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HEADQUARTERS NEWS
We are delighted to welcome Jeameeka White to our Headquarters’ staff. Jeameeka is a New Bern native, which in itself is somewhat unique, given the number of transplants in this area (such as us). Jeameeka will be handling all matters related to the administration of our iNARTE certification programs, while Judy Sydow will continue to administer our FCC Licensure programs. Jeameeka is widely experienced and holds a Masters degree in Business Administration. You can contact her by e-mail at Jeameeka@inarte.us with any questions or requests you may have.

We also welcome Dr. Terry Welsher to our Board of Directors for 2010. Terry is the Senior Vice President at Dangelmeyer Associates, a training and consulting engineering company, specializing in ESD Control. Terry is also Vice President of the ESD Association this year, and with his help and guidance we expect to build a much stronger bond between the ESDA and iNARTE that should provide advantages for the members of both organizations.

FCC LICENSURE
iNARTE is a COLE Manager for the FCC Licensure programs. We are able to arrange FCC examinations for anyone interested at any of our almost 200 Authorized Test Centers. One of the most popular programs is the General Radiotelephone Operators License, GROL, which requires passing FCC examination in written Elements 1 and 3. The GROL is also accepted by iNARTE as evidence of knowledge in the telecommunications discipline and holders can apply for iNARTE Junior Technician certification without further examination. Possession of a GROL has also become a requirement for many engineers and technicians working on direct government contracts to supply electrical and electronic equipment.

In 2009 we saw a 20% increase in applications for this license and much interest in purchasing the latest training manuals and copies of the Element questions, many of which were changed and reissued by the FCC in 2009. Adding a GROL to your credentials is becoming of greater and greater value.

iNARTE is now selling the latest GROL study guide, GROL + RADAR, 2009 by Gordon West with Pete Trotter. This book contains the new FCC Question Pools released on the 25th of June 2009. It contains everything you need to study and pass the FCC MROP, GROL & Radar Examinations.

The book includes the complete, official FCC question pools for:
- Element 1, Radio Law, Element 3, General Radiotelephone Operator and
- Element 8, Radar Endorsement. Each with answers and explanations for every question.
THE ROAD AHEAD

While there are a few early shoots of optimism concerning the general economic situation, it is clear that consumer confidence has not yet returned. Without that market support, most corporations and companies are not going to be adding jobs any time soon. In fact we are still seeing job losses in many of the areas of technology served by iNARTE.

In decades past, Certification has been shown to provide improved earning power for individuals. Today it can provide a measure of job security, and when necessary a passport to another career. We recently received the following e-mail from one of our certified EMC Engineers who was able to get a new position, even though it involved a major relocation:

“Having iNARTE Certifications was a real factor in getting my new job. I will be the new EMI Lab Manager for a large defense contractor. I’m getting a pretty good sign-on bonus, relocation benefit and a significant increase in pay. I know it would have been a lot tougher getting this job had I not had my iNARTE certifications.”

We cannot guarantee such good fortune for everyone, but we do believe that certification provides an important, independent validation of an individual’s skills and experience. This may be all you need to avoid getting caught in the scaling back process, or perhaps to get that all important first interview for a new position.

Whether or not you hold an iNARTE certificate, it is important today to remain current with changes and advances in technology, specifications and standards. This year iNARTE will be helping you to do this by sponsoring and supporting a number of important workshops and tutorials, shown below.

Several other workshops are in the pipeline, so be sure to visit the iNARTE web site regularly to be sure not to miss those in your region or field of interest.

<table>
<thead>
<tr>
<th>WHEN</th>
<th>WHAT</th>
<th>WHERE</th>
<th>PARTNER/PRESENTER(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 16-19</td>
<td>Laboratory Auditor ISO 17025 Training and Credentialing</td>
<td>Atlanta, GA Airport Marriott</td>
<td>ANSI-ASQ National Accreditation Board, (AClass)</td>
</tr>
<tr>
<td></td>
<td><a href="http://www.narte.org/d/AClass2010Flyer.pdf">www.narte.org/d/AClass2010Flyer.pdf</a></td>
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</tr>
<tr>
<td>March 25-26</td>
<td>HPEM/HEMP/IEMI Workshop</td>
<td>Freemont, CA Underwriters Laboratories, CCS</td>
<td>Dr. William Radasky, IEEE Fellow, EMP Fellow, Chairman of IEC SC 77C, and President of Metatech Corporation.</td>
</tr>
<tr>
<td></td>
<td><a href="http://www.narte.org/h/HPEM.asp">www.narte.org/h/HPEM.asp</a></td>
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<td></td>
</tr>
<tr>
<td>April 12</td>
<td>Personal Development through Engineering Excellence</td>
<td>Beijing, China APEMC2010</td>
<td>Brian Lawrence, iNARTE</td>
</tr>
<tr>
<td></td>
<td>Top 10 EMC Design Rules for Achieving Compliance</td>
<td></td>
<td>William Graff, ATCB</td>
</tr>
<tr>
<td></td>
<td>Introducing the new ANSI C63.10 standards for unlicensed wireless devices</td>
<td></td>
<td>Michael Windler, UL</td>
</tr>
<tr>
<td></td>
<td>Overview of current of FCC rules for compliance</td>
<td></td>
<td>Elya Joffe, KTM Project Engineering</td>
</tr>
<tr>
<td>June 15–16</td>
<td>Workshop on ANSI C63.10 - 2009 Testing Unlicensed Wireless Devices</td>
<td>Northbrook, IL Underwriters Laboratories</td>
<td>Art Wall (Radio Regulatory Consultants) Mike Windler (UL), Bob Delisi (UL) Bill Hurst (FCC)</td>
</tr>
<tr>
<td></td>
<td><a href="http://www.narte.org/h/ANSIC63.10Workshop.asp">www.narte.org/h/ANSIC63.10Workshop.asp</a></td>
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<tr>
<td>Sept. 14–17</td>
<td>Laboratory Auditor ISO 17025 Training and Credentialing</td>
<td>Chicago, IL Marriot O’Hare Airport</td>
<td>ANSI-ASQ National Accreditation Board, (AClass)</td>
</tr>
<tr>
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<td><a href="http://www.narte.org/d/AClass2010Flyer.pdf">www.narte.org/d/AClass2010Flyer.pdf</a></td>
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</tbody>
</table>
Two of the more important publications in the area of Electromagnetic Compatibility (EMC) and Measurement Uncertainty (MU) are LAB 34 and CISPR 16-4-2. EMC and Measurement Uncertainty are receiving more attention as other CISPR Product Family Standards begin to adopt MU. LAB 34 is “The Expression of Uncertainty in EMC Testing” and is published by the United Kingdom Accreditation Service (UKAS). CISPR 16-4-2 is published by the International Electrotechnical Commission (IEC) and is titled “Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods – Part 4-2: Uncertainties, Statistics, and Limit Modeling – Uncertainty in EMC Measurements.” This article compares and contrasts the two MU documents.

**BASIS FOR THE DOCUMENTS**

Both Measurement Uncertainty documents are based on the International Standards Organization (ISO) *Guide to the Expression of Uncertainty in Measurement* (GUM), 1993, corrected and reprinted in 1995. This publication is the grandfather of all Measurement Uncertainty documentation and is often referred to, simply, as the “GUM.” However, it should be noted that the “GUM” has been cancelled and replaced by “ISO/IEC Guide 98-3 – Uncertainty of Measurement – Guide to the Expression of Uncertainty of Measurement (GUM:1995).” The first edition of ISO/IEC Guide 98-3 was published in 2008. (Note – IEC is the International Electrotechnical Commission; a sister organization to the ISO).

When the “GUM” was first published in 1993 (after almost a 16-year development period), it introduced a new general perspective on errors, tolerances, and measurement variances. Many seminars and workshops occurred, after the initial release of the “GUM”, to help engineers understand the new concepts of Measurement Uncertainty and specifically, Measurement Uncertainty and EMC.

Within a year of the release of the GUM, the British had released an EMC Measurement Uncertainty document called NIS 81 – “The Treatment of Uncertainty in EMC Measurements”; it was published by the National Measurement Accreditation Service (NAMAS) in May of 1994. This was a first attempt to address EMC and Measurement Uncertainty. NIS 81 had a number of mistakes in it and it was replaced by LAB 34; which was first released in August of 2002.

CISPR 16-4-2 was spun-off from CISPR 16-4 (Uncertainty in EMC Measurements) in November of 2003.

So, since 2003, there have been two fairly stable documents that have addressed MU and EMC. Since both documents are based on the original “GUM”, there is a great deal of commonality between the two MU references.

This can be seen by reviewing Figure 1, the Table of Contents of both documents; LAB 34 and CISPR 16-4-2.
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Antennas...

And Kits too.

A.H. Systems
EMC and Measurement Uncertainty

It can be seen that both documents have an Introductory paragraph, a References paragraph, a General paragraph on Concepts and/or Scope, a paragraph on Measurement Uncertainty budgets, and Examples of Measurement Uncertainty. This article will be primarily devoted to comparing and contrasting some of the Measurement Uncertainty Examples.

<table>
<thead>
<tr>
<th>LAB 34</th>
<th>CISPR 16-4-2</th>
</tr>
</thead>
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<tr>
<td>1 – Introduction</td>
<td>Foreword, Introduction and Table Recapitulating Cross-References</td>
</tr>
<tr>
<td>2 – Concepts</td>
<td>1 - Scope</td>
</tr>
<tr>
<td>3 – Steps in Establishing an Uncertainty Budget</td>
<td>2 – Normative References</td>
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<tr>
<td>4 – Compliance with Specification</td>
<td>3 – Definitions and Symbols</td>
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<td>5 - (Normative) References</td>
<td>4 – Measurement Instrumentation Uncertainty</td>
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<tr>
<td>6 - Acknowledgements</td>
<td>Annex A (informative) – Basis for Ucispr Values in Table 1</td>
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<tr>
<td>Appendix A – Examples of Typical Uncertainty Budgets</td>
<td>Bibliography</td>
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<tr>
<td>Appendix B - Calculation of kp</td>
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<tr>
<td>Appendix C – Calculation of Uncertainty in Logarithmic or Linear Quantities</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1: Tables of Contents**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Source of Uncertainty</th>
<th>Value</th>
<th>Probability distribution</th>
<th>Divisor</th>
<th>$u_i(y)$</th>
<th>$(u_i(y))^2$</th>
<th>$v_i$ or $v_{eff}$</th>
<th>$U_i^4(y)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_i$</td>
<td>Receiver Reading</td>
<td>0.05</td>
<td>rectangular</td>
<td>1.732</td>
<td>0.03</td>
<td>0.001</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$L_c$</td>
<td>Attenuation AMN-receiver</td>
<td>0.40</td>
<td>normal 2</td>
<td>2.000</td>
<td>0.20</td>
<td>0.040</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$L_{AMN}$</td>
<td>AMN Voltage division factor</td>
<td>0.20</td>
<td>normal 2</td>
<td>2.000</td>
<td>0.10</td>
<td>0.010</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$dV_{SW}$</td>
<td>Receiver Sine Wave</td>
<td>1.00</td>
<td>rectangular</td>
<td>1.732</td>
<td>0.58</td>
<td>0.333</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$dV_{PA}$</td>
<td>Receiver Pulse Amplitude</td>
<td>1.50</td>
<td>rectangular</td>
<td>1.732</td>
<td>0.87</td>
<td>0.750</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$dV_{pr}$</td>
<td>Receiver Pulse repetition</td>
<td>1.50</td>
<td>rectangular</td>
<td>1.732</td>
<td>0.87</td>
<td>0.750</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$dV_{nf}$</td>
<td>Noise Floor Proximity</td>
<td>0.00</td>
<td>rectangular</td>
<td>1.732</td>
<td>0.00</td>
<td>0.000</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$dZ$</td>
<td>AMN Impedance</td>
<td>3.60</td>
<td>triangular</td>
<td>2.449</td>
<td>1.47</td>
<td>2.160</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$F_{STEP}$</td>
<td>Frequency step error</td>
<td>0.00</td>
<td>rectangular</td>
<td>1.732</td>
<td>0.00</td>
<td>0.000</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$M$</td>
<td>Mismatch</td>
<td>-0.89</td>
<td>U-shaped</td>
<td>1.414</td>
<td>-0.63</td>
<td>0.397</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>$R_S$</td>
<td>Measurement Systems Repeatability</td>
<td>0.50</td>
<td>normal 1</td>
<td>1.000</td>
<td>0.50</td>
<td>0.250</td>
<td>9</td>
<td>0.007</td>
</tr>
<tr>
<td>$R_{EUT}$</td>
<td>Repeatability of EUT</td>
<td>0.00</td>
<td>normal 1</td>
<td>1.000</td>
<td>0.00</td>
<td>0.000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$u_i(F_S)$</td>
<td>Combined Standard Uncertainty</td>
<td>normal</td>
<td></td>
<td>2.17</td>
<td>4.691</td>
<td>&gt;3000</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>$U(F_S)$</td>
<td>Expanded Uncertainty</td>
<td>normal k+</td>
<td>2.00</td>
<td>4.3</td>
<td>&gt;3000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2: Conducted Disturbances – LAB 34 – 9 kHz to 150 kHz**
COMPARISON OF CONDUCTED EMISSIONS

In LAB 34, the conducted disturbance (conducted emission) from 9 kHz to 150 kHz standard uncertainties are shown in Figure 2. The standard uncertainties include the Receiver Reading, the Attenuation of the Artificial Mains Network (AMN)-Receiver combination, the AMN Voltage Division Factor, the Receiver Sine Wave, the Receiver Pulse Amplitude, the Noise Floor Proximity, the AMN Impedance, a Frequency Step Error, Mismatch (Receiver Voltage Reflection Coefficient and AMN + Cable), Measurement System Repeatability, and Repeatability of the Equipment Under Test (EUT). Table A.1 of CISPR 16-4-2 includes all these values except for Frequency Step Error, Measurement System Repeatability, and Repeatability of the EUT. However, since LAB 34 assigns values of zero to Frequency Step Error and Repeatability of the EUT, the only difference between the tables and their standard uncertainties is Measurement System Repeatability with a standard uncertainty of 0.5 dB.

Subtracting that value from the Combined Standard Uncertainties for LAB 34 as shown in Figure 2, we arrive at a Combined Standard Uncertainty of 2.11 dB. Assuming a k = 2 coverage factor, we arrive at a value of 4.22 dB for the Expanded Measurement Uncertainty (EMU). Comparing that to CISPR 16-4-2, we see that “16-4-2” has a value of 3.97 dB for its Expanded Measurement Uncertainty; thus, we have a difference of 0.25 dB between the two documents.

Most of this difference seems to be from Attenuation of the AMN-receiver combination which is 0.4 dB in LAB 34 and only 0.1 dB in CISPR 16-4-2. A second reduced-factor in “16-4-2” is the AMN impedance; the standard uncertainty for that in “16-4-2” is 1.37 dB while in LAB 34 it is 1.47 dB.

Looking at the next higher frequency range for conducted emissions, 150 kHz to 30 MHz, as shown in A2 of LAB 34 and Table A.2 of CISPR 16-4-2, we see an Expanded Measurement Uncertainty (EMU) of 3.9 dB in LAB 34 and an Expanded Measurement Uncertainty of 3.6 dB in CISPR 16-4-2. If we subtract the Measurement System Repeatability standard uncertainty from LAB 34, we arrive at an EMU of 3.7 dB thus leaving us with a difference between the two documents of only 0.1 dB for conducted emissions between 150 kHz and 30 MHz.

RADIATED EMISSIONS

There are a number of radiated emissions (radiated disturbances) that could be reviewed depending on the antenna-to-EUT distance and the horizontal versus vertical polarization of the antenna. I chose a 3-meter antenna distance for this analysis with a vertical polarization of the log-periodic antenna and a frequency range of 300 – 1000 MHz.
## EMC and Measurement Uncertainty

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Source of Uncertainty</th>
<th>Value</th>
<th>Probability distribution</th>
<th>Divisor</th>
<th>$c_i$</th>
<th>$u_i(y)$</th>
<th>$(u_i(y))^2$</th>
<th>$v_i$ or $v_{eff}$</th>
<th>$U_i^2(y)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_I$</td>
<td>Receiver Indication</td>
<td>0.05</td>
<td>rectangular</td>
<td>1.732</td>
<td>1</td>
<td>0.03</td>
<td>0.001</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>$dV_{SW}$</td>
<td>Receiver Since Wave</td>
<td>1.00</td>
<td>normal 2</td>
<td>2.000</td>
<td>1</td>
<td>0.50</td>
<td>0.250</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>$dV_{PA}$</td>
<td>Receiver Pulse Amplitude</td>
<td>1.50</td>
<td>rectangular</td>
<td>1.732</td>
<td>1</td>
<td>0.87</td>
<td>0.750</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>$dV_{PR}$</td>
<td>Receiver Pulse repetition</td>
<td>1.50</td>
<td>rectangular</td>
<td>1.732</td>
<td>1</td>
<td>0.87</td>
<td>0.750</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>$dV_{NF}$</td>
<td>Noise Floor Proximity</td>
<td>0.50</td>
<td>normal 2</td>
<td>2.000</td>
<td>1</td>
<td>0.25</td>
<td>0.063</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>$A_F$</td>
<td>Antenna Factor Calibration</td>
<td>1.00</td>
<td>normal 2</td>
<td>2.000</td>
<td>1</td>
<td>0.50</td>
<td>0.250</td>
<td>$\infty$</td>
<td>0</td>
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<tr>
<td>$C_L$</td>
<td>Cable Loss</td>
<td>0.50</td>
<td>normal 2</td>
<td>2.000</td>
<td>1</td>
<td>0.25</td>
<td>0.063</td>
<td>$\infty$</td>
<td>0</td>
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<tr>
<td>$A_D$</td>
<td>Antenna Directivity</td>
<td>3.00</td>
<td>rectangular</td>
<td>1.732</td>
<td>1</td>
<td>1.73</td>
<td>3.000</td>
<td>$\infty$</td>
<td>0</td>
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<tr>
<td>$A_H$</td>
<td>Antenna Factor Height Dependence</td>
<td>0.50</td>
<td>rectangular</td>
<td>1.732</td>
<td>1</td>
<td>0.29</td>
<td>0.083</td>
<td>$\infty$</td>
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<tr>
<td>$A_p$</td>
<td>Antenna Phase Centre Variation</td>
<td>1.00</td>
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<td>1.732</td>
<td>1</td>
<td>0.58</td>
<td>0.333</td>
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<td>$A_I$</td>
<td>Antenna Factor Frequency Interpolation</td>
<td>0.25</td>
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<td>1.732</td>
<td>1</td>
<td>0.14</td>
<td>0.021</td>
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<td>$S_I$</td>
<td>Site Imperfections</td>
<td>4.00</td>
<td>triangular</td>
<td>2.449</td>
<td>1</td>
<td>1.63</td>
<td>2.667</td>
<td>$\infty$</td>
<td>0</td>
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<td>$D_V$</td>
<td>Measurement Distance Variation</td>
<td>0.60</td>
<td>rectangular</td>
<td>1.732</td>
<td>1</td>
<td>0.35</td>
<td>0.120</td>
<td>$\infty$</td>
<td>0</td>
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<td>$D_{BAL}$</td>
<td>Antenna Balance</td>
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<td>1.732</td>
<td>1</td>
<td>0.00</td>
<td>0.000</td>
<td>$\infty$</td>
<td>0</td>
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<tr>
<td>$D_{Cross}$</td>
<td>Cross Polarization</td>
<td>0.90</td>
<td>rectangular</td>
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<td>0.52</td>
<td>0.270</td>
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<td>$F_{step}$</td>
<td>Frequency step error</td>
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<td>1</td>
<td>0.00</td>
<td>0.000</td>
<td>$\infty$</td>
<td>0</td>
</tr>
<tr>
<td>$M$</td>
<td>Mismatch</td>
<td>-0.54</td>
<td>U-shaped</td>
<td>-</td>
<td>1</td>
<td>-0.38</td>
<td>0.144</td>
<td>$\infty$</td>
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<tr>
<td></td>
<td>Receiver VRC   0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Antenna+Cable VRC 0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_S$</td>
<td>Measurement of System Repeatability</td>
<td>0.50</td>
<td>normal 1</td>
<td>1.000</td>
<td>1</td>
<td>0.50</td>
<td>0.250</td>
<td>9</td>
<td>0.0069</td>
</tr>
<tr>
<td>$R_{EUT}$</td>
<td>Repeatability of EUT</td>
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<td>1</td>
<td>0.00</td>
<td>0.000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$u_i(y)$</td>
<td>Combined Standard Uncertainty</td>
<td></td>
<td>normal</td>
<td></td>
<td></td>
<td>3.00</td>
<td>9.014</td>
<td>&gt;11000</td>
<td>0.0069</td>
</tr>
<tr>
<td>$U(y)$</td>
<td>Expanded Uncertainty</td>
<td></td>
<td>normal k=</td>
<td>2.00</td>
<td></td>
<td>6.0</td>
<td></td>
<td>&gt;11000</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3:** Radiated Emissions, Vertical, 300 MHz to 1000 MHz, 3-meter distance
As seen from Figure 3, the number of standard uncertainty factors has increased from the previous conducted emission examples. The list of standard uncertainty factors includes Receiver Indication, Receiver Sine Wave, Receiver Pulse Amplitude, Receiver Pulse Repetition, Noise Floor Proximity, Antenna Factor Calibration, Cable Loss, Antenna Directivity, Antenna Factor Height Dependence, Antenna Phase Center Variation, Antenna Factor Frequency Interpolation, Site Imperfections, Measurement Distance Variation, Antenna Balance, Cross Polarization, Frequency Step Error, Mismatch, Measurement System Repeatability, and Repeatability of EUT.

LAB 34 has three elements in its table that are not in “16-4-2”; they are Frequency Step Error, Measurement System Repeatability, and Repeatability of the EUT. Both Frequency Step Error and Repeatability of the EUT are zero in LAB 34, they don’t contribute to the Combined Standard Uncertainty. However, Measurement System Repeatability is 0.5 in LAB 34; subtracting that from the Standard Uncertainty Table leaves us with an Expanded Measurement Uncertainty for 300 MHz to 1000 MHz of 5.90 dB. The equivalent number from “16-4-2” is 5.18 dB. It should be noted that the “16-4-2” table includes a factor for Table Height of 0.1 dB. If we subtract that from the “16-4-2” table, we still have a value of 5.18 dB (the factor is so small it contributes very little to the expanded measurement uncertainty). This is a difference of 0.72 dB between the two documents for vertical polarization.

The major difference maker between the two documents is antenna directivity: LAB 34 has a value of 3.0 dB while “16-4-2” has a factor of only 1.0 dB for that value.

LAB 34 has an expanded measurement uncertainty (EMU) of 4.9 dB for Vertical Polarization at 10-meters from 300 MHz to 1000 MHz; if we subtract the Measurement System Repeatability factor; we have an EMU of 4.76 dB. CISPR 16-4-2 has an EMU of 5.05 dB for this same situation. Obviously, with a difference of only 0.29 dB, we have very similar numbers for 10-meter vertical radiated field strength.

For horizontal radiated emissions, with a biconical antenna, from 30 MHz to 300 MHz, LAB 34 has no examples. CISPR 16-4-2 has an EMU of 4.95 dB for 3-meters and 4.94 dB for 10-meters.

CISPR 16-4-2 actually covers the frequency range from 30 MHz to 200 MHz while LAB 34 covers the frequency range from 30 MHz to 300 MHz; both with biconical antennas. For purposes of this paper, it was assumed that CISPR 16-4-2 would be able to cover up to 300 MHz with the same Emission Measurement Uncertainty values as LAB 34.
It should be noted that the examples in both LAB 34 and CISPR 16-4-2 use typical values in their examples; an EMC Lab must generate its own measurement uncertainty values from calibration certificates, equipment manuals, or from a series of measurements for a statistical analysis (Type A).

**OTHER MATERIAL COVERED IN THE TWO DOCUMENTS**

**LAB 34**

LAB 34 has the following examples of typical uncertainty budgets:

1. Conducted Disturbances (Emissions) - 9 kHz to 150 kHz using 50 ohm/50 microhenry Artificial Mains Network
2. Conducted Disturbances (Emissions) – 150 kHz to 30 MHz using 50 ohm/50 microhenry Artificial Mains Network
3. Discontinuous Emissions from 150 kHz to 30 MHz using 50 ohm/50 microhenry Artificial Mains Network
4. Radiated Field Strength – 30 dBUV/m to 60 dBUV/m – Biconical Antenna – 30 MHz to 300 MHz – Vertical Polarization at 3 meters and 10 meters
5. Radiated Field Strength - 30 dBUV/m to 60 dBUV/m – Log Periodic Antenna – 300 MHz to 1000 MHz – Vertical Polarization at 3 meters
6. Radiated Field Strength - 30 dBUV/m to 60 dBUV/m – Log Periodic Antenna – 300 MHz to 1000 MHz – Vertical Polarization at 10 meters
7. Disturbance Power – 30 MHz to 300 MHz
8. Electrostatic Discharge – Negative Discharge Current, Negative Discharge Voltage, and Negative Rise Time
9. Radiated Immunity – Re-Establishment of Pre-Calibrated Field Level and Dynamic Feedback Field Level
10. Conducted Immunity - Re-Establishment of Pre-Calibrated Conducted Field Level and Limiting of Pre-Calibrated Conducted Voltage Level by Monitor Coil
11. Internal Calibration – Insertion Loss Uncertainty Budget

LAB 34 also has an Appendix B which calculates a k_p when random errors in a measurement-system are comparable in magnitude to the systematic errors. k_p is a coverage factor greater than 2 in order to assure a 95% level of confidence. Also, Appendix C is a discussion of calculation of uncertainty in logarithmic or linear quantities.

