



# EMC SOCIETY of AUSTRALIA NEWSLETTER

The official newsletter of the Electromagnetic Compatibility Society of Australia  
IEAust 11 National Circuit Barton ACT 2600

A SOCIETY OF THE INSTITUTION OF ENGINEERS AUSTRALIA

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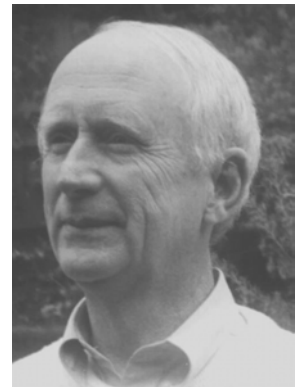
November 2001

## MESSAGE FROM THE CHAIRMAN

The EMC Society recently held our Annual General meeting, and a report from the Chairman appears in this issue. The report shows a generally healthy Society, financially viable and with a stable membership. However, when I was perusing the latest membership list, the fact that we have only a small number of student members was noticeable. Membership is now free of charge to students, and I urge all members to encourage students to join the Society.

Government activity in the field of EMC continues to be directed to the traditional goal of the protection of radiocommunications and broadcasting. Much commercial EMC activity continues to be directed to the goal of solving compatibility problems.

We have compulsory EMC standards administered by the Australian Communications Authority. Manufacturers of industrial devices are obliged to meet EMC standards to protect radio and television, not to protect other industrial devices. This situation has existed for some considerable time, so I guess we must be happy with it (?). It is fortuitous that most industrial devices are robust compared to communications and broadcast receivers, so protection of the receivers does provide protection for some industrial devices.



I remember one of my first experiences in EMC was trying to solve an incompatibility between electronic and electrical devices in a frozen food factory. The incompatibility resulted in the closure of a production line with consequent loss of production and annoyance to the operators and factory management. That same incompatibility resulted in the comical (to some!) unscheduled despatch of carefully-metered amounts of tomato sauce onto an empty conveyor. While factory staff attempted to clean up the mess I attempted to clean up the EMC mess of radiated and conducted interference caused by motor speed controls designed with no consideration of EMC. Industrial equipment newly installed in the factory met no EMC standards for radiated or conducted EMI.

Mandatory EMC standards were not in force in Australia at the time. Whilst a few responsible and aware manufacturers of industrial equipment at the time had in-house EMC standards, most did not. It was a case of "buyer beware." But the buyer can only beware, if he is "aware." Perhaps it is the role of organisations such as the EMC Society to make the community more aware.

From time to time the EMC Society Council receives information that would be of interest to members or would like input from members between Newsletters. Such information can be passed on if we have email addresses, so if you would like to be involved please advise us of your current email address. A short message to John Hyne at [jhyne@unite.com.au](mailto:jhyne@unite.com.au) will get you on the list.

If you subsequently change your address, it will be up to you to advise us.

As this will be the last Newsletter for 2001, may I take this opportunity to wish all members and readers the compliments of the Christmas season and good luck in solving your EMC problems in 2002.

John Hyne, MIEAust., CPEng.

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## LETTER FROM THE EDITOR



The November issue of the newsletter is the final issue for the year 2001 and reminds us that Christmas is not too far away. Elections for the National Council will be held in the new year and requests for nominations for the council will be mailed out with this newsletter.

The IEEE symposium on EMC was held in Montreal, from the 13<sup>th</sup> to 17<sup>th</sup> August. A number of our members travelled to Canada to participate in the Symposium; among them were David Johnston, Franz Schlagenhauser, Chris Zombolas, Roger Farrell and Gordana Felic. A brief report on the Symposium appears in the newsletter.

In addition to the above named travellers, a group of three engineers from DSTO including council member Kevin Goldsmith also attended the 2001 Reverberation Chamber Anechoic Chamber and OATS Users Meeting which was held at the Hyatt Regency Bellevue, Washington State during the period 4<sup>th</sup> to 7<sup>th</sup> June. A report on that meeting is included in this newsletter.

Technical papers featured in this issue include Part 1 of an article by Dr. Franz Schlagenhauser on Computer Simulation in EMC and a paper by Keith Armstrong on Design Techniques for EMC. Franz has started delving deeply into computer simulation and we look forward to Part 2 of this subject which we hope to publish in the year 2002.

Keith, who is a partner in Cherry Clough Consultants, UK, is well known in the field of EMC and author of a number of books on the subject. Keith visited us during the year and impressed our members with his in depth knowledge of the subject at a technical presentation. We thank Keith for his permission to publish this paper.

I would like to take this opportunity to wish all members and families a happy and joyful festive season and look forward to your continued support in the year 2002.

Jack Pluck  
Editor

# CHAIRMAN'S REPORT TO ANNUAL GENERAL MEETING

The Annual General Meeting of the EMC Society of Australia was held at 21 Bedford Street, North Melbourne at 6:30 p.m. on 16<sup>th</sup> October 2001.

The Chairman, John Hyne, reported on the previous year's activity as follows:-

## MEMBERSHIP

Membership of the Society continues to be stable in terms of numbers and composition. However, the number of Student members is low and members are asked to encourage students to take up membership which is now free of charge.

Our status as a technical society of the Institution of Engineers Australia allows membership applications and subscriptions to be processed by the I.E.Aust. Some individual enquiries concerning membership were also received directly by the Society.

## NATIONAL COUNCIL

The Society has an active and enthusiastic National Council and thanks are due to the Council members for their support of the Society. The Society operated with a national council of nine members. Membership was drawn from industry and federal government departments with a special interest in EMC.

## TECHNICAL PROGRAM

The Society had an active program of technical presentations with local and international speakers addressing members on a range of topics. Advantage was taken of visits to Australia by distinguished overseas speakers from Germany and UK who were invited to extend their programs to address our members. This provided a cost effective way of enabling local members to hear such speakers and allowed the visitors to establish contact with local EMC practitioners and industry. Such meetings were held in Sydney, Melbourne and Perth.

Our technical presentations enabled the EMC community to share experiences and provided opportunities for Continuing Professional Development for our I.E.Aust. members.

## FINANCE

Detailed financial information is available in the Treasurer's Report. This shows that the Society is financially healthy and this has allowed us to confidently embark on activities such as our program of technical presentations. It also allows us to contemplate sponsorship of some conference activities in the future.

## NEWSLETTER

Our self-funding Newsletter is mailed to members several times a year and also serves as a vehicle for promoting the Society to others. Under the guidance of editor Jack Pluck the Newsletter continued to present articles and papers of a high standard, and to attract industry support through institutional listings. The Newsletter is receiving articles for publication from overseas as well as locally. Requests were received for articles from the Newsletter to be reprinted in other publications.

## EMC SOCIETY WEB SITE

The Society has operated a Web site through the good offices of one of our Council members, Emile Barco, and recently was encouraged to transfer the site to one provided by the IEAust. This has not proved entirely successful, due to limitations of the new site and discussions are continuing to improve the Society's Web presence.

## STUDENT PAPER COMPETITION

The EMC Society is running the Student Paper competition again this year to encourage EMC activity in tertiary institutions. Information was provided to institutions throughout Australia. The competition offers a \$1,000 cash prize and is open to tertiary students at any level.

## CHAPTERS

The Society wishes to foster the formation of Chapters in centres other than Melbourne and intends to build on the nucleus of members in Sydney, Adelaide and Perth. Assistance has been given in providing speakers for technical presentations in these centres. Franz Schlagenhauser is our representative in Perth and Stephen Brine in Sydney and the Council thanks them for their efforts in working towards the formation of Chapters in these two cities.

## REPRESENTATION

Committee members Steve Offer, Graeme Richardson and Malcolm Mulcare continue to serve on relevant local and international committees in the field of EMC standards.

On behalf of the members of the Society I thank those dedicated Council members for their support of the Society during the past year. The growing status of the Society is due to their efforts. Particular thanks are due to our Newsletter Editor Jack Pluck, our convenor of technical presentations Emile Barco, and our Secretary-Treasurer Kingsley McRae.

John Hyne Chairman, National Council EMC Society

## DESIGN TECHNIQUES FOR EMC – CIRCUIT DESIGN, AND CHOICE OF COMPONENTS

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### The project EMC lifecycle

The EMC issues in a new project lifecycle are summarised below:

- Establishment of the target electromagnetic specifications for the new product, including:
  - The electromagnetic environment it must withstand (including continuous, high-probability, and low-probability disturbance events) and the degradation in performance to be allowed during disturbance events;
  - Its possible proximity to sensitive apparatus and allowable consequences, hence the emissions specifications;
  - Whether there are any safety issues requiring additional electromagnetic performance specifications. Safety compliance is covered by safety directives, not by EMC Directive;
  - All the EMC standards to be met, regulatory compliance documentation to be created, and how much "due diligence" to apply in each case (consider all markets, any customer's in-house specifications, etc.).
- System design:
  - Employ system-level best-practices ("bottom-up");
  - flow the "top-level" EMC specifications down into the various system blocks ("top down").
- **System** block (electronic) designs:
  - Employ electrical/electronic hardware design best-practices ("bottom-up") (*covered by these six articles*);
  - Simulate EMC of designs prior to creating hardware, perform simple EMC tests on early prototypes, more standardised EMC tests on first production issue.
- **Employ** best-practice EMC techniques in software design.
- **Achieve** regulatory compliance for all target markets.
- **Employ** EMC techniques in QA to control:
  - All changes in assembly, including wiring routes and component substitutions;
  - All electrical/electronic/mechanical design modifications and software bug-fixes; All variants.
- **Sell** only into the markets originally designed for;
  - To add new markets go through the initial electromagnetic specification stage again.
- **Investigate** all complaints of interference problems
  - Feed any resulting improvements to design back into existing designs and new products (a corrective action loop).

This may look quite daunting, but it is only what successful professional marketers and engineers already know to do, so as not to expose their company to excessive commercial and/or legal risks.

As electronic technology becomes more advanced, more advanced management and design techniques (such as EMC) are required. There is no escaping the ratcheting effects of new electronic technologies if a company wants to remain profitable and competitive.

But new electronics technologies are creating the world's largest market, expected to exceed US\$1 trillion annually in value (that's \$1 million billion) within a couple of years and continue to increase at 15% or so per annum after that. Rewards are there for those that can take the pace.

The following outlines a number of the most important best-EMC-practices. They deal with "what" and "how" issues, rather than with why they are needed or why they work. A good understanding of the basics of EMC is a great benefit in helping to prevent under or over-engineering, but goes beyond the scope of these articles.

### 1. Circuit design and choice of components for EMC

Correct choice of active and passive components, and good circuit design techniques used from the beginning of a new design and development project, will help achieve EMC compliance in the most cost-effective way, reducing the cost, size, and weight of the eventual filtering and shielding required.

These techniques also improve digital signal integrity and analogue signal-to-noise, and can save at least one iteration of hardware and software. This will help new products achieve their functional specifications, and get to market, earlier. These EMC techniques should be seen as a part of a company's competitive edge, for maximum commercial benefit.

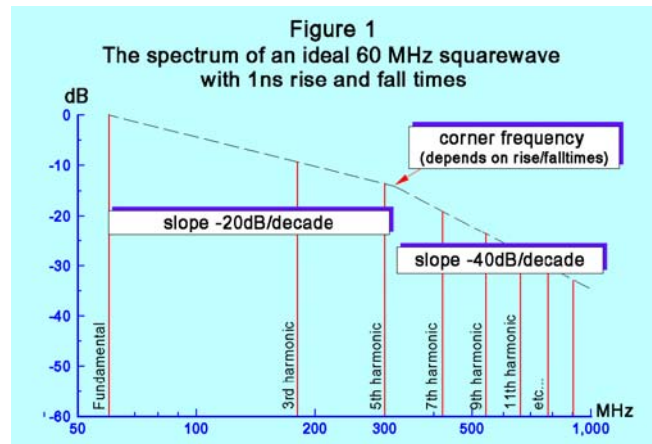
#### 1.1 Digital components and circuit design for EMC

##### 1.1.1 Choosing components

Most digital IC manufacturers have at least one glue-logic range with low emissions, and a few versions of I/O chips with improved immunity to ESD. Some offer VLSI in "EMC friendly" versions (some "EMC" microprocessors have 40 dB lower emissions than regular versions).

