIRBORNE EQUIPMENT		
Section	**Change**	**Description**
17	-	Voltage Spikes
18	2	Audio Frequency Conducted Susceptibility Power Inputs
19	-	Induced Signal Susceptibility
20	1	Radio Frequency Susceptibility (Radiated and Conducted)
21	-	Emission of Radio Frequency Energy
22	3	Lightning Induced Transient Susceptibility
23	-	Lightning Direct Effects
25	-	Electrostatic Discharge

MIL-STD-461
DEPARTMENT OF DEFENSE INTERFACE STANDARD REQUIREMENTS FOR THE CONTROL OF ELECTRMAGNETIC INTERFERENCE CHARACTERISTICS OF SUBSYSTEMS AND EQUIPMENT

MIL-STD-461
DEPARTMENT OF DEFENSE INTERFACE STANDARD
REQUIREMENTS FOR THE CONTROL OF ELECTROMAGNETIC INTERFACE CHARACTERISTICS OF SUBSYSTEMS AND EQUIPMENT

MIL-STD-461C			MIL-STD-461D			MIL-STD-461C		
TEST	DESCRIPTION	FREQ	TEST	DESCRIPTION	FREQ	TEST	DESCRIPTION	FREQ
Ce01	Power/Signal Leads	30 Hz-15 kHz	Ce101	Power Leads	30 Hz-10 kHz	Ce101	Power Leads	30 Hz-10 kHz
Ce03	Power/Signal Leads	15 kHz-50 MHZ	Ce102	Power Leads	10 kHz-10 MHZ	Ce102	Power Leads	10 kHz-10 MHZ
Ce06	Antenna Terminal	10 kHz-26 Ghz	Ce106	Antenna Terminal	10 kHz-40 Ghz	Ce106	Antenna Terminal	10 kHz-40 Ghz
Ce07	Power Leads	Spikes / Time Domain	N.A			N.A		
Cs01	Power Leads	30 Hz-50 kHz	Cs101	Power Leads	30 Hz-50 kHz	Cs101	Power Leads	30 Hz-150 kHz
Cs02	Power Leads	50 kHz-400 MHZ						
Cs03	Intermodulation	15 kHz-10 Ghz	Cs103	Antenna Port-Intermodulation	15 kHz-10 Ghz	Cs103	Antenna Port-Intermodulation	15 kHz-10 Ghz
Cs04	Undesired Sig. Rejection	30 Hz-20 Ghz	Cs104	Antenna Port-Rej. of Undesired Sig.	30 Hz-20 Ghz	Cs104	Antenna Port-Rej. of Undesired Sig.	30 Hz-20 Ghz
Cs05	Cross Modulation	30 Hz-20 Ghz	Cs105	Antenna Port-Cross Modulation	30 Hz-20 Ghz	Cs105	Antenna Port-Cross Modulation	30 Hz-20 Ghz
Cs06	Spikes, Power Leads		N.A			N.A		
Cs07	Squelch Ckts							
Cs09	Structure Common Mode Current	60 Hz-100 kHz	N.A			N.A		
Cs10	Damped Sinusoidal Transients (Terminals)	10 kHz-100 MHZ	N.A			N.A		
Cs11	Damped Sinusoidal Transients (Cables)	10 kHz-100 MHZ	N.A			N.A		
Re01	Magnetic Field	30 Hz-50 kHz	Re101	Magnetic Field	30 Hz-100 kHz	Re101	Magnetic Field	30 Hz-100 kHz
Re02	Electric Field	14 kHz-10 Ghz	Re102	Electric Field	10 kHz-18 Ghz	Re102	Electric Field	10 kHz-18 Ghz
Re03	Spurious & Harmonic	10 kHz-40 Ghz	Re103	Antenna Spurious & Harmonic	10 kHz-40 Ghz	Re103	Antenna Spurious & Harmonic	10 kHz-40 Ghz
Rs01	Magnetic Field, Equipment and Cables	30 Hz-50 kHz	Rs101	Magnetic Field	30 Hz-100 kHz	Rs101	Magnetic Field	30 Hz-100 kHz
Rs02	Magnetic Induction, Equipment and Cables	Power line & Spike	N.A			N.A		