LAB 34 also has a discussion of Compliance with Specification in Section 4. It outlines different scenarios of meeting a specification when using “uncertainty intervals.”

<table>
<thead>
<tr>
<th>Quantity</th>
<th>LAB 34 Expanded Measurement Emission Value</th>
<th>CISPR 16-4-2 Expanded Measurement Value</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conducted Emission – 9 kHz – 150 kHz</td>
<td>4.22 dB</td>
<td>3.97 dB</td>
<td>0.25 dB</td>
</tr>
<tr>
<td>Conducted Emission – 150 kHz – 30 MHz</td>
<td>3.70 dB</td>
<td>3.60 dB</td>
<td>0.10 dB</td>
</tr>
<tr>
<td>Radiated Emission – 3-meters – Vertical – 30 MHz – 300 MHz</td>
<td>5.32 dB</td>
<td>5.06 dB</td>
<td>0.26 dB</td>
</tr>
<tr>
<td>Radiated Emission – 3-meters – Horizontal – 30 MHz – 300 MHz</td>
<td>5.32 dB</td>
<td>4.95 dB</td>
<td>0.37 dB</td>
</tr>
<tr>
<td>Radiated Emissions – 3-meters – Vertical – 300 – 1000 MHz</td>
<td>5.9 dB</td>
<td>5.18 dB</td>
<td>0.72 dB</td>
</tr>
<tr>
<td>Radiated Emissions – 3-meters – Horizontal – 300 – 1000 MHz</td>
<td>No data</td>
<td>4.95 dB</td>
<td>N/A</td>
</tr>
<tr>
<td>Radiated Emission – 10-meters – Vertical – 30 MHz – 300 MHz</td>
<td>5.32 dB</td>
<td>5.04 dB</td>
<td>0.28 dB</td>
</tr>
<tr>
<td>Radiated Emission – 10-meters – Horizontal – 30 MHz – 300 MHz</td>
<td>No data</td>
<td>4.94 dB</td>
<td>N/A</td>
</tr>
<tr>
<td>Radiated Emissions – 10-meters – Vertical – 300 – 1000 MHz</td>
<td>4.76 dB</td>
<td>5.05 dB</td>
<td>0.29 dB</td>
</tr>
<tr>
<td>Radiated Emissions – 10 meters – Horizontal - 300 -1000 MHz</td>
<td>5.32 dB</td>
<td>4.95 dB</td>
<td>0.37 dB</td>
</tr>
</tbody>
</table>

*Figure 4: Summary of Emission Measurement Uncertainty Values*
CISPR 16-4-2

CISPR 16-4-2 has the following examples of typical uncertainty budgets:

1. Conducted Disturbances (Emissions) from 9 kHz to 150 kHz using a 50 ohm/50 microhenry + 5 ohm Artificial Mains Network

2. Conducted Disturbances (Emissions) from 50 kHz to 30 MHz using a 50 ohm/50 microhenry Artificial Mains Network

3. Disturbance Power Measurements – 30 MHz to 300 MHz

4. Horizontally polarized radiated disturbances from 30 MHz to 200 MHz using a biconical antenna at a distance of 3 meters, 10 meters, or 30 meters

5. Vertically polarized radiated disturbances from 30 MHz to 200 MHz using a biconical antenna at a distance of 3 meters, 10 meters, or 30 meters

6. Horizontally polarized radiated disturbances from 200 MHz to 1000 MHz using a log-periodic antenna at a distance of 3 meters, 10 meters, or 30 meters

7. Vertically polarized radiated disturbances from 200 MHz to 1000 MHz using a log-periodic antenna at a distance of 3 meters, 10 meters, or 30 meters

In Annex A of CISPR 16-4-2, there is an excellent discussion of the input quantities for the examples of measurement uncertainty in 16-4-2.

Table 1 of CISPR 16-4-2 has Values of Ucispr which are referenced by other CISPR standards. These values are 4.0 dB for conducted disturbances on the mains port from 9 kHz to 150 kHz and 3.6 dB from 150 kHz to 30 MHz. Also, 4.5 dB is the value for disturbance power from 30 MHz to 300 MHz. Finally, radiated disturbance (electric field strength on an open area test site or alternative test site) for 30 MHz to 1000 MHz is 5.2 dB. The radiated disturbance number is the largest of the radiated disturbance values of 5.06, 4.95, 5.18, 4.95, 5.04, 4.94, 5.05 and 4.95 in the eight examples in CISPR 16-4-2.

At the present time, the two CISPR standards that call out CISPR 16-4-2 and its Ucispr are CISPR 11, Edition 5.0 (2009-05) and CISPR 22, Edition 6.0 (2008-09).

In CISPR 11, it is covered in Clause (Paragraph) 12.5 (Measurement Uncertainty). It says the following: “Determining compliance with the limits in this standard shall be based on the results of the compliance measurements taking into account the considerations on measurement instrumentation uncertainty. Where applicable, measurement instrumentation uncertainty shall be treated as specified in CISPR 16-4-2.”

In CISPR 22, it is covered in Clause (Paragraph) 11 (Measurement Uncertainty). It says the following: “The results of measurements of emission from Information Technology Equipment (ITE) shall reference the measurement instrumentation uncertainty considerations contained in CISPR 16-4-2. Determining compliance with the limits in this standard shall be based on the results of the compliance measurement, not taking into account measurement instrumentation uncertainty. However, the measurement uncertainty of the measurement instrumentation and its associated connections between the various instruments in the measurement chain shall be calculated and both the measurement results and the calculated uncertainty shall appear in the test report.”

SUMMARY

It can be seen that there is a close correlation between the two EMC Measurement Uncertainty documents discussed in this paper. Both LAB 34 and CISPR 16-4-2 can be used by EMC Labs as reference documents for their lab operations, lab measurement uncertainty calculations, and for accreditation purposes. As more CISPR, regional, and national standards adopt Measurement Uncertainty criteria, the two subject documents will become increasingly important for an EMC Lab.

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Common Mode Filtering Performances of Planar EBG Structures

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B. Archambeault & S. Connor, IBM

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In the design of the link path for the modern low voltage high-speed differential digital signals one of the technical challenges is the containment of their common mode (CM) harmonic components [1]. These components have a twofold negative effect: (a) they are associated to a loss of signal energy due to the differential-to-common mode conversion and resulting in an implicit attenuation of the intentional differential signal and (b) they are the cause of EMI radiation when they leave the board assembly through connectors and cables. The origin of these components is always related to some unbalancing (geometrical and/or electrical) [2] of the whole signal path, from the driver to the receiver. While the primary remedy to CM components is the elimination of any unbalance this is impractical or impossible in most real world applications. The secondary remedy is the filtering of the common mode portion of the signal. This filtering is usually performed by using discrete components, but they have drawbacks since they use board space, add cost, and often introduce unacceptable levels of differential mode attenuation.

Electromagnetic Bandgap (EBG) structures are a subset of Frequency Selective Surfaces. Introduced in 1999 [3] their use has been extended to Printed Circuit Board (PCB) application mainly in the field of power integrity (PI) [4-5]. Recently also their impact on the signal integrity (SI) of digital signals referenced to them have been considered, measured and predicted [6-8]. In [9] it has been systematically studied the physical mechanisms governing the electromagnetic (EM) coupling between a microstrip line (μstrip) referenced to the patterned plane of an EBG structure and the cavity formed by the patterned plane and the continuous plane underneath it. A proper design of the EBG structure allows locating the resonances, and therefore the notches of the transfer scattering parameter $S_{21}$ between the input and output port of the signal path in a way to perform the selective attenuation of predetermined signal’s harmonic.

This article is organized as follows: Single Ended Microstrip Over An EBG Plane looks at the impact on $S_{21}$ of the positions of the EBG plane and a single ended (SE) μstrip routed on top of it constituting the signal’s path. The calculations are carried out by using a three dimensional (3D) full wave field simulator based on the Finite Integration Technique (FIT) [10-11]. Differential Microstrip Over EBG Plane considers the same problem of Single Ended Microstrip Over An EBG Plane but with a differential microstrip. The mixed mode scattering parameters ($S_{mn}$) [12] are used to evaluate the CM, DM and mixed components of the signal. EBG Structures Without Connecting Bridges proposes a slightly
different new structure to better perform the filtering action. Finally *Conclusions* offers some concluding remarks.

**SINGLE ENDED MICROSTRIP OVER AN EBG PLANE**

In [9] the fundamental mechanisms of the coupling between signal lines and EBG structures are discussed and the correlation between the frequency spectrum of the transfer scattering parameter $|S_{PI}^{21}(\omega)|$ in the cavity and the transfer parameter $|S_{SI}^{21}(\omega)|$ of the interconnect (in this case an L-shaped 50Ω microstrip line) referenced to the EBG patterned plane is computed. The basic geometry considered consists of a patterned EBG plane. The plane is made of six square patches ($a = b = 13.7$ mm) organized in 3 rows and 2 columns; the patches are separated by a gap of $g = 1.3$ mm and connected by metallic bridges of width $w = 0.4$ mm as in Figure 1. The EBG patterned layer is separated by the next continuous plane by an FR4 dielectric layer ($\varepsilon_r = 4.4$ and $\tan \delta = 0.02$) whose thickness is $d = 0.4$ mm. The frequency response of the two mentioned transfer functions, the $|S_{PI}(\omega)|$ both for the PI and for the SI problem, allows identifying three frequency regions: the region before the bandgap (BBG), the bandgap region (BG) characterized by its starting ($f_{\text{Low}}$) and ending ($f_{\text{High}}$) frequencies and the region after the bandgap (ABG). In the BBG there is a strict correlation between the resonances of the EBG structure (cavity formed by the

![Figure 1: (a) Top view of a 3 x 2 planar EBG structure with L-shaped µstrip and (b) frequency spectrum of $|S_{PI}^{21}|$ (continue) and $|S_{SI}^{21}|$ (dashed).](image)
Common Mode Filtering Performances of Planar EBG Structures

patterned plane and the continuous plane) shown by the $|S_{21}^{pl}|$ and the notches of the µstrip transfer function, the $|S_{21}^{SI}|$. The comparison between $|S_{21}^{pl}|$ and $|S_{21}^{SI}|$ is shown in Figure 1b.

At these resonant frequencies the EM field associated to the electric signal on the µstrip is strongly coupled to the resonating cavity through the EBG patterned plane; therefore part of the energy launched at the transmitting port is lost along the signal path and does not reach the receiving ports of the µstrip.

This is illustrated in Figure 2a and 2b where the spatial distribution of the $|E_z|$, the vertical component of the electric field, is plotted at $f_1 = 520$ MHz and $f_2 = 1$ GHz. These frequencies are similar (but not the same) to the first self resonant frequency ($f_{SRF} = 900$ MHz), to the TM$_{10}$ (1.64 GHz) and TM$_{01}$ (2.49 GHz) modes of the cavity with the same external dimensions ($a = 28.7$ mm, $b = 43.7$ mm). In particular they are less than those values due to the excess inductance due to the bridges and to the dimensions of the patches.

At the non-resonance frequency of the EBG/Fully plane cavity most of the $E_z$-field is confined below the µstrip (dark region in Figure 2a); at the resonance the $E$-field is coupled into the cavity reducing the transmitted signal at the receiving port of the µstrip. In (1) the starting frequency of the BG region is given, as was defined in [13]:

$$f_{Low} = \frac{1}{\pi \sqrt{\frac{1}{C_p + \frac{L_{bridge}}{d}}}}$$ (1)

$$C_p = \frac{\varepsilon_r b^2}{d}$$ (2a)

$$L_p = \mu d$$ (2b)

$$L_{bridge} = k_1 \ln \left( \frac{2 \pi d}{w} \right)$$ (2c)

$C_p$ and $L_p$ are the capacitance and the inductance of the patch, respectively; $L_{bridge}$ is the inductance of the bridge and $k_1 = 0.2$ nH/mm. Substituting (2) into (1) and after some algebra one has

$$f_{Low} = \frac{1}{\pi \sqrt{\varepsilon_r \frac{b^2}{c^2} + 2k_1 \varepsilon_r \frac{b^2}{d} + k_1 \varepsilon_r \ln \left( \frac{d}{w} \right)}}$$ (3)

where $c$ is the propagation speed. If the condition $d = w$ is met then (3) becomes

$$f_{Low} = \frac{1}{\pi b \sqrt{\varepsilon_r \mu + 2k_1 \frac{g}{d}}}$$ (4)

Therefore $f_{Low}$ will depend only on the dimensions of the patches (b), on the gap width (g) and on the distance from the continuous plane underneath (d).

In the BG region the EM field in the cavity is negligible ($|S_{21}^{pl}|$ well below -30 dB), thus voltage between the EBG plane and the full plane becomes very small and the two planes can be considered equipotential. The signal return currents, although referenced to a patterned plane, do not see the impact of the pattern and behaves as the plane were continuous. This is shown in the flat behavior of $|S_{21}^{SI}|$ in Figure 1b and from the spatial distribution of E at $f_2 = 4$ GHz (inside the BG) in Figure 3.

In the ABG region the resonance of $|S_{21}^{pl}|$ are related to the dimensions of the single patch. In Figure 1 the peaks in the region 5 to 10 GHz are corresponding to the frequencies of $f_3 = 5.21$ GHz and $f_4 = 7.38$ GHz, exactly coincident with the modes frequencies $TM_{10}$ and $TM_{01}$ of the virtual elementary cavity formed by the single patch whose dimensions are, in this case, $a = b = 13.7$ mm. This is also substantiated by the fact that the approximate expression for the evaluation of $f_{High}$ [13] is

$$f_{TM} = \frac{c_0}{2 \pi \sqrt{\varepsilon_r \frac{b}{m_1}}} = \frac{c_0}{2 b \sqrt{\varepsilon_r}} = f_{High}$$ (5)

Figure 2: Spatial distribution of $|E|$ in the BBG region: (a) at $f_1$ not at a cavity resonance and (b) at $f_2$ at cavity resonance

Figure 3: Spatial distribution of $|E|$ in the BG region at $f_2$.
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where b is the larger dimension of the single patch. Equation 5 is simply the lowest resonant frequency of the virtual cavity mentioned above. At these resonant frequencies $|S_{21}^n|$ shows deep notches interleaved by regions in which it remains very close to 0 dB. Figure 4a shows the geometry for a planar EBG structure build up by 3 x 4 metallic patches whose dimensions are $a = 9.95$ mm and $b = 8.7$ mm. They are separated by a gap of $g = 1.3$ mm and connected by metallic bridges whose width is $w = 0.4$ mm. The thickness of the metal layer is $t = 17$ µm and the thickness of the dielectric between the patterned plane and the continuous one is $d = 0.4$ mm. The dielectric above and below the patterned plane has $\varepsilon_r = 4.4$ and $\tan \delta = 0.02$. The L-shaped μstrip line has been designed to have a nominal characteristic impedance over a continuous plane of 50 Ω and its projection on the patterned plane is at 12w from the center of the bridges.

In Figure 4b the relevant frequencies $f_{TM00} = f_{TM01} = 7.18$ GHz, $f_{TM01} = 8.21$ GHz are marked on the frequency spectrum of $|S_{21}^n|$. $f_{TM11} = 11$ GHz is not visible since it is outside of the computed frequency range. At this stage the behavior of a SE interconnection over an EBG plane is characterized and the next step is looking at the behavior of a differential link.

**DIFFERENTIAL MICROSTRIP OVER EBG PLANE**

High-speed digital signals are very often transmitted over differential interconnections due to their robustness to CM interferences. Figure 5 shows the evolution from the SE μstrip studied above (Figure 5a) and the differential one (Figure 5b). The differential structure has the same EBG geometry of the 3 x 2 SE described in Single Ended Microstrip Over An EBG Plane and the two differential lines, designed to have a differential characteristic impedance of 100 Ω, are symmetrically placed on the left and right side of the center of the SE one. In this way a more meaningful comparison between the electromagnetic performances of the two structures can be achieved.
The relevant mixed-mode parameters $S_{\text{mm}}$, in particular $S_{21e}$ and $S_{21c}$, have been computed for the differential structure. Figure 6 shows as the frequency spectrum of $|S_{21e}|$ almost coincides with that of $S_{21}$ for the SE configuration.

This expected result allows one to extend the considerations done in the previous Sections to the (unwanted) common mode components of the differential signal.

Figure 7 compares the frequency spectra of $|S_{21d}|$, $|S_{21cc}|$ and $|S_{21}|$ of the differential μstrip and $|S_{21cc}|$ of the EBG structure.

From Figure 7 one can conclude that the differential transmission properties of the differential line ($S_{21d}$) are not affected at all by the presence of the patterned EBG plane. This is due to the mutual strong electromagnetic coupling with which the differential lines are designed. Conversely, the common mode components along the same line encounters several bandgaps (and their dual passband) in which their transmission is inhibited (or allowed). These bandgaps are strictly correlated to the resonant properties of the EBG structure that, in turn, depends on the geometrical dimensions of the board. Therefore the bandgap of $S_{21cc}$ can be tuned at convenience by changing the board dimensions, and specific harmonic components of the signal filtered out without spoiling the wanted transmitted differential signal.

**EBG STRUCTURES WITHOUT CONNECTING BRIDGES**

The distance of the projection of the μstrip (SE or differential) from the connecting bridges plays a significant role in the performances of the EBG structure. In [9] a systematic analysis of this mechanism has been carried out: the result is that greater distance between the trace and the bridge result in deeper notches in $|S_{21cc}|$.

The distance from the bridges is practically irrelevant for the location in frequency of the notches and peaks. Due to these considerations, the natural extension of this concept is to maximize the distance between the traces and the bridges or, in the extreme, to eliminate the interconnecting bridges. This configuration “without bridges” (w/o bridges) would preclude the use of this structure as part of a power delivery network (PDN) because of the lack of a galvanic connection between parts of the plane.

Three EBG configurations with a SE μstrip line on top are considered: the 3 x 2 and 3 x 4 introduced in “Single Ended Microstrip Over An EBG Plane” and another 3 x 2 (named “large” or “L”) whose dimensions are: a = 18.0 mm, b = 17.9 mm, g = 1.3 mm, w = 0.4 mm, t = 17 μm and d = 0.4 mm. The dielectric above and below the patterned plane has $\varepsilon_r = 4.4$ and $\tan \delta = 0.02$. In Figure 8 the frequency spectrum of $|S_{21}|$ for these three configurations with and without the presence of the bridges are compared.

In these results it is clearly shown that the lack of the bridges increases the stopband properties at low frequency of the cavity formed by the patterned plane and the continuous one, that is, up to 4-5 GHz the transfer of the S-parameter w/o bridge configurations is very small. Just above the bandgap of the configurations with bridges the two $|S_{21}|$ (with and w/o bridges) become very similar.

![Figure 7: Frequency spectrum of $|S_{21d}|$ (dot-dash), $|S_{21cc}|$ (dashed) and $|S_{21}|$ (continue).](image-url)
EMC/EMI
Common Mode Filtering Performances of Planar EBG Structures

At high frequencies, in the ABG region, the dimensions a and b of the single patches dominate the electromagnetic behavior of the structure independently by the presence of the bridges (that being mainly inductive, have associated an impedance that increases with frequency). The very small values of $|S_{pm}^{21}|$ implies a small value of $|E|$ and hence a condition of virtual short circuit between the two planes.

This equipotential condition between the two planes is reflected in a high (almost 0 dB) and flat shape of $|S_{st}^{21}|$, the transfer S-parameter of the µstrip, as shown in Figure 9. By comparing Figure 8a ($\alpha = a, b, c$) with the corresponding Figure 9a, it is evident as the notches in $|S_{st}^{21}|$ for configurations w/o bridges are associated in the ABG region with the peaks of $|S_{pm}^{21}|$, that in turn are related to the dimensions of the single patch of the patterned plane.

CONCLUSIONS

In this work the physical mechanisms governing the functioning of a planar EBG structure are illustrated. In the frequency range BBG the resonances of both $|S_{pm}^{21}|$ and of

![Figure 8: Frequency spectrum of $|S_{pm}^{21}|$ with (continue) and w/o (dashed) bridges for (a) 3 x 2, (b) 3 x 4 and (c) 3 x 2L.](image1)

![Figure 9: Frequency spectrum of $|S_{st}^{21}|$ with (continue) and w/o (dashed) bridges for (a) 3 x 2, (b) 3 x 4 and (c) 3 x 2L.](image2)
Common Mode Filtering Performances of Planar EBG Structures

[S_{si}^{-2}] are associated to the external dimension of the overall EBG board. In the BG region an equipotential condition of the plane implies a $[S_{si}]^{-1}$ very flat and close to 0 dB. The BG ends at the first resonance of the virtual cavity formed by a single patch and its projection on the continuous plane. From this frequency on there is an alternating of peaks and nulls related to the TM resonances of the above mentioned virtual cavity.

From the proposed results it turns out that CM filtering of differential pair signals it is possible and that the notch frequencies of the EBG filter estimated.

ACKNOWLEDGMENT

Authors wish to thank Ing. E. Macera of the UAq EMC Laboratory for his valuable comments and discussions. This work was partially supported by the Italian Ministry of University (MIUR) under a Program for the Development of Research of National Interest (PRIN grant # 2006095890).

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EMI: Why Digital Devices Radiate

by Glen Dash
Ampyx LLC

We will begin with an experiment.

We built the circuit shown in Figure 2. A 6.25” by 4.5” (15.9 cm by 11.4 cm) printed circuit board was constructed with the topside of the board reserved for a V+ plane and the bottom side for a V- plane. A clock oscillator, an Epson SG51P, was placed to one side of the board, spaced 3.75” (9.5 cm) away from a 74HC02 device serving as a load. The power supply consisted of a 9-volt battery feeding a 7805 regulator whose output was loaded with a 10 microfarad tantalum capacitor. Placed beneath the clock oscillator and the 74HC02 device were .02 uF wafer type bypass capacitors from Circuit Components Inc., Part No. 293A14. The board was made out of a phenolic material and was .07” (1.8 mm) thick.

In order to connect the source to the load, a wire was used. It was placed adjacent to the underside of the board. The wire’s conductor was solid copper .03” (.76 mm) in diameter. Its insulation was .015” (.38 mm) thick. A 50 ohm carbon composition resistor was connected immediately to the output of the clock driver. A 50 picofarad capacitor was placed at the input of the 74HC02 device to simulate heavy loading. The clock oscillator had specs typical of a HC device. In order to simulate the effect of radiation of the attached I/O, two telescoping antenna elements were attached to either side of the PCB and were electrically connected only to the V-plane.

Emissions tests were performed at an open field test site. The site had been previously checked against open area test site standards and had been accredited by NIST. Measurements

Figure 1: Here in the simplest of circuits, a clock oscillator drives a load with current returning either through a wire or trace as in (a) or through a return plane as in (b). Both designs can create EMI. Some inductance will exist in the return path causing any wires connected directly or incrementally to it to radiate. A plane has less inductance than a wire or trace, but significant emissions can arise from both designs.
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Figure 2: We assembled and tested this circuit to see if theory would correctly predict observed emissions.
were taken atop a .8 meter wooden turntable which was rotated to detect maximum emissions. As expected, when the attached telescoping antennas were tuned for resonance, maximum emissions at the resonant frequency were observed when the telescoping arms lay parallel to a horizontally polarized antenna. Measurements were performed at a distance of 10 meters and the antenna was raised and lowered to detect maximum emissions over a 1 to 4 meter range.

We began our study by focusing on one frequency, the fifth harmonic of the clock at 125 MHz. The telescoping elements were tuned to resonance at that frequency and left there for the duration of the test. The circuit shown in Figure 2 produced 39.4 dBUV/m of radiation at 10 meters.

Our next task was to explain why this circuit radiates, calculate the predicted radiation and see if it matched our measured results.

It is now well established one mechanism causing radiation at these frequencies is that illustrated in Figure 1. A clock or clock/driver combination serves as a source driving a distant load. The signal produced is a trapezoidal wave (square wave with finite rise and fall times) and the source has an internal resistance, $R_s$, and inductance, $L_s$. The load ($Z_2$ in Figure 1) is a logic gate, which, for MOS based technologies, can be modeled as a capacitance. A series resistance, $R_s$, is sometimes inserted at the source end to suppress ringing.

Theory states that the “driven wire,” that is the wire connecting the source to the load can be characterized as an inductor. Similarly, the return trace (Figure 1a) or plane (Figure 1b) can also be characterized as an inductor at 125 MHz ($Z_3$). A return plane has a considerably lower inductance than a return trace.

If we know the current passing through the return plane or trace, then by using the inductance various models predict we can calculate a voltage drop across the return trace or plane. This voltage drop will drive any wires attached to the return path as if they were antennas. Basically, the return trace or plane serves as a low impedance voltage source driving attached wires. Any wires directly or incrementally connected to the return traces or plane will radiate. In a worst-case scenario, the wires attached to the return trace or plane can be stretched out to form a dipole resonant at one of the harmonics of the clock oscillator. That is what was done here.