Most digital circuits are clocked with square waves, which have a very high harmonic content, as shown by figure 1. The faster the clock rate, and the sharper the edges, the higher the frequency and emissions levels of the harmonics. So always choose the slowest clock rate, and the slowest edge rate that will still allow the product to achieve its specification. Never use AC when HC will do. Never use HC when CMOS 4000 will do. Choose integrated circuits with advanced signal integrity and EMC features, such as:

- **adjacent** power and ground pins
- **multiple** power and ground pins
- **reduced** output voltage swing
- (although this improves emissions, it could worsen immunity performance in some situations, so a compromise may be needed)
- **controlled** slew rates
- **transmission-line** matching I/Os
- **differential** signalling
- **low** ground bounce
- **low** levels of emissions
- **high** levels of immunity to ESD and other disturbing phenomena
- **low** input capacitance
- **output** drive capability no larger than need for the application
- **low** levels of power supply transient currents (sometimes called "shoot-through currents") - which should have guaranteed minimum or maximum (as appropriate) levels in their data sheets.



Parts with the same type number and specifications from different manufacturers can have significantly different EMC performance - something it is important to control in production to ensure continuing compliance in serial manufacture.

Suppliers of high-technology ICs may provide detailed EMC design instructions, as Intel does for its Pentium MMO chips. Get them, and follow them closely. Detailed EMC design advice shows that the manufacturer cares about the real needs of his customers, and may tip the balance when choosing devices.

Where IC EMC performance is unknown, correct selection at an early design stage can be made by EMC testing a variety of contenders in a simple standard functional circuit that at least runs their clocks, preferably performs operations on high-rate data too.

Testing for emissions can easily be done in a few minutes on a standard test bench with a close-field magnetic loop probe connected to a spectrum analyser (or a wideband oscilloscope). Some devices will be obviously much quieter than others. Testing for immunity can use the same probe connected to the output of a signal generator (continuous RF or transient) - but if it is a proprietary probe (and not just a shorted turn of wire) first check that its power handling is adequate.

Close-field probes need to be held almost touching the devices or PCBs being probed. To locate the "hottest spots" and maximise probe orientation they should first be scanned in a horizontal and vertical matrix over the whole area (holding the probe in different orientations at 90° to each other for each direction), then concentrating on the areas with the strongest signals.

### 1.1.2 IC sockets are bad

IC sockets are very bad for EMC, and directly soldered surface-mount chips (or chip and wire, or similar direct chip termination techniques) are preferred. Smaller ICs with smaller bondwires and leadframes are better, with BGA and similar styles of chip packaging being the best possible to date.

Often the emissions and susceptibility of PROMs mounted on sockets (or, worse still, sockets containing battery backup) ruin an otherwise good design. Field-programmable SMD PROMS soldered to the PCB are preferred.

Motherboards with ZIF sockets and spring-mounted heatsinks for their processors (to allow easy upgrading) are going to require additional costs on filtering and shielding, even so it will help to choose surface-mounted ZIF sockets with the shortest lengths of internal metalwork for their contacts.

### 1.1.3 Circuit techniques

- **Level** detection (rather than edge-detection) preferred for control inputs and keypresses;
- **Use** digital edge-rates that are as slow and smooth as possible (without compromising skew limits);
- **On** prototype PCBs allow for control of logic edge speed or bandwidths (e.g. with soft ferrite beads or series resistors at driven ends);
- **Keep** load capacitance low;
  - Fit pull-ups for open-collector drivers near to the output devices, using the highest resistor values that will work (although this improves emissions, it could worsen immunity performance in some situations, so a compromise may be needed);
- **Processor** heatsinks isolated from chop by thermal conductor and RF bonded at multiple points to the ground plane around the processor;

**High** quality RF bypassing (decoupling) of power supplies is vital at every power pin (dealt with by the 5th article in this series);

- **Good** quality power monitor needed to protect against supply dips, brownouts, surges and transients;
- **A** good quality watchdog also needed;
- **Never** use programmable devices for watchdogs or power monitors;
- **Appropriate** circuit and software techniques also required for power monitors and watchdogs so that they cope with most eventualities, depending on the criticality of the product, (not discussed further in this series of articles);

Use transmission line techniques wherever the rise/fall time of the logic signal edge is shorter than the "round trip time" of the signal in the PCB track (transmission lines are described in detail in the 5<sup>th</sup> article in this series);

- rule of thumb: round trip time equals 13ps for every millimetre of track length;
- for best EMC use transmission line techniques for tracks which are even shorter than this rule of thumb suggests.

Some digital ICs emit high level fields from their own bodies, and often benefit from being shielded by their own little metal box soldered to the PCB ground plane. Shielding at PCB level is very low-cost, but can't always be applied to devices that run hot and need free air circulation.

Clock circuits are usually the worst offenders for emissions, and their PCB tracks will be the most critical nets on a PCB, requiring component layout to be adjusted to minimise clock track length and keep each clock track on one layer with no via holes.

When a clock must travel a long distance to a number of loads, fit a clock buffer near the loads so the long track (or wire) has smaller currents in it. Where relative skew is not a problem clock edges in the long track should be well-rounded, even sine-waves, squared up by the buffer near the loads.

### 1.1.4 Spread-spectrum clocking

So-called "spread-spectrum clocking" is a recent technique that reduces the measured emissions, although it doesn't actually reduce the instantaneous emitted power so could still cause the same levels of interference with some fast-responding devices. It modulates the clock frequency by 1 or 2% to spread the harmonics and give a lower peak measurement on CISPR16 or FCC emissions tests. The reduction in measured emissions relies upon the bandwidths and integration time constants of the test receivers, so is a bit of a trick, but has been accepted by the FCC and is in common use in the US and EU. The modulation rates in the audio band so as not to compromise clock squareness specifications. Figure 2 shows an example of an emission improvement for one clock harmonic.

Debate continues about the possible effects of spread-spectrum clocking on complex digital ICs with the suppliers claiming no problems and some pundits still urging caution, but at least one major manufacturer of high-quality PC motherboards is using this technique as standard on new products.

Spread-spectrum clocking should not be used for timing-critical communications links, such as Ethernet, Fibre channel, FDDI, ATM, SONET, and ADSL.

Most of the problems with emissions from digital circuits are due to synchronous clocking. Asynchronous logic techniques (such as the AMULET microprocessors being developed by Prof. Steve Furber's group at UMIST) will dramatically reduce the total amount of emissions and also achieve a true spread-spectrum instead of concentrating emissions at narrow clock harmonics.

## 1.2 Analogue components and circuit design

### 1.2.1 Choosing analogue components

Choosing analogue components for EMC is not as straightforward as for digital. For emissions, slew rates, voltage swings, and output drive capability should be selected for the minimum necessary. But it is immunity that has the greatest problems for most active analogue parts, and it is difficult to prescribe useful EMC purchasing features.

Opamps with the same type number and specifications from different manufacturers can have significantly different EMC performance - something it is important to control in production to ensure continuing compliance in serial manufacture.

Manufacturers of especially sensitive analogue parts (and data converters) may publish EMC or signal-to-noise recommendations for circuit design and/or PCB layout. This shows they care about the real need of their customers, and may help tip the balance when making a purchasing decision.

### 1.2.2 Preventing demodulation problems

Most of the immunity problems with analogue devices are caused by RF demodulation.

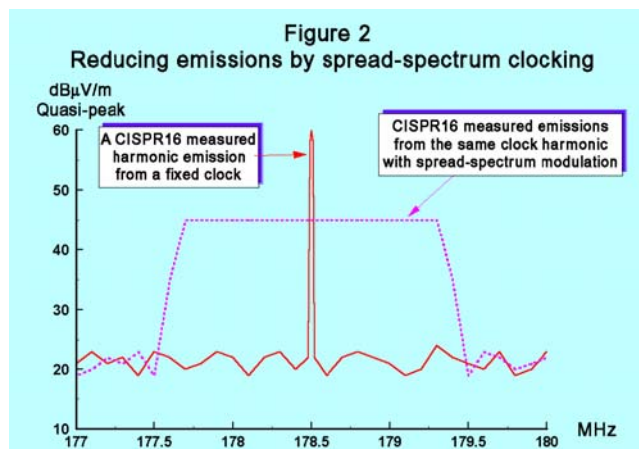
Opamps are very sensitive to RF interference on all their pins, regardless of the feedback schemes employed (see figure 3).

All semiconductors demodulate RF, but it is more of a problem for analogue.

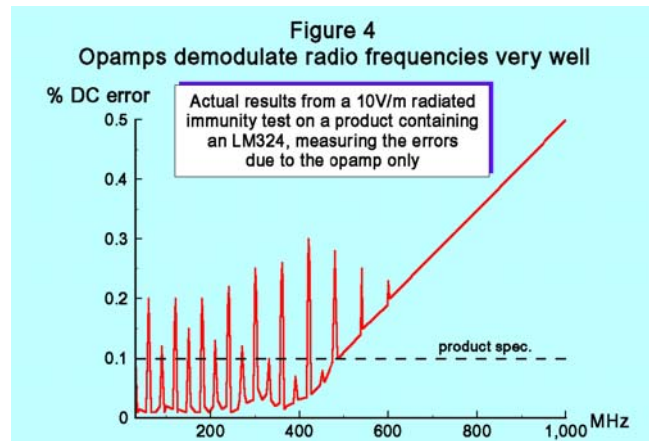
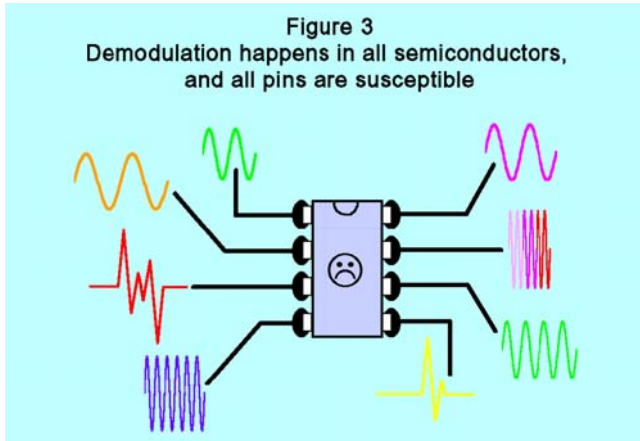
Even slow opamps will happily demodulate interference up to cellphone frequencies and beyond, as shown by the real product test results of figure 4.

To help prevent demodulation, analogue circuits need to remain linear and stable during interference. Feedback circuits especially need to be stable and linear over as wide a frequency range as possible.

This often requires that capacitive loads are buffered with a small resistance which is outside the feedback loop, and often requires a small resistor (often around 560R) in series with any integrator feedback capacitors with values above 5pF.



Test for stability and linearity by injecting small but fast-edged (<1ns risetime) square waves into inputs (and possibly into outputs and power supplies, via small capacitors). The fundamental frequency of the square waves must be within the intended passband of the circuit. The circuit's output should be checked with a 100MHz (at least) oscilloscope and probes for overshoot and ringing, even for audio or instrument circuits. For higher-speed analogue circuits use an appropriately faster 'scope and take great care with probing techniques. Overshoot heights of more than 50% of the signal's height indicates poor stability. Overshoots should be well-damped. Any long periods of ringing (say, longer than two cycles) or bursts of oscillation indicate stability problems. The above test should be done without any input or output filtering applied. It could use a swept frequency instead of a square wave with a spectrum analyser instead of an oscilloscope (reveals resonant frequencies more easily).