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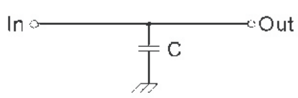
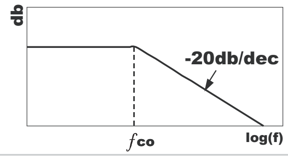
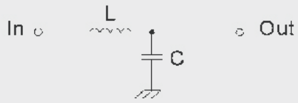
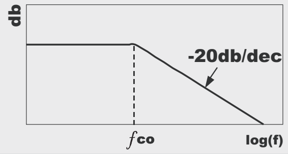
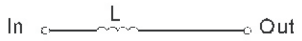
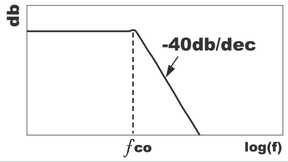
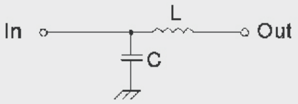
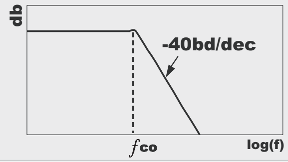
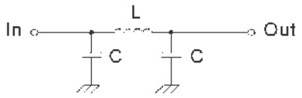
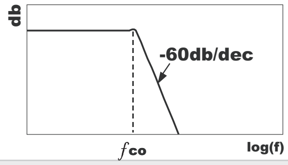
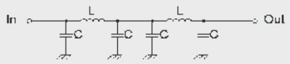
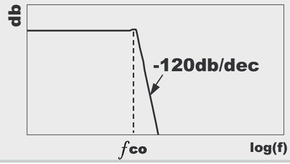
MIL-STD-461 DEPARTMENT OF DEFENSE INTERFACE STANDARD REQUIREMENTS FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF SUBSYSTEMS AND EQUIPMENT								
MIL - STD - 461C			MIL - STD - 461D			MIL - STD - 461E		
TEST	DESCRIPTION	FREQ	TEST	DESCRIPTION	FREQ	TEST	DESCRIPTION	FREQ
Rs03	Elastic Field, Equipment and Cables	14kHz-40GHz	Rs103	Electric Field	10kHz-40GHz	Rs103	Electric Field	2MHz-40GHz
Rs05	Electromag. Pulse Field	Transients	Rs105	Transient Electromag.Field	Transients	Rs105	Transient Electromag.Field	Transients
N.A			Cs109	Structure Current	60Hz-100kHz	Cs109	Structure Current	60Hz-100kHz
N.A			Cs114	Bulk Cable Injection	10kHz-400MHz	Cs114	Bulk Cable Injection	10kHz-200MHz
N.A			Cs115	Bulk Cable Injection	Impulse	Cs115	Bulk Cable Injection	Impulse
N.A			Cs116	Damp Sine Transients-Cables, and Power Leads	10kHz-100MHz	Cs116	Damp Sine Transients-Cables, and Power Leads	10kHz-100MHz

Design Notes

Selecting Filter Topology

Low pass passive filters are most commonly used to reduce EMI. There are several basic topologies of these filters: C and C^2, I, L, J, π, Double π, (or Hi - Filter). Selecting the wrong filter topology may result in system oscillation and malfunction. Selecting the right filter topology is critical to significant EMI reduction and best system performance. The available Corry Micronics filter topologies, performances and applications are described in the following table.

Note that an "in" label indicates connector front end and an "out" label indicates connector rear end.

Filter Topology Name	Filter Scheme	Application	Theoretical f_{co} (Cut-off Frequency)	Theoretical Insertion Loss
C And C^2		■ The best performance is achieved when used with high impedance load and source ■ Theoretical slope: -20db/dec	$f_{co} = \frac{1}{\pi RC}$	
I		■ The best performance is achieved when used with low impedance load and source ■ Theoretical slope: -20db/dec	$f_{co} = \frac{R}{\pi L}$	
L		■ The best performance is achieved when used with high impedance load and low impedance source ■ Theoretical slope: -40db/dec	$f_{co} = \frac{1}{\pi\sqrt{LC}}$	
J		■ The best performance is achieved when used with low impedance load and high impedance source ■ Theoretical slope: -40db/dec	$f_{co} = \frac{1}{\pi\sqrt{LC}}$	
Pi		■ The best performance is achieved when used with high impedance load and source ■ Theoretical slope: -60db/dec	$f_{co} = \frac{1}{\pi\sqrt{2LC}}$	
Hi		■ The best performance is achieved when used with high impedance load and source ■ Theoretical slope: -120db/dec	$f_{co} = \frac{1}{\pi\sqrt{2LC}}$	

Design Notes

Estimation of Filter Cut-off Frequency

Once the filter topology is selected, the filter cut-off frequency can be determined.