A Tektronix CT1 current probe was used to measure the current through the driven wire. The current waveform is shown in Figure 3. The amplitude of the current was also measured by using a spectrum analyzer. At a frequency of 125 MHz the amplitude of the current measured was 2.8 milliamps RMS. (The current probe was removed during EMI testing.)
The inductance of the return plane, according to Kaden as reported by Leferink [1], is:

\[ L_{\text{return plane}} = \frac{\mu_0 l}{2\pi} \left( \frac{d}{w} \right) \text{ Henries} \]

\[ \approx 2 \left( \frac{d}{w} \right) \text{nH/cm} \]

Where:
- \( L_{\text{return plane}} \) = return plane inductance
- \( w \) = width of the plane in meters
- \( d \) = distance between the driven trace and the return plane in meters
- \( l \) = length of the driven trace in meters, \( l >> d \)
- \( \mu_0 = \) permeability of free space = \( 4\pi \times 10^{-7} \) Henries/meter

Hockanson, et al made a slightly different prediction [2]. It is:

\[ L_{\text{return plane}} = k \left( \frac{d}{w} \right) \text{nH/cm} \]

The constant \( k \) is geometry dependent. It is a function of the current distribution in the return plane. Kaden’s formula assumes that the return current spreads out evenly across the return plane. But this is not so. It is now known that the current in the return plane concentrates beneath the driven trace. The constant \( k \) therefore can be difficult to predict. Estimates place \( k \) between 2 and 5.

We’ll use the upper limit of this range, \( k=5 \) to arrive at a worst-case prediction for the radiation. Inserting the values for the circuit in Figure 2 (\( d=7.6 \) mm, \( w=114 \) mm, \( l=9.5 \) cm) yields an inductance value for the return plane of .033 nH/cm or .32 nH in total. At 125 MHz an impedance of \( .25 \) ohms would result due to this inductance. The voltage drop across the return can be readily computed from the measured current at 125 MHz (2.8 milliamps). The voltage across the return, the model predicts, is .07 Volts.

This voltage drives the attached telescoping antenna, the arms of which were adjusted to half wave resonance creating a half wave resonant dipole. We can calculate the predicted free space emissions from a half wave resonant dipole using the following formula [3]:

\[ E(V/m) = 5.5 \frac{G_{\text{ant}}}{r} \frac{V_r}{\sqrt{Z_{\text{ant}}}} \]

\[ E(V/m) = \left( \frac{7}{10} \right) \frac{V_r}{\sqrt{73}} \times 0.082 V_r \]
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Where:

\[ E(V/m) = \text{free space field strength} \]
\[ G_{\text{ant}} = \text{gain of a resonant half wave dipole over isotropic} = 2.1 \text{ dBi} = 1.3 \]
\[ r = \text{distance from the circuit to the measuring antenna in meters} = 10 \text{ meters} \]
\[ V_r = \text{the voltage dropped across the return plane} = 0.07 \text{ Volts} \]
\[ Z_{\text{ant}} = \text{impedance of the radiating antenna} = 73 \text{ ohms for a half wave dipole.} \]

Our model predicts free space radiation of 35.2 dBuV/m at 10 meters.

Testing over a ground plane affects the impedance of the radiating antenna somewhat and provides for ground reflection. As an approximation, we can assume that the net of these effects is to increase emissions by 5 dB at 125 MHz.

Using this adjustment, our model predicts emissions of 40.2 dBuV/m, quite close to the measured value.

Our simple circuit of Figure 2 used solid power planes. Practical power planes, however, are not solid but are interrupted by holes and gaps. Models proposed by researchers predict that emissions will rise dramatically if the return plane is interrupted with a slit as shown in Figure 4. The slit cuts completely through the PCB, interrupting both the V+ and V- planes. It is 0.065” (1.65 mm) wide and extends from one edge of the board to a point 1” (2.54 cm) past the trace. The measured emissions at 125 MHz did rise dramatically, to 59.8 dBuV/m.

Hill, et al., [4] models the increased inductance by analyzing the gap as a shorted transmission line. Dash, et al [5] calculates this inductance to be:

\[ L_{\text{gap}} = \frac{10}{2 + \ln\left(\frac{w}{s}\right)} \text{nH/cm} \]

Where:

\[ w = \text{the width of the plane to the left and right of the slot in meters} \]
\[ s = \text{the width of the slot itself in meters} \]
\[ w >> s \text{ and } L_{\text{gap}} << \lambda \]

Applying this formula to our test circuit \((s=1.65 \text{ mm}, \ w=6.86 \text{ cm})\) and considering that \(L_{\text{gap}} = 2.54 \text{ cm yields a predicted value of return plane inductance of 4.4 nH resulting in predicted emissions of 63.0 dBuV/m at 10 meters. This}}
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Researchers also agree that if the return plane is interrupted by holes rather than a slit, the increased inductance caused by the presence of the holes will increase emissions only slightly. Figure 5 shows the circuit of Figure 2 with holes drilled through the plane, interrupting both the V+ and V- planes. Holes were placed .16” (4.1 mm) center to center and were .125” (3.2 mm) in diameter. No change in emissions was noted at 125 MHz due to the presence of the holes.

Next, we evaluated an unorthodox method for reducing emissions from an imperfect return plane [6]. This method uses a common mode choke located near the clock. In theory, the presence of the common mode choke should force current to return through the return wire, the one that passes through the common mode choke, instead of through the return plane. Even if the return plane was inductive because of the presence of an opening such as a slit, little voltage would be dropped across the return plane simply because the RF current does not pass through it.

We used the circuit of Figure 6. The return plane was gapped as in Figure 4. A twisted pair consisting of 24 AWG magnet wire was passed through two Fair-Rite 2643000801 No. 43 type ferrite beads 1 1/2 times and was then connected the clock and the load. The return wire was connected to the ground plane immediately adjacent to the clock and the load. Emissions fell dramatically at 125 MHz, to 38.7 dBuV/m at 10 meters.

<table>
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<tr>
<th>Test Conditions</th>
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<th>Predicted Emissions (dBuV/m at 10m)</th>
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<td>Solid Return Plane</td>
<td>Figure 2</td>
<td>39.4</td>
<td>40.2</td>
</tr>
<tr>
<td>Slotted Return Plane</td>
<td>Figure 4</td>
<td>59.8</td>
<td>63.0</td>
</tr>
<tr>
<td>Holed Return Plane</td>
<td>Figure 5</td>
<td>40.2</td>
<td>~ 41</td>
</tr>
<tr>
<td>Slotted Return Plane with CM Choke</td>
<td>Figure 6</td>
<td>38.7</td>
<td>-</td>
</tr>
<tr>
<td>Solid Return Plane with CM Choke</td>
<td>N/A</td>
<td>32.7</td>
<td>-</td>
</tr>
<tr>
<td>Clock Running Alone with No Wires Attached</td>
<td>N/A</td>
<td>29.7</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Radiation detected at 125 MHz is shown under varying conditions.
Emissions were then measured using a circuit that employed both a common mode choke, as shown in Figure 6, and the solid ground plane of Figure 2. Emissions fell once again, this time to 32.7 dBiV/m.

As a final test, the connection between the clock and the load was removed so that the clock oscillator could run by itself without any wires attached. At 125 MHz the clock oscillator, operating alone and fed power through solid V+ and V- planes, produced 29.7 dBiV/m of emissions, only 3 dB less than the emissions produced by the use of a combination of a common mode choke and a solid return plane. Data is summarized in Table 1.

So far, so good. Theory works well at 125 MHz. But theory does not work well at the ninth harmonic, 225 MHz (Table 2). In fact, what is remarkable about the 225 MHz data is that it was seemingly unaffected by anything that we did. The logical conclusion to be drawn was that emissions at the higher harmonics were

![Figure 7: Variously called I_{dd} Delta, Idd Noise or “Shoot Through” current, a spike in supply current drawn occurs as a MOS gate changes state.](image)

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not so much due to current on the driven wire but were
due to some internal mechanism in the integrated circuits
themselves.

The integrated circuits used were of the MOS family. Figure 7 shows the basic structure of a MOS device. P channel and
N channel devices serve as switches alternately connecting
the output to V+ and V-, depending on the input voltage. Very
little current flows from V+ to V- when a gate is either in its
high or low state. For example, when the input of a gate is
in its high state, the N channel FET is turned on connecting
the output to V-. The P channel device is in its off state and
presents a very high impedance between V+ and the output.
Therefore, little current flows between V+ and V-. The same
situation is true in reverse when input is low and the output
is high. In the transition region, however, current does flow
from V+ to V-. This current is a function of input voltage, and
is shown in Figure 7. It peaks somewhere in the middle of
the input voltage range, and is known as “I_{dd} Delta,” “I_{dd} Noise”
or sometimes as “shoot through” current.

Figure 8 shows the spike in supply current caused by I_{dd} Delta creates a current flow
through the return plane.

The effect of I_{dd} Delta is to produce a
very brief current pulse every time the
gate changes state. The net result is a
current pulse on the supply planes of
approximately 1 milliamp peak and about
1 nanosecond in width each time a typical
74HC02 gate switches.

Unfortunately, the amount of radiation we
can expect due to I_{dd} Delta can be difficult
to predict. For one thing, manufacturers
rarely cite I_{dd} Delta in their data sheets.
For another, I_{dd} Delta is highly variable.
Among other things it is a function of the
supply voltage, varying as a function of
V_{cc} to the 2.2 power. [7].

Figure 8 shows how this current pulse turns
into a voltage across the return plane.
I_{dd} Noise current mostly passes through
any bypass capacitor immediately adjacent
to the integrated circuit. However, the
impedance of that capacitor is finite, and
some of the current is fed back through the
supply planes. This creates a noise voltage
due to the impedance of the return plane.

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Figure</th>
<th>Measured Emissions (dBuV/m at 10m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Return Plane</td>
<td>Figure 2</td>
<td>50.2</td>
</tr>
<tr>
<td>Slatted Return Plane</td>
<td>Figure 4</td>
<td>51.2</td>
</tr>
<tr>
<td>Holed Return Plane</td>
<td>Figure 5</td>
<td>50.1</td>
</tr>
<tr>
<td>Slatted Return Plane with CM Choke</td>
<td>Figure 6</td>
<td>49.6</td>
</tr>
<tr>
<td>Solid Return Plane with CM Choke</td>
<td>N/A</td>
<td>50.1</td>
</tr>
</tbody>
</table>

**Table 2:** Radiation detected at 225 MHz under varying conditions is shown. Unlike the radiation detected at 125 MHz, the changing conditions did not affect the radiation at 225 MHz significantly.

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Circuit of Figure 4</th>
<th>Circuit of Figure 9b</th>
<th>Reduction (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>41.3</td>
<td>27.3</td>
<td>14.0</td>
</tr>
<tr>
<td>125</td>
<td>59.8</td>
<td>31.2</td>
<td>28.6</td>
</tr>
<tr>
<td>175</td>
<td>53.4</td>
<td>34.3</td>
<td>19.1</td>
</tr>
<tr>
<td>225</td>
<td>51.2</td>
<td>33.6</td>
<td>17.6</td>
</tr>
<tr>
<td>275</td>
<td>33.8</td>
<td>27.8</td>
<td>6.0</td>
</tr>
<tr>
<td>325</td>
<td>48.4</td>
<td>22.7</td>
<td>25.7</td>
</tr>
<tr>
<td>375</td>
<td>48.4</td>
<td>&lt;20</td>
<td>&gt;28.4</td>
</tr>
<tr>
<td>425</td>
<td>39.4</td>
<td>&lt;20</td>
<td>&gt;19.4</td>
</tr>
<tr>
<td>475</td>
<td>37.3</td>
<td>&lt;20</td>
<td>&gt;17.3</td>
</tr>
<tr>
<td>525</td>
<td>31.7</td>
<td>&lt;20</td>
<td>&gt;11.7</td>
</tr>
</tbody>
</table>

**Table 3:** Reductions in Emissions (dB/uV at 10m)

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Figure 9: A small pi filter on the supply of the 25 MHz clock as shown in (b) dramatically reduced radiation at 225 MHz. Even a short length of wire as shown in (c) significantly reduced radiation by forming an LC filter. The filter works by reducing $I_{dd}\Delta t$. 
As mentioned, our test circuit already had wafer type capacitors placed immediately below the ICs. So as a further experiment, we isolated the V+ pin (pin 14 on both devices) from the V+ plane. A wire was connected as shown in Figure 9c. Although identical on a schematic, this configuration provided some filtering because of the wire’s inductance. Test results show a reduction of 9 dB at 225 MHz. The next step was to add a second bypass capacitor as shown in Figure 9b (a 1000 picofarad surface mount multilayer type) and to replace the wire with a surface mount device designed to increase series impedance over a wide frequency range. A TDK MMZ2012S301 was chosen which, according to the manufacturer’s data sheet, exhibits an impedance of greater than 300 ohms at the frequencies of interest. An additional reduction of more than 19 dB was noted.

Table 3 demonstrates the results of our efforts. Note that improvement was achieved without using any filtering near our “I/O” (telescoping elements) or shielding.

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Glen Dash is the author of numerous papers on electromagnetics. He was educated at MIT and was the founder of several companies dedicated to helping companies achieve regulatory compliance. Currently he operates the Glen Dash Foundation which uses ground penetrating radar to map archaeological sites, principally in Egypt.

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Know The Theory of Partial Inductance to Control Emissions

by Glen Dash
Ampyx LLC

The theory of partial inductance is a powerful tool for understanding why digital circuits radiate and in designing strategies to mitigate this radiation. In fact, it can be fairly said that nothing is more central to understanding EMI phenomena than understanding the theory of partial inductance.

We will begin with the classic definition of inductance. Inductance is defined as the ratio of magnetic flux that passes through a surface bounded by a closed loop to the magnitude of the current generating that flux. Mathematically:

$$L = \frac{\psi}{I}$$

Where:
- \(L\) = Inductance in Henries
- \(\psi\) = Magnetic flux through a surface bounded by a closed loop
- \(I\) = Current generating \(\psi\) in Amps

The “surface bounded by a closed path” could be any surface, but often what is meant is the area enclosed by a planar wire loop. Strictly speaking, inductance is only defined for closed paths, that is complete loops. However, physicists have found it useful to assign a partial inductance to portions of a loop. The concept is illustrated in Figure 1. Current flowing in a loop creates a magnetic field passing through a surface bounded by the loop itself. That allows calculation of the loop’s inductance from Equation 1. In order to assign a partial inductance to a portion of a loop, the flux that is generated by the current in the portion of the loop is calculated and the portion is assigned a partial inductance.

Figure 1: A loop of wire carrying current \(I\) has an inductance equal to the ratio of the magnetic flux through the loop divided by the current. Here, lines of flux are shown either as moving into the plane of the page (cross within a circle) or out of it (dot within a circle). A portion of the loop can be assigned a partial inductance by calculating the flux through the pie shaped area outside the loop.
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Figure 2: The return plane has a partial inductance and therefore will exhibit a voltage drop $V_r$ across it. This voltage drop causes wires connected to the return to radiate.

Figure 3: The partial inductance of a straight segment of wire can be calculated by taking the flux through the shaded area and dividing it by the current.

Figure 4: A pair of wires (a) carrying opposing currents will produce opposing fields in the shaded areas. Taking the net flux through the shaded area above wire 1 and dividing by the current on wire 1 allows us to compute the “total” partial inductance of that segment of wire 1. In the same manner, the partial inductance of a segment of a return plane can be calculated by taking the flux through the shaded area below the plane as in (b) and dividing by the current passing through the plane.
inductance to a portion of the loop, we can divide the loop into segments and, with a fair degree of physical accuracy, state that each segment has its own partial inductance. Adding the partial inductances of the segments together equals the total inductance.

To assign a partial inductance to a segment of a loop, the segment is identified and then an area, either inside or outside the loop, is assigned as shown in Figure 1. Measuring the total flux through either of these areas and dividing it by the current in the segment yields the partial inductance. Usually the area outside the loop is used.

The concept of partial inductance is useful for solving problems that would otherwise seem intractable. Take, for example, the calculation of the inductance of a single straight, infinitely long wire. In theory, only loops have inductance. Nonetheless, we have all experienced situations where a wire seems to have an inductance per unit length even where the current loop seems impossible to define. Using the concept of partial inductance, however, we calculate the drop expected per unit length of wire due to inductance (Figure 3). The flux through the area shown in Figure 3 – which is defined as a surface of infinite length perpendicular to a selected segment of the wire – divided by the current in that segment yields the partial inductance.

So far we have been talking about the inductance of a single wire isolated in space. Wires however, are rarely so isolated. Take, for example, the two parallel wires shown in Figure 4. Here, the partial inductance of a segment is due both to the flux generated by the current flowing in wire 1 and the flux generated by the current flowing in wire 2.

$$L_{p \text{tot}} = L_{11} - L_{12}$$

Where:

$L_{p \text{tot}}$ = “Total” partial inductance of a segment of wire 1.

$L_{11}$ = Partial inductance of wire 1 due to the flux generated by the current on wire 1.

$L_{12}$ = Partial inductance of wire 1 due to the flux generated by the current on wire 2.

$L_{11}$ is known as the self partial inductance. The term $L_{12}$ is known as the mutual partial inductance. The total partial inductance of a

Figure 5: An ideal shielded cable (a) exhibits no return inductance. However, all practical shielded cables have some flux leakage (b). The flux around the shield causes it to exhibit an inductance and a voltage drop as shown in (c). This voltage drop can cause the shield to radiate.

Figure 6: An open wire transmission line produces a classical dipole like magnetic flux pattern as shown in (a). The pattern produced by a wire over an infinite return plane (b) is the same (at least above the plane).
Know The Theory of Partial Inductance to Control Emissions

The sign on the right side of this equation is a function of the direction of the current in wire 2. If the current in wire 2 flows in the same direction as the current in wire 1 then the equation becomes:

\[ L_{p_{\text{tot}}} = L_{11} + L_{12} \]

The effect of wire 2 is then to raise the inductance of wire 1.

For symmetrical structures such as the two wires of Figure 4(a), the calculation of partial inductance is straightforward. For structures that are not symmetrical, however, such as the classic case of a wire over a plane (Figure 4(b)), the calculations become considerably more complex. Nonetheless, some important insight can be gained by keeping these things in mind:

1. The total inductance of any loop can, by definition, be calculated by taking the flux through a surface bounded by the loop and dividing it by the current.

2. The partial inductance of a segment of a signal wire (Figure 4(b)) can be calculated by mapping a rectangular area outside the loop formed by the signal wire and the plane as shown. Calculating the flux in this area and dividing by the current yields the partial inductance of that segment.

Figure 7: Real return planes are finite in size, so some flux leaks around the edges of the return plane, accounting for its partial inductance.

Figure 8: Some common geometries. The return partial inductance is tabulated for each in Table 1.

Figure 9: Gaps (a) and holes (c) can raise the return plane’s impedance. Figure 9 (b) is a side view of the arrangement.
3. The partial inductance of a segment of the return plane is calculated by identifying a rectangular area beneath the return plane and calculating the flux through it. That flux divided by the current yields the partial inductance of that segment of the plane.

The larger the return plane’s partial inductance, the greater the radiation that is likely to result. Consider the case of a digital clock driving a load (Figure 2). Any inductance in the return plane will cause a voltage drop across it. That voltage will cause wires attached to the return plane to radiate like an antenna. Neglecting resistances, the voltage drop is equal to:

\[ V_r = j \omega L_p I_r \]

Where:
- \( V_r \) = Voltage dropped across the return plane
- \( \omega \) = Frequency in radians per second = \( 2\pi f \)
- \( L_p \) = Partial inductance of the return plane
- \( I_r \) = Current through the return plane

Controlling the partial inductance of the return plane is therefore of great importance in controlling emissions. Making the return plane infinitely wide will result in a return plane partial inductance of zero. An infinitely wide return plane will prevent any lines of magnetic flux from passing through it.

Note that the same logic applies to the case of the ideal shielded cable (Figure 5(a)). Here, all the lines of flux created by the center conductor are trapped within the shield. No lines of flux extend beyond the shield and therefore the partial inductance of the shield is zero. The center conductor, through the sum of its partial inductances, represents all the inductance of a circuit formed by the center conductor and the shield.

In the case of a shielded cable, any flux that is lost (that is, which circulates around the shield rather than within it) accounts for partial inductance of the shield and will result in a voltage drop across a portion of the shield. That voltage will drive the rest of the cable, and devices attached to it, as if they were antennas. The same concept of “lost flux” can be applied to the case of a wire over a plane. Flux that wraps around the plane is essentially lost and minimizing this lost flux is a key to minimizing the voltage drop across the plane (Figure 7).

In a 1995 paper [2] Leferink tabulated the predicted partial inductances of the return conductors in various circuits (Figures 8 and 9 and Table 1). To make things manageable, Leferink had to make a number of assumptions. These were:
1. All of the marked dimensions in Figures 8 and 9 are considered to be small compared to the wavelength of interest.

2. The current distribution in the signal conductor (or to use Leferink’s terminology, the Flux Generating Conductor, FGC) is considered to be uniform.

3. The length of any transmission line formed is much greater than all the other dimensions.

4. The radius $r$ where shown or the thickness $t$ are considered to be equal for the signal conductor and the return conductor.

The formulas allow us to predict, to at least a first approximation, the partial inductance associated with some common geometries. Take, for example, a trace suspended above a plane (Figure 8(c)). The formulas predict that the effective inductance falls as the width of the plane is increased. We also can calculate the effect of moving a signal conductor closer to the edge of a plane (Figure 8(d)). Here the formulas predict that the inductance of the return plane will rise as the signal conductor gets closer to the edge of the plane. However, this rise is small until the signal conductor gets quite close to the edge (Figure 10).

<table>
<thead>
<tr>
<th>Description of Circuit</th>
<th>Figure</th>
<th>$L_{p}$—Partial Inductance of Return</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal Shielded Cable</td>
<td>5(a)</td>
<td>0</td>
<td>Ideal Case</td>
</tr>
<tr>
<td>Open Wire Transmission Line</td>
<td>8(a)</td>
<td>$\frac{\mu l}{2\pi} \ln \left( \frac{d}{r} - 1 \right)$</td>
<td>Radii equal</td>
</tr>
<tr>
<td>Traces Side by Side</td>
<td>8(b)</td>
<td>$\frac{\mu l}{2\pi} \ln \left( \frac{1+\frac{\pi}{2}w+t}{1-\frac{\pi}{2}w+t} \right)$</td>
<td>Edge effects ignored</td>
</tr>
<tr>
<td>Microstrip</td>
<td>8(c)</td>
<td>$\frac{\mu l}{2\pi} \ln \left( \frac{w+t+\pi\left(d-\frac{t}{2}\right)}{w+\left(1+\frac{\pi}{2}\right)t} \right)$</td>
<td>After Leferink (Ref. 6)</td>
</tr>
<tr>
<td>Microstrip</td>
<td>8(c)</td>
<td>$\frac{\mu l}{4\pi} kd \quad 2 \leq k \leq 5$</td>
<td>After Hockanson (Ref. 7)</td>
</tr>
<tr>
<td>Offset Microstrip</td>
<td>8(d)</td>
<td>$\frac{\mu l}{2\pi} \left( \frac{1}{w} \right) \int_{x_1}^{x_2} \left( \arctan \frac{q}{x} + \arctan \frac{w-q}{x} \right) dx$</td>
<td></td>
</tr>
<tr>
<td>Stripline</td>
<td>8(e)</td>
<td>$\frac{\mu l}{2\pi} \left( \frac{d}{b} \right) \ln \left( \frac{\pi d}{w+1} \right) - \ln \left( \frac{\pi d + w}{\pi d + w} \right) + \frac{b-d}{b} \left[ \ln \left( \frac{\pi(b-d) + w}{w + 1} \right) - \ln \left( \frac{\pi b + w}{\pi b} \right) \right]$</td>
<td>After Buesink (Ref. 4)</td>
</tr>
<tr>
<td>Return Plane with Gap</td>
<td>9(a), 9(b)</td>
<td>$L_{plane} + \frac{\mu l}{2\pi} \ln \frac{g}{t}$</td>
<td>$g \geq d$</td>
</tr>
<tr>
<td>Return Plane with Holes</td>
<td>9(b), 9(c)</td>
<td>$L_{plane} + \frac{\mu r^3}{3\pi^2 d^2} \sqrt{\frac{t}{r}}$</td>
<td>After Kaden (Ref. 5) $v =$ holes per unit length</td>
</tr>
</tbody>
</table>

**Table 1**

*Note: $l$ in the equations above is the length of the return or a portion of the return. It does not appear in Figure 8. Inductances are in Henries. In terms of inductance per unit length, the term $\frac{\mu}{2\pi} = 2nH/cm$. [2]*

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Finally, we can use the formulas to predict the increase in a return plane’s inductance due to holes or a gap in the return plane. For a gap whose dimensions are \( l = 10\,\text{mm} \), \( g = 50\,\text{mm} \) and \( t = 0.035\,\text{mm} \), \( L_{\text{gap}} = 14.5\,\text{nH} \). For a plane studded with holes of \( r = 1\,\text{mm} \) and \( d = 1.6\,\text{mm} \), each hole over which the signal wire passes will contribute 17 \( \mu \text{H} \). Small holes in the return plane do not tend to increase inductance markedly, though gaps do.