### 1.2.3 Other analogue circuit techniques

Having achieved a stable and linear circuit, all its connections may need protecting by filters. Digital circuits in the same product will put noise on all internal connections, external connections suffer from the entire external electromagnetic environment. Filtering will be covered in the 3rd article in this series.

Never try to filter or control RF bandwidth for EMC with active circuits - only use passive (preferably RC) filters. The integrator feedback method is only effective at frequencies where the opamp has considerably more open-loop gain than the closed-loop gain required by its circuit. It *cannot* control frequency response at higher frequencies.

Avoid the use of very high-impedance inputs or outputs. Comparators must have hysteresis (positive feedback) to prevent false output transitions due to noise and interference, also to prevent oscillation near to the trip point. Don't use faster output-slewing comparators than are really necessary: keep  $dV/dt$  low.

Transmission line techniques may be essential for high-speed analogue signals (e.g. RF signals) depending on the length of their connection and the highest frequency to be communicated (see the 5<sup>th</sup> section of this series). Even for low-frequency signals, immunity will be improved by using transmission line techniques for interconnections.

Some analogue ICs are particularly susceptible to high level fields in their own bodies. These may benefit from being shielded by their own little metal box soldered to the PCB ground plane (if heat dissipation allows).

Analogue parts need high-quality RF bypassing (decoupling) of their power supplies, in a similar way to digital parts. RF bypassing is described in the 5<sup>th</sup> part of this series. But low frequency power supply bypassing is often needed because the power supply noise rejection ratio (PSRR) of analogue parts are usually poor for frequencies above 1 kHz. RC or LC filtering of each analogue power rail at each opamp, comparator, or data converter, may be needed. The corner frequency and slope of such power supply filters should compensate for the corner frequency and slope of device PSRR, to achieve the desired PSRR over the whole frequency range of interest.

Not many EMC design guides mention RF design. This is because RF designers are generally very good with most continuous EMC phenomena. However, local oscillators and IF frequencies can often be allowed to leak rather too much, so may need more attention to shielding and filtering.

## 1.3 Switch-mode design

This technology is inherently electromagnetically noisy and will produce lots of interference if not firmly controlled, as outlined below. These techniques will also help make switch-mode power supplies low-noise enough to power sensitive analogue circuits.

### 1.3.1 Choice of topology and devices

Always switch power softly rather than abruptly, keeping both  $dV/dt$  and  $dI/dt$  low at all times. There are a number of circuit topologies which produce minimum emissions by reducing  $dV/dt$  and/or  $dI/dt$ , whilst also reducing the stresses on the switching transistors. These include ZVS (zero-voltage switching), ZCS (zero current switching), resonant mode (a type of ZCS), SEPIC (single-ended primary inductance converter), Cuk (an integrated magnetics topology, named after its inventor), etc.

It is not true that reducing switching time always leads to efficiency improvements, because the RF resonances of the magnetic components will require increasingly lossy snubbing and eventually diminishing returns will be observed. For the most cost-effective design overall, a degree of soft-switching trades a % or two of efficiency for much lower costs and sizes of filtering and shielding.

### 1.3.2 Snubbing

Snubbing is usually required to protect the switching transistors from the peak voltages produced by the resonance of parasitic elements, shown by figure 5.

Snubbers are connected across the winding in question, and also reduce emissions. Snubbers come in many types: RC snubbers are usually the best for EMC but can run hotter than other types.

Be prepared to compromise, and beware of using inductive resistors in snubbers.

### 1.3.3 Heatsinks

Heatsinks have around 50 pF of capacitance to the collectors or drains of each T0247 power device, so can create strong emissions. Merely connecting a heatsink directly to chassis just injects noise into the earth and may not reduce emissions overall. Preferably connect them directly to an appropriate circuit node - one of the primary DC power rails - taking full account of all safety requirements. Shielded heatsink insulators may instead be fitted to the switching transistors, with their shielded inner layer connected to a primary rail, the heatsink remaining isolated or else connected to chassis.

Heatsinks can also be capacitively connected to the hazardous rail, and it may be possible to "tune" the capacitance with the length of its leads and PCB tracks, to minimise the most troublesome frequencies. Allow for some iteration on a prototype to find the best heatsink suppression method.

### 1.3.4 Rectifiers

The rectifiers used for primary flywheels and secondary rectifiers can cause a great deal of noise due to their reverse current flow. Best to use fast soft-switching types, as shown by figure 6.

### 1.3.5 Problems and solutions relating to magnetic components

Pay particular attention to closing the magnetic circuits of inductors and transformers, e.g. using toroids or gapless cores. Iron powder toroidal cores are available for energy-storage magnetics. If air gaps have to be used, an *overall* shorted turn may reduce leakage fields.

Primary switching noise is injected via the interwinding capacitance of isolating transformers, creating common-mode noise in the secondaries. These noise currents are difficult to filter, and travel long distances to keep Mr. Kirchoff happy, thereby creating emissions problems.

A very powerful technique is to provide a local return path for these currents with small (safety approved!) capacitors connected between the secondary ground and one of the primary power rails. Don't exceed the total earth leakage current specification of the safety standard. These capacitors also help any filters on the secondaries to work much better.

Interwinding screens in an isolating transformer can suppress primary switching noise in the secondaries even more. Up to five screens is not unheard of, but three is more likely. The screen adjacent to the primary winding usually connects to a primary power rail, the screen adjacent to the secondary windings usually connects to the common output ground (if there is one), the centre screen usually connects to chassis. Be prepared to iterate a prototype to find their best connections.

The above two techniques also reduce the secondary switching noise which appears at the input.

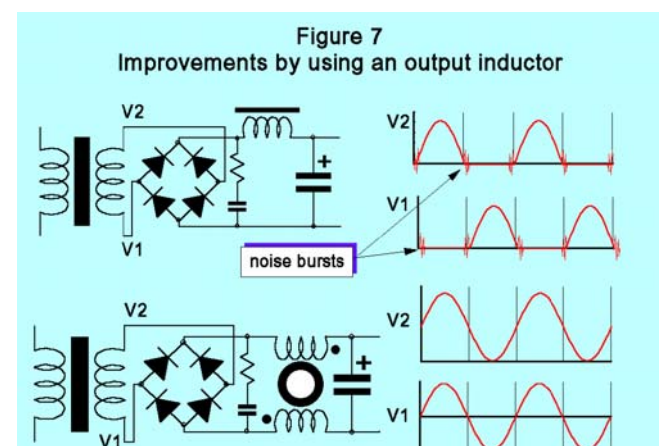
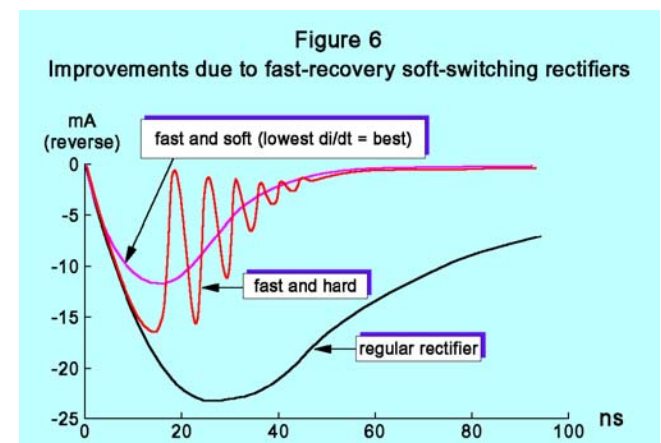
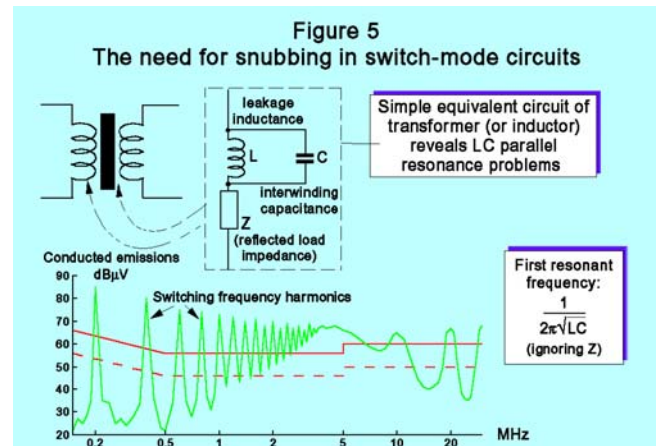
A suitably-sized output inductor can reduce the noise in the transformer windings considerably (and the DC ripple and noise) by making the secondary AC voltages into half-sine-waves, as shown by figure 7.

This still suffers bursts of noise at the waveform discontinuities, and it is better to use a suitably-dimensioned two-winding magnetic component, as shown in the lower part of figure 7, where the dots mark the starts of the windings (usual convention).

This achieves noise-free full sine waves on the secondary windings, improving DC ripple and noise as well as emissions.

### 1.3.6 Spread-spectrum clocking

A similar technique to digital spread-spectrum clocking can be beneficial in switch-mode power conversion by preventing emissions from becoming concentrated at a few narrowband frequencies. The spreading range can often be much larger than 1



or 2%, and some high-power converter manufacturers use almost white noise.

## 1.4 Signal communication components and circuit design

### 1.4.1 Non-metallic communications are best

Metallic communications have a number of EMC problems. Best communications for EMC purposes are infrared (e.g. IRDA) or fibre-optic, as long as the transmitters are not too noisy and the receivers are immune enough (metal-can shielded types are now more readily available).

It is often possible to bring metal-free fibre-optic cables right through the walls of shielded enclosures to PCBs or modules inside, without compromising the enclosure shielding, whereas metallic cables need to be filtered and/or shield bonded at the points where they cross shielded enclosure boundaries.

### 1.4.2 Techniques for metallic communications

Single-ended signal communication techniques have very poor EMC performance for both emissions and immunity, and are best restricted to low frequency, low data rate, or short distance applications. They are usually all right as long as they remain on a PCB with a solid ground plane under all the tracks and don't go through any connectors or cables, which means that the single-PCB product is often the most cost-effective.

High-frequency or long-distance signals should be sent/received as balanced signals (sometimes even on PCBs) for good signal integrity and EMC, and this is going to be a main issue in this sub-section.

Figure 8 shows examples of good and bad practices when connecting a millivolt output transducer to an amplifier via a cable.

Connecting cable screens to 0V is very bad, pigtails are very bad, and grounding cable screens at one end only is bad practice also. Worries about cable screen heating in larger or industrial premises are best dealt with by running the communications cable over a parallel earth conductor (PEC) to equalise potentials at both ends, and not by "lifting the screen" at one end.

This PEC could be earth-meshed structural metalwork, a conduit, or a heavy gauge cable run especially for that purpose. Further discussion on best EMC practices in cable installations is outside the scope of this series, but IEC 61000-5-2 will be very helpful.

For low frequency signals (say, under 1 MHz) higher voltage levels in the communication link are better, for reasons of immunity, but for frequencies above 10MHz this leads to high levels of emissions so lower voltages are preferred as the best compromise (e.g. as used by ECL and LVD chips).

Transmission line techniques may be essential for high-speed analogue or digital signals, depending on the length of their connection and the highest frequency to be communicated (see the 5<sup>th</sup> section of this series). Even for low-frequency signals, immunity will be improved by using transmission line techniques for their interconnections.

Balanced drive/receive circuits are much more effective at reducing emissions and improving immunity. RS485 is an example of a balanced communication scheme. It becomes vitally important to achieve a good balance over the whole frequency range. Balanced in/out receive/drive chips are a very good start, but isolation transformers can be used instead and add the benefit of extending the common-mode immunity beyond the supply rails.

