International regulations regarding electromagnetic compatibility (EMC) affect many aspects of circuit and system design. However, there are many techniques that can be applied generally to reduce both the emissions from and susceptibility to, electromagnetic interference (EMI).

As a manufacturer of electronic components, Murata Power Solutions is committed to minimizing emissions from its own components and to helping its customers achieve EMC compliance by correct component choice and design. To this end Murata Power Solutions has compiled the following list of general design recommendations.

1. POWER SUPPLY CONSIDERATIONS
   - Eliminate loops in supply lines (see figure 1).
   - Decouple supply lines at local boundaries (use RCL filters with low Q, see figure 2).
   - Place high speed sections close to the power line input, slowest section furthest away (reduces power plane transients, see figure 3).

2. SIGNAL LINE CONSIDERATIONS
   - Use low pass filters on signal lines to reduce bandwidth to minimum necessary.
   - Keep feed and return loops close on wide bandwidth signal lines.
   - Terminate lines carrying HF or RF signals correctly (this minimizes reflection, ringing and overshoot, see figure 5).
   - Terminate lines carrying signals external to a board at the board edge, avoid lead terminations within the board and loose leads crossing the board.
   - Avoid cabling or tracking which is close to a quarter wavelength of the signal frequency, this can produce resonance within the signal conductor.
   - Track all signals on the board, avoid ‘flying leads’ across the board.
   - Minimize rise and fall times on signal and clock edges (sharp edges produce wide hf spectra), slew rate limiting also reduces crosstalk (see figure 6).

3. PCB CONSIDERATIONS
   - Avoid slit apertures in PCB layout, particularly in ground planes or near current paths.
   - Areas of high impedance give rise to high EMI, use wide tracks for power lines.
   - Make signal tracks stripline and include a
4. COMPONENT CONSIDERATIONS

- Locate biasing and pull up/down components close to driver/bias points.
- Minimize output drive from clock circuits.
- Use common mode chokes between current carrying and signal lines to increase coupling and cancel stray fields (see figure 14).
- Decouple close to chip supply lines, which reduces component noise and power line transients (see figure 15).
- Use low impedance capacitors for decoupling and bypassing (ceramic multilayer types are preferred due to high resonant frequency and stability).
- Use discrete components for filters where possible (surface mount is preferable due to lower parasitics and antenna effects of terminations on through hole parts).
- Include filtering of cables and over voltage protection at their terminations (this is especially important for cabling which is external to the system, if possible all...
external cabling should be isolated at the equipment boundary.
- Minimize capacitive loading on digital outputs by minimizing fan-out, especially on CMOS ICs (this reduces current loading and surge per IC).
- If available, use shielding on fast switching circuits, mains power supply components and low power circuitry (shielding is expensive and should be a ‘last resort’ option).

In general, keeping the bandwidth of all parts of the system to a minimum and isolating circuits where possible reduces susceptibility and emissions. Considerations which are applicable to reducing noise levels are equally applicable to EMC compliance, EMC compliant circuits should obviously exhibit low noise levels.

5. EMC SPECIFIC COMPONENTS

As a supplier of isolator components, Murata Power Solutions provides a range of parts which can offer simple solutions to EMC problems within an existing circuit. The range of components Murata Power Solutions produces which can be used for specific EMC problems includes transformer isolators, standard inductors and common mode chokes.

6. INDUCTORS

The ranges of inductors available from Murata Power Solutions are targeted mainly at the power market, and are ideal for reducing EMI on power lines and for filtering high current signals. In switched mode power supply (SMPS) circuits inductors for both energy storage and line filtering are available (see figure 16). It is recommended that a toroidal or shielded inductor be used if EMC problems are suspected. Toroidal inductors maintain the magnetic field within the core shape and hence have virtually zero radiated field. The susceptibility of a toroid is also negligible due to the shape, since an applied magnetic field would generate an equal and opposite current component in the wire (self cancelling).

At power sections of various circuit functions, an inductor between the local supply and the main feed provides good filtering of the supply and reduces noise from localized circuits in the system polluting the main power line (see figure 2). Selection should be made by current handling and relative switching speed of the circuit section. Generally low values of inductance are preferred due to the associated low DC resistance.