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**Figure 10:** Moving a trace towards the edge of a return plane raises its inductance.

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Inadvertent magnetic and electric field coupling among circuits limits the dynamic range of amplifiers, lowers noise margins and creates unwanted noise. While every engineer knows that shielding can prevent coupling, for many shielding is a vaguely understood concept. Perhaps part of the reason is the way that shielding concepts are traditionally taught – physicist’s concept of fields and flux is usually used. It is possible however to explain shielding theory using more familiar circuit concepts.

For example, Figure 1(a) shows a circuit in which an alternating current electric field is created between two plates called the “source” and “receptor” plates respectively. A voltage source is shown connected to the source plate through impedance $Z_1$. The electric field produced is coupled capacitively to the receptor plate. Coupled voltages create coupled currents which flow through $Z_2$.

We can provide a shield by placing a metal plate between the two plates as shown in Figure 1(b). If the plate is large enough it will intercept the bulk of the electric field lines between source and receptor plates. The circuit equivalent is shown in Figure 1(c). If impedance $Z_3$ is low enough, little voltage will be transmitted from the voltage source to the load $Z_2$.

For electric shielding to be effective two factors must be present. First, as noted, the shield has to be physically large enough to intercept most of the flux between source and receptor. A shield completely surrounding the source or receptor works best. Partial shields like that shown in Figure 1(b) can often be effective, but must be connected to either the source or a load return to work. Secondly, impedance $Z_3$ has to be small enough to shunt currents away from the load.

**Figure 1:** Electric field coupling is capacitive in nature. Placing a metal plate between the source and receptor interrupts the capacitive coupling. To be effective the shield plate must be large enough to intercept substantially all the flux generated by the source and must be connected to either the source or receptor circuit through a low impedance connection.
Magnetic shielding operates through a different principle illustrated in Figure 2(b). There a highly conductive metal plate is placed between a source and receptor coil. The changing magnetic flux created by the source coil creates circulating currents in the shield known as eddy currents. If the shield is conductive enough, the frequency high enough, and shield large enough, these eddy currents will cancel the source field at the shield’s surface. The “skin effect” keeps the magnetic field from penetrating very far into the shield.

The circuit equivalent is shown in Figure 3. The shield can be thought of as a kind of shorted secondary, shorting out signals that otherwise would be coupled to the load, $Z_2$.

To be effective, magnetic field shields of this type must be large enough to intercept substantially all the lines of flux between source and receptor. They also must have low impedance. For example, if the shield in Figure 2(b) was split down the middle there would very little shielding effect. Currents attempting to circulate would not be able to cross the split portion of the shield and would not be able to create a magnetic field sufficient to cancel the source field at its surface. This would be equivalent to replacing $Z_1$ in Figure 3 with an open circuit. Anything which raises the surface resistivity or increases the inductance of the shield will also limit its effectiveness. Along with splits in the shield, long thin gaps in the shield can have this effect.

Figure 2: This magnetic field shield relies on the generation of eddy currents within the metal plate to cancel the source field at its surface and prevent it from coupling to the receptor coil.
As with electric field shields, best performance requires a shield that completely encloses the source or receptor. However, as the circuit models make clear, magnetic shields do not have to be connected back to the source or load to be effective unless, as described below, such connections are required to provide the complete current loop needed for flux cancellation.

The application of these principles to wire shielding is illustrated in Figure 4. Figure 4(a) shows two wires over a common ground plane. Currents in the source wire can couple electrically (capacitively) and magnetically (inductively) to the receptor wire. To provide for electric field shielding it is only necessary for the shield over the receptor wire to be connected to a return at one end. To provide magnetic shielding, however, connections at both ends are required in order to provide for the “shorted secondary” effect.

Keep in mind that we are dealing with near field effects here. Circuit models of this sort are really only useful when the source and receptor are near one another. Where they are not, simple plates will rarely do the job -- far fields just bend right around them. For effective far field shielding, one really has no choice but to completely enclose the source or receptor in a conductive box.

Glen Dash is the author of numerous papers on electromagnetics. He was educated at MIT and was the founder of several companies dedicated to helping companies achieve regulatory compliance. Currently he operates the Glen Dash Foundation which uses ground penetrating radar to map archaeological sites, principally in Egypt.

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Figure 3: The magnetic field shielding employed in Figure 2 can be understood using the “shorted secondary” concept.

Figure 4: Here we apply the principals of electric and magnetic shielding to the case of a wire suspended over a return plane. An electric field shield only requires a grounded connection at one end, whereas a magnetic field shield must be connected at both ends to be effective.
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- Custom Electronic Components Shielding
- Prototyping
- Manufacturing Capabilities
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- Design Capabilities
- Performance Testing
- Production Capabilities
Minimizing Ringing and Crosstalk

by Glen Dash
Ampyx LLC

When viewed on a schematic, a wire is just a wire. However, when risetimes shrink to a few nanoseconds or less, wires become radiators. To conduct signals with good fidelity at these speeds, wires should be paired with their returns, forming transmission lines.

A wire over a return plane forms a kind of transmission line known as a microstrip. A trace between two planes forms a stripline. Both must be well designed to avoid ringing and crosstalk. To avoid ringing, impedances must be matched. To avoid crosstalk, spacings must be selected with care. Even in an age of automated routing checks and signal integrity software, controlling ringing and crosstalk is part science, part art.

Transmission line effects become significant when the trace is long enough, or the risetime is fast enough, for propagation times to be significant. One oft-cited rule of thumb states the following [4]:

Maximum Length for a Microstrip = 9 × tᵣ
Maximum Length for a Stripline = 7 × tᵣ

Where:
Maximum Length = Maximum length of the trace in centimeters before transmission line effects must be considered.
tᵣ = Risetime in nanoseconds

### Calculation

<table>
<thead>
<tr>
<th>For a Microstrip:</th>
<th>[ Z₀ = \frac{87}{\sqrt{εᵣ} + 1.41} \ln \left( \frac{5.98H}{.8W + T} \right) ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₀ = ( \frac{.67(εᵣ + 1.41)}{\ln \left( \frac{5.98H}{.8W + T} \right)} )</td>
<td></td>
</tr>
</tbody>
</table>

For an Embedded Microstrip:

Where: \( r' = r \left( 1 - e^{-\left( \frac{1.55H}{H} \right)} \right) \)

| C₀ = \( \frac{1.41r'}{\ln \left( \frac{5.98H}{.8W + T} \right)} \) |

<table>
<thead>
<tr>
<th>For a Stripline:</th>
<th>[ Z₀ = \frac{60}{\sqrt{εᵣ} \ln \left( \frac{1.96(2H + T)}{.8W + T} \right)} ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₀ = ( \frac{1.41εᵣ}{\ln \left( \frac{3.81H}{.8W + T} \right)} )</td>
<td></td>
</tr>
</tbody>
</table>

Notes: \( Z₀ \) is in ohms, \( C₀ \) is in pf/inch. See Figure 2 for dimensions.

**Table 1: Characteristic Impedances of Microstrips and Stripes**

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For a risetime of .9 nsec, this translates to 8.1 cm for microstrips and 6.3 cm for striplines. Since it is rarely possible to keep all traces so short, impedances need to be matched to control ringing.

One of these four impedance-matching methods are generally applied:
1. Series termination in “standard” or “star” topography,
2. DC parallel termination,
3. AC parallel termination, or
4. Diode termination.

Of these, series termination is the clear favorite among digital hardware designers. Its advantage is in its simplicity. Its chief disadvantage is in its implementation. Accurately calculating a real-world transmission line’s impedance can be tricky.

DC parallel termination is a modern name for the traditional impedance matching topology used by communications engineers. Conceptually, it is the most straight-forward. A load impedance is chosen to match the impedance of the transmission line. For logic circuits, however, DC parallel termination has significant disadvantages and is rarely used. It lowers the impedance as seen from the driver and increases power dissipation.

AC parallel termination solves some of these problems. Its chief disadvantage is in its need for a capacitor at the load end.

Diode termination works as follows. Since the impedance of a diode changes dynamically with current, it is possible to dynamically match the impedance of a transmission line. In practice, however, diode termination can be difficult to implement. Very fast diodes are required and nonlinear effects can be generated.

For topologies other than diode termination, proper implementation requires that the transmission line impedance be known. Handbook formulas such as those shown in the table provide insight, but in practice are often inadequate. For example, author Douglas Brooks points out that the formula for an embedded microstrip shown in Table 1 can only be considered reliable if the same dielectric material is used both

---

**Figure 1:** Of the topologies available to designers, the series termination is a clear favorite among digital designers. A “star” topology can be used to drive widely spaced loads.

**Figure 2:** Transmission line types commonly used in PCB designs. For characteristic impedance and capacitance per unit length, see Table 1. [2]
above and below the signal trace, and if the dielectric above the trace is more than 4 mils thick. Similar limitations apply to the other formulas.

Fortunately, software is widely available that takes such matters into consideration. For freeware versions, check out Polar Instrument’s site at www.polarinstruments.com, designer Barry Olney’s site at www.icd.com.au, or UltraCad Design’s site at www.ultracad.com.

Once the characteristic impedance has been established, the topology best suited for implementing series termination depends on (1) the number of loads driven and (2) their physical proximity. When a single driver is driving a single load or a group of loads placed in close proximity the matching resistor (R) should be equal to the characteristic impedance (Z₀) minus the resistance of the driver (RΩ). (Typical trace impedances are 60 to 100 ohms, and driver impedances, 2 to 20 ohms.) Where loads are widely separated, a scheme known as “star routing” can be used which places a separate resistor in each line (Figure 1). Note that the impedance as seen by the driver is equal to impedance of all the connections in parallel. In order to prevent excessive loading, the parallel impedance of all these traces must be much greater than the output impedance of the driver. Drive limitations can crop up even when relatively few branches are used, and well before the device’s fan out is reached.

Predicting exactly what happens to a transmitted pulse when series termination is used can be complex. Motorola provides a useful reference [6]. Since series termination matches the source end of the line, pulses sent down the line are reflected and absorbed at the source end. Because of that, a type of distortion known as “stair casing” is inherent in the design and must be kept within acceptable limits.

Crosstalk is a primarily near field phenomenon. Depending on the relative placement of “source” and “victim” traces, it can be analyzed primarily as an electric field problem (voltage driven, capacitive in nature) or a magnetic field problem (current driven, inductive in nature). As a general rule, traces placed one over another will primarily exhibit capacitive coupling, whereas two traces placed side by side primarily couple magnetically. We will refer to the two as examples of “capacitive” and “inductive” crosstalk respectively.

Capacitive crosstalk is the easiest grasp. The two traces form a capacitor. Minimizing problems means minimizing the size of the capacitor. Therefore, high-speed traces on adjacent layers of a printed circuit board should not be run one on top of the other. Such traces, if crossed at all, should cross at right angles, limiting the area of the capacitor formed.

Two traces placed side-by-side as in Figure 3(b) form a kind of transformer. The magnetic field produced by one couples to the other. The coupled signals travel down the victim line both toward the load and backwards toward the source. In practice, it is the “backward crosstalk” that generally proves to be the most troublesome.

The degree of inductive crosstalk experienced is largely due to three factors: (1) the common length of the two traces, (2) the edge-to-edge separation between traces, and (3) the distance between the traces and the nearest power plane.
Obviously, the most straightforward method of reducing inductive crosstalk is to shorten the common length among any two traces. But this solution is often not as practical as it at first might seem. To see why this is so, think of the two traces as two windings on a transformer. The coupling between the driven and victim line is analogous to the coupling coefficient of a transformer. As a practical matter, this coupling coefficient gets near unity for closely spaced, parallel traces even if they run parallel for only a few inches. Once the coupling is at unity, making the traces longer will not hurt much. Conversely, making them slightly shorter will not help much either. The common length at which coupling approaches unity is known as the “critical length” or the “saturation point.”

Because the critical point is reached so readily, it is often more practical to focus on two other factors which affect inductive crosstalk, the spacing between the traces and their height above the nearest power plane. We will want to keep coupling below a permissible level, say 5% for TTL to TTL coupling. Figure 6 can be used as a guide. For example, if the height above the nearest ground plane is 5 mils, use a trace-to-trace separation of approximately 15 mils. If the height is 10 mils, the trace-to-trace separation will have to be closer to 30 mils.

The amount of coupling allowed should be tailored to the technology used. Five percent is usually sufficient when both the victim line and the driven line are MOS, or both are TTL. In the case of mixed logic, such as when a MOS line runs parallel to an ECL or PCI bus, less coupling should be allowed. [3]

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Figure 5: The “critical length” for two closely spaced parallel traces is the common length at which the coupling coefficient is close to one. Beyond this point, making the common length longer will not make things worse, nor will shortening the traces slightly make things much better. Therefore, it is often better to concentrate on the trace-to-trace spacing and the distance above the nearest power plane as illustrated in Figure 6. [3]

Figure 6: Once the height above the nearest power plane is known, trace to trace spacing can be selected to reduce coupling to an acceptable level. [3]
Do you supply products into Europe? If you supply products that come within the scope of the EMC Directive 2004/108/EC, the application of harmonized standards provides the simplest means of demonstrating conformity with the protection requirements (emission and immunity) of the Directive.

This article will provide you with essential information on the selection and use of the appropriate standards for your product.

**HOW DO STANDARDS AND DIRECTIVES INTERACT?**

Directives such as the EMC Directive are so called “new approach” directives. These were introduced from 1985 onwards as a means of speeding up the creation of technical requirements that could be applied throughout Europe. Before that date the regulations contained all the technical requirements for products within their scope. Agreeing on these requirements was a lengthy process, and the legislation was inflexible, incapable of responding quickly enough to technical innovation.

New approach directives set out only the essential requirements in general terms; the technical requirements are contained in harmonized standards that underpin them. However, an important feature of new approach directives is that the use of harmonized standards is always voluntary. The manufacturer can demonstrate conformity with the essential requirements by other means provided that they justify their approach in technical documentation that shows the technical analysis that they have followed.

Most manufacturers apply the requirements of the harmonized standards because they define the technical requirements clearly and are the equivalent of carrying out the electromagnetic compatibility assessment required by the EMC Directive. They also have the advantage that compliance in full with the requirements of all the relevant harmonized standards provides a "presumption of conformity" with the essential requirements of the directive. This means that the market surveillance authorities must presume that a product that is stated to meet the requirements of the harmonized standards meets the technical requirements of the directive, and they cannot remove products from the market unless they can demonstrate that a product does not comply. Where the harmonized standards have not been applied in full, this presumption does not exist.

**WHAT IS A HARMONIZED STANDARD?**

Europe has a series of standards prefixed “EN” - European Norm. These are written by the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI). The vast majority of ENs that are relevant for the EMC Directive are produced by CENELEC.

Harmonized standards are ENs produced by CEN, CENELEC or ETSI, following a mandate issued by the European Commission, for use with one or more directives. The lists of harmonized standards suitable for each Directive are published from time to time in an official publication called the Official Journal of the European Union, often referred to as “the Official Journal” or “the OJ".
This article will describe the application of the standards produced by CENELEC to products in order to meet the requirements of the EMC Directive. The principles for the standards produced by CEN are similar. ETSI standards are produced entirely in Europe and do not have international equivalents.

WHY DOESN’T EUROPE USE INTERNATIONAL STANDARDS PUBLISHED BY IEC?

The majority of ENs are not written exclusively in Europe, but are based on international standards; in many cases the technical content is identical. In the case of CENELEC in 2008, 78.1% of standards published were identical to IEC standards (including CISPR) and a further 4.5% were based on IEC standards (including CISPR), with some modification for European requirements.

An agreement between CENELEC and IEC ensures that any new standardization work required to be produced by CENELEC is first of all offered to IEC, to allow an international version to be produced. CENELEC then takes the text of the international standard in order to produce the EN. Only if IEC rejects the offer, or cannot complete the work to required deadlines, does CENELEC work on the production of the standard.

European legislation is constructed in a manner that requires harmonized standards setting out the technical requirements of a directive to be voted on as European standards. As a consequence, international standards are subject to two votes in Europe, once as the international standard and once as the EN. If both votes are positive, two versions of the same standard are published, the IEC and the EN.

If the international vote is positive, but the voting in Europe shows that there is insufficient support for publication as an EN, then changes are made to the requirements in the EN until a positive vote is achieved. These differences are called “common modifications”. Common modifications may consist of addition of, deletion of, or changes to requirements or test methods.

Another reason why the EN version is published is that IEC standards are recommendations that come into effect immediately; the superseded standard is withdrawn when the new version is published. If this were to have the legal status of a harmonized standard, the change in requirements would be too abrupt to allow industry time to adapt their products to the new requirements. The European versions have a (usually) three year transition period from the date the standard is ratified to the date that the superseded standard is withdrawn. This period applies to all types of standards, and the date of withdrawal of the superseded standard is published inside the front cover of the EN standard. In the case of harmonized standards listed in the Official Journal, the date published in each list in the OJ becomes the relevant date in respect of the application of the standard under that particular directive.

TYPES OF STANDARDS

EMC standards are of several different types: product, product family, generic and basic. Product and product family standards define the requirements and test methods for a small range of products. Generic standards define the requirements and test methods for those product types that are not covered by the more specific product and product family standards. Generic standards are based on types of environment rather than product categories. Finally, basic standards set out test methods or provide guidance and background information. They may contain recommendations but do not set absolute requirements. Consequently, basic standards do not of themselves provide a presumption of conformity. Rather they provide standardized test methods that can be referenced from the other standard types.

HOW TO SELECT HARMONIZED STANDARDS - THE LIST IN THE OFFICIAL JOURNAL OF THE EUROPEAN UNION

The latest list of harmonized standards that provide a presumption of conformity under the EMC Directive (at the time of writing this article) is available in PDF format at this link (www.incompliancemag.com/link/1001_100) although there has been a change in the date in respect of the 1998 edition of EN 55022 (www.incompliancemag.com/link/1001_101).
EMC Standards from a European Perspective

It will be seen that there are four columns in the table, and that there is an entry for each standard, with any amendments being identified separately. The first column identifies the standardization body that publishes the standard. The second column provides the number and title of the standard. Where the standard is based on an international standard the number is shown in brackets below the title. Where the EN contains common modifications, “modified” is shown.

The third and fourth columns deal with the editions of the standards and amendments that provide a presumption of conformity. For each standard or amendment, the third column lists the standard that is superseded by that standard or amendment. Often, in the case of a new edition of the standard, the superseded standard is the previous edition of the standard and any amendments to it, but it can be the relevant generic standards where a new standard is published that covers products that were not previously within the scope of a product or product family standard.

Amendments are dealt with separately, so for example the superseded standard in the case of an amendment 2 is the standard with its amendment 1. Amendment 2 of the standard has to be applied with effect from the date given for the presumption of conformity to be valid.

The fourth column, entitled “date of cessation of presumption of conformity of the superseded standard” provides the relevant dates. The date is chosen by the Commission; it is generally the same as the date associated with the three year transition period set by CENELEC, but is some exceptional cases it is different. The date listed in this column is definitive in respect of the legal position on whether the correct edition of a standard has been selected. In cases where the date of cessation is earlier than the date that the list was published, it is shown as “date expired” and the relevant date is shown in brackets.

Notes to the list explain the requirements in particular circumstances and in contrast to notes in standards, these notes have legislative effect.

**DETERMINING WHICH STANDARDS ARE RELEVANT**

The selected harmonized standards should make a complete provision for emissions and immunity, at both high and low frequencies. In selecting standards from the list in the OJ, the manufacturer should be aware that more specific standards take precedence over more general standards and that the harmonics and flicker standards, EN 61000-3-2 and EN 61000-3-3 respectively, apply to all products intended for connection to the public low-voltage mains electricity supply.

An important principle is that the intended function and use of the equipment determines the standard(s) that should be applied, not the technology employed. Therefore, although a washing machine may contain a microprocessor for controlling its operation, it remains a domestic appliance, and is therefore within the scope of the standards EN 55014-1 and EN 55014-2, and not EN 55022 and EN 55024.

In general, the scopes of the product standards are mutually exclusive. However convergence of functionality is creating products for which requirements are not complete within existing standards. New standards such as CISPR 32 and CISPR 35 are being developed for emissions and immunity, respectively, of multimedia equipment, and these will be harmonized in Europe as EN 55032 and EN 55035. Until such time as more comprehensive standards are available, it may be necessary to apply the parts of more than one standard for each aspect. For example, a computer with a broadcast television reception function will come within the scope of EN 55022 and EN 55024 as an information technology product, but parts of EN 55013 and EN 55020 will need to be applied in respect of the broadcast reception functions, in order to make a complete assessment of the EMC performance for all aspects of the equipment. This still represents a simpler approach for the manufacturer than carrying out an electromagnetic compatibility assessment of the product in accordance with Annex II, point 2 of the EMC Directive.

Although the titles of harmonized standards can be a useful indication of appropriate standards, it is often necessary to examine the scope and even the content of a standard to check its applicability to a particular product. For example, the harmonized standard EN 55014-1 is entitled *Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus* yet within its scope are the following (non exhaustive list): Cine projectors, automatic dispensing (vending) machines, juke boxes, pinball machines, gaming machines with a winnings-payout mechanism, electric fences, cow milking machines, and air conditioners.

The complete list should be examined in its entirety for more specific standards that would take precedence. For example, EN 55022 and EN 55024 apply to information technology equipment, a subset of which is telecommunications equipment. However these standards are not those that should be applied to network telecommunications equipment because the OJ list contains a more specific standard, EN 300 386 produced by ETSI that has the scope of telecommunications network equipment.

**WHICH EDITIONS OF THE STANDARDS CAN/MUST BE USED?**

In the case of EMC harmonized standards listed in the Official Journal, the standard provides a presumption of conformity with the relevant essential requirements as soon as it is included in the list, and published by at least one national standards body. This may be some months after the standard is actually published by national standards bodies. During the period up to the date of cessation of presumption of conformity of the superseded standard, both the new and superseded
editions provide a presumption of conformity. The superseded standard ceases to provide this presumption on the date given, so manufacturers using the standard should update their declarations of conformity accordingly, having first satisfied themselves that their product complies with the requirements of the new edition.

Many harmonized standards refer to basic standards for test methods, and these references may be dated or undated. In the case of dated references the specific edition of the referenced standard, including any amendments specified, must be used, even if a later edition of that standard has been published.

With undated references, the latest edition of the referenced standard must be used, although the previous edition may be used up to its date of withdrawal. A dated reference provides more certainty for the manufacturer, and the majority of new EMC standards being produced by the main EMC committees are now adopting dated references. This may not be the case, however, for standards that contain EMC requirements along with other requirements that are produced by the product standards committees.

A special case occurs where the referenced standard is itself a harmonized standard listed in the Official Journal. This can occur where for historical reasons a product family standard defines test methods within the body of the standard because suitable basic standards were not available at the time that the first edition of the product family standard was written. Another harmonized standard then makes reference to the product family standard.

The principle to be followed in this case, where the reference is dated, is that the standard for the product in question is the primary requirement, and that the edition of the referenced standard that is to be used is the one determined by the product standard. Thus, the dated reference is followed, irrespective of whether that edition is listed in the currently valid list in the Official Journal.

**WHAT IS ANNEX ZA IN THE EUROPEAN STANDARDS?**

When an international standard is ratified by CENELEC as an EN, the national standards bodies that publish the standard take the entire international text (subject to any common modifications that have been necessary). This means that throughout the text, references to other standards will be to their international versions. For Europe, it is the EN versions of these standards that are the relevant references, and Annex ZA has been developed to deal with this. It is so designated to ensure that it comes after the normative and informative annexes of the international text.

Annex ZA consists of five columns. The first two provide the number and date of the international version of the standard as referenced in the international body text of the standard. The third column provides the title of the referenced document. The
third and fourth columns provide the number and date of the corresponding European version of the referenced standard that must be used for the correct application of the standard. Where no equivalent is published a dash appears in the right hand columns, and the internal version must be used.

If a year is not given in the fifth column, the reference is undated. It is possible for the international version to be an undated reference and for the EN reference to be dated.

It is recognized that the wording of Annexes ZA as currently provided is not entirely clear, and work is in hand in Europe to improve this situation.

ANNEX ZZ

The informative Annex ZZ in harmonized standards is a relatively recent innovation that is being introduced as standards are amended or new editions are published. It seeks to provide guidance to users of the standards on the coverage in the standard of essential requirements under various directives. It should be used with care, because it does not indicate whether the standard makes a complete provision in respect of the essential requirements that it identifies, or whether other standards must be applied in addition. For example, EN 55022 contains an Annex ZZ that indicates that it covers EMC emission aspects for the EMC Directive 2004/108/EC and the R&TTE Directive 1999/5/EC. However it does not indicate that the harmonics and flicker standards are applicable, in addition, for equipment within its scope that is connected to the public low-voltage electricity supply.

INTERPRETATION SHEETS

In some cases, a requirement in a standard is found to be unclear or ambiguous, yet the problem is not sufficient to warrant an immediate amendment to the standard. Such cases are dealt with by an Interpretation Sheet. These are a relatively new development, and may be published to clarify a requirement in a standard, but not to modify it; such changes would be the subject of an amendment.