Balanced construction twisted-pair or twinaxial cables are necessary to get the best emissions and immunity performance, and very small differences in twist (and even the dielectric constants of the pigments used to colour the insulations) can be important. Balance is so important that in high-performance circuits even a physically balanced (mirror-image) PCB layout will be needed, using the same PCB layers. The quality of the balance achieved is measured as the common-mode rejection ratio (CMRR).

When transformers are used to achieve galvanic isolation their interwinding capacitance limits their CMRR at higher frequencies, and they generally require a common-mode choke in series to maintain good balance over the whole frequency range of interest.

The CM choke always goes closest to the cable or connector.

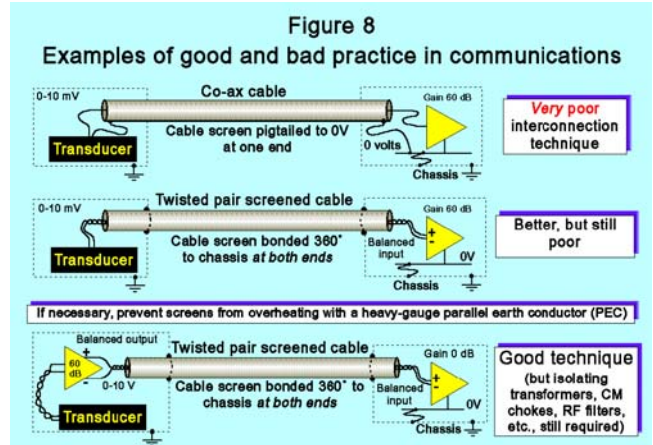
Where a balanced in/out chip is used its CMRR also rolls off at higher frequencies, so it needs a CM choke too.

Figure 9 shows these two examples, equally applicable to providing good emissions and immunity for digital or analogue communications at any speed or frequency range.

Figure 10 shows how the transformer and choke are selected to provide a good overall CMRR over the whole range of interest (for a high-speed data example).

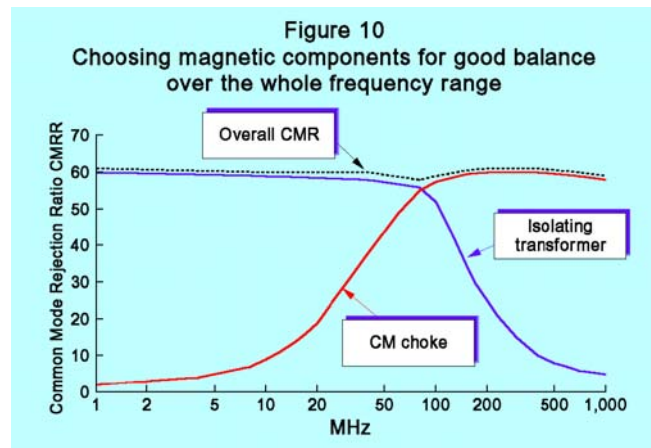
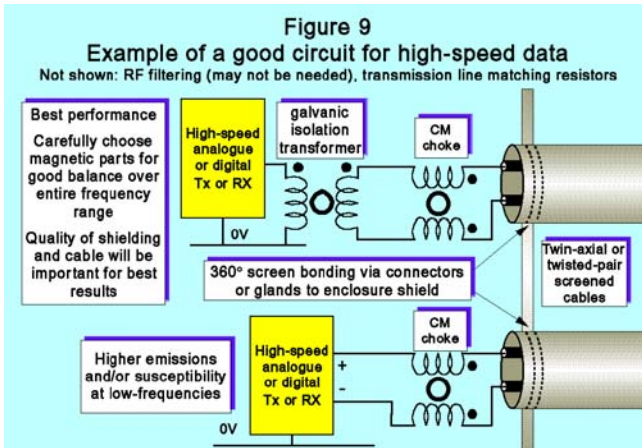
For a professional audio communication link the signal frequencies extend to 20kHz or less, so the isolating transformer will be large. Its large interwinding capacitance rolls its CMRR off to zero before 1 MHz, so the CM choke then needs to be larger to provide CMRR down to 100 kHz or less. It is difficult to find a choke that has good CMRR from 100kHz to 1,000 MHz, so two chokes with different specifications may be needed in series to cover the range. Where co-axial cables are used instead of the twisted-pairs or twinax preferred, EMC and signal integrity suffers, and the techniques of figure 11 will help achieve the best possible performance.

Many communications are still low frequency or low rate, and their signals are not particularly prone to causing emissions or suffering from interference. e.g. analogue to/from 8-bit converters will not be as sensitive as that from 12-bit converters, whereas 16 and higher number of bits will be very sensitive indeed.



Such signals are often sent down single wires in multiconductor cables to save cost, as shown by Figure 12 (an example of an RS232 application).

Where a conductor has N cores, it is best to connect it to the electronics at each end with a CM choke with N windings. Figure 12 shows a seven winding choke used for an eight-core cable, because one of the conductors is dedicated to "frame ground" according to the RS232 standard. (The frame ground lead is not likely to carry heavy currents and require a PEC because RS232 is only used for short-distances.)



RS232 only suits short distances because its single-ended signals lose their integrity rapidly as they radiate their energy as emissions. So although figure 12 (and the bottom circuit in figure 11) looks easy enough, the use of single-ended signals will require attention to CM choke and/or cable and/or connector quality. (Cable and connector types and qualities are discussed in the 2nd part of this series.)

Using drivers with very slow output edges (preferably slew-rate limited) can ease emissions problems significantly. Alternatively, standard drivers can be passively filtered to reduce their high-frequency content.

### 1.4.3 Opto-isolation

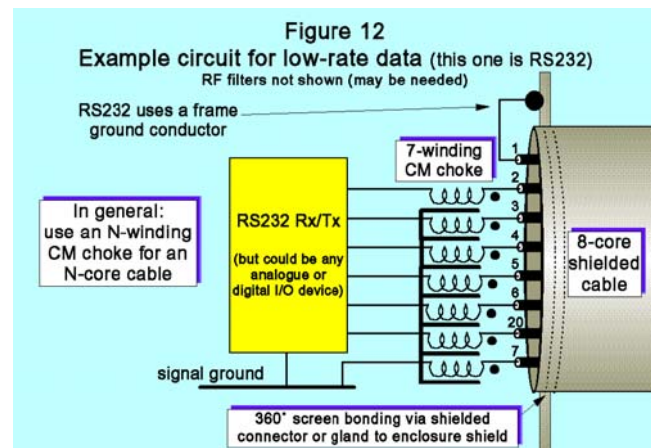
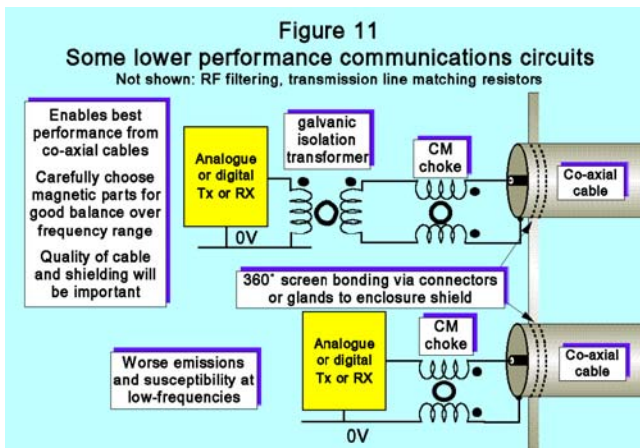
Opto-isolation is a common technique for digital signals, but the input-output capacitance of typical opto-coupler is around 1 pF - this creates a low enough impedance at frequencies above 10MHz to interact with the circuit impedances and destroy the balance of the signals in the cable.

As before, the selection of a suitable common-mode choke will restore the balance at high frequencies, allowing fast-edged signals to be communicated with fewer emissions or immunity problems.

Figure 13 shows an example of good practices in a high-speed optically isolated link.

Many opto-couplers are used for slow data signals and often use coaxial or multi-conductor cables with a single wire for each signal (and a common return). In these cases a single soft ferrite bead in series with each signal line to an opto-coupler may be all that is needed to control high frequency interference.

Analogue signals can now benefit also from opto-isolation with up to 0.1 % linearity (e.g. using IL300 and the like).



### 1.4.4 External I/O protection

External I/O is exposed to the full range of electromagnetic phenomena. The better circuits in the above figures should need less filtering or protection, for a given signal and semiconductors.

All the above communication circuits may need additional filtering for emissions or immunity with continuous EMC phenomena. For ESD, transient, and surge phenomena the upper circuits of figures 9 and 11, and figure 13, are well-protected providing their isolating transformers or opto-couplers will withstand the voltage stresses applied. RF filtering can also give some protection against ESD or fast transients.

The above circuits without isolating transformers or opto-couplers will almost certainly need overvoltage protection with

diodes or transient suppressors, although heavy filtering might be adequate if data rates or frequencies are very low. For control signals a series 10k or 100k resistor closest to the connector followed by a 100 nF or 10 nF capacitor to the PCB ground plane makes a marvellous barrier against almost all EMC phenomena, but does not allow rapid changes in logic state. Digital communications generally need a robust digital protocol (see below) to prevent data corruption, as protection devices only prevent actual damage to the semiconductors.

Allow for additional protection devices on a prototype board, and test it as early as possible to see which are needed.

**1.4.5 "Earth-free" and "floating" communications**

Another name for galvanic isolation is "earth free" or "floating", but these terms are often misunderstood or misused.

The above circuits using isolating transformers or opto-couplers are all "earth-free" and "floating", because no currents from the communications devices are assumed to flow between Tx and Rx via the 0V or chassis. This is true even though their cable screens are bonded at *both* ends to local chassis (enclosure shield). In fact, leakage currents flow through parasitic capacitances, and when CMRR is poor they can reach surprisingly large values.

The terms "earth-free" and "floating" are also sometimes applied to electronically balanced inputs or outputs, such as the lower circuit of figure 9. Although good CMRR performance will still give low leakage via 0V or chassis, such circuits are not galvanically isolated and are intrinsically more vulnerable to surges. Electronically balanced circuits also have a reputation for suffering from instability when one of the two lines is accidentally connected to ground.

Don't forget that the quality of the isolation achieved in practice is limited by the isolation performance of the power supplies supplying each side.

*Never* try to achieve "earth-free" operation by removing the protective earth from any equipment - this creates serious safety hazards and immediately contravenes several mandatory laws. If "ground loops" are a problem, use the proper circuit and installation techniques (e.g. PECs) and never compromise safety.

It is best to avoid jargon phrases like "earth-free" and "floating", instead state what is actually required or meant in plain circuit terms.

When screens *cannot* be connected at both ends

In some applications it is mandatory not to connect equipment grounds via cable screens or other conductors. The equipment concerned is still connected to main supply system's earth, but the earthing system is controlled in a special way. This does *not* help to achieve EMC at low cost. A screen connection at only one end will make the balance of the circuit and its conductors more important, and it will be more difficult and expensive to achieve a given EMC performance for a given signal.

Attention to creepage and clearances will also be important for safety reasons. In larger installations: when screens are not bonded at both ends, surges can cause arcing at the unconnected end possibly causing fire or toxic fumes. People can also receive shocks if they happen to be touching the screen and other equipment when a surge arrives. Clearly, not connecting the screens at both ends must place extra electrical and EMC stresses on some of the circuit components and cables, making surge, transient, and ESD damage more likely.

**1.4.6 Hazardous area and intrinsically safe communications**

Special barrier devices to limit the maximum power available in normal and fault conditions, and other restrictions, may be required. The EMC performance of these devices, which are made by specialist companies, is crucial. Further discussion is beyond the scope of this series.