In systems with a reactive load or driver a matched termination may be required using a passive reactive circuit. The frequency response of the load/driver needs to be known, but can be matched by a relatively simple and easily characterized RCL network.

Another area where inductors can be used with great benefit to the EMI of a circuit is in an amplifier bias network (see figure 17). Using an inductive element in the bias or compensation arms, a filter can be added to the circuit without loading the signal with additional inductance. Careful choice of inductance value is required and placement close to the amplifier is essential. This method is suitable for filtering HF noise, particularly on video and VHF/UHF TV type signals.

7. COMMON MODE CHOKES

Common mode chokes can be employed in signal lines to eliminate common mode noise or EMI on cables or induced in signal tracks (see figure 14). The choke should be located as near to the driver/receiver circuit as possible, or at the entry point of a signal to a board. The choke works by cancelling interference appearing on both signal and return lines (i.e. induced EMI) while allowing differential mode signals and DC to pass.

Suitable choice of inductance will also help in maintaining a match to the characteristic line impedance and acts as a filter to bandwidth-limit the termination.

Any of Murata Power Solutions’ transformers with a 1:1 ratio can be employed as a common mode signal choke. Murata Power Solutions also has a portfolio of customer-specific chokes and can design a common mode choke for a customer’s circuit application.

8. TRANSFORMERS

The main EMC benefit of using a transformer is in providing an isolation barrier between a signal line and the signal processing circuit (particularly where the signal line exits the board or system). This is true of signals being driven or received, since isolating the line reduces common mode noise and eliminates ground (or signal return) potential differences between systems.

One particular area where high noise immunity is essential is in thyristor/triac driving circuits, where the transformer is providing isolation between a mains driven load and a logic based controller (see figure 18). The isolating pulse transformer provides much better noise immunity than an insulated gate bipolar transistor (IGBT) due to inherently lower coupling capacitance (typically tens of pF for a pulse transformer compared to nF for power IGBT devices). The lower coupling capacitance improves the circuit’s immunity to noise on the mains and from the power switching device.

9. ISOLATED DC-DC CONVERTERS

An isolated DC-DC Converter can provide a significant benefit to reducing susceptibility...
and conducted emission by isolating both power rail and ground from the system supply (see figure 4).

Isolated DC-DC converters are switching devices and as such have a characteristic switching frequency which may need some additional filtering (see figure 21).

10. CE MARKING
The above recommendations, if followed, should help complete systems achieve CE certification first time. They should give a designer more confidence in their circuit’s ability to meet the EC directive.

11. PRE-COMPLIANCE TESTING
CONDUCTED LINE EMISSIONS OF DC SUPPLIED CIRCUITS
Power supply (PSU) designers will be well aware of the requirement of their power supply to provide clean DC voltage to the target circuit and not to disturb the AC mains voltage. However, the PSU designer may often have no idea of the noise that can potentially be introduced by the target circuit, likewise the DC circuit designer (digital or analogue) may not be aware of the requirements of the PSU as far as acceptable generated noise levels are concerned.

The aim of the following sections is to bridge this gap, to provide a method for testing the DC circuit in isolation from its final PSU and enable additional filtering to be specified.

12. PRE-COMPLIANCE LIMITS
There are no specified EMC limit lines for DC rails, hence there are no specified tests in the EC or CENELEC regulations that can be applied directly. Likewise a converter and the DC supplied circuit may be considered as sub-systems at best, possibly even components. Consequently on their own they may be exempt from the EC directive. The tests conducted can therefore only be considered as pre-compliance tests, the end system would have to be fully compliance tested for full CE certification. However, if the system is to be certified via the Technical Construction File (TCF) route, the individual pre-compliance tests may be used as part of the TCF.

13. STANDARD TEST METHOD
Having no EN standard relies on the user implementing the closest equivalent test standard to the existing EMC regulations for mains borne emissions.