In the British Standard version of ENs, Interpretation Sheets are included as amendments to the standard, but this is not the case for all national implementations of ENs. The existence of interpretation sheets may be checked in the online catalogue on the CENELEC website www.cenelec.eu, where putting the number of the standard (without “EN”) in the search box on the top right hand side of the home page will produce a list of current and draft documents associated with that standard. In respect of the application of a standard and the presumption of conformity under a directive, Interpretation Sheets are guidance, and therefore such documents referring to harmonized standards are not listed in the Official Journal. The presumption of conformity is not affected if they are not followed, but since they represent the official opinion of the responsible standards committees, it would be prudent to follow the interpretation.

ALTERNATIVE TEST METHODS

Many harmonized EMC standards offer alternative test methods for demonstration with the requirements. The question has arisen in recent years as to how these should be considered, especially if a challenge is made by market surveillance authorities to a declaration of conformity under the EMC Directive that is supported by compliance with such standards.

The subject has proved to be controversial, but the interpretation in Europe is clear, resulting in a statement in the European Commission’s Guide for the EMC Directive 2004/108/EC. This states “alternative test and measurement methods, when introduced into a harmonized standard for the same purpose are considered, together with their associated limits, as equivalent regarding the provision of a presumption of conformity with the protection requirements”.

European standards are being checked for consistency with this position, and in some cases this results in a change (by common modification) from the international equivalent. The wording in EN 55022:2006 dealing with this issue reads as follows: “Where alternative test methods are described in the following subclauses, compliance with the requirements of the subclause may be demonstrated by either or any of the methods described.”

DOCUMENTS PROVIDING FURTHER GUIDANCE

CENELEC has produced Guides 24 and 25 to provide explanations of the use of harmonized standards for EMC. They may be downloaded free of charge from the following web page http://www.cenelec.eu/Cenelec/CENELEC+in+action/default.htm.

Guide 25 Guide on the use of standards for the implementation of the EMC Directive will be the most useful for manufacturers, although Guide 24 EMC standardization for product committees also provides useful background information.

The third editions of these guides are about to be published, and may be available by the time this article appears in print. These update the references to the new EMC Directive 2004/108/EC and to other documents.

Brian Jones is an independent EMC Consultant, specializing in compliance with European legislation and standards. He is also secretary to the CENELEC EMC committee TC210, but is writing here in a personal capacity, and his views do not necessarily reflect the views of any organization. He may be contacted at emc@brianjones.co.uk.
List of EMC Directive Standards

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**EN 50065-1:2001**
Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz - Part 1: General requirements, frequency bands and electromagnetic disturbances

**EN 50065-2-1:2003**
Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz - Part 2-1: Immunity requirements for mains communications equipment and systems operating in the range of frequencies 95 kHz to 148.5 kHz and intended for use in residential, commercial and light industrial environments, Amendment A1:2005 to EN 50065-2-1:2003

**EN 50065-2-2:2003**
Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz - Part 2-2: Immunity requirements for mains communications equipment and systems operating in the range of frequencies 95 kHz to 148.5 kHz and intended for use in industrial environments, Amendment A1:2005 to EN 50065-2-2:2003

**EN 50065-2-3:2003**
Signalling on low-voltage electrical installations in the frequency range 3 kHz to 148.5 kHz - Part 2-3: Immunity requirements for mains communications equipment and systems operating in the range of frequencies 3 kHz to 95 kHz and intended for use by electricity suppliers and distributors, Amendment A1:2005 to EN 50065-2-3:2003

**EN 50083-2:2001**

**EN 50083-2:2006**
Cable networks for television signals, sound signals and interactive services - Part 2: Electromagnetic compatibility for equipment

**EN 50090-2-2:1996**

**EN 50121-1:2006**
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**EN 60870-2-1:1996**
Telecontrol equipment and systems - Part 2: Operating conditions - Section 1: Power supply and electromagnetic compatibility, (IEC 60870-2-1:1995)

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Maritime navigation and radiocommunication equipment and systems - General requirements - Methods of testing and required test results, (IEC 60945:2002)

**EN 60947-1:2004**
Low-voltage switchgear and controlgear - Part 1: General rules, (IEC 60947-1:2004), Note 6

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Low-voltage switchgear and controlgear - Part 1: General rules, (IEC 60947-1:2007), Note 6

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Low-voltage switchgear and controlgear - Part 5-6: Control circuit devices and switching elements - DC interface for proximity sensors and switching amplifiers (NAMUR), (IEC 60947-5-6:1999)

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Arc welding equipment - Part 10: Electromagnetic compatibility (EMC) requirements, (IEC 60974-10:2002 (Modified))

EN 60974-10:2007
Arc welding equipment - Part 10: Electromagnetic compatibility (EMC) requirements, (IEC 60974-10:2007)

EN 61000-3-2:2006
Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current <= 16 A per phase), (IEC 61000-3-2:2005)

EN 61000-3-3:1995

EN 61000-3-11:2000
Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current <= 75 A and subject to conditional connection, (IEC 61000-3-11:2000)

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Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and <= 75 A per phase, (IEC 61000-3-12:2004)

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- **EN 61000-6-4:2001**
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  Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCB’s) - Part 1: General rules, (IEC 61008-1:1996 (Modified), + A1:2002 (Modified))

- **EN 61009-1:1994**

- **EN 61009-1:2004**
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- **EN 61131-2:2003**

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- **EN 61204-3:2000**
  Low voltage power supplies, d.c. output - Part 3: Electromagnetic compatibility (EMC), (IEC 61204-3:2000)

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  Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 1: General requirements, (IEC 61326-1:2005)

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  Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-1: Particular requirements - Test configurations, operational conditions and performance criteria for sensitive test and measurement equipment for EMC unprotected applications, (IEC 61326-2-1:2005)

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- **EN 61326-2-5:2006**
  Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-5: Particular requirements - Test configurations, operational conditions and performance criteria for field devices with interfaces according to IEC 61784-1, CP 3/2, (IEC 61326-2-5:2006)

- **EN 61543:1995**
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**EN 61800-3:2004**
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**EN 61812-1:1996**

**EN 62020:1998**
Low-voltage switchgear and controlgear - Controller-device interfaces (CDIs) - Part 1: General rules, (IEC 62026-1:2007), Note 13

**EN 62040-2:2006**
Uninterruptible power systems (UPS) - Part 2: Electromagnetic compatibility (EMC) requirements, (IEC 62040-2:2005)

**EN 62052-11:2003**
Electricity metering equipment (AC) - General requirements, tests and test conditions - Part 11: Metering equipment, (IEC 62052-11:2003), Note 9

**EN 62052-21:2004**
Electricity metering equipment (a.c.) - General requirements, tests and test conditions - Part 21: Tariff and load control equipment, (IEC 62052-21:2004), Note 11

**EN 62053-11:2003**
Electricity metering equipment (a.c.) - Particular requirements - Part 11: Electromechanical meters for active energy (classes 0,5, 1 and 2), (IEC 62053-11:2003)

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Continuous handling equipment and systems - Safety and EMC requirements for equipment for mechanical handling of bulk materials except fixed belt conveyors

**EN 619:2002**
Continuous handling equipment and systems - Safety and EMC requirements for equipment for mechanical handling of unit loads

**EN 620:2002**
Continuous handling equipment and systems - Safety and EMC requirements for fixed belt conveyors for bulk materials

**EN 1155:1997**
Building hardware - Electrically powered hold-open devices for swing doors - Requirements and test methods

**EN 12015:2004**
Electromagnetic compatibility - Product family standard for lifts, escalators and moving walks - Emission

Electromagnetic compatibility - Product family standard for lifts, escalators and moving walks - Immunity
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**ETSI**

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**General remark:** when there is a stroke in column 3 (reference of the superseded standard), it means that the referenced standard may not be used without amendment or particular part for EMC purpose.

**Note 1:** Generally the date of cessation of presumption of conformity will be the date of withdrawal ("dow"), set by the European Standardisation Organisation, but attention of users of these standards is drawn to the fact that in certain exceptional cases this can be otherwise.

**Note 2.1:** The new (or amended) standard has the same scope as the superseded standard. On the date stated, the superseded standard ceases to give presumption of conformity with the essential requirements of the directive.

**Note 2.2:** The new standard has a broader scope than the superseded standard. On the date stated the superseded standard ceases to give presumption of conformity with the essential requirements of the directive.

**Note 2.3:** The new standard has a narrower scope than the superseded standard. On the date stated the (partially) superseded standard ceases to give presumption of conformity with the essential requirements of the directive for those products that fall within the scope of the new standard. Presumption of conformity with the essential requirements of the directive for products that still fall within the scope of the (partially) superseded standard, but that do not fall within the scope of the new standard, is unaffected.

**Note 3:** In case of amendments, the referenced standard is EN CCCCC:YYYY, its previous amendments, if any, and the new, quoted amendment. The superseded standard (column 3) therefore consists of EN CCCCC:YYYY and its previous amendments, if any, but without the new quoted amendment. On the date stated, the superseded standard ceases to give presumption of conformity with the essential requirements of the directive.

**Note 6:** EN 60947-1:1999 does not give presumption of conformity without another part of the standard. EN 60947-1:2004 does not give presumption of conformity without another part of the standard.

**Note 8:** EN 55012 is applicable for giving presumption of conformity under Directive 2004/108/EC for those vehicles, boats and internal combustion engine-driven devices that are not within the scope of directives 95/54/EC, 97/24/EC, 2000/2/EC or 2004/104/EC.

**Note 9:** EN 62052-11:2003 does not give presumption of conformity without a part of the EN 62053 series.

**Note 11:** EN 62052-21:2004 does not give presumption of conformity without a part of the EN 62054 series.

**Note 13:** EN 62026-1:2007 does not give presumption of conformity without another part of the standard.

The list published on OJ C 126 of 2009-06-05 replaces all the previous lists published in the Official Journal of the European Communities.
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**Company Roots**

We trace our earliest roots to the 1930’s when the Ray Proof Company began producing x-ray shielding for the medical market. In 1995, EMCO, Rantec and Ray Proof joined together to form EMC Test Systems, known then as ETS. Later, other companies were acquired; Euroshield Oy, Lindgren RF Enclosures, Holaday Industries, and Acoustic Systems. Today our company is known as ETS-Lindgren.

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Headquartered in Cedar Park, Texas, ETS-Lindgren conducts business around the globe.

Our diverse and highly skilled global workforce consists of approximately 750 employees in North America, Europe, and Asia. We have four manufacturing facilities in the US, and one each in Great Britain, Finland, and China.

Our sales network of more than 60 independent representative and distributor organizations provides knowledgeable sales, service and support around the world.

**Commitment, Growth and Investment**

ETS-Lindgren is committed to our industry and encourages our employees to participate in standards committees, as speakers and session chairs at symposiums, and as authors and lecturers. It would be difficult to attend a symposium and not see an ETS-Lindgren team member in front of a podium, or read a journal or trade magazine without reading something authored by one of our engineers.

Our growth is propelled by meeting our customer’s need for systems and components that provide reliable service, repeatable results, and value at a fair price. Our history of success and proven track record virtually eliminates risky outcomes for our customers.

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As a company and as individuals, ETS-Lindgren take great pride in contributing to the communities where we live and work. Our efforts include the support of local charities, one of which benefits children with hearing disabilities. We also care about the environment and are proud of the many ways in which our employees work to safeguard it.

Our persistent efforts to improve on our safe work environment continue to pay off. We provide ongoing safety training and awareness, and a safe place to work.

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ETS-Lindgren recognizes the importance EMC has in a world increasingly dependent on electronic devices operating safely and compliance with regulatory standards. That’s why our employees work daily to design, manufacture and support the systems and components our customers can depend on.
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EMC-PARTNER and HV TECHNOLOGIES provide a wide range of conducted transient immunity (susceptibility) test systems with impulse outputs up to 100kV / 100kA. These systems provide full compliance testing capability to a broad range of impulse test standards specified by CE Mark, Commercial, Industrial, Military, Avionics, Power Distribution, Surge Protection Device, Insulation, and Component regulatory environments.

**Question:** How does one manufacturer produce so many different products?

**Answer:** By using the same basic building blocks in different configurations.

**6kV Solid State Building Block Circuit**

The broad array of products offered by EMC-PARTNER are made possible through intelligent use of their patented and proprietary 6kV High Voltage Switching Modules. This technique and technology not only increases product range, they also eliminate problems traditionally associated with high voltage transient generators.

**Wide Product Range**

The various transient generators contain anywhere from 1 to 72 of these 6kV building block circuits. Each circuit contains an energy storage capacitor and a solid state high voltage switch. The circuits are arranged in appropriate series and parallel combinations to produce the desired open circuit voltage and short circuit current and wave shape in conjunction with a lumped R-L-C pulse shaping circuit.

**Precision Wave Shape and Timing**

A trigger signal is simultaneously sent via fiber optics to each switching circuit. This enables discrete switches to function as one. The final output pulse is crisp without any smearing caused by switch time variations and repeatable. An added benefit of this technique is unparalleled ability to synchronize pulses to AC power frequency or to create the complex multiple stroke and multiple burst patterns specified in Avionics standard like DO 160 section 22.

**Troublesome Waveform Tamed – Damped Oscillatory Wave**

The EMC-PARTNER solid state high voltage switching approach combined with elegant wave shaping circuit design solves several problems in generating a waveform which is becoming more prevalent; the Damped Oscillatory Wave (DOW). Variations of the DOW are called out by Military, Avionics, and Electric Power Apparatus test standards worldwide. The latter being driven new products for SMART GRID upgrades.

The DOWs are repetitive waveforms produced in “bursts”. Individual pulses must meet very specific tolerances. The solid state switching handles the burst issue. Circuit design addresses the damping and symmetry problems of the DOW.

All DOW test standards specify a Damping Rate or Factor; sometimes called Q, which requires that subsequent peaks decrease in magnitude within certain tolerances. Many DOW generators produce pulses in which the first several peaks do not dampen at all. In some cases they even increase in magnitude! (See Figure 1)

EMC-PARTNER avoids this problem by employing unique circuitry to provide the necessary waveform symmetry (See Figure 2). This enables the true differential output specified in Section 5.3.4 “Test Mode Capability” of IEEE Std. C37.90.1-2002 specifies that the generator must have two floating independent outputs with balanced differential output. It also positions EMC-PARTNER as the only vendor able to provide the “fast” damped oscillatory waveforms of IEC 61000-4-18 at 3, 10, and 30MHz.

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Spira offers the finest and most reliable EMI/RFI shielding gaskets and honeycomb filters in the market, at very competitive prices. The company was founded by one of the leading EMI design engineers in the industry. Spira’s commitment is to provide quality-engineered products, on-time delivery, superior customer service and technical support. Spira is ISO-9001 and AS9100 certified.

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*** All of TÜVRheinland’s EMC labs are approved by the Federal Communications Commission, Wi-Fi Alliance and the ZigBee Alliance. They are also accredited by the U.S. National Institute of Standards and Technology under the National Voluntary Laboratory Accreditation Program.
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With the destabilization of the economy, many companies are looking for ways to increase profits and performance within their particular industry. The electronics industry is no exception. Many electronics companies are working towards improved quality and reliability at the same rate as improving the performance of the products they manufacture.

The ESD Association released an ESD Technology Road Map in 2005 and is currently updating it for current trends in an effort to create awareness within the global electronics industry of changes that were, and are, right around the corner. The Road Map pointed out that numerous mainstream electronic parts and components would reach assembly factories with a lower level of ESD protection than could have been expected just a few years earlier. This prediction in the Road Map has come true. The manufacturing industry may have become a bit complacent in the past few years since many design schemes offered very good levels of ESD protection. However, the ever increasing demands for enhanced performance, speed, storage capacity, bandwidth, and an increasing scale of integration has led to a significant reduction of on-chip protection. This, combined with an increase in physical package size, has exacerbated the ESD damage issue in the manufacturing environment. Nowhere is this more evident than in the world of wireless communication devices and other portable electronic equipment. The features crammed into a pocket sized cell phone are truly amazing and many more features are on the way. As consumers demand and are granted more features and higher performance, manufacturers must adapt to handling increased ESD susceptibility in their parts.

The ESD Association Standards Committee is charged with keeping pace with the industry demands for increased performance. The existing Standards, Standard Test Methods, Standard Practices, and Technical Reports assist in the design and monitoring of the Electrostatic Protected Area (EPA), and also assist in the testing of ESD sensitive electronic components. Many of the existing documents relate to controlling electrostatic charge on personnel and stationary work areas. However, with the ever increasing emphasis on automated handling, the need to evaluate and monitor what is occurring inside of process equipment is growing daily. In the typical factory, a shift is being made from Human Body Model device susceptibility as the major concern, to Charge Device Model considerations.

One major effort that the ESD Association Standards Committee has undertaken is a joint document development activity with JEDEC. JEDEC Solid State Technology Association and the ESD Association entered into a Memorandum of Understanding for the development of joint standards and publications in the field of device electrostatic discharge (ESD) sensitivity testing. Under the agreement, the ESD Association and JEDEC have formed a Joint Task Force for the standardization work in which volunteers from the ESD Association and JEDEC member companies can participate. This collaboration between the ESDA and JEDEC has paved the way for the development of harmonized test methods for ESD, which will ultimately reduce uncertainty about test standards among manufacturers and suppliers in the solid state industry. At the time of this publication, ESDA/JEDEC JDS-001-2010, a joint HBM document, is
being released for distribution. This document will replace ANSI/ESD S5.1-2007 and JEDEC JESD22-A114F, the current industry test methods and specifications for Human Body Model device testing. A second joint committee is currently working on a joint Charged Device Model (CDM) document with a goal of publishing in 2011. These efforts will assist manufacturers of devices by providing one test method and specification instead of multiple, almost - but not quite identical, versions of device testing methods.

There is no question that the existing ESD Association Standards such as ANSI/ESD S20.20 (Program Development) and ANSI/ESD S541 (Packaging for Shipment) are important to industry. These documents are downloaded from www.esda.org in excess of 1,000 times per month on average, and it is expected that the new joint device testing documents will be in similar demand. Additionally, the ESD Technology Road Map has had approximately 26,000 downloads from 2006 to 2009. The industry is paying attention.

The factory Certification Bodies report strong interest in Certification to S20.20, and the world of consultants in this area report that inquiries for assistance remain at a very high level. Individual education also seems of interest once again as 46 professionals have obtained Certified ESD Program Manager status and many more are attempting to qualify as Certified ESD Control Program Managers.

A large percentage of the certification program requirements are based on Standards and the other related documents produced by the ESD Association Standards Committee.

**WHO USES ESD STANDARDS AND WHY?**

The list of users of ESD Standards is quite broad; manufacturers, purchasers, and users of ESD sensitive devices and products, manufacturers and distributors of ESD control products, certification bodies, and third party testers of ESD control products.

The reasons to use ESD Standards are numerous:

- They help assure consistency of the reported susceptibility of ESD sensitive products.
- They help assure consistency of ESD control products and services.
- They provide a means of objective evaluation and comparison among competitive ESD control products.
- They help reduce conflicts between users and suppliers of ESD control products.
- They help in developing, implementing, auditing, and certifying ESD control programs.
- They help reduce confusion in the marketplace.

In the United States the use of ESD standards continues to be voluntary. However, their use can be written into contracts or purchasing agreements between buyer and seller. In much of the rest of the world the use of standards, where they exist, is compulsory.

**GENERAL TYPES OF STANDARDS**

As recently as 1990 there were relatively few reliable ESD standards, and many of them were developed for applications other than electronics. In this new century the landscape has changed significantly, with an increasing number of ESD standards developed specifically for the electronics industry.

ESD Association standards can be categorized into four main groups.

First, there are those documents that provide ESD program guidance or requirements. These documents are classified as *standards (S)*, as they all have specific requirements that must be met.

Examples of standards are:
- ANSI/ESD S20.20-2007 Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
- ANSI/ESD S6.1-2009 Grounding; and

The second document category is classified as *standard test methods (STM)*. These documents contain procedures that can be used to evaluate device sensitivity or ESD control products, materials, or processes. The procedures called out in a standard test method should provide reproducible test results when tested by two separate labs.

![Citel Inc. Advertorial](image-url)
Examples of standard test methods are:

- ANSI/ESD STM3.1-2006 Ionization

The third document category is classified as a standard practice (SP). A standard practice contains content similar to those found in a standard test method, but a standard practice is not sufficiently developed to ensure that two labs will get the same result when the procedure is followed. In many cases a standard practice is released so that industry can begin to use it, while the working group continues their efforts (to make the test method repeatable and reproducible) with the goal of potentially elevating the document to a standard test method.

Examples of standard practices are:

- ANSI/ESD SP10.1-2007 Automated Handling Equipment (AHE)
- ANSI/ESD SP5.6-2009 Sensitivity Testing Human Metal Model – Component Level

The last category of standards documents include advisories and technical reports. These types of documents are used to provide educational information to the industry.

Examples of advisories (ADV) and technical reports (TR) are:

- TR20.20, ESD Handbook. This document is a companion publication to ANSI/ESD S20.20 and provides detailed background information on the requirements of the standard, as well as a wealth of information on ESD control issues.
- ESD ADV1.0, Glossary of Terms. This document lists definitions and explanations of various terms used in Association Standards and documents. It also includes other terms commonly used in the electronics industry.

WHO ARE THE PRIMARY STANDARDS DEVELOPERS?

Although there are a number of organizations such as IEST, IDEMA, SEMI, and JEDEC involved in ESD standards development, the ESD Association Standards Committee (an ANSI-accredited standards development organization) has become the focal point for the development of ESD standards in the industry. The ESD Association also represents the United States on the International Electrotechnical Commission’s Technical Committee 101-Electrostatics. The ESD Association has currently published 35 standards documents, 23 technical reports and 3 advisory documents covering material and program requirements, electrostatic device sensitivity, and test methodology for evaluating ESD control materials and products.

The International Electrotechnical Commission (IEC) has adopted 5 ESD documents. These documents have been published as follows:

- ANSI/ESD S1.1-2006 Wrist Straps
- ANSI/ESD STM3.1-2006 Ionization
- ANSI/ESD STM11.31-2006 Bags
- ANSI/ESD STM2.1-1997 Garments

This document has been submitted at the TC47 Committee Draft for Vote (CDV) level:

- ANSI/ESD SP5.5.1-2008 Electrostatic Discharge Sensitivity Testing Transmission Line Pulse (TLP) Component Level

Traditionally, the U.S. military has spearheaded the development of specific standards and specifications with regard to ESD control in the United States. Today, however, U.S. military agencies are taking a less proactive approach, relying on commercially developed standards rather than developing standards themselves. OMB Circular A119 is a directive that was given by the United States government to other government agencies to use voluntary consensus standards instead of rule-making.

The international community, led by the International Electrotechnical Commission (IEC), has also taken an active role in standards development. Europe’s CENELEC has issued a European electrostatic standard, EN 61340-5-1 Protection of Electronic Devices from Electrostatic Phenomena - General Requirements, that was adopted as a European Norm.

SUMMARY

The technical and manufacturing communities will need to monitor processes to make sure they are capable of handling parts with greater ESD sensitivity than they have had to deal with in recent years. Keeping up with the changes in the electronics industry is a task that the ESD Association Standards Committee must face on nearly a daily basis - a daunting task for a volunteer organization.

The ESD Association is the largest industry group dedicated to advancing the theory and the practice of ESD avoidance, with more than 1,500 members worldwide. Readers can learn more about the association and its work at www.esda.org.

Standards from the ESD Association are available by contacting:

- ESD Association, 7900 Turin Road, Building 3, Rome, NY 13440; Phone: 315-339-6937; fax: 315-339-6793; e-mail: info@esdsa.org; website: www.esda.org.
REFERENCES


CURRENT ESD ASSOCIATION STANDARDS

COMMITTEE DOCUMENTS

ANSI/ESD S1.1-2006 Wrist Straps
This document establishes test methods for evaluating the electrical and mechanical characteristics of wrist straps. It includes improved test methods and performance limits for evaluation, acceptance, and functional testing of wrist straps.

ESD DSTM2.1-2009 Garments
This standard test method provides test methods for measuring the electrical resistance of garments used to control electrostatic discharge. It covers procedures for measuring sleeve-to-sleeve and point-to-point resistance.

ANSI/ESD STM3.1-2006 Ionization
Test methods and procedures for evaluating and selecting air ionization equipment and systems are covered in this standard test method. The document establishes measurement techniques to determine ion balance and charge neutralization time for ionizers.

ANSI/ESD SP3.3-2006 Periodic Verification of Air Ionizers
This standard practice provides test methods and procedures for periodic verification of the performance of air ionization equipment and systems (ionizers).

ANSI/ESD S4.1-2006 Worksurfaces - Resistance Measurements
This standard establishes test methods for measuring the electrical resistance of worksurface materials used at workstations for protection of ESD susceptible items. It includes methods for evaluating and selecting materials.

ANSI/ESD STM4.2-2006 ESD Protective Worksurfaces - Charge Dissipation Characteristics
This standard test method provides a test method to measure the electrostatic charge dissipation characteristics of worksurfaces used for ESD control.

This standard test method updates and revises an existing standard. It establishes a procedure for testing, evaluating and classifying the ESD sensitivity of components to the defined Human Body Model (HBM).