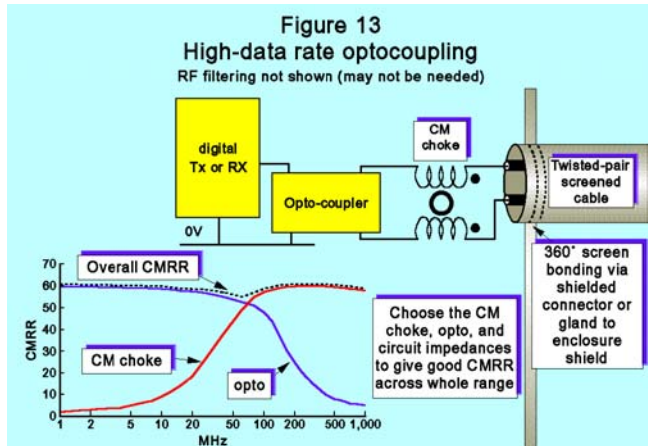
**1.4.7 Communication protocols**

The data protocols used for digital communications are vital for both emissions and immunity, and it is much better to purchase chips that implement proven protocols than to try to develop them yourself. Simple protocols are easy, but they are very poor for EMC. Chips implementing CAN, MIL-STD-1553, LONWORKS, etc, have hundreds of man-years experience with interference control built into them, which no normal project team can ever hope to equal. Spend the extra few dollars on robust protocols, it will be worth it. Protocols are not discussed further in this series.

**1.5 Choosing passive components**

All passive components contain parasitic resistance, capacitance, and inductance. At the high frequencies at which many EMC problems occur these parasitic elements often dominate, making the components behave completely differently. e.g.: at high frequencies a film resistor becomes either a capacitor (due to its shunt C of around 0.2pF) or an inductor (due to its lead inductance and spiral tolerancing). These two can even resonate to give even more complex behaviour. Wire-wound resistors are useless above a few kHz, whereas film resistors under 1 k usually remain resistive up to a few hundred MHz. A capacitor will resonate due to the effect of its internal and lead inductances, and above its first resonance it will have a predominantly inductive impedance. Surface mounted components are preferred for good EMC because their parasitic elements are much lower and they provide their nominal value up to a much higher frequency. e.g. SMD resistors under 1 k are usually still resistive at 1,000 MHz.

All components are also limited by their power handling capacity (especially for surges handling), dV/dt capacity (solid tantalum capacitors go short-circuit if their dV/dt is exceeded), dl/dt, etc. Passive components can also suffer severe temperature coefficients, or need de-rating. SMD parts have lower power ratings than leaded, but since most power occurs at





## COMPUTER SIMULATION IN EMC – PART I

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### 1. Introduction

As a designer of electronic products you have to make sure that these products will comply with the relevant EMC requirements. These requirements can be specified in the EMC regulation for the intended market, e.g. the Australian EMC Framework, the European EMC Directive or the US FCC rules. Or they may be chosen according to military standards, MIL-STD 461x being the most famous, or tailor-made for a specific system. Whether your product does comply with these requirements will, in most cases be found by testing in accordance with the appropriate methods. This, however, is possible only after you can put your hand on the finished product or at least on a representative prototype. Representative here means in respect to its EMC performance, not only in respect to its function. And while TESTING itself, in many cases, is quite acceptable as far as time and costs are concerned, FAILING a test may be catastrophic, resulting in time-to-market delay, requiring additional resources for re-design, etc. Also, the pure test results often do not unveil the reasons for the failure and give little insight in what is going on inside a box.

#### 1-1 Simulation vs. testing

There is no simple answer to the question: what is better, simulation or testing? Instead let us get an understanding of some principle aspects of both testing and simulation. Good testing consists of two parts: good equipment, and a correct test procedure. You may have the best EMI receiver available, it is calibrated and is working just fine - but it does NOT measure an electric field strength. What it does measure is the voltage applied to its input terminal. It is up to the operator to ensure that an antenna is connected correctly, and that the antenna is positioned correctly to pick up the electric field, and that the equipment under test is operated correctly to produce this field, and that the environment does not influence the field distribution. And just because some smart software adds an antenna factor and changes the unit from dBm to dBuV/m on the display does not mean that you, the operator, do not have to look very carefully after the test set up.

Computer simulation is quite similar. A simulation program, in the most general and abstract terms, takes input data, applies a more or less sophisticated algorithm to them, and produces some output data. Just because the simulation gives you nice pictures and numbers does not mean that the system you INTENDED to simulate will produce the same results. In addition to having appropriate simulation software the user also has to use it correctly. As with the EMI receiver, it is not sufficient that you have a good tool, you also have to use it correctly.

But if suitable software is used correctly then correct, reliable and useful simulation results can be achieved.

#### 1-2 Classification of simulation packages

Simulation software addressing EMC issues can be classified in several categories:

##### 1-2-1 Numerical field calculation

This type of software is typically based on Maxwell's equations in one form or the other, or other physical principles like systems always going in a stage where they contain a minimum amount of energy. Programs in this group often have a bit of a theoretical overhead, are usually based on sound physical grounds, and result in most cases in serious number crunching. (Yes, you will need a serious computer.) They will be the focus of this article.

##### 1-2-2 Expert systems

These programs check whether certain design rules have been violated; what may cause potential EMC problems. Examples for design rules could be the separation of noisy traces from traces connected to external cables on a PCB, the distance of decoupling capacitors from noise sources, the maximum size of openings in a shielding cabinet, etc. Violating these rules MAY cause EMC problems, and observing them MAY result in an acceptable EMC behavior. Often these programs are closely related to signal integrity issues, and their application is based on the assumption that what is good for signal integrity must be good for EMC. This assumption is true, but only partially. When using any of these systems, the user must know the guidelines that are applied, and must know their relevance to the problem under investigation.

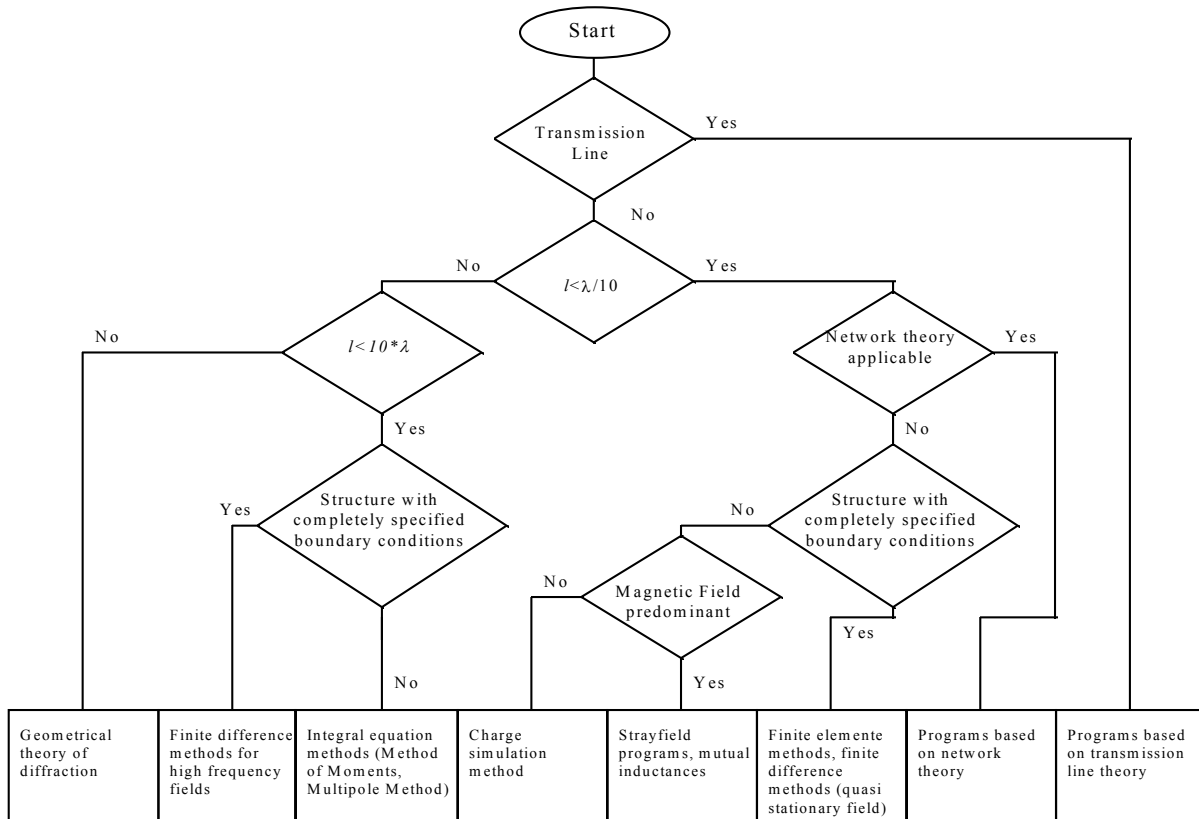
### 2 Numerical field calculation

#### 2-1 Calculation methods

Electric and magnetic fields are described by a set of partial differential equations named after James Clark Maxwell. The task in numerical field calculation is to define all relevant boundary conditions and then find a solution for these equations, fulfilling these boundary conditions. Several mathematical methods can be used as basis for numerical field simulation software. The most important ones, together with their specific advantages and disadvantages, are listed below. This list is, however, not complete and the pros and cons can be subject to discussion. Absorbing boundary conditions have been developed to deal with radiating structures in finite difference/finite element, the size of structures that can be simulated with a particular method depends on the hardware and hybrid methods are more and more introduced.

### 2-1-1 Network Analysis

Network analysis programs are based on Kirchhoff's current and voltage laws. An electric network is constructed of nodes and network elements, the respective equation system is set up and solved.



**Figure 1. Flow chart for selecting a suitable simulation method**

$\lambda$ : wavelength  
 $l$ : typical dimensions of the structure

- + Fast
- Good insight in effect of parameters variation
- Programs are available in frequency and time domain
- Only 'zero'-dimensional problems (electrically small)
- Propagation effects are not considered
- Parameters for equivalent elements must be known

### 2-1-2 Transmission Line Theory

Per-unit-length parameters for inductance, resistance, capacitance and admittance are determined and a correlation between voltages and currents is defined, forming partial differential equations. The voltage change per unit length depends on the time variation of each line current, and the current change per unit length depends on the time variation of each line voltage. Propagation times are considered only along the transmission line axis, but not from one conductor to the other.

- + Fast (Calculation typically independent of length of lines)
- Parameter variation possible (good insight in physical background)
- Coupling into Transmission lines can be considered
- Programs are available in frequency and time domain
- Radiation only under certain restrictions
- TEM Mode requirements (cross section  $\ll \lambda$ )
- Problems at resonance frequencies possible, if no losses are considered
- Per unit length parameters must be known

### 2-1-3 Method of Moments

A current distribution is determined that fulfills boundary conditions for the electrical and/or magnetic field along conducting wires, on conducting surfaces and on boundaries of material with different electric parameters ( $\sigma$ ,  $\epsilon$ ,  $\mu$ ). These boundary conditions are e.g. vanishing tangential electric field on the surface of perfect conductors. Based on such a current distribution electric and magnetic field strength values at arbitrary points can be determined.

- + Versatile method for arbitrary 2D/3D structures
- Mature programs available (Competition driven development)
- Radiation problems can be handled extremely well

- Lumped elements can easily be included
- Dielectric material ( $\epsilon$ ,  $\mu$ ,  $\sigma$ ) can be considered
- Problems at resonances of cavities are possible
- Time domain versions are not currently available(?)
- Calculation time goes up with  $n^3$  ( $f^6$ ) or ( $n \cdot \ln(n)$ ) for iterative solvers?)
- Dielectric material doubles the number of unknowns
- Calculation time can be a problem

#### 2-1-4 Multiple Multipole Method

Radiating multipoles are placed near boundaries between different material and their electric properties are determined so that boundary conditions for the electric and/or magnetic field are met on these boundaries.