The removal of input line effects is performed on AC mains connected systems by using a line impedance stabilisation network (LISN) on both live and neutral lines and referenced to the mains earth as a ground plane. This has been directly copied for the testing of DC supplied circuits. Using any DC PSU with an earth terminal, both the positive and ground (or 0V) lines are filtered with a LISN referenced to the earth terminal. Each LISN is constructed in accordance with CISPR 16 for 50Ω/50μH line impedance (see figure 22).

Where a DC/DC converter has no earth connection, only power in and power out, the path for any common mode noise is through stray capacitances to earth. These may be from the converter body, external wiring or through any load connected. Noise measurements in this case are therefore only relative and an accurate record of the test set up should be taken to allow comparative measurements. Note that even with no stray capacitance to earth, a LISN meeting CISPR 16 will output a signal of half of the differential mode noise level from its RF monitor.

In many systems the mains earth will in fact be the case ground plane. If it is known that the 0V line is the ground plane reference the earth reference can be connected to the 0V line at the supply, with both LISNs still on the DC supply lines (the LISN on the 0V line should still be connected as this gives an indication of likely ground line noise). Circuits supplied with multiple DC lines will require a LISN on each power feed and the noise measured on each of the power lines.

14. SHIELDING
At all times the DC powered circuit under test (CUT), LISN and all cables connecting any measurement equipment, loads and supply lines should be shielded. The shielding is to prevent possible pick-up on cables and the CUT from external EMC sources (e.g. other equipment close by, radiated emissions from the PSU etc). The shielding is again referenced to mains earth.

When measuring small circuits or individual components, the whole part can often be fitted into a metal enclosure for testing. All power and test entry points should be via shielded connectors, preferably high frequency BNC types. The LISN should be shielded and external to the enclosure containing the test circuit (see figure 23).

15. DC TARGET CIRCUIT UNDER TEST EXAMPLE
There are innumerable circuit configurations that could be used as a test circuit as an example. However, it was decided to use a board level DC-DC converter with a resistive output load. Board level DC-DC converters are a commonplace item on many PC boards and in instrumentation and processing equipment. The advantage of using a DC-DC converter as an example is that it has a known characteristic switching frequency (see figure 24), hence a stable noise spectrum can be obtained easily.

The DC-DC converter used was a Murata Power Solutions NMS1212C, 12V input, 12V dual output device delivering a total 2W of power with a typical characteristic switching frequency of 35kHz. This device has a number of line spectra below the EC EMC lower limit for conducted emissions (150kHz), but no sub-harmonics below its fundamental switching frequency.

16. CIRCUIT CONDITIONS
To ensure that worst case conditions, as far as EMC is concerned, are applied to the CUT it is necessary to have some knowledge of the circuit operation, hence it is usually best specified by the CUT designer.

In the case of the NMS DC-DC converter, worst case is at full load (i.e. 2W output) with maximum input voltage (see figure 25), although the input voltage actually had a minimal effect within its allowed tolerance. Other worst case conditions may be difficult to apply (e.g. high temperature, see figure 26) due to the nature of the test environment, however, some gauge of how these may effect the EMC performance should be considered.

Where circuit loading conditions and their effect on EMC are not known, tests can be done in-situ on the CUT prior to the pre-compliance test.
17. RESOLUTION BANDWIDTH AND SPECTRA OBTAINED

One of the first problems may be to decide on the resolution required for the pre-compliance tests. To maintain compatibility with the EC directive for mains emissions, a 9kHz resolution bandwidth (RBW) should be used for conducted line measurements. In circuits with only a few line emissions this may be suitable, however, with analogue processing circuits or asynchronous logic there are likely to be some wideband spectra. It is also possible that individual line spectra may change with loading conditions but within a predefined envelope, hence widening the RBW can encompass this envelope.

If we consider the NMS again, as a square wave push-pull converter there are two main switching peaks, one at the switching frequency (35kHz) and another at twice the switching frequency (reflected full wave rectification, see figure 24). There are also harmonics of these across the whole emissions spectrum (falling significantly at 5MHz, see figure 27). In the frequency range of interest between 150kHz and 30 MHz, there are therefore 853 individual line spectra if resolved at 9kHz RBW. Variation in tolerance of components, input voltage and loading could change the operating frequency by as much as 20%, hence more than 200 additional lines could be added or subtracted from the spectra. Overall the envelope tends to remain fairly constant, hence simply widening the RBW to 120kHz gives the envelope function and not the individual line spectra (see figure 28). The information is now easier to use and understand and possible variations should be encompassed by this envelope.