ANSI/ESD SP5.1.1-2006 Human Body Model (HBM) and Machine Model (MM) Alternative Test Method: Supply Pin Ganging – Component Level
This standard practice (SP) document establishes an alternative test method (Supply Pin Ganging) to perform Human Body Model (HBM) or Machine Model (MM) component level ESD tests when the component or device pin count exceeds the ESD Simulator tester channels.

ANSI/ESD SP5.1.2-2006 Human Body Model (HBM) and Machine Model (MM) Alternative Test Method: Split Signal Pin – Component Level
This standard practice (SP) document establishes an alternative test method (Split Signal Pin) to perform Human Body Model (HBM) or Machine Model (MM) component level ESD tests when the component or device pin count exceeds the ESD Simulator tester channels.

ANSI/ESD S5.2-2009 Electrostatic Discharge Sensitivity Testing - Machine Model (MM) Component Level
This standard test method establishes a test procedure for evaluating the ESD sensitivity of components to a defined machine model (MM). It also provides a system of classifying the sensitivity of these components.

ANSI/ESD S5.3.1-2009 Charged Device Model (CDM) - Component Level
This standard test method establishes the procedures for testing, evaluating, and classifying the ESD sensitivity components to a defined charged device model.

ANSI/ESD SP5.3.2-2008 Sensitivity Testing Socketed Device (SDM) Component Level
This standard practice provides a test method for generating a “Socketed Device Model” (SDM) test on a component integrated circuit (IC) device.

ANSI/ESD SP5.4-2008 Transient Latch-up Testing - Component Level Supply Transient Stimulation
This standard practice was developed to instruct the reader on the methods and materials needed to perform transient latch-up testing.

ANSI/ESD STM5.5.1-2008 Electrostatic Discharge Sensitivity Testing Transmission Line Pulse (TLP) Component Level
This standard practice defines a method for pulse testing to evaluate the voltage current response of the component under test.

ANSI/ESD SP5.5.2-2007, Electrostatic Discharge Sensitivity Testing - Very Fast Transmission Line Pulse (VF-TLP) - Component Level
This document pertains to very fast transmission line pulse (VF-TLP) testing techniques of semiconductor components. It establishes guidelines and standard practices presently used by development, research, and reliability engineers in both
universities and industry for VF-TLP testing. This document explains a methodology for both testing and reporting information associated with VF-TLP testing.

**ANSI/ESD S6.1-2009 Grounding**
This standard specifies the parameters, materials, equipment and test procedures necessary to choose, establish, vary and maintain an Electrostatic Discharge Control grounding system for use within an ESD Protected area for protection of ESD susceptible items, and specifies the criteria for establishing ESD Bonding.

Measurement of the electrical resistance of various floor materials such as floor coverings, mats, and floor finishes is covered in this document.

**ANSI/ESD S8.1-2007 Symbols - ESD Awareness**
Three types of ESD awareness symbols are established by this document. The first symbol is to be used on a device or assembly to indicate that it is susceptible to electrostatic charge. The second symbol is to be used on items and materials intended to provide electrostatic protection. The third symbol indicates the common point ground.

**ANSI/ESD STM9.1-2006 Footwear - Resistive Characterization**
This standard defines a test method for measuring the electrical resistance of shoes used for ESD control in the electronics environment. A companion document covering foot grounders is in the draft stage.

**ESD SP9.2-2003 Footwear - Foot Grounders Resistive Characterization (not to include static control shoes)**
This standard practice was developed to provide test methods for evaluating foot grounders and foot grounder systems used to electrically bond or ground personnel as part of an ESD Control Program. Static control shoes are tested using ANSI/ESD STM9.1.

**ANSI/ESD SP10.1-2007 Automated Handling Equipment (AHE)**
This standard practice provides procedures for evaluating the electrostatic environment associated with automated handling equipment.

This standard defines a direct current test method for measuring electrical resistance of static dissipative planar materials used in packaging of ESD sensitive devices and components.

This standard test method provides test methods for measuring the volume resistance of static dissipative planar materials used in the packaging of ESD sensitive devices and components.

**ESD STM11.13-2009 Two Point Resistance Measurement**
This standard test method measures the resistance between two points on a materials’ surface without consideration of the materials’ means of achieving conductivity. This test method was established for measuring resistance where the concentric ring electrodes of ESD Standard Test Method 11.11 cannot be used.

**ANSI/ESD STM11.31-2006 Bags**
This standard provides a method for testing and determining the shielding capabilities of electrostatic shielding bags.

**ANSI/ESD STM12.1-2006 Seating - Resistive Measurement**
This standard provides test methods for measuring the electrical resistance of seating used to control ESD.

**ESD STM13.1-2000 Electrical Soldering/Desoldering Hand Tools**
This standard test method provides electric soldering/desoldering hand tool test methods for measuring the electrical leakage and tip to ground reference point resistance, and provides parameters for EOS safe soldering operation.

**ANSI/ESD SP14.1-2004 System Level Electrostatic Discharge (ESD) Simulator Verification**
This standard practice was developed to provide guidance to designers, manufacturers, and calibration facilities for verification and specification of the systems and fixtures used to measure simulator discharge currents.

**ESD SP14.3-2009 System Level Electrostatic Discharge (ESD) Measurement of Cable Discharge Current**
This standard describes a system for making measurements of the discharge current from charged cables and verifying that the system bandwidth is adequate for capturing the fast initial spike that is known to exist at the beginning of the discharge.

**ANSI/ESD SP15.1-2005 In-Use Resistance Testing of Gloves and Finger Cots**
This standard practice provides test procedures for measuring the intrinsic electrical resistance of gloves and finger cots.

This standard provides administrative, technical requirements and guidance for establishing, implementing, and maintaining an ESD Control Program.

**ANSI/ESD STM97.1-2006 Floor Materials and Footwear - Resistance Measurement in Combination with a Person**
This standard test method provides for measuring the electrical resistance of floor materials, footwear and personnel together, as a system.
ANSI/ESD STM97.2-2006: Floor Materials and Footwear - Voltage Measurement in Combination with a Person
This standard test method provides for measuring the electrostatic voltage on a person in combination with floor materials and footwear, as a system.

ANSI/ESD S541-2008 Packaging Materials for ESD Sensitive Items
This standard defines the packaging properties needed to protect electrostatic discharge sensitive (ESDS) electronic items through all phases of production, transport and storage. The document discusses application requirements and references the testing methods for evaluating packaging and packaging materials for those properties.

CURRENT ESD ASSOCIATION STANDARDS COMMITTEE ADVISORY DOCUMENTS
ESD Association Advisory documents are not standards, but they provide general information for the industry as well as additional information to aid in better understanding of association standards.

ESD ADV1.0-2009 Glossary of Terms
Definitions and explanations of various terms used in Association Standards and documents are covered in this Advisory. It also includes other terms commonly used in the electronics industry.

ESD ADV11.2-1995 Triboelectric Charge Accumulation Testing
The complex phenomenon of triboelectric charging is discussed in this Advisory. It covers the theory and effects of tribocharging and it reviews procedures and problems associated with various test methods that are often used to evaluate triboelectrification characteristics.

ESD ADV53.1-1995 ESD Protective Workstations
This advisory document defines the minimum requirements for a basic ESD protective workstation used in ESD sensitive areas. It provides a test method for evaluating and monitoring workstations.

CURRENT ESD ASSOCIATION STANDARDS COMMITTEE TECHNICAL REPORTS
ESD TR1.0-01-01, Survey of Constant (Continuous) Monitors for Wrist Straps
ESD TR2.0-01-00, Consideration for Developing ESD Garment Specifications
ESD TR2.0-02-00, Static Electricity Hazards of Triboelectrically Charged Garments
ESD TR3.0-01-02 Alternate Techniques for Measuring Ionizer Offset Voltage and Discharge Time
ESD TR3.0-02-05, Selection and Acceptance of Air Ionizers
ESD TR4.0-01-02, Survey of Worksurfaces and Grounding Mechanisms
ESD TR5.2-01-01, Machine Model (MM) Electrostatic Discharge (ESD) Investigation – Reduction in Pulse Number and Delay Time
ESD TR5.3.2-01-00, Socket Device Model (SDM) Tester
ESD TR5.4-01-00, Transient Induced Latch-Up (TLU)
ESD TR5.4-02-08, Determination of CMOS Latch-up Susceptibility - Transient Latch-up - Technical Report No. 2
ESD TR5.5-01-08 Transmission Line Pulse (TLP)
ESD TR5.5-02-08 Transmission Line Pulse Round Robin
ESD TR5.6-01-09, Human Metal Model (HMM)
ESD TR10.0-01-02, Measurement and ESD Control Issues for Automated Equipment Handling of ESD Sensitive Devices below 100 Volts
ESD TR13.0-01-99, EOS Safe Soldering Iron Requirements
ESD TR14.0-01-00, Calculation of Uncertainty Associated with Measurement of Electrostatic Discharge (ESD) Current
ESD TR15.0-01-99, ESD Glove and Finger Cots
ESD TR 20.20-2008, ESD Handbook
ESD TR50.0-01-99, Can Static Electricity be Measured?
ESD TR50.0-02-99, High Resistance Ohmmeters – Voltage Measurements
ESD TR50.0-03-03, Voltage and Energy Susceptible Device Concepts, Including Latency Considerations
ESD TR53-01-06 Compliance Verification of ESD Protective Equipment and Materials
ESD TR55.0-01-04, Electrostatic Guidelines and Considerations for Cleanrooms and Clean Manufacturing
All ESD control products are not created equal. In fact, there are products on the market that despite the claims, fall below the expected performance when put into service.

The manufacturing of ESD control products (wrist straps, footwear, flooring, mats, ionizers, shielding bags, etc.) for handling electronic devices is a multi-million dollar business. There are many options available for almost all types of ESD control products and they cover a wide range in performance and price.

For decades, companies have made significant investments into their ESD control programs, yet many of these companies do not (or cannot) verify that the controls they selected are providing them with the protection they need. Over the past several years, the ESD Association and the International Electrotechnical Commission (IEC) have developed testing standards for the qualification of ESD control materials. Industry professionals from both organizations have developed and validated test methods that provide reliable and repeatable performance characteristics when followed precisely. It is critical that companies verify that ESD control products meet their needs before they put them into service.

Ron Gibson, Sr. ESD Consultant at Celestica, who performs product qualification testing on ESD control products for Celestica worldwide, is very aware of the importance of qualification testing.

“I tested 110 products in 2008/09 for Celestica. Of the 110 only 28% of the products met industry standards from the ESDA or IEC while 72% did not. The items tested consisted of packaging (various), garments, work surfaces, gloves and tape products, and came from sources in Europe, Asia and North America.”

Currently, the developers of the ANSI/ESD S2020 standard have made qualification testing a requirement for compliance to the standards. In order to meet the product qualification requirements, users of the ANSI/ESD S2020 have three choices: internal qualification testing, independent laboratory testing and the product manufacturers’ data sheet.

QUALIFICATION TESTING

Unlike compliance verification testing, which is conducted on the factory floor during regularly scheduled audits, qualification testing is typically conducted during the initial selection of ESD control products and materials. Qualification testing requires a controlled lab environment and lab grade test instruments. Product samples typically must be pre-conditioned in 12% (±3%) and 50% (±5%) relative humidity at 23 ±1°C for a minimum of 48 hours prior to, and during testing. In many cases, this conditioning requires a bench top enclosure, and in the case of larger samples (chairs, floors and bench tops) it may require the use of a walk-in environmental chamber. Testing at both high and low humidity reveals product performance in a wide range of environmental conditions.
What if you do not have the controlled environment or test instruments required for ESD qualification testing? The standards provide you with additional options for product qualification.

INDEPENDENT LAB TESTING

Independent laboratory testing can be used by the end user to qualify and select products intended for ESD control in their factory. Independent labs have been used for many years, primarily by product manufacturers to provide end users with test data that validates their performance claims. When selecting an independent lab for ESD product testing, it is important to verify that the lab has a strong understanding of, and the capability to perform, industry standard test methods.

SUPPLIER DATA SHEETS

The third and easiest option comes with a degree of risk. Although manufacturers’ data sheets are acceptable documentation for product qualification they should be scrutinized very carefully before relying on them for product selection. During a review of data sheets posted on internet web sites by various manufacturers, there were a number of instances where the test method cited on the data sheet was not the correct method to use for the product. Both ANSI/ESD S20.20 and IEC 61340-5-1 list the specific standard test method in the product qualification section of the standard. It is important that the test method stated on the data sheet matches the requirement in the standard.

PRODUCT PERFORMANCE DETERMINES LEVEL OF CONTROL

Both the ANSI/ESDA and IEC standards are designed to protect devices down to 100 volts Human Body Model (HBM) and the required limits are designed with the 100 volt level in mind. However, today devices with sensitivity thresholds of less than 100 volts are becoming more prevalent and in these instances the required limits in the standards may not be enough to provide adequate protection. By simply modifying the limits, the standards can be used for these more sensitive devices, as illustrated in Figure 1. When the resistance to ground is less than 10 MΩ, we can expect the voltage on personnel to be less than 40 volts.

One common example is the use of ESD control flooring and footwear to ground personnel. The use of an ESD control floor and footwear program, which allows personnel the flexibility to move throughout the production area, is typically the largest single investment in ESD control. The standards require a system resistance (person, footwear and flooring to ground) of <35 MΩ. Laboratory testing has shown that resistance to ground has a direct correlation to the maximum voltage on a person. By keeping the system resistance < 35 MΩ, it is unlikely that the body voltage will ever reach 100 volts. By reducing the system resistance, you will limit the peak voltage on the person.

When making this type of investment however, it is wise to conduct body voltage generation testing as well. There are instruments available that will measure, record and calculate the body voltage generation potential with specific floors, footwear and people. Only by conducting this test will you know the level to which you can control personnel charging. Figure 2 illustrates an example of a report generated from the ANSI/ESD STM97.2 voltage generation test method. With the flooring and footwear combination used in this test, we see that there is no chance that body voltage will exceed 75 volts and a less than 2.28% chance that the voltage will ever exceed 50 volts. This is very valuable data for demonstrating ESD process capability.

There are many ESD control products available in the market today. It is in the best interest of the end user of these products to ensure that they are providing the protection required to minimize yield losses attributed to ESD damage, and that they meet the corporate ESD Program requirements.

Craig Zander is the Sales Manager for Prostat Corporation, manufacturer of ESD auditing instruments and kits. Craig has been in the ESD control industry for over 20 years and served as Vice-Chair of the ESDA Standards Organization for nearly 10 years. He can be reached at czander@prostatcorp.com.

![Figure 1](image1)

Data acquired using Prostat PGA-710 courtesy of Stephen Halperin & Associates, Ltd.  

![Figure 2](image2)
As manufacturers design new products and update the design of old products, many times they sell and offer for sale different designs with differing levels of safety and quality. There are many reasons for the differences including multi-functional uses of the product, different price points (e.g. good, better, and best), requests by customers, adoption of safety improvements, and inconsistent regulations and standards between the U.S. and foreign countries. This article will explore the legal and practical risks in selling products with these differences and what manufacturers can do to minimize the risk.

**LAW OF DESIGN DEFECTS**

The Restatement Third, Torts: Products Liability (1998) (hereinafter “Restatement”), in §2, comment a, said that “[t]he emphasis is on creating incentives for manufacturers to achieve optimal levels of safety in designing and marketing products.” However, comment a went on to say that “[s]ociety does not benefit from products that are excessively safe...any more than it benefits from products that are too risky. Society benefits most when the right, or optimal, amount of product safety is achieved.”

The Restatement then sets forth tests that apply to defects in design and warnings and instructions. The focus is on a “reasonable alternative design” or “reasonable alternative warnings and instructions” that were available at the time of sale or distribution at a reasonable cost and their omission rendered the product not reasonably safe. Restatement, §2, comment d.

Since the focus is on a “reasonable alternative,” the fact that the manufacturer has or is contemplating selling its products with different levels of safety raises huge questions for the manufacturer to ponder.

What is the right or optimal level of safety? Can I sell safer products within the U.S.? Can I sell safer products in foreign countries because foreign standards require it and sell a less safe product in the U.S.? Can I offer safety devices as options, either in the U.S. or in foreign countries? These are all difficult questions to answer. And, as with many legal questions, there is no clear answer in most situations.

**SELLING PRODUCTS WITH DIFFERENT LEVELS OF SAFETY**

In general, many manufacturers or entire industries sell products with different levels of safety. The automotive industry is the first one that comes to mind.

Small automobiles with the minimum number of required air bags are not as safe as bigger, stronger cars that have many more air bags. I don’t think anyone disputes this. In fact, the safer cars are sometimes marketed as being safer. In light of the general law, isn’t this risky?

If these small cars comply with all applicable governmental safety regulations, then the manufacturer can argue that the product is reasonably safe. The fact that this manufacturer or other manufacturers can and do make safer products does not diminish the argument.

Despite compliance with government regulations, a plaintiff can still argue that mere compliance (or in the case of other products, industry standards) did not result in a reasonably safe product and that it should have been made safer. And proof of the feasibility of the safer design is based on the fact that this manufacturer or another manufacturer did sell a safer product in the U.S. or elsewhere.

Any manufacturer needs to anticipate this argument and be prepared to prove that its product was reasonably safe.
Call for Papers, Workshops, and Tutorials

The IEEE Product Safety Engineering Society seeks original, unpublished papers and tutorials on all aspects of product safety and compliance engineering including, but not limited to:

**Product Specific:** Medical, consumer, computer (IT), test and measurement, power supplies, telecommunication, industrial control, electric tools, home appliances, cellular and wireless, etc.

**Hazard Specific:** Electrical, mechanical, fire, thermal, chemical, optical, software, functional safety, control reliability, product reliability, risk assessment, etc.

**EMC / RF:** Electromagnetic emissions, electromagnetic immunity, regulatory, Introduction to EMC/RF for the safety and compliance engineer.

**Components:** Batteries, insulation, optocouplers, capacitors, transformers, current-limiters, fuses, lasers, ferrites, cables, connectors, electromagnetic suppression & protection, surge protectors, printed wiring boards, etc.

**Certification:** Product safety, electromagnetic emissions, electromagnetic immunity, environmental, processes, safety testing, regulatory, product liability, etc.

**Standards Activities:** Development, interpretations, status, interpretations, country requirements, Laboratory Accreditation, etc.

**Research:** Body physiological responses to various hazardous energy sources, unique safeguard schemes, electrically-caused fire, forensic methods, etc.

**Environmental:** RoHS, WEEE, EuP (Energy-using Products), Energy Star, Packaging Directives, REACH (Chemical), CeC, etc.

**Demonstrations:** Demonstrations of product safety testing techniques including mechanical, electrical, fire, etc.

**Author’s Schedule**
- Intent to present and topic: May 30, 2010
- Draft e-paper: June 30, 2010
- Notification of Acceptance: July 30, 2010
- Complete e-paper: August 30, 2010

Prospective authors should submit e-papers using the on-line submission system accessible through the Symposium web site. Comprehensive submission instructions including paper templates are also available.
Is there anything optional about safety?

Even though there were safer products being offered in the marketplace. Some manufacturers don’t want to run the risk of having to defend the adequacy of the less safe product and they, instead, sell the safest version of their product in every market where they do business. This can be difficult if customers do not like the additional safety features or are unwilling or unable to pay for it.

**OPTIONAL SAFETY**

Taking this one step further, is it ever acceptable for a manufacturer to have a “reasonable alternative design” and offer it to the customer as an option? In a sense, the scenario outlined above involving selling different levels of safety is analogous to an option. With safety options, the consumer is confronted with products that have different safety features and gets to pick which one it wants, needs, and can afford.

But in the relevant cases in this area, the facts are a little different. The manufacturer offers a safety device as an option and puts the burden on the customer to decide whether or not to purchase it. There are many well known examples of such products:

- A motorcycle with highway bars
- Vehicles with back-up alarms
- Vehicles with rollover or falling object protective structures
- Safety devices that protect against crane contact with power lines

And the issue could even arise when the consumer walks into the retailer and can purchase safety accessories made by other manufacturers. This includes a bell and light for a bicycle, goggles for a power tool, and a variety of helmets for motorcycles, bicycles, ATVs, skis, etc.

Who has the responsibility to provide a reasonably safe product – the accessory or product manufacturer, retailer, consumer, or user? When should the option be mandatory? And, how far do these entities have to go in informing the purchaser about the appropriateness of purchasing the option or feature?

The cases arise when the customer is offered, either directly or indirectly, the optional safety device and rejects it. An accident occurs and the argument is that the injury would have been prevented if the safety device had been sold with the product and its omission rendered the product not reasonably safe.

The case law has been fairly fact specific, but some of the decisions do offer a basis for analyzing the facts after an incident occurs and before sale when making a decision on whether to make a device mandatory or optional.

According to the case law, the main rationale to allow a safety feature to be optional is that it only provides safety in certain uses or environments. And so some purchasers should be able to decide if the option is necessary for their intended use.

Making it optional also prevents the purchaser from paying for safety that it doesn’t need and to allow the purchaser to use the product in more situations than it can be used with an option that is mandatory.

Another way for the manufacturer to deal with the situation is to make the safety device mandatory, but removable. The problem with doing this arises when purchasers/users are likely to remove it and never replace it. Then the injured party could argue that there was a defective design and that the guard should have been permanent or at least difficult to remove. This becomes “reasonably foreseeable misuse.”

**CASE LAW**

Unfortunately, the law is “muddled and quite sparse” according to Professor David Owen in his products liability hornbook. There are cases on both sides – safety devices can be optional and safety devices should be mandatory – but they provide some useful insights.

An early case on this subject is Bexiga v. Havir Mfg. Corp., 290 A.2d 281 (N.J. 1972) involving a punch press. The New Jersey Supreme Court ruled that the manufacturer was not in the best position to install available safety devices on industrial machinery and that these decisions should not be left to purchasers. Therefore, this case has stood for the proposition that manufacturers may not delegate design decisions relating to safety to purchasers.

The key issue in this case is that the court believed that the safety device, a two-button on/off switch, was necessary for safety and was feasible and did not make the machine unusable for its intended function. While this switch was not offered as an option, this case started the doctrine that safety is mandatory and you cannot delegate responsibility to provide a safe product to the purchaser. However the court would allow a safety device to be optional where it made “the machine unusable for its intended purpose.” *Id.* A number of courts followed this doctrine.

In 1978, two cases came down with a different conclusion. See *Biss v. Tenneco, Inc.*, 409 N.Y.S.2d 874 (App. Div.1978) (garbage truck without a back-up alarm) and *Verge v. Ford Motor Co.*, 581 F.2d 384 (3d Cir.1978) (V.I. law) (rollover protective structure for a loader). Both cases hinged on the expertise of the purchaser in deciding whether the optional devices should have been purchased for their uses.

Despite the different conclusions, *Biss, Verge* and *Bexiga* all held that a safety device can be optional on “multi-functional products if there is no standard safety feature that will allow each function to operate unimpeded.” Owen, *Products Liability 2d Edition*, page 564. Over the years, courts enunciated additional factors such as whether the purchaser could install the safety device, whether the hazard was obvious, whether the cost of the safety feature was high, and whether other manufacturers provided the feature as an option. *Id.*
In 1999, the New York Court of Appeals decided *Scarangella v. Thomas Built Buses*, 717 N.E. 2d 679. The court held that a product that does not incorporate available safety devices is not defective as a matter of law if:

- Buyer is thoroughly knowledgeable about the product and its use
- Buyer is aware of the availability of the safety device
- In some normal uses, the product is not unreasonably dangerous without the safety device
- Buyer can balance the benefits and risks of not having the safety device in its intended use

In effect, it is the buyer, not the manufacturer, who is performing the risk assessment that should be performed when designing a product. See “Risk Assessment and Product Liability,” (with Bruce Main), For the Defense, Defense Research Institute, Inc., April 2001.

The New York Court of Appeals addressed this issue again recently and considered the *Scarangella* factors in *Passante v. Agway Consumer Products, Inc.*, 2009 NY Slip Op. 03588 (May 5, 2009). *Passante* dealt with an optional device that attached a tractor-trailer to a loading dock and provided a warning indicating when it was safe to enter the trailer and when the truck could be safely driven away. The purchaser refused to buy this option and the plaintiff was hurt.

The Court of Appeals ruled 4-3 that the *Scarangella* factors had not been met and that summary judgment was not appropriate. The dissenting judges said that the majority was basically overruling *Scarangella* without specifically saying so and that this would have economic consequences for manufacturers selling into New York who no longer have a roadmap for how to deal with optional safety devices before sale.

For more discussion on the litigation and warnings issues, see Mike Hoenig’s excellent analysis in the May 11, 2009 New York Law Journal entitled “Optional Safety Equipment and the Savvy Purchaser.”

**PRACTICAL CONSIDERATIONS**

Since one tenet of product liability prevention is to try and prevent the accident in the first place, let’s see if we can come up with some good practices when dealing with additional safety devices and whether they should be mandatory or optional.

As discussed above, the manufacturer needs to employ all necessary safety analytical procedures before deciding on the original design and warnings and instructions. The base product, without any potentially optional equipment or safer design, must be reasonably safe for its intended use. If there is additional safety equipment that would be operable in most foreseeable uses, then it is probably better to provide it as mandatory and provide a way to remove it or move it out of the way during some aspect of operation. And then, be sure to clearly describe when it should be used in the manual.