- + Suitable for radiation problems
- Fast for certain type of problems
- Good results for 'smooth' structures
- Dielectric material ( $\epsilon$ ,  $\mu$ ,  $\sigma$ ) can be considered
- Problems with sharp edges and thin wires
- Positioning and choice of Multipoles requires some experience

#### 2-1-5 Finite Element Method

The space within a completely closed boundary is partitioned in small polyeders (usually tetrahedra), and the field strength within each tetrahedron is expressed in terms of the potentials on the corners or along the edges. The boundary conditions for these potentials is that the total energy stored in this space is a minimum.

- + Versatile method for arbitrary 2D and 3D structures
- Mature programs available (Competition driven development)
- Inhomogeneous structures can be handled extremely well
- Suitable for fields inside cavities and behavior of wave guides
- Dielectric material ( $\epsilon$ ,  $\mu$ ,  $\sigma$ ) can be considered
- Volume with completely closed boundaries is required
- Radiation problems require specification of absorbing boundary conditions
- Problems with structures having extremely different dimensions
- Calculation time can be quite high

#### 2-1-6 Finite Difference Time Domain

Maxwell's equations in the differential form are expressed as difference equations and the resulting equations system is solved.

- The method, like the Finite Element Method, requires a system which is terminated by a completely closed boundary.
- + Versatile method for arbitrary 2D and 3D structures
- Time domain method allowing handling of nonlinear problems
- Radiation problems require artificial Absorbing Boundary Conditions
- CW solutions may require long calculation times
- Instabilities are possible for low loss structures with high Quality factor

#### 2-1-7 Geometrical/Uniform Theory of Diffraction (GTD/UTD)

This method assumes a structure that is large in respect to the considered wavelength. Interaction between source and sink points is given only via distinctive rays: direct ray, reflected rays, rays scattered on edges and corners etc.

- + Fast for high frequency problems
- Meshing/Calculation time independent of frequency
- Suitable for RCS calculation
- Ray tracing results can be used for all frequencies
- Structure must be electrically large
- Sources and sinks must be in the far field region
- No near field solutions are possible
- Ray tracing involves nonlinear equations and can be a problem
- Complex radiating sources difficult to simulate

#### 2-1-8 Hybrid Methods

Connecting different methods to overcome the shortcomings which every single one has will extend the type of problems that can be handled by computer simulation.

#### 2-2 Selection criteria

When looking for software there are also other parameters to take into account:

- 2-2-1 How intense will the software be used? Will it be used only sporadically or on a full time basis? Will the users be experienced EMC engineers with a solid theoretical background or engineers with experience rather in PCB design or testing and measurement?
- 2-2-2 Is the software to be combined with PCB design work, making easy transfer of data between the layout software and the field calculation software an important issue? Will it be used for the simulation of more mechanical structures, e.g. the analysis of antennas on ship or aircraft, so that data of a mechanical CAD software are to be used?
- 2-2-3 Are the simulation models likely to be variations of a limited number of basic structures, e.g. PCB ground/power planes with a number of strip-lines? Then the import of data and their easy modification will be important. If each simulation task will be of a completely different nature, making models from scratch should be easier, their modification being of lesser importance.
- 2-2-4 What is the budget for the software? The price for software ranges from basically free to 6-digit figures. Free software comes usually with very limited user interfaces and little or no support. Expensive software is not always better, but is usually easier to use, and has options of data import and export. Also - as more versatile and powerful software, more complicated to use.

### 3 The simulation procedure

Solving a simulation problem involves several steps, that shall be addressed now in more detail.

#### 3-1 Thinking about the input data/Modeling

How can the physical structure, already existent in reality or still in the design stage, be transferred into a simulation model? The most crucial question hereby is: what details can you neglect without degrading the quality of the results? You may also have to guess some of the parameters, especially if you are early in the design and not all input data are known.

#### 3-2 Generating the input data/Meshing

Once you know what you want simulate, you have to generate the input data in the format that is required by your particular software. Whereas the first part can be a bit of art, this is, in most cases, hard and boring work.

#### 3-3 Checking the input data

After the input data have been generated the model must be checked. Many programs come, to some degree, with built-in check routines. These routines, however, are limited to syntax and formal aspects of the model, e.g. whether boundary conditions are specified for all boundaries, or whether the mesh-size is sufficiently small for the resulting wave length. The programs can not know whether your model reflects the physical structure you want to model. If you have two parallel strip-lines over a ground plane, the code can not know whether they should be connected with each other at the end, or both grounded, and, if you want to ground them, whether it should be a short circuit, an inductance, or whatever impedance. Remember: a computer does what you tell it to do, not what you want it to do.

#### 3-4 Running the program

If you run a large model for the first time it may be good idea to estimate the required solution time. For most methods the solution time will increase with  $n^p$  where  $n$  is the number of unknowns, and  $p$  a number between 1 and 3.

#### 3-5 Checking the results

After the program has finished, the results must be checked. If the program was running in the background or writes to background files, checking error-log files may be a good idea. Do electric and magnetic fields meet boundary conditions, e.g. are their tangential components equal at both sides? Is the electric field perpendicular to perfect conductors? Is the current distribution smooth on large, flat areas, and does it concentrate around edges? Does the electric charge concentrate on edges? Does the wavelength correspond with the propagation speed in the particular medium? And most important: does the result 'look right'? There will come a point where some experience is quite helpful in deciding whether to put simulation results in a report or in a garbage bin.

#### 3-6 Post processing

In some cases the software will produce the results in the desired format. In other instances post-processing will be necessary to some extent. That can be scaling, converting between S-parameters and other representations of network parameters, e.g. Z- or Y-matrix, combining the fields produced by different excitation scenarios, combining the results of different models in one diagram, or combining them with measured results.

### 4 Examples

A few examples shall now illustrate what sort of EMC related problems can be solved by computer simulation. They are not intended to explain the theory behind the particular methods or to emphasize particular results – they rather want to give some suggestions and stimulations.

### 4.1 Filter Simulation (network theory)

An application for a network analysis program would be the simulation of a filter, as shown in Figure 2. This is a simple problem in terms of numerical issues, but it may be difficult to obtain exact input parameters. And the resulting insertion loss, as can be seen from Figure 3, depends, at least for higher frequencies, on these stray elements.

The insertion loss for the ideal filter increases for increasing frequency ad infinitum. When stray elements are considered, additional resonances occur, and the insertion loss, compared to the ideal filter, is significantly less. When an additional inductance representing a bad pig-tail connection is included, the behavior changes completely. Now the insertion decreases above a frequency of 3 MHz

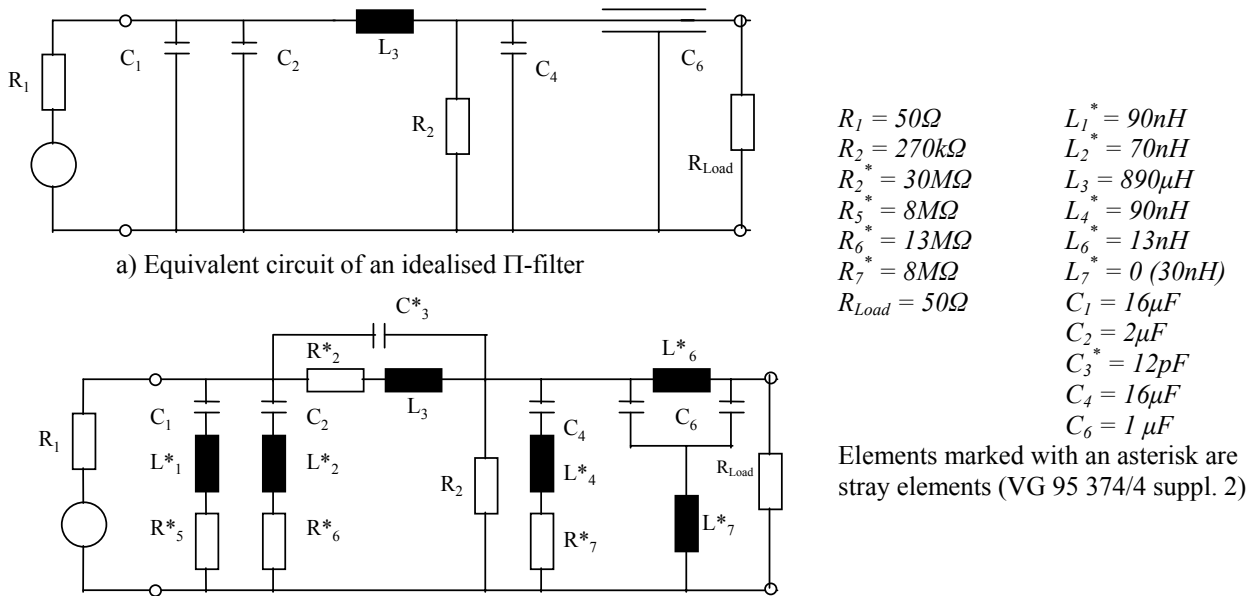


Figure 2: Idealised and realistic filter models

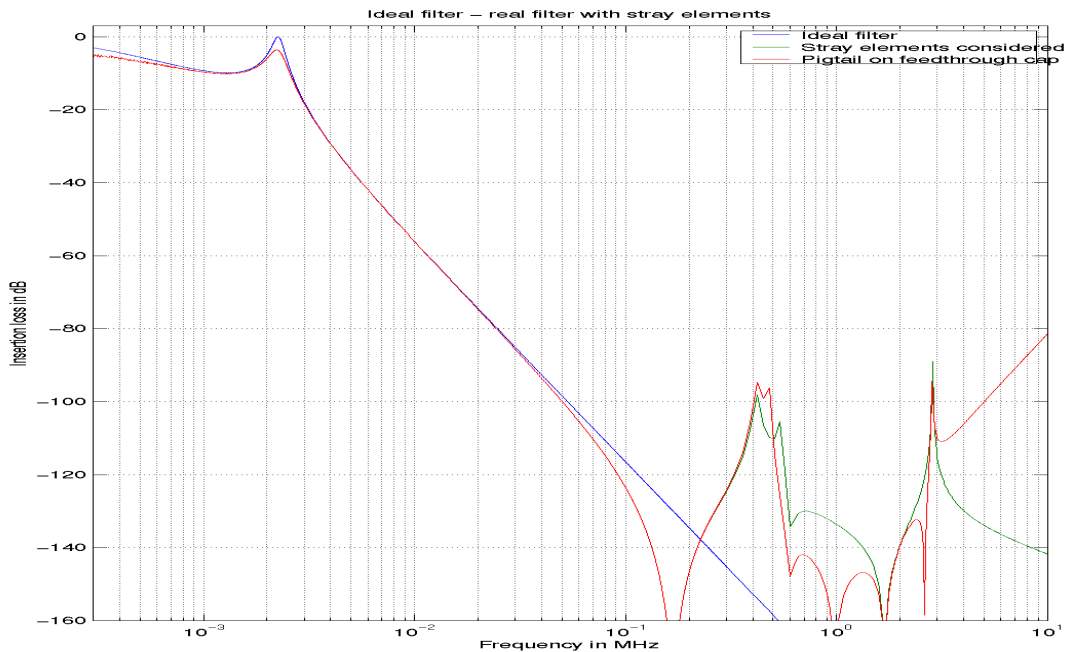


Figure 3: Insertion loss for various filter models

## 4.2 Conductor in a cable tray (Transmission line theory)

The next examples consider transmission line models. A conductor in, beside, or under a metallic cable tray is considered (Figure 4). The cable tray is U-shaped with a width of 20 cm, the sides are 10 cm high, its length is 20 m. It is placed 0.5 m above a perfect conducting plane and grounded at both ends. The cable tray is modeled by parallel conductors of 0.8 mm radius, separated by 5 mm.