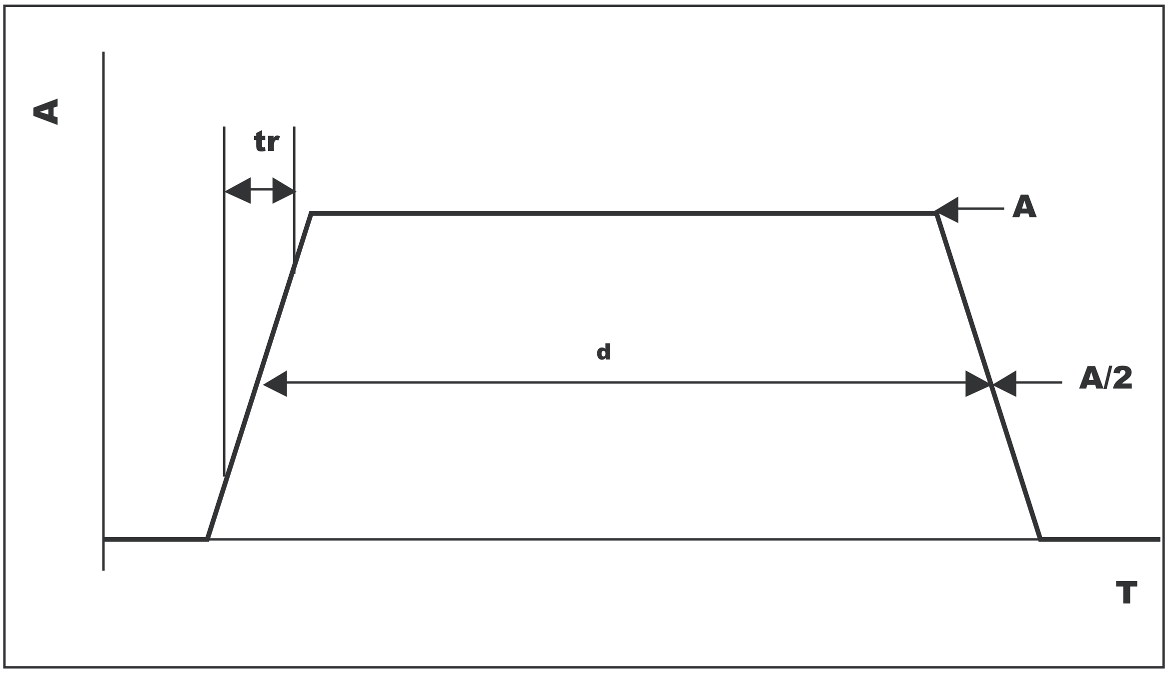
This filter cut-off frequency is defined as the -3db attenuation frequency. Attenuation -3db do means that half of the transmitted power is dissipated across the filter. The -3db cut-off frequency is considered to be the highest operation limit of the low pass filter range. The filter will attenuate dramatically all signals with frequency above the cut-off frequency.

If the selected cut-off frequency will be too low in comparison to the signal frequency and rise time, the filter distort the signal shape. If it will be too high, undesired high frequency noise will be a part of the signal shape. Therefore the selection of the proper cut-off frequency is crucial to the signal integrity

To make the proper selection of the cut-off frequency, the designer must estimate the spectrum of the signal.

The data pulse usually used in electronic systems is trapezoid in shape, with finite rise and fall times.

Single Trapezoid



A - the pulse amplitude.

d - the pulse duration is the time interval in which the pulse value is higher than 50% of the amplitude.