When considering making safety devices optional, the manufacturer must consider, in part, industry standards and what other manufacturers of similar products do. Therefore, if all other manufacturers sell a certain safety feature as standard, it would be very hard to justify offering it as an option. And if all offer it as an option, the manufacturer should consider how these other manufacturers are providing information to the purchaser on when it is appropriate to purchase and use the option.

While this may not be the last word on this issue – other manufacturers may not be doing an adequate job of describing the option and when it is to be used – it should be a good start for the analysis. Another good rule of thumb is to do better than your competitor in providing information about the option and when it is to be used. In that way, if the competitor is not doing enough, at least you can say that you tried to do better.

Ultimately, if the device is going to be optional, the manufacturer wants to be able to point to the factors in *Scarangella* and other cases in establishing a basis for arguing that the purchaser is sophisticated, knowledgeable about the option and the uses of the product, and is able to make a decision as to whether it should be purchased. To better prove that the typical purchaser is sufficiently sophisticated, it might be a good idea to do a random survey of some purchasers to see if they understand the information you have provided and that they have made the “correct” decision on whether to purchase the option and when it should be used.

**CONCLUSION**

Optional safety devices can be tricky. Purchasers don’t want to spend money on a device that they don’t need in most of the situations in which they will use the product. And you don’t want to make your product cost more than your competitor’s product by making the option mandatory out of an overly conservative calculation of potential risk and liability.

Given the sparseness of the case law, it is imperative that you consider the leading cases and what guidance they provide and look to how options are handled in the standards, if at all, and within your industry.

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Leveraging Safety and EMC Skills in Energy Regulatory Compliance

by Tim Calland, P.E.
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Editor’s Note: The paper on which this article is based was originally presented at the 2009 IEEE International Symposium on Product Compliance Engineering. It is being reprinted here, with permission, from the proceedings of the 2009 IEEE International Symposium on Product Compliance Engineering. Copyright 2009 IEEE.

Regulations mandating energy-efficient design and performance in a variety of consumer products are emerging throughout the world. Compliance organizations can leverage technical skills already in place and scale to meet the increased responsibilities.

Traditionally, Environmental Compliance teams have focused on testing for restricted substances and designing products for recyclability. Now the term “environmental” has been expanded to include scientific measurement of volts, amps, watts, power factor, time, mass, distance, temperature, and customer habits. Reducing the energy used by today’s digital gadgets requires a basic conceptual understanding that crosses multiple disciplines including hardware, software, silicon, and yes, even Nielsen families. Many of the basic skills associated with electrical safety and EMC compliance are in demand in order to properly measure energy consumed in manufacturing, distribution, use, and end of life. This paper provides an overview of the requirements, some insight as to where they are heading, and some practical comments on how to design for and prove compliance to today’s and tomorrow’s green standards.

Before I make that connection, I would like to review briefly how we got here today with a brief history of emerging technical regulations.

A BRIEF HISTORY OF EMERGING REGULATIONS

Safety

Many of us mark the Chicago Columbian Exposition of 1893, one of the first “World’s Fairs,” as the birth of regulatory product compliance. An ambitious fire inspector named William Henry Merrill smelled opportunity in the smoke from burning paper-maché-festooned electrical exhibits. After getting funding from the insurance companies, he set up a little lab in a room over the local fire station, did some tests and hung out a shingle that said “Underwriters Laboratories.” The rest is history. [1]

Some of the international readers may point out that at least twenty years earlier in Prussia, as steam technology began to mature, exploding boilers pointed out a need for development and implementation of standards and inspectors. A number of “DÜVs”, Dampfkessel Überwachungs Verein or Steamboiler Testing Laboratories, emerged in what came to be Germany. As the DÜVs expanded their scope, they became TÜVs, or Technischer Überwachungs-Verein, Technical Surveillance Associations. As the industrial revolution spread throughout the world, similar problems uncovered similar needs, and similar infrastructures were developed to help protect the locals from harm. [2]
**Electromagnetic Compatibility**

Over time, new technologies providing new benefits for society also introduced new risks. An infrastructure supporting the standards writers, testing laboratories, factory and installation inspectors and certification organizations began to take hold. The Communications Act of 1934 empowered the FCC to regulate the use of intentional and unintentional radiators and to assure electromagnetic compatibility [3] and the demand for proof of technical compliance expanded.

As global regulatory infrastructure began to grow, manufacturers realized they needed to employ experts in these emerging regulations in order to assure compliance in their target markets. In many cases, management of electrical safety and electromagnetic compatibility could be handled by small teams of compliance engineers with electrical engineering skills. Instrumentation and technical background along with a common interest in technical compliance often resulted in cross-functional skill sets.

**REGULATION OF ENVIRONMENTAL ISSUES**

In 1970, U.S. Environmental Protection Agency (EPA) was formed as part of the response to growing public concern and a grass roots movement to “do something” about the deteriorating conditions of water, air, and land. [4] In the beginning, most of the concerns were focused on pollution, restricted substances, recycling and the like.

**Restricted Substances and Recycling**

In July of 2006, DIRECTIVE 2002/95/EC of the European Parliament on the restriction of the use of certain hazardous substances in electrical and electronic equipment, also known as the Restriction of Hazardous Substances (RoHS) Directive, went into effect. This directive banned all but small amounts of lead, mercury, cadmium, some types of chromium and some brominated fire retardants, which, ironically, had previously been favorites of the safety compliance regulators. [5]

With the advent of environmental regulation, a new class of technical issues, more grounded in chemistry and earth sciences than electrical engineering, needed to be addressed. Manufacturers responded with “environmental compliance” teams, focusing more on material selection and procurement, rather than on product design and performance. These teams may have emerged from the electrical compliance department. More often than not, they grew from the same part of the organization that was responsible for occupational health and social responsibility.

The last decade has witnessed with increasing certainty accelerated climate change due to the increased release of “Greenhouse Gases” into the atmosphere. The primary GhG, carbon dioxide, results from the combustion of fossil fuels in the production of energy and is aggravated by accelerating global deforestation. As a result, environmental regulation has expanded to include efficient use of energy to reduce the need for fossil fuel-derived electricity.

Energy Performance Standards started out as voluntary efforts through Energy Star in the US, Appliance Codes of Conduct in the EU, and other measures throughout the world. These standards were originally meant to identify the top performers in various product categories. However, with the reality of Global Climate Change sinking in, jurisdictions throughout the world began mandating Minimum Energy Performance Standards (MEPS) for many products to comply with. In 2005, for all practical purposes there were no mandatory MEPS requirements for consumer products. Now there are requirements in place for numerous different products in various jurisdictions throughout the world. What follows is an overview of some of the most common MEPS with perhaps the biggest impact to consumer electronics and information technology.

**ENERGY REGULATION OVERVIEW**

**Energy Star External Power Supplies, Computers, Audio/Video, Set-Top Boxes**

First, we need to take a step back and look at the largest and most successful voluntary program, Energy Star. In 1992 the EPA introduced ENERGY STAR as a voluntary labeling program designed to identify and promote energy-efficient products to reduce greenhouse gas emissions. Computers and monitors were the first labeled products. [6] Over time, Energy Star emerged as the preeminent energy standards-writing body in the world.

Standards written by Energy Star, intended to set the highest bar for energy performance in various product categories, have been adopted whole or in part to become the minimum requirements for various jurisdictions. The difference between best-in-class performance and minimum performance is usually differentiated by staggering of effective dates. For example, the Level III [7] Energy Star performance standard for External Single-Output [8] Power Supplies (EPSs) became effective in July 2005. The California Energy Commission made the same requirements mandatory for all EPSs effective July 2006.

**Energy Star Program Requirements for External Single-Output Power Supplies**

Energy Star Level IV [7], effective July 2006, shown in Table 1, is currently in effect in the state of California, Australia, New Zealand, and will come into effect in Canada this year, and in the EU in April 2010.

The latest Energy Star Criteria, Level V, shown in Table 2, the table below, effective July 2008, become effective in
In addition to standardizing acceptable energy levels, Energy Star and the EPA also standardized the test methodology, in US EPA “Test Method for Calculating the Energy Efficiency of Single-Voltage External AC-DC and AC-AC Power Supplies.” [9]

**Energy Star Computer Requirements**

So far, the tendency to turn voluntary Energy Star requirements into law has more or less been limited to requirements for external power supplies. However, U.S. Government procurement policy mandates Energy Star compliance with many purchased products. This has the effect of making Energy Star compliance mandatory for ITE as well.

The current edition of Energy Star Program Requirements for Computers 5.0 [10], contains multiple-input internal power supply efficiency test methodology [11] similar to the efficiency requirements for external power supplies and defines efficiency limits of: 85% minimum efficiency at 50% of rated output and 82% minimum efficiency at 20% and 100% of rated output, with Power Factor > 0.9 at 100% of rated output. It also introduces the concept of Typical Energy Consumption (TEC). Typical Energy Consumption is the sum of power used in off, sleep, and idle modes multiplied by the time typically spent in each mode per year.

\[
E_{\text{TEC}} = \frac{8760}{1000} \times (P_{\text{off}} \times T_{\text{off}} + P_{\text{sleep}} \times T_{\text{sleep}} + P_{\text{idle}} \times T_{\text{idle}})
\]

The mode time is based on a typical usage profile agreed upon by the stakeholders, and is expressed in KWhr/year. Different usage profiles are defined for notebooks, desktops, and work stations. In order to meet the limits, the computer must be shipped with an enabled energy management system that automatically scales down power from active to idle, to sleep to off in such a way that the TEC is not exceeded. Effective with this version are energy requirements for video game consoles.

<table>
<thead>
<tr>
<th>Nameplate Output</th>
<th>Minimum Efficiency in Active Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 watt</td>
<td>0.5 * Nameplate Output</td>
</tr>
<tr>
<td>≥ 1 and ≤ 51 watts</td>
<td>0.09*Ln (Nameplate Output) + 0.5</td>
</tr>
<tr>
<td>&gt; 51 watts</td>
<td>0.85</td>
</tr>
</tbody>
</table>

**Maximum Energy Consumption in No-Load Mode**

| Any output       | 0.5 watts                         |

Where Ln (Nameplate Output) = Natural Logarithm of the nameplate output expressed in watts

It should be noted that Energy Star also has program requirements for Audio Video, Lighting, HVAC and battery chargers, along with a variety of household appliances and even buildings. [12]

**California Energy Commission**

In 1976, in response to a legislative mandate to reduce energy consumption, the California Energy Commission established Appliance Efficiency Regulations. As previously mentioned, the CEC has vigorously embraced the Energy Star program requirements for External Power Supplies. The regulations have been updated periodically to allow consideration and possible incorporation of new energy efficiency technologies and methods and include requirements for a variety of other electronic products, including consumer audio and video equipment such as televisions, compact audio products, digital versatile disc players, and digital versatile disc recorders. [13]

**Ecodesign of Energy-using Products**

In 2005, Directive 2005/32/EC was passed by the European Commission. This directive, commonly referred to as the “EuP Directive,” established a framework for the setting of what were described as “ecodesign” requirements for energy-using products. The directive calls for identification of large classes of electrical products which, in an effort to decrease the production of greenhouse gases, could possibly be designed to use less energy. The directive lays out the procedure to develop and mandate energy-use limits and mechanisms, along with a regulatory structure to verify that products placed on the market comply with the new limits. [14] The mandates, called, “Implementing Measures,” (IMs) are based on product specific “Lots.” Under the EU New Approach scheme, products will need CE marking indicating compliance with IMs. After the effective dates of the Implementing Measures, products will need to comply with the IMs in addition to all other applicable New Approach Directives such as the Low Voltage Directive, The EMC Directive and the RTTE Directive, among others.

Among the lots identified are Lot 3, Personal Computers and Monitors; Lot 4, Imaging Equipment (copiers, faxes, printers, scanners, etc.); Lot 5, Televisions; Lot 6, Standby and off-mode losses of Energy using Products; Lot 7, External Power Supplies; Lot 18, and Set-top boxes. To date, of the categories above, Implementing Measures have only been published for Lot 6, Standby and off-mode losses of Energy using Products, and Lot 7, External Power Supplies.

**Lot 6, Standby and off-mode losses of Energy using Products**

The unique thing about the Lot 6 Implementing Measure is that it is a “horizontal” measure. Rather than focus on one product or product group, it includes all consumer electronics and ITE within its scope.
At this point it should be noted that there are various definitions of Standby and Off Mode. However, for most of the regulations mentioned in this article, “standby mode” means a condition where the equipment is connected to the mains power source and provides only a reactivation function – i.e., a function facilitating the activation of other modes, such as arming a sensor to detect a hand-held remote control. “Off mode” means a condition in which the equipment is connected to the mains power source and is not providing any function.

Effective January 2010, the Lot 6 IM mandates that power consumption of equipment in any off mode condition shall not exceed 1.00 W. Power consumption of equipment in any condition providing only a reactivation function shall not exceed 1.00 W. Power consumption of equipment in any condition providing only information or status display, or providing only a combination of reactivation function and information or status display, shall not exceed 2.00 W.

The IM also requires that equipment provide Off mode and/or Standby mode, and/or another condition which does not exceed the applicable power consumption requirements for off mode and/or standby mode when the equipment is connected to the mains power source.

Effective January 2013, the Off-mode and Standby mode power levels drop from one watt to one half watt (One watt for products with status displays). Additionally, equipment must offer a power management function that switches the equipment after a short period of time automatically into Standby mode or Off mode, or another condition which meets the power level for those modes. The power management function must be activated before delivery.

**Lot 7, External Power Supplies**

Effective April 2010, External power supplies must meet Energy Star Level IV EPS requirements. In April 2011, EPSs must meet Energy Star level V [7].

**Department of Energy**

In 2007, the Congress passed the ‘Energy Independence and Security Act, (EISA) “To move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to protect consumers, to increase the efficiency of products, buildings, and vehicles, to promote research on and deploy greenhouse gas capture and storage options, and to improve the energy performance of the Federal Government, and for other purposes.” [15] Appliance Energy Efficiency requirements are included in Subtitle A. The present scope includes External power supplies, Battery chargers, and Standby mode, among other products and modalities. Some of these requirements are now in effect; others are still under development.

**Natural Resources Canada**

**Background**

Canada began regulating energy efficiency in 1995 through the Department of Natural Resources of Canada, NRCan. In 2007, NRCan announced that Canada will put in place standards to limit the amount of power consumed by external power supplies, and by certain products in standby mode. [16]

**External Power Supplies (EPSs)**

NRCan is proposing to mandate minimum energy performance standards for External Power Supplies imported or shipped inter-provincially for sale or lease in Canada. The definition and power levels are the same Energy Star Level IV. The test procedure is CSA-C381.1-08, Test method for calculating the energy efficiency of single-voltage external ac-dc and ac-ac power supplies. This methodology is harmonized with Energy Star Test Method for Calculating the Energy Efficiency of Single-Voltage External Ac-dc and Ac-ac Power Supplies [9].

Unique to Canada, the EPSs must be tested and certified by an accredited third-party, and bear a verification mark indicating that the energy performance of the product has been verified. This proposal, now on hold, was originally slated to come into effect as early as September of this year.

**Standby Power**

NRCan is also proposing to amend Canada’s Energy Efficiency Regulations to minimum standby energy requirements for Compact Audio Product, Televisions, Video Playing/Recording Products, Computer Printers, and Multifunction Devices.

The proposed energy efficiency limits for standby power will be as per the limits shown in Table 3

<table>
<thead>
<tr>
<th>Nameplate Output Power ($P_{no}$)</th>
<th>Minimum Average Efficiency in Active Mode (expressed as a decimal) $^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to ≤ 1 watt</td>
<td>$\geq 0.480 \times P_{no} + 0.140$</td>
</tr>
<tr>
<td>&gt; 1 to ≤ 49 watts</td>
<td>$\geq [0.0626 \times \ln (P_{no})] + 0.622$</td>
</tr>
<tr>
<td>&gt; 49 watts</td>
<td>$\geq 0.870$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nameplate Output Power ($P_{no}$)</th>
<th>Maximum Power in No-Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to &lt; 10 watts</td>
<td>≤ 0.5 watts</td>
</tr>
<tr>
<td>≥ 10 to ≤ 250 watts</td>
<td>≤ 0.75 watts</td>
</tr>
</tbody>
</table>

*Table 2: Energy Star Level V*
As is the case for EPSs, these products are required to be tested and certified by an accredited third party and bear a verification mark. The initial proposal, originally scheduled to come into effect as early as September of this year, is intended to harmonize the current California limits for these products. The requirements are on hold as of this writing. The standard for these products will be strengthened to a 1W target one year after the higher limits come into force.


Australia/New Zealand Minimum Energy Performance Standards

External Power Supplies imported after December 1, 2008 are required to meet Energy Star Level IV requirements. They must be registered on line by March 2010. [17] The standard is AS/NZS 4665, Performance of external power supplies, and is technically identical to the test method used by the US EPA in the Energy Star program. [9]

Korea Standby Power Reduction Regulation

Korea e-Standby requirements are based on Article 18-21 of the Korea Rational Energy Utilization Act and the Ministry of Knowledge Economy’s Notification, e-Standby Program Application Regulation. [18] The purpose of the program is to “save standby power systematically by encouraging the manufacturers to produce and sell the energy-saving products that meet the energy-saving standards suggested by Ministry of Knowledge Economy (MKE) and Korea Energy Management Corporation (KEMCO).” This program is unique in that although it does not mandate minimum energy performance standards, it requires markings indicating whether or not appliances in scope meet those standards. The standby requirement is one watt. Products in scope are TVs, VCRs, audio players, DVD players, bidets, set top boxes, microwave ovens, cordless phones, door phones, modems, computers, monitors, printers, fax machines, copiers, scanners, multifunction devices, home gateways, and energy saving & controlling devices. The marking requirement goes into effect as shown in Table 4.

Other Emerging Energy Requirements

It is not the objective of this article to be an all-inclusive compendium of all product-specific energy requirements – the task is simply too large and the playing field is constantly changing. The EuP Directive contains an open-ended mandate of “continuous improvement in the overall environmental impact of those (energy-using) products.” China has adapted voluntary requirements modeled after Energy Star. Meanwhile, Energy Star requirements are constantly setting higher and higher bars. It is reasonable to assume that energy requirements for most electrical products will become the norm, rather than the exception for most significant world markets over the twenty-first century.

TRACKING AND INFLUENCING

With the advent of the IECEE CB Scheme, CISPR and other organizations working for globally harmonized standards, along with the maturity of safety and EMC standardization, the standards-writing process for these disciplines has slowed down to a crawl. Not so with energy. Nature abhors a vacuum, and there is big vacuum begging to be filled with various green initiatives. As we speak, all over the world well-meaning and not-so-well-meaning individuals, NGOs and government bureaucrats are taking virtual pens to virtual paper writing new energy standards for all kinds of products. These new requirements often go into effect with minimum lead-time, causing an expensive scramble to make last-minute modifications, or, worse yet, products turned back at the border.

At the same time, there is a need for a technical presence in these meetings that understands the products and the intention of the requirements from a technical point of view. For the most part the standards are written by consensus and stakeholders are welcome, provided they have the bandwidth to help with the process. The good news is

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Tier 1 Limits (2009)</th>
<th>Tier 2 Limits (2011)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact Audio Products</td>
<td>= 2W</td>
<td>= 1W in standby mode</td>
</tr>
<tr>
<td>Televisions</td>
<td>= 4W</td>
<td>= 1W in standby mode</td>
</tr>
<tr>
<td>Video Products</td>
<td>= 3W</td>
<td>= 1W in standby mode</td>
</tr>
<tr>
<td>Printers (Small and Standard Size format)</td>
<td>= 2W</td>
<td>= 1W in standby mode</td>
</tr>
<tr>
<td>Multi-function Devices</td>
<td>= 4W</td>
<td>= 2W in standby mode</td>
</tr>
</tbody>
</table>

Table 3: NRCAN Standby Requirements

<table>
<thead>
<tr>
<th>Date</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008.8.28</td>
<td>TVs, computers, monitors, printers, multi-function devices</td>
</tr>
<tr>
<td>2009.7.1</td>
<td>set-top boxes, microwave ovens</td>
</tr>
<tr>
<td>2010.1.1</td>
<td>VCRs, audio players, DVD players, radios, door phones, cord/cordless phones, electronic toilet seats, fax machines, copiers, scanners, modems, home gateways</td>
</tr>
</tbody>
</table>

Table 4: Korea Energy Effective Dates
that many of the standards being written now are picked up by jurisdictions throughout the world, so harmonization is not the issue it once was with safety standards, for example. The trick is in knowing where to look for new standards in development.

**Standards-Writing Organizations**

**Energy Star**
As noted previously, voluntary high-performance standards developed for EPS by Energy Star have become the mandatory minimum bar in California, Canada, the EU, Australia and New Zealand.

**California Energy Commission**
The state of California is not afraid to mandate standards where they see a need. And unless you are prepared to either abandon the California market or make a separate sku for San Francisco, you need to consider California requirements to be US requirements.

**United States Department of Energy and Environmental Protection Agency**
With the Obama administration and the introduction of EISA, these organizations are reviewing all kinds of energy policies and considering additional product-based regulations.

**NRCan**
Natural Resources Canada is seeking a more robust regulatory structure for energy-related issues. They have stated their intention to harmonize with the EU and with California, but are prepared to issue local differences if they deem them appropriate.

These ministries are responsible for development of all implementing measures for the Ecodesign EuP Directive.

**IEC Technical Committees**
The International Technical Commission includes technical committees developing international model standards for energy efficiency of consumer electronic equipment including standard measurement methods for the power use of televisions, set top boxes (STB), audio equipment, multifunction equipment, and information and communication technology (ICT) products (TC 108 TA 12) [21], and TC 111, WG 2, Environmentally conscious design for electrical and electronic products and systems [22], among others.

**Trade Organizations**
A number of trade organizations closely track emerging environmental regulations, including energy regulations in particular. Below is a short description of some involved in this area.

**(US) Information Technology Industry Council Energy and Environment Committee [23]**
The ITIC E&E Working Group is chartered to educate policy makers, the media and the public about the critical role information technology plays in helping government, businesses and consumers manage and save energy. They promote IT as a critical component in mitigating the environmental impact of electricity generation and usage.

**(US) Consumer Electronics Association Energy Committee [24]**
CEA works with state and local policy makers on energy efficiency issues related to consumer technology products. They are particularly strong with regard to Energy Star activities. They also actively represent the consumer electronics industry before federal policy makers and agencies, such as the U.S. Environmental Protection Agency and the U.S. Department of Energy.

**(EU) DigitalEurope (formerly EICTA) [25]**
DigitalEurope leads efforts coordinating industry participation in the development of most of the EuP implementing measures impacting electronics in Europe.

**DESIGN FOR ENERGY**

**Basic Principles**
The energy in question is the electrical power required to perform a function multiplied by time required for the function to be performed. The metrics are volts, amps and time. For some products, computers, power factor may also be specified. The basic principles are just as much common sense as good engineering. Following is a brief, high-level overview.

**Define Power Budgets For All Operating Modes**
First, identify all user modes. A game console, for example, may be used for active gaming, on-line shopping, music playback, DVD playback, photo display. Identify circuits required to deliver these functions and the power and time required for each.

**Define Usage Profiles**
Second, make sure you understand how your product is being used. If you recall, I mentioned Nielsen Families at the beginning of this article. An essential part of designing an
Leveraging Safety and EMC Skills in Energy Regulatory Compliance

Product Safety

Efficient product is in understanding how your customers use it. Surveys or other methods can help you determine how your customers use your product. For a typical customer (whatever that is) how long is the device typically operating in each mode? How long is it idle? How long is it turned off? Energy Star has already done this for complex set-top boxes and computers. Table 5 shows a typical usage profile and Typical Energy Consumption (TEC) limits for computers.

Pareto, Priority, Optimize – Min Power and Time

Third, multiply the power per mode by the time in mode. Look for low hanging fruit and tackle them first.

\[
E_{TEC} = \frac{8760}{1000} \times (P_{off} \times T_{off} + P_{sleep} \times T_{sleep} + P_{idle} \times T_{idle})
\]

Identify High Power Components, Systems and Processes

For a PC, look at the CPU and GPU first to optimize active mode power. Design or select silicon that effectively powers down inactive cores and modules. Look at internal clocks so that high-power components are only on for the minimum amount of time required to do the intended function. Look at functions associated with the south bridge for standby and off-mode power. Use firmware that optimizes energy by turning off, turning on, speeding up and slowing down high-energy circuitry as needed.

Leverage Die Shrink

Take advantage of Moore’s Law in a whole new way. Through relatively predictable advances in integrated circuit technology, the cost of computing power and the energy required to deliver that computing power decreases over time. This phenomenon results in newer, more powerful personal computers developed on an annual basis. Leveraging the same phenomenon, manufacturers can hold the processing power constant and reduce the energy needed to perform the computing function. In addition to the reduction of energy, the materials used in production can be scaled down and the price can be reduced accordingly. This can be realized with many high-power and high-loss components – CPU, GPU, memory, etc. At the same time, look at reducing cost by reducing component size, cooling capacity, enclosure size, etc. because of the lower power needs.

Increase Power Supply Efficiency

Back in the day of linear power supplies, you were lucky to get 40% efficiency (Power out/Power in). Modern switch-mode power supply efficiencies start around 80%. Use of more efficient front-end components, more robust cores, etc. can bring that number up to 90%, but expect disproportionate increase in component count and cost to get those last few percentage points.