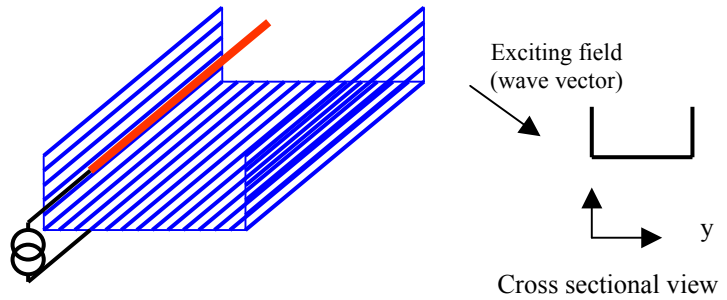


Figure 4: Conductor in Cable tray

The conductor has a radius of 2.5 mm and could represent the shield of a coax cable. At five different heights ( $z=55$  cm, 52 cm, 51 cm, 49 cm, 48 cm) the conductor is moved along the  $y$ -axis from  $y=-5$  cm to  $y=25$  cm. The characteristic impedance of the conductor in the cable tray is shown in Fig. 5. It decreases as the conductor, being outside, comes closer to the cable tray. If the conductor is inside the cable tray ( $z=55$  cm, 52 cm, 51 cm) the characteristic impedance increases as it moves away from the side walls towards the centre of the cable tray. If the conductor is under the cable tray ( $z=49$  cm, 48 cm) the characteristic impedance decreases monotonously when moving towards the centre of the cable tray.

The configuration of the previous example is now exposed to a plane wave. The conductor is connected to the cable tray at both ends via resistors of 5 Ohm. The angles between the wave vector and the  $z$ - and the  $x$ -axis are  $150^\circ$  and  $90^\circ$ , respectively, the electric field vector is parallel to the  $x$ -axis and thus parallel to the cable tray and the conductor. The electric field follows a double-exponential function:

$$e(t) = E_0 \cdot (e^{-t/\tau_1} - e^{-t/\tau_2}),$$

$$\text{with: } E_0 = 1V/m, \tau_1 = 250ns, \tau_2 = 5ns.$$

While moving the conductor along the same paths as in the previous example, the induced current is calculated and its peak values are shown in Fig. 6. Despite the unsymmetric excitation in respect to the  $x$ - $z$ -plane, the results are symmetrical for a symmetrical location of the conductor. The induced current decreases as the conductor is moved closer to the surface of the cable tray. Minimum currents are induced when the conductor is placed in the corners inside the cable tray.

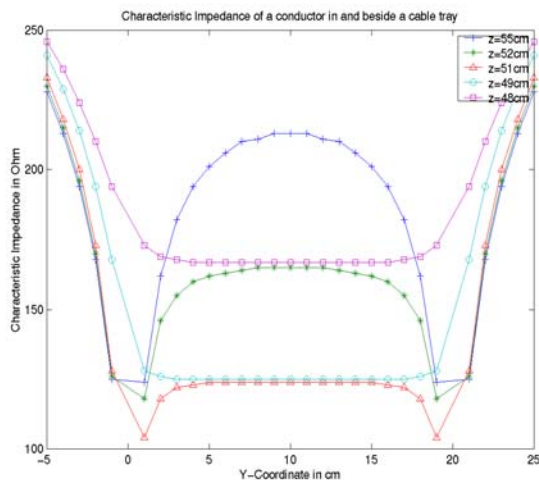


Figure 5: Characteristic impedance

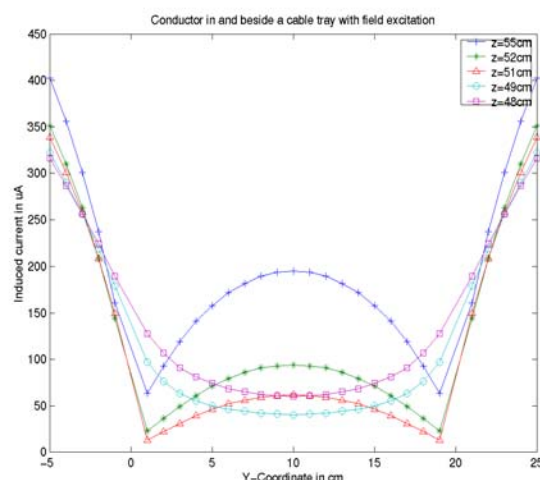
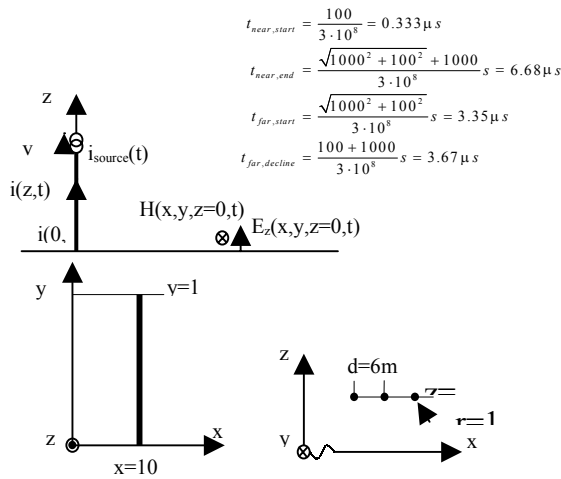


Figure 6: Induced currents

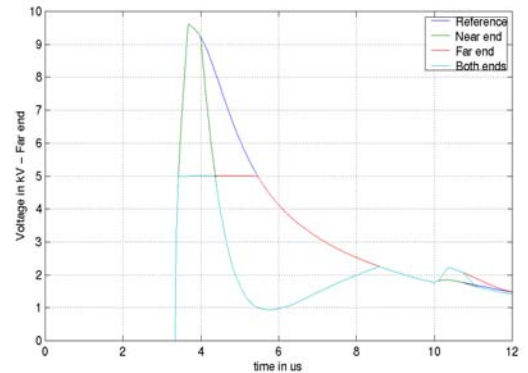
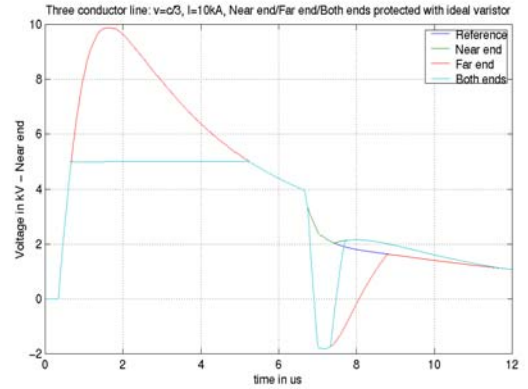
## 4.3 Lightning induced transients (transmission line theory)

The field due to an indirect lightning stroke can produce high voltages, in overhead transmission lines, which may have to be limited by nonlinear protective devices. The lightning discharge can be described by a Travelling Current Source model. A current source travels with about 1/3 of the speed of light from the point of the discharge along the lightning channel. From this source a current flows down to the point of discharge with the speed of light. The electric and magnetic fields produced by the resulting current distribution along the lightning channel can be calculated for arbitrary observation points, e.g. along the position of a transmission line, and the induced currents and voltages can then be derived. The simulation then overcomes the problem that lightning strokes in nature happen randomly and their parameters, such as rise time and maximum current, vary over a wide range. These parameters are known from extensive measurement and can be used as input data for simulations. Lightning strokes with identical parameters can be repeated and their effect on different configurations investigated.

The effect of different types of protective devices at different locations can then be compared. Figure 8 compares the voltage at the near and far end of a transmission line where no, one, and both ends are protected by a voltage arrester. It is interesting to notice that, for that particular excitation scenario, the voltage at the far end reaches the same values as at the near end, but the resulting pulse is significantly shorter. Placing a protective device at only one end provides protection only for that end and may even increase the stress level on the other



**Figure 7.** Lighting Channel and 3-conductor overhead line



**Figure 8:** Near and far end voltages

## 5 Conclusions

Computer simulation is a useful tool to:

- 5.1 predict the electromagnetic need to build representative prototypes;
- 5.2 eliminate the influence of peripheral equipment needed for excitation and measurement; and
- 5.3 ensure excellent control over parameter variations

More examples based on other simulation tools will be presented in Part II of this article in one of the future issues of this Newsletter.

## 6 References

More information on computer simulation and the different simulation methods is available in books and on the internet. A very useful site with many links is the home pages of the University of Missouri-Rolla: <http://emclab.UMR.edu> and of the Applied Computational Electromagnetic Society <http://aces.ee.olemiss.edu>.

# NEWS FROM USA

## EMC STANDARDS ACTIVITIES

The Standards Development Committee of the EMC Society of IEEE is addressing the problem of evaluating the performance of installed power line filters which encounter widely varying source and load impedances. MIL-STD-220A which was developed by the US Department of Defence in 1952 is still often used for characterizing power line filter behaviour and often produces very misleading results. Working Group P1560 is seeking to rectify this long standing problem and invites opinions, recommendations and assistance from interested parties to help finalise this task.

## INTERNATIONAL IEEE SYMPOSIUM on EMC, 2001

This year's IEEE Symposium on EMC was held in Montreal, Canada, from 13 to 17 August 2001 and, as usual, a great number of EMC experts from all over the globe came together to meet, exchange information, and learn from each other. The technical presentations, with no doubt the core of this event, were accompanied by a technical exhibition, and meetings of the IEEE technical committees also took place during the conference. It was once again a big event, and it is difficult to name particular highlights, as every participant would find himself or herself attracted to different topics.

Testing has always been and still is an important issue. Well established and proven (?) test environments and procedures are still challenged as were shown in several presentations. The influence of non-conducting tables on field strength measurements and the calibration of ESD generators and discharge units can be mentioned as examples. Both issues were addressed in Montreal.

Reverberation chambers or mode stirred chambers were covered in a special session. They become more and more established as test facilities and the results achieved in this type of environment seem to be increasingly well accepted. But while it is known and can be demonstrated that they work, it is also interesting to find out why and how they work. To see the biggest such chamber in the world you don't have to go overseas: DSTO in Adelaide is the place to visit.

Computer simulation is another important topic, and no conference could claim to cover the area of EMC in a comprehensive manner without including it. If you believe some vendors of software then everything is possible, and it's easy and it's idiot-proof. Interestingly, very few of these vendors are seen presenting papers in the technical part of the symposium. There, the issue of computer simulation is typically looked at from a more theoretical field- calculation-point-of-view

And in this respect, reliable field simulation software does exist, ever increasing number of canonical problems can be solved, and computer simulation can be used to identify design weaknesses and find improvements. For the evaluation of complex electronic products in respect to compliance with the relevant standards: you still have to go to the test lab (and for the foreseeable future: you will have to).

Standardisation and regulation were other topics covered extensively in Montreal. Several presentations addressed the way in which the IEEE EMC Society reviews and publishes technical papers.

Australia was extremely well represented this year with five (yes: FIVE) papers given by Gordana Felic of The University of Melbourne (the winner of last years student paper competition run by the Australian EMC Society); by Chi Chung Wong of the Royal Melbourne Institute of Technology; by Chris Zombolas of EMC Technologies; and by Franz Schlagenhauser of The University of Western Australia. The best paper award this year was given to Marco Klingler of the French Research Institute on Transport and Safety (INRETS), and Marco told me he is actually an Australian citizen, raised in Melbourne.

Scientific Journals and Transactions are good and valuable means to keep yourself informed what is going on the EMC community. But you have to go to symposia to understand the background: during the presentations you hear how well everything goes, during the coffee break you hear how difficult it was to get the results, and during the evening in the pub, you may hear what didn't work. I want to encourage everybody: attend conferences and symposia, and try to present your own papers. It's much more fun to be there as a presenter. And when do we have the first EMC conference in Australia?