Widening the RBW should only be done in situations where there is wideband noise or a large number of closely related individual spectra. Most circuits will be able to use a 9kHz RBW. It should also be noted that when using a spectrum analyzer the effective noise floor is raised when the RBW is widened, hence the lower level measured noise can be swamped out by this effect. It is always worth trying the narrowest RBW first then widening as and when necessary.

18. SPECTRA DETECTION METHOD

There are three common methods of measuring amplitude of conducted line spectra; peak detection, average detection and quasi-peak detection. Peak detection is the instantaneous measurement of the peak amplitude of the signal, essentially best for continuous wave spectra and quick ‘snap-shots’ of the emissions. Average detection measures the average amplitude over a time period, within the measurement bandwidth. Quasi-peak detection is designed to simulate a subjective human type response to a pulse type interference. Quasi-peak weights rise and fall times of the pulsation of signal with particular time constants.

A continuous wave signal would be identical with all three detection methods, infrequent pulsed interference would be lower via quasi-peak detection and highest using peak detection.

19. USING THE EMISSIONS SPECTRA INFORMATION

If the emissions exceed desired limits, the circuit could be redesigned or the PCB layout changed to reduce noise, or there could be additional filtering added at the PSU input to the DC circuit.
Filtering may be the lowest cost option for getting the circuit through pre-compliance tests. If redesign represents a major investment in time and money, simply adding a capacitor and inductor to the input line may only add minimal cost and drop the noise by 20dB at the problem frequency. Alternatively you may even have to specify to the PSU designer that the PSU must give a specified noise rejection, 20dB to noise below 1MHz for example.

The standard EMC limit lines can be placed as overlays on the noise emissions to determine what rejection the PSU requires. Often this is not quite as straightforward as it sounds as PSU output capacitors and CUT input capacitors may result in a significantly higher rejection than would be suggested by simply using 50Ω noise sources (the PSU and CUT are unlikely to have 50Ω impedance, or even matched impedances). As stated previously, these tests are only pre-compliance and further tests with the PSU and circuit in the target system will have to be conducted prior to certifying the completed product.

20. RELEVANT STANDARDS
The following are some of the relevant EMC standards applicable in various countries that the above design notes are intended to address.
FCC 15J/SUB Part B
VDE 0871
CISPR 16
CISPR 22
EN 55022
EC Directive 2004/108/EC

21. ABBREVIATIONS
ANSI American National Standards Institute
BSI British Standards Institute
CE Certificate of EMC Compliance
CENELEC Comite European de Normalisation Electrotechnique
CISPR Comite International Special des Perturbations Radioelectriques
CSA Canadian Standards Authority
DEMKO Dansk Standard (Denmark)
DIN Deutsches Institut fur Normung (Germany)
DTI Department of Trade and Industry (UK)
EC European Community
EIA Electronic Industries Association
EN European Standard (Norme European)
EMC ElectroMagnetic Compatibility
EMI ElectroMagnetic Interference
ETSI European Telecommunications Standards Institute
FCC Federal Communications Commission (US)
HF High Frequency
IEC International Electrotechnical Commission
ISO International Organisation for Standardisation
ITU International Telecommunication Union
JISC Japanese Industrial Standards Committee
NSF Norges Standardiseringsforbund (Norway)
RF Radio Frequency
TCF Technical Construction File
SAA Standards Australia
SCC Standards Council of Canada
SFA Finnish Standards Association
SEMKO Svenska Elektviska Kommissionen (Sweden)
UHF Ultra High Frequency
UL Underwriters Laboratory (USA)
UNI Enteazionale Italiano di Unificazione (Italy)
VDE Verband Deutsche Electrotechniker (Germany)
VHF Very High Frequency