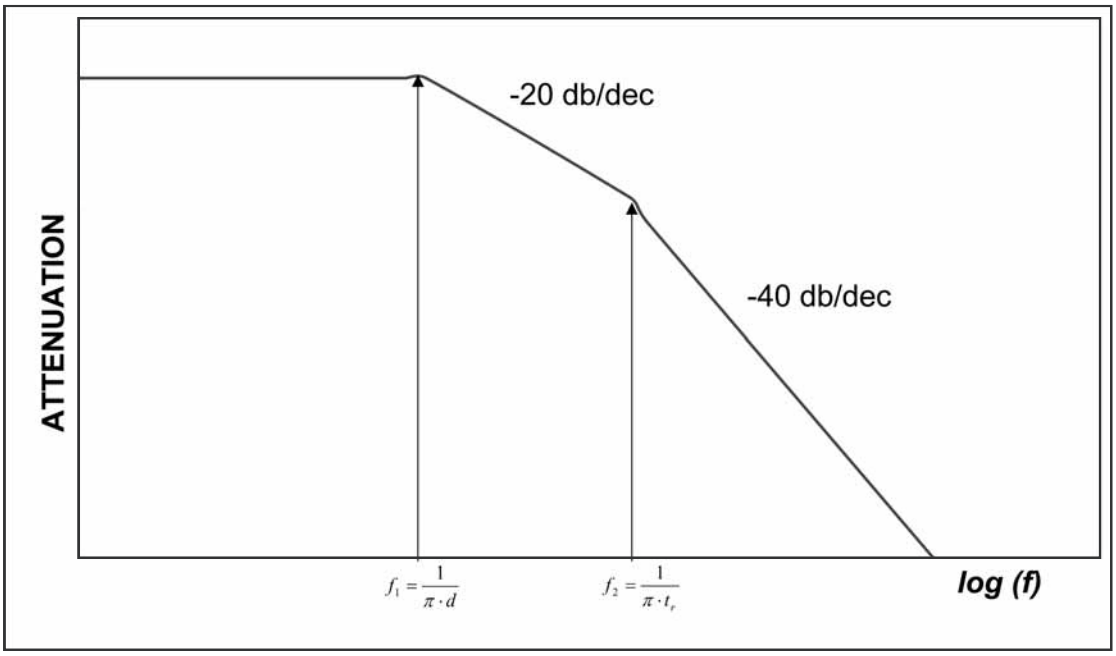
t_r - the pulse rise time is the required time for the signal to go from 10% to 90% of its amplitude.

Analyzing the pulse using the Fourier method, the following frequency domain graph is obtained.

The graph can help designers in estimating the spectrum of trapezoidal pulses.

Design Notes

Spectrum of trapezoidal data pulse



f_1 - the first corner frequency; f_2 - the second corner frequency

Please note that the amplitude (dB) of the spectrum is different for a single data pulse and for a data pulse train, but the corner frequencies remain the same:

$$f_1 = \frac{1}{\pi \cdot d} \quad ; \quad f_2 = \frac{1}{\pi \cdot t_r}$$

The proper filter cut-off frequency can be estimated by the following rule of the thumb:

$$f_{co} = 10 \cdot f_2$$

where f_{co} is filter cut-off frequency.

If an estimation of the cut-off frequency is based on f_1 instead of f_2 and/or the coefficient is selected than 10, the resulting filtered signal could be distorted.

However, in many cases the designer uses the devices with very fast rise and fall times (t_r & t_f) while the signal duration (d) is very long compared to the transition times. The t_r is not a critical factor in these cases. Slowing down the transition times (t_r & t_f) at those designs is possible and actually can be a very good idea. So the estimated cut-off frequency of the filter can be determined as follows.

$$f_{co} = (2 \div 3) \cdot f_2$$

When using both the filter and the transient protection on the similar signal line, the approximation of the common cut-off frequency can be calculated using the equation of the C Filter presented on page 75 and assuming the total capacitance of the filter and the transient protection to that equation.