Franz Schlagenhauser  
Western Australian Centre for EMC Technology (WACET)

## **THE 2001 REVERBERATION CHAMBER, ANECHOIC CHAMBER AND OPEN AREA TEST SITE USERS MEETING – HYATT REGENCY BELLEVUE, WASHINGTON STATE, JUNE 4 TO 7**

The clear focus of this year's meeting was on Reverberation Chamber developments and a pre-meeting workshop on the measurement of shielding effectiveness. The techniques described in the standards were discussed from a perspective of the technical and systematic errors in the procedure in contrast to the errors associated with the measurement instruments. The insertion loss method used in MIL-STD-285 and IEEE 299 were described as fundamentally flawed, with the refinements of IEEE 299 producing the "same wrong answer every time." The discussion was quite lively.

The two day meeting started with a discussion on TC 77 from the IEC, and the historical and current requirements for radiated immunity testing and susceptibility on transmission line measurements in reverberation chambers. A research thrust that produced a number of papers was in the use of reverberation chambers at low frequencies, i.e. in the TEM cell mode. The topics for the rest of the papers varied enormously from hour to hour with most speakers and papers being relatively informal. While it may seem strange to mix the topics, it kept the audience alert as we all tried to cope with the differing concepts being discussed from plane waves in free space to complex wave structure in resonant cavities. A new development that is very appealing to some has come from the US Navy who with Mission Research Corp. in the US have developed an RF to Optical Fibre transmission system for RF measurement that operates from 100MHz to 18GHz. It has a nominal 0dB loss with up to 300 m of optical fibre cable, much better performance than can be achieved from cable.

A trade show was a new feature of this year's meeting with a modest 29 businesses represented. The more personal atmosphere of this meeting and trade show helped the attendees gain some real access to their suppliers and the suppliers to their customers. A preliminary discussion meeting was held after the Users group for those interested in forming a committee to develop an Emissions Standard for reverberation chambers. Reverberation chambers are very well suited to emission measurements if the results can be accepted in units of total radiated power rather than the current field strength at a distance units. The discussion quickly resolved the acceptability of the emission standard would be related to the commercial viability of its application rather than the purity of its science.

Kevin Goldsmith

## **NEWS FROM EUROPE**

### **MOBILE PHONES**

The European Commission has announced the publication of a new standard, EN50360 – Product Standard, to demonstrate the compliance of mobile phones with basic restrictions to human exposure to electromagnetic fields (300MHz – 3GHz). This standard requires manufacturers of mobile phones to comply with strict limits on the exposure of users to electromagnetic waves. Some mobile phones now carry specific absorption rate (SAR) data giving indication of radiation emission levels. The move follows the Stewart Report recommendation last year that mobile phone companies should supply this data to customers to allow them to make their own decisions regarding health risks.

## CISPR

CISPR, the international standards committee which deals with EMC has formally announced that it is to restructure its committees to reflect the convergence of information, telecoms and multimedia technologies. A new subcommittee, CISPR/I has been set up which will replace and combine the activities of the broadcast equipment group CISPR/E and the ITE group. These subcommittees have previously been responsible for the standards CISPR 13, 20, 22 and 24, and the formation of CISPR/I presages the convergence of these standards.

The secretariat of the new committee will be in Japan under Kenji Okazaki of Sony. Britain's Martin Wright of BT will chair the new group.

## NEWS FROM ACA

### DRAFT NEW EMR HUMAN EXPOSURE STANDARD

The ACA released a draft new *Radiocommunications (Electromagnetic Radiation—Human Exposure) Standard 2001* for public comment during October.

It is intended that the new Standard commence on 1 January 2002 and replace the *Radiocommunications (Electromagnetic Radiation — Human Exposure) Standard 1999*.

The following comments are derived from the ACA explanatory statement accompanying the draft.

The ACA introduced regulatory arrangements in February 1999 and extended them in June 2000 to capture a broader range of devices. The current arrangements are limited to certain radiocommunications transmitters including cellular mobile telephone, cordless telephone and satellite telephone handsets as well as cellular mobile telecommunications base stations. January 2002 sees the introduction of the final stage of implementation for radiocommunications transmitters with integral antennas.

Industry, community and government stakeholders have been involved in all phases of the development of this new regime.

The reference standard on which the ACA legislative instrument is based is AS/NZS 2772.1(Int):1998, a technical standard that sets human exposure limits to RF fields. Although this standard has lapsed as a Standards Australia document, the ACA has adopted some of the provisions in it and included them in its EMR subordinate legislation. Thus the selected provisions remain current and have legal effect.

The most important of the defining characteristics of the devices to which this standard applies is that they must be mobile or portable and have an integral antenna.

Certain devices will be exempt from this standard. Devices that are intended to be used only at sea to alert rescue authorities to the location of sea craft and/or persons in distress will not be subject to EMR human exposure limits as the immediate life saving potential of the devices overrides the substantially less risk of harm due to exposure to EMR.

#### **Transitional application in 2002**

The provisions of *Radiocommunications (Electromagnetic Radiation—Human Exposure) Standard 1999* will continue to apply until 31 December 2002 to those radiocommunications transmitters that were manufactured or imported before 1 January 2002 and to which the old standard applies.

#### **Application of Standard on or after 1 January 2003**

Provision is made for a 12 month "grace" period for compliance with the standard for certain radiocommunications transmitters. Specifically, transmitters that are capable of operating in the 3kHz to 300 GHz frequency band but were first offered for supply in Australia before this standard came into effect (ie 1 January 2002) do not have to comply with the standard until 1 January 2003.

Consideration is given to the characteristics of certain radiocommunications devices that are not usually used by members of the general public but by persons whose use of such transmitters is coincidental to their work and who, by virtue of their training, either through work or other means, are aware of the potential risk of exposure to RF fields. Emergency services personnel and amateur radio operators would be included in this group. Most users of these devices receive training in their correct and safe use through their employment, user associations, at point of sale, and/or in the instructional material provided by the manufacturer. Although such devices operate at higher power than a cellular mobile telephone, the operation on a push-to-talk basis is quite different to that of a cellular mobile phone. Because the devices operate on a push-to-talk basis—and the radio cannot transmit without instruction from the user—the user is aware when the device is transmitting and when it is not. For this reason, the ACA considers that users of these devices are aware of the potential risk of exposure to RF fields from the transmitters and is applying the aware user provisions of AS/NZS 2772.1(Int):1998 to them.

The Standard specifies a method that must be used to test the devices subject to this standard to ascertain their compliance with the human exposure limits. The test method is part of the standard and describes the measurement requirements for testing compliance with basic SAR restrictions for mobile and portable transmitting equipment that has an integral antenna where the normal position of use is close to the human head; and is capable of operating in the frequency band 800 MHz to 2500 MHz. Testing of other devices is to be in accordance with AS/NZS 2772.2 as in force from time to time.

## STUDENT MEMBERSHIP

The National Council of the EMC Society has announced that Student Membership of the Society is now free. We invite all students undergoing study in tertiary education in associated disciplines, electronics or electrical technologies to join our society. Membership is not restricted to these specific fields and indeed, anyone who has an interest in EMC is encouraged to join.

Membership of the Society entitles members to receive free the quarterly newsletter, attend technical presentations and provide access to information and personnel who may assist students in their studies.

For more details please contact the secretary – Kingsley McRae – telephone 03 9762 6733 or [kingsley@rfi-ind.com.au](mailto:kingsley@rfi-ind.com.au)

## CALENDAR OF EVENTS

### 2001

**December 3 - 8** Seventh International conference on Electromagnetic Interference and Compatibility. Bangalore, India

### 2002

**May 21 – 24** Sponsored by the Chinese Institute of Electronics (CIE)  
2002 International Symposium and Technical Exhibition on EMC, Beijing, China  
Professor Liu, Dayong  
Phone: +8610 68283463 Fax: +8610 68283458  
[dylu@public.bta.net.cn](mailto:dylu@public.bta.net.cn) [www.cie-china.org/emc2002/](http://www.cie-china.org/emc2002/)

**June 25 – 28** **16<sup>th</sup> International** Wroclaw Symposium and Exhibition on EMC  
(The conference language will be English)  
General information: Mr. W.Moron, Mr. D.Wiecek  
Phone: +4871 348 3051  
Fax: +4871 3728 878 [emc@il.wroc.pl](mailto:emc@il.wroc.pl)  
Post: EMC Symposium, Box 2141, 51-645 Wroclaw 12, Poland

**August 19 – 23** **IEEE EMC Symposium Minnesota**  
Hyatt Regency, Minneapolis  
Dan Hoolihan +1 651 213 0966 [d.hoolihan@ieee.org](mailto:d.hoolihan@ieee.org)

**September 9 – 13** **EMC Europe 2002**  
Organised by the Associazione Elettrotecnica ed Elettronica Italiana, the University of Rome “La Sapienza”, the University of L’Aquila, the University of Naples “Frederico II”, Sorrento, Italy.  
Massimo Iandolo Phone: +39 02 77790 218 / 230 Fax: +39 02 798817  
[emceurope2002@aei.it](mailto:emceurope2002@aei.it)

## NEW MEMBERS

For those who have not yet joined our EMC Society we would ask you to fill in our membership application form and encourage your colleagues to follow suit. If you have applied for membership but not yet received an invoice from IEAust, would you please fill in and submit a new application.

## MAILBOX

We invite all our members and readers to participate in our quarterly newsletter. In order to produce a better newsletter and provide our readers with the information and items of interest looked for, we welcome your comment, advice and criticism. Particularly, we would look forward to receiving technical articles, amusing anecdotes and items of general interest to the EMC community.

## CORPORATE MEMBERSHIP

The EMC Society offers corporate Membership to organisations who may wish to nominate up to three people for membership. It also provides an important source of funding to the Society and we would like to take this opportunity to recognise the 2000 corporate Members.

**ADVANTEC ELECTRONICS Pty Ltd** is a registered NATA test house with accreditations for testing to TS001, TS002, TS004, TS006 and TS008.

Contact: David Stocks (02) 9477 7757

**DEPARTMENT OF DEFENCE** Defence Communications Regulatory Affairs.

Contact: Neal Miller (02) 6265 0522

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Contact: Lucy Krieg (02) 9525 2766

**ROBERT BOSCH AUSTRALIA** is a manufacturer of white goods and specialised electronic automotive products.

Contact: Steve Offer (03) 9541 5474

**TENIX DEFENCE SYSTEMS** is a manufacturer of specialised defence systems.

Contact: David Willetts (03) 9244 4134

**The EMC Society would like to express gratitude to Advantec, Department of Defence, Rittal, Robert Bosch, and Tenix for their support in 2001.**

## Institutional Listings

The IEAust Electromagnetic Compatibility Society is grateful for the assistance given by the firms listed and invites application for Institutional Listings from other firms interested in the electromagnetic compatibility field.

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IEC 1000-4-2 ESD  
IEC 1000-4-3 Radiated RF  
IEC 1000-4-4 Transients  
IEC 1000-4-5 HV Surge  
IEC 1000-4-6 Conducted RF  
IEC 1000-4-8 H Fields  
IEC 1000-4-11 PS Interruptions

### All C-Tick Standards

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AS/NZS 1044 / CISPR 14: Appliances  
AS/NZS 1053 / CISPR 13: TV, Radio, Audio  
AS/NZS 2064 / CISPR 11: ISM  
AS/NZS 3548 / CISPR22: ITE  
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# GOOD. BETTER. BOSCH

An Institutional Listing recognises contributions to support the publication of **THE IE AUST ELECTROMAGNETIC COMPATIBILITY SOCIETY** newsletter. Minimum rates are \$200.00 for a listing in one issue. Larger contributions will be most welcome. No agency fee is granted for soliciting such contributions. Inquiries, or contributions made payable to the EMC Society, plus instructions on how you wish your Institutional Listing to appear, should be sent to the Editor, EMC Society Newsletter, IE Aust, 11 National Circuit, Barton, A.C.T. 2600.