$$f_{co} = \frac{1}{\pi R C_2} \quad ; \quad C_T = C_F + C_{TF}$$

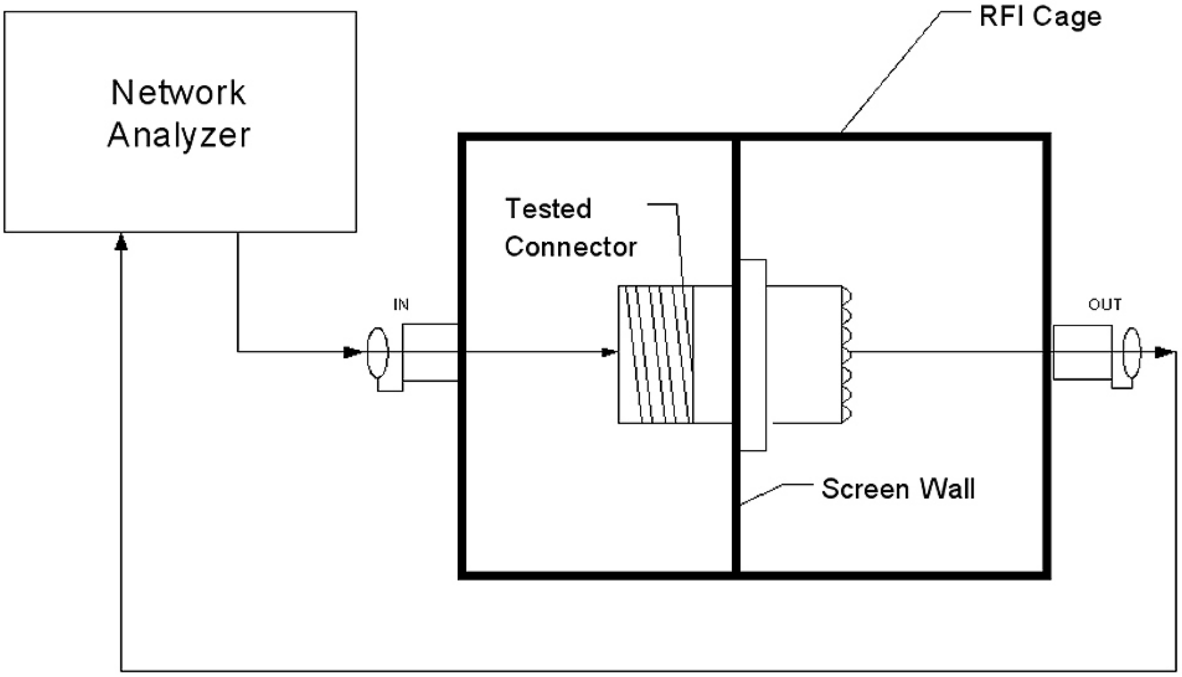
C_T - Total Capacitance
C_F - Typical Capacitance of the Filter
C_{TF} - The Capacitance of Transient Protection

Design Notes

Measuring the Filter Performance

We measure filter performance in accordance with MIL-STD-220 with a 50Ω system and no load.

The test set-up we use is as follows:



Filter Performance at non-50Ω System

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Filter Performance in Non-50Ω System

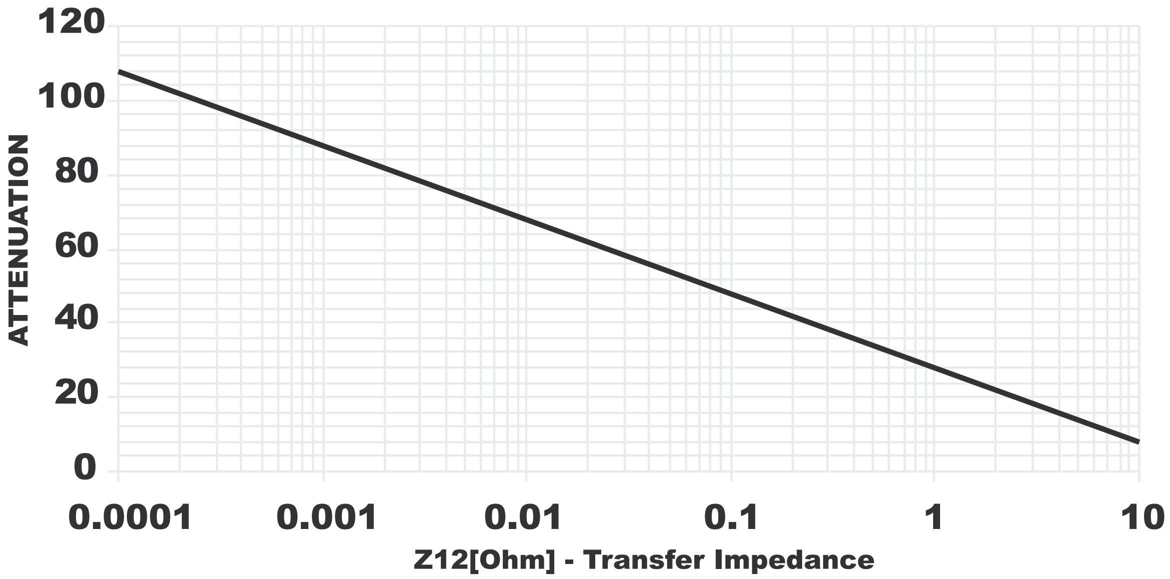
If your system is not 50Ω matched, you can use the following formula for predicting the filter performance when used with other sources and/or load impedances:

$$\text{Att. [db]} = \log_{10}[\ 1+Z_sZ_L/(Z_{12}(Z_s + Z_L))]$$

Z_S - Source Impedance
Z_L - Load Impedance
Z_{12} - Transfer Impedance

The transfer impedance Z_{12} can be calculated using the following graph:

Attenuation vs. Transfer Impedance in 50Ω System



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