Monetize Changes

For the most part, decrease in energy means decrease in costs. Some of the savings are realized by the user. However, a product that uses less power uses proportionately smaller power supplies, wiring, support components, fans, cabinets, etc. This can help offset costs associated with energy improvement in other areas, such as power supply efficiency.

COMPLIANCE TEST METHODOLOGY

Energy Compliance Testing is a matter of measuring volts, amps and time. A good electrical lab should already have equipment needed – a well-regulated AC source with a range from 100 to 240 V, 50 to 60 Hz, with sufficient current to test the EUT, a laboratory grade power analyzer, and some electronic loads for power supply testing should be sufficient.

Production Variations and Measurement Uncertainty

Using manufacturing techniques consistent with industry standard practice, variations in power consumption between otherwise identical CPU/GPU combinations may be as high as +/- 10%. Make sure your production falls within the tolerance limits of the standard.

Sample Calculations – Typical Energy Consumption

One common metric for product energy efficiency is kilowatt hours per year. Recall the Energy Star Typical Energy Consumption formula for computers:

\[
E_{TEC} = \frac{8760}{1000} \times (P_{off} \times T_{off} + P_{sleep} \times T_{sleep} + P_{idle} \times T_{idle})
\]

Because Energy Star does not put a cap on total active power at this time, this formula does not include active mode in the calculation. For the purpose of this exercise, we will add it in. The active mode power can be found by measurement and the time is simply the sum of the percentage of time in use of the other modes from the usage profile subtracted from 100%. It must be noted that there is a lot of opportunity for measurement error in this calculation as well as the following, and using the methodology and metrics presently available, we can only expect to arrive at a gross approximation. Avoid the illusion of precision. Beware of too many significant digits!

Let’s assume that we have conducted a usage study and determined that in a typical household application averaged over a year, a typical desktop computer is in active use one hour per day (4.2%) and needs 200 watts to do so. It is idling four hours per day (9.6%) of the time at 60 watts. The computer sleeps the rest of the day (100%-4.2%-9.6% =86%) at five watts. It is never off. So:
Leveraging Safety and EMC Skills in Energy Regulatory Compliance

\[
E_{\text{TEC}} = (8760/1000) \times (P_{\text{off}} \times 0 + 5W_{\text{sleep}} \times .86 + 60W_{\text{idle}} \times .096 + 200W_{\text{active}} \times .042) = (\text{about}) 200 \text{ kWh/year}
\]

Assumption:

The usage profile is an accurate representation of the entire population of units in service over the course of a year.

GREENHOUSE GAS TRACKING AND LABELING – THE MOST IMPORTANT COMPLIANCE ISSUE OF THE 21ST CENTURY

This year Congress made history by passing the Waxman-Markey American Clean Energy and Security Act of 2009 (ACES). This comprehensive approach to America’s energy policy charts a new course towards a clean energy economy. This bill and similar bills going through legislatures throughout the world open the door to Cap-and-Trade monetization of emission of greenhouse gases.

Meanwhile, last July, Walmart announced an initiative to develop a new sustainability index that will grade various suppliers and products by a range of environmental and sustainable factors. The move is intended to require manufacturers to label their products in such a way that lets consumers easily discern the sustainability of one product over the other. It is anticipated that the labels will contain information about the product’s “carbon footprint,” or energy consumed in the product lifecycle. Wal-Mart has invited Costco, Target and Kroger to work together in developing the index. [27]

Explanation of terminology

Greenhouse gases are gases identified as contributing to global climate change. They include carbon dioxide, water vapor, methane, nitrous oxide, ozone and chlorofluorocarbons. Greenhouse gas emissions are typically measured in carbon dioxide equivalents. Carbon dioxide equivalency (CO2e) for a gas is obtained by multiplying the mass and the global warming potential (GWP) of the gas. It is commonly measured in metric tons of CO2 equivalent and this term is often referred to as a “carbon footprint.” For example, the GWP for methane over 100 years is 25 and for nitrous oxide 298. This means that emissions of 1 million metric tons of methane and nitrous oxide respectively is equivalent to emissions of 25 and 298 million metric tons of carbon dioxide.

Determination of total carbon dioxide and carbon dioxide equivalents emitted in the extraction of raw materials, manufacture of components and final assembly, logistics, distribution, product use and end-of-life disposal and recycling is referred to as “Life Cycle Assessment” or LCA. The field of study is often informally referred to as carbon accounting. The resulting numbers may very well be used one day to determine taxes, or, as is the case in the Waxman-Markey bill, metrics for cap-and-trade regulation.

Obstacles to consistent metrology

The primary reason why complete product lifecycle carbon accounting isn’t done routinely today is because the metrics haven’t been agreed upon and there is tremendous variability from one individual product to the next, even when manufactured with the same raw materials in the same factory on the same day, shipped and sold in the same region, used by next door neighbors on the same electrical grid. However, a

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<td>Category A: ≤ 148.0</td>
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<td>Category B: ≤ 175.0</td>
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<td>Category C: ≤ 209.0</td>
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<td>Category D: 4 GB</td>
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<tr>
<td>Premium Graphics (for Discrete GPUs with specified Frame Buffer Widths)</td>
<td>35 kWh (FB Width ≤ 128-bit)</td>
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<tr>
<td>Cat. A, B</td>
<td>50 kWh (FB Width &gt; 128-bit)</td>
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<tr>
<td>Cat. C, D</td>
<td></td>
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<tr>
<td>Additional Internal Storage</td>
<td>25 kWh</td>
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Table 5: Profile and Energy Consumption
massive effort is underway to do just that as illustrated by the Waxman-Markey bill and the Walmart sustainability index. From a manufacturer’s resource allocation point of view, it is hard to guess today whether this will ultimately be the responsibility of the compliance department, the accounting department, or a combination of the two. At any rate, there is work to be done for competent staff with the right skills. This will grow to a compliance issue calling for accounting skills as well as the ability to convert volts and amps and time to kilowatt-hours per year and metric tons of equivalent CO₂. This is the information that will show up on product labels and on tax statements.

**Sample Calculations – Carbon Dioxide Equivalent**

Probably the best way to illustrate some of the difficulties with carbon metrology is to continue with our example computer. We determined that the typical energy consumption for this particular product is found by:

$$E_{\text{SEC}} = (8760/1000) \times (P_{\text{off}} \times 0 + 5W_{\text{deep}} \times 0.86 + 60W_{\text{idle}} \times 0.96 + 200W_{\text{active}} \times 0.042)$$

$$= (about) 200 \text{ kWhr/year}$$

**Assumption:**

The usage profile is an accurate representation of the entire population of units in service over the course of a year.

Of course, that doesn’t give us all we need for calculating CO₂. The missing information is: how much CO₂ is released into the atmosphere in the generation of 200 kilowatt-hours? The answer is, it depends.

Electrical utilities use hard coal, soft coal, fuel oil, natural gas, biomass, hydro, wind, geothermal, and nuclear sources to generate power. When deriving power from a grid, emissions can vary considerably over time or location given the net contribution of the sum of generating stations on the grid and the particular mix of GhGs coming from those generating stations. For example, the EPA calculates the average CO2 emissions from the generation of power in the state of Washington to be 331 lb/MWhr. They calculate average CO2 emissions from North Dakota to be 2325 lb/MWhr. Average CO2 emissions for the aggregate US are 1329 lb/MWhr. [28] Note that to simplify this calculation, contribution of other GhGs is not included. So, using the US aggregate number of 1329 lb/MWhr:

$$\text{CO}_2 \text{ emitted in use} = \frac{200 \text{ kWhr} \times 1329 \text{ lb/MWhr} \times 1 \text{ Kg}}{\text{Year} \times 1000\text{kWhr/MWhr} \times 2.2 \text{ lb}}$$

$$= (about) 100 \text{ Kg CO}_2 \text{ per computer per year}$$

**Assumptions:**

1. The usage profile is an accurate representation of the entire population of units in service over the course of a year.
2. This calculation assumes one year of product use. For total product life CO₂ in use, the calculation would need to be multiplied by the total average number of years the product is in service.
3. The population of units is distributed throughout the US proportional to the aggregate of all generation sources.
4. Other GHGs emitted in use do not make a significant contribution.
5. Uncertainty only allows for one significant digit.

As more complex measurements are made, more assumptions must follow. For a total Life Cycle Assessment, electrical and fossil fuel energy used in design, extraction, refining, milling, processing, assembling, transporting, recycling and incinerating must also be calculated on an aggregate basis, then extrapolated to a single-product level, with many, many more assumptions. The more complex the product, the more monumental this task becomes, and the more opportunities to introduce error occur.

Uncertainties notwithstanding, it is reasonable to expect that mandatory and market-driven rules calling for LCA emissions information to be provided to consumers will emerge soon. It is the responsibility of technical regulatory subject matter experts to assure the metrics have some validity at the end of the day.

**SUGGESTED ENERGY COMPLIANCE ORGANIZATIONAL STRUCTURE**

By now you’ve probably noticed that there are a lot of similarities between energy compliance and safety compliance. Because of the environmental nature of energy issues, a manufacturer with a robust environmental compliance team already in place may be inclined at first blush to assign responsibility for energy compliance to the environmental team. However, management of energy compliance through a team skilled in Safety and EMC may make more sense from a resource allocation perspective. An existing electrical compliance resource within an organization can incrementally “scale up” to manage energy compliance, whereas an environmental team may need to recruit an electrical test and engineering team to meet the growing demands of energy compliance.

A basic job description for an energy compliance engineer would include a strong background in electrical engineering, working knowledge of electrical test equipment, the ability to read, understand, interpret, and contribute to the development of electrical technical standards, the ability to track emerging
Leveraging Safety and EMC Skills in Energy Regulatory Compliance

global regulations and implement processes and procedures to assure compliance with those regulations, and contribute knowledge to the design and implementation of energy-efficient products and systems.

Most if not all of these skills are required for a good EMC or electrical safety engineer as well. Depending on the variety and volume of products to be evaluated, a compliance team may wish to develop individuals with skills in all three fields or develop depth of expertise in individual subject-matter expertise in each discipline. Even in that case, cross-training will enable the compliance manager to optimize staff utilization during peak and off times. Regardless of organizational structure, the design and manufacture of products compliant in all disciplines requires a systems-level approach to assure that one area of compliance is not overlooked or undone through the efforts of another area of compliance.

CONCLUSION

Much of technical regulatory compliance can be viewed as a sub-discipline of electrical engineering. Over time, electrical engineering skill sets have been utilized in the area of product safety and electromagnetic compatibility. Very real twenty-first century concerns regarding the impact of global climate change on life on earth are resulting in a multitude of technical regulations that have a potential impact on many consumer and enterprise products in markets throughout the world. Modern manufacturers and test houses must scale up to assure compliance with these emerging regulations. That being said, similarities in test methods and instrumentation as well as engineering disciplines allow for an organic scaling of existing compliance organizations rather than the need to start from scratch in order to meet these new requirements.

NOTES

8. NOTE: No requirements have been agreed upon for external multiple-output power supplies as of this writing.
24. CEA, www.ce.org/AboutCEA/CEAInitiatives/3638.asp
Ben Franklin: “Nothing can be said to be certain except death and taxes.” If Franklin were alive today, he would have many items to add to that statement. In the electronics industry – and its supply chains – a contemporary item he would include is product environmental compliance.

Since the European Union (EU) passed the Restriction on the use of certain Hazardous Substances (RoHS) and Waste Electrical and Electronic Equipment (WEEE) directives in 2003, the world has begun to pay more and more attention to product environmental compliance. Eco-Compliance legislation impacting the electronics industry and its supply chains has grown exponentially. Jurisdictions implementing legislation that impacts the electronics industry include: China, South Korea, Japan, Taiwan, Argentina, Brazil, Chile, Columbia, Venezuela, Canada and United States of America. Many are similar to the European Union’s legislation; but none are using it verbatim.

In addition to RoHS and WEEE type legislations, the EU instituted an updated regulation regarding chemicals, mixtures, and articles. Registration, Evaluation, Authorization of Chemicals Regulation (REACH) began affecting the electronics industry a few years ago, and has now become the basis for many compliance activities.

WHAT’S EXPECTED IN 2010?

Remember “2010: A Space Odyssey” and the question – “What’s going to happen now?” No one has a crystal ball to foresee the future, but there are some major changes proceeding within the global product environmental compliance space. The EU is revisiting the RoHS directive, China is working on their first RoHS product catalog, and many more jurisdictions are enacting take-back legislation for electronic waste.

In addition to RoHS and WEEE-type legislations which focus on electronics, some jurisdictions are investigating and enacting more general regulations of chemicals and substances within products. Legislations such as EU REACH and the California Green Chemistry Initiative focus on all products, not just electronics.

**RoHS – European Union**

In the EU, the RoHS and WEEE directives are currently under recast – the EU term for rewrite and review. The first reading is to be in early 2010. Some of the anticipated modifications are:

- Change in scope from specific categories to an open scope of all electronics unless specifically excluded
- Recasting the RoHS Directive as a New Approach Directive (CE Mark)
The latest Implementing Measure of the Eco Design Directive (ErP) formerly Eup, affects the power supplies of over thirty product categories. And it's just the tip of the green iceberg. More and more, consumers are weighing environmental considerations into their choices. And environmental compliance is becoming much more comprehensive, engaging nearly every stage of the product lifecycle and every link in the supply chain.

That's why you need a testing and certification partner like Intertek. We deliver a faster, more complete solution for all your safety, performance and environmental certification needs. Our engineers are experts in the products they test and the industries they serve, and our network of laboratories around the world ensure local service for global certifications. To lower your impact, visit our site and download our latest white paper.

The Energy-related Products Directive cuts across multiple product categories and touches all stages of a product's lifecycle.

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The discussion of open-scope will eliminate the misinterpretation of whether or not a particular product is within the scope of EU RoHS. The discussion of including the RoHS directive within the New Approach directives will significantly impact how companies approach compliance going forward. If recast as a New Approach directive the RoHS directive will then require products to have CE certification and be labeled with the CE mark to indicate compliance. This means companies will need to maintain and be able to present supporting documentation to an auditor when asked.

RoHS – People’s Republic of China
Also expected in the first half of 2010 is the publication of China’s initial product catalog for its RoHS-type legislation. A draft of the product catalog was published for comment in October 2009. A brief comment period of 30 days allowed for industry review and input. As part of the draft publication, a timeline was given for publication of early 2010 – likely February. Within the draft, an implementation period of 10 months was drafted. Based on this, if the draft catalog is agreed to and published in early 2010, enforcement to the new catalog could happen as early as 01 January 2011.

Products included within the draft catalog were listed as: phones (land-line and mobile), computer printers and mobile terminals. For each of the products listed within the catalog, allowances for specific use of restricted substances were listed. These are very similar, though not exactly the same, as some of the exemptions allowed within the EU’s RoHS Directive and its amendments.

Chemicals Regulation – EU REACH
As product environmental compliance continues to expand, all roads are pointing towards chemicals regulation, such as the EU’s REACH Regulation. Not unique to the electronics industry and its supply chain, REACH impacts all products. Though the main focus affects chemical and mixture manufacturers, it does have requirements for articles manufacturers (e.g. product manufacturers). There is still debate over whether or not to include sub-components of products.

With REACH impacting the entire supply chain for all products, it has solidified the movement of product environmental compliance to a process based approach. Some highlights of REACH are listed below. Look for more information in the other articles in this issue for the specifics of REACH and its Substances of Very High Concern (SVHCs).

- Only a handful of SVHCs used within electronics
- Additional substances expected to be added annually
- Information disclosure required where SVHCs are present
- Disclosure information for other substances once over threshold amounts.

SUSTAINING COMPLIANCE
When companies started working on RoHS compliance in 2002-2003, most were taking the approach of “we’re going to do this once and be done”. This is no longer the case: laws are constantly changing and methods used by enforcement bodies are constantly evolving. The need for a process-based approach is vital. Companies must be able to sustain, maintain and adjust their program in a variety of ways. A proactive approach, not simply reacting to changes, is a must to stay on the path of product environmental compliance.

The project-based approach of “one and done” has been debunked by many companies. Companies now have teams of people working on product environment compliance, not just component engineers gathering data sheets. In 2008, the Consumer Electronics Association report estimated the amount spent on RoHS compliance within the electronics industry was over $32B USD. This amount was just the amount spent on RoHS, not REACH or WEEE. Since then, more and more companies are working towards compliance with more than just the EU RoHS directive. Companies are dealing with regulation and compliance in almost every industrialized jurisdiction they ship product.

In Figure 1, the CEA estimation is expanded to include all environmental compliance legislation impacting products. The figure represents an estimation and extrapolation of the money spent per the CEA report by electronics industry (and its supply chain)
for each new, product-based environmental compliance legislation or regulation. REACH will eventually eclipse RoHS – as more and more companies will demand full materials declaration from their supply chain to assist in the process-based approach for compliance with multiple jurisdictions and legislations. The amount spent each year will continue to increase as laws continue to be enacted, revised and expanded around the globe. Implementing a process-based approach is becoming an industry norm. If there is one thing you take away from this article, it should be that product environmental compliance is an evolving process; not a “one and done” project.

TOTAL COMPLIANCE

With the constant changes to product eco-compliance legislation, a process needs to be implemented when preparing and maintaining a product environmental compliance program. If a project is started for each new variation of legislation, there will not be continuity within the system, nor the ability to compare information gathered for different jurisdictional requirements. Total product environmental compliance needs to be rooted in a process based approach.

Elements of a process based approach are shown in Figure 2. Many companies have some of these elements within an internal program; others have several sources they use to complete their program. You must have information on all the pieces of the pie to have a totally compliant program. If you would like more information on the figure below, please e-mail the author for copies of the previous publications.

LESSONS LEARNED & BEST PRACTICES

Lesson 1: Implement a process approach to product environmental compliance

With the constant changes to product eco-compliance legislation, a process needs to be implemented. If a project is started for each new variation of legislation, there will not be continuity within the system, nor the ability to compare information gathered for different jurisdictional requirements. Throughout the years, best practices within product environmental compliance have been established.

As these best practices relate to implementing a process approach to compliance, the next three lessons learned and best practices all highlight the importance of the ultimate best practice – a process based approach.

Lesson 2: Be ready for an audit

Audits are no longer just being done by government or enforcement agencies. Some companies are requiring their suppliers to pass an internal audit before continuing to do business with that supplier. An average small company with non-complex products takes around three months to gather basic information. To implement a complete product environmental compliance program, it takes around six months. Neither companies – nor enforcement agencies – will wait while you put the information together. In the case of being audited by the enforcement authority in Ireland, a turn-around time of 24 hours is expected for all compliance materials.

A best practice is to be ready for an audit at any time. Remote access to data & information allows for instant access to compliance information. Technical compliance files should include: component data, corporate policies and procedures, classification/justification documents, roadmap(s) of activities, and use of any exemptions or allowances within the legislation.

For part data and information within the database, it should be searchable by component, part number, supplier status, substance, exemption/variation, just to name a few criteria. From reports in 2008 and 2009, almost 50% of companies fail...
compliance audits for RoHS. The top reasons for failure were responsiveness, completeness of information, sustainability of program, and misuse/misinterpretation of exemptions.

**Lesson 3: Gather full materials declarations**

With more and more countries creating requirements for materials reporting requirements or materials restrictions – such as RoHS-type and REACH-type legislation, full materials declarations information is becoming more and more prominent. Countries with existing requirements are looking at adding additional substances.

If you are able to gather full materials information by weight, it allows for manipulation of the data regardless of the regulation. Gathering full materials information is a best practice when working on multiple environmental requirements. In addition, it is recommended the information be listed in a database by CAS number. This allows for the ability to search database for a specific substance when it is called into question.

**Lesson 4: Stay current**

Education is a corner stone of a successful implementation and maintenance of a product environmental compliance program. With changes happening to existing legislation and new legislation being drafted or created, one needs a variety of tools for keeping informed. Some of the best sources for up-to-date information are: industry involvement or industry events; targeted reports – not general knowledge databases or “tech rags”; or a targeted news service. There is good information available on blogs or listserv – but be wary of this information as much of it is opinion, not fact. Make sure the information you’re using comes from a reputable source and can be verified.

**IT KEEPS GOING AND GOING AND GOING...**

“We’re way beyond RoHS and WEEE at this point. Product eco-compliance requirements continue to expand and change. The two major things to remember when implementing a compliance program:

1. A process-based approach should be implemented for product environmental compliance activities. It is no longer a “one and done” project.

2. Product environmental compliance requirements are not going away, and will continually change and evolve.

Any electrical or electronic equipment sold in the world will need to comply with a product environmental legislation at some point. Ben Franklin may have given rise to our title… but the Energizer Bunny® brings it home – the requirements keep “going and going and going...”

**REFERENCES/USEFUL WEBSITES**

- www.berr.gov.uk/whatwedo/sectors/sustainability/rohs/page29048.html
- www.berr.gov.uk/whatwedo/sectors/sustainability/weee/page30269.html
- www.rohs.gov.uk/
- www.hse.gov.uk/reach/index.htm

Krista Botsford, Botsford EcoTech Partners LLC, can be contacted at kbots@botsfordeco.com or by visiting www.BotsfordEcoTech.com.

“Going Green” – in terms of product environmental compliance – is a conscious corporate decision. It is a change to critical thinking and the way your company does business. It is a corporate decision to prepare for the future and go beyond simple substance restrictions declarations. It is designing a product to account for the product’s end of life requirements which impact waste management.

It is compliance - not chaos. It is a crisp presentation of corporate environmental stewardship within its products. A company needs to eliminate the risks of not being able to provide accurate and complete product environmental compliance information to auditors or customers. The inability to provide this information in a timely, organized manner can ultimately lead to a finding of non-compliance.
Best Practices for REACH Compliance Management for Electronics OEMs

by Larry Yen
GreenSoft Technology, Inc.

THE REACH ERA

The regulation referred to as REACH (Registration, Evaluation and Authorization of Chemicals), came into effect in European Union Member States in June of 2007. The intent of REACH is to regulate chemicals that can cause cancer and other diseases.

REACH applies to thousands of chemicals (substances) that are used or present in electrical equipment. REACH also applies to mixtures or solutions of substances (preparations), and end products (articles). Substances of Very High Concern (SVHCs), are the most hazardous and harmful substances and are highly regulated. Products containing SVHCs may not receive authorization if a safer alternative exists.

REACH affects all organizations that export, manufacture, or use chemicals. Early planning and good communications are urgently needed to avoid disruptions in the supply chain. Parts and equipment manufacturers will be affected by unexpected withdrawal of substances from their suppliers due to REACH.

Compliance with REACH will require manufacturers to have more detailed knowledge of the substances they use or are present in their products. The burden of compliance falls not just on large OEMs that export to the EU. Small and medium enterprises (SMEs) also share the burden of compliance, even if they do not directly export to the EU. Large OEMs are responding to REACH by developing compliance standards of their own and asking their suppliers for chemical composition data on products.

Complying with RoHS, which regulated just 6 substances and related compounds, was a difficult enough task. REACH regulates more than 30,000 substances. Making the task even more difficult are changes to the SVHC list. On January 13, 2010, the European Chemicals Agency added 14 chemical substances to the Candidate List of SVHC for authorization, bringing the total to 29 substances. The ECA promises to revise the SVHC list twice a year. The task of collecting detailed information about which substances are contained in products will be extensive and ongoing.

THE CHALLENGES OF REACH COMPLIANCE FOR ELECTRONICS OEMS

Data Collection

The biggest challenge for electronics OEMs in managing REACH compliance is to discover the chemical composition of all components and materials used in their products. With full knowledge of the chemicals used, OEMs can create a compliance plan that will work short and long-term. However, collecting chemical substance information from suppliers is a tedious and resource-intensive job. It takes numerous phone calls or e-mails; suppliers often do not understand aspects of regulations such as SVHCs; and suppliers sometimes demand a rationale for sharing information.

Ask for full-disclosure substance data whenever possible. When the SVHC list changes, for example, you don’t have to ask for more data in the future if you have full disclosure data already. If full-disclosure data is not available from a supplier,
at the very least, try to obtain a non-use SVHC statement or certificate. Ideally, suppliers should inform you about their use of SVHC when it exceeds 0.1% in concentration. In reality, it is risky not to pursue this data and to rely only on suppliers to provide notification.

**Data Validation and Consolidation**

The second challenge begins after chemical substance data starts to arrive from suppliers. The data may not be clean and it needs to be validated. Here are some common problems:

1. The chemical substance name does not match the CAS number;
2. The CAS number is incomplete or missing;
3. Two different substances use the same CAS number;
4. Different suppliers refer to identical substances with different names and different CAS numbers.

In Figure 1, SiO2 is correlated to two different CAS numbers. In this case, and in all others where data cleansing and consolidation has not taken place, it is not possible to generate an accurate rollup of the total weight of chemicals used in the product.

Resolving these issues is necessary before conducting substance analysis for REACH compliance.

**Establishment of Chemical Substance Database**

The third challenge is to establish an enterprise-level chemical substance database covering all components used to build the products. A software system is necessary to manage the enterprise-level chemical substance database. The system needs to be able to roll up substance data from homogeneous materials. In order to help identify problem areas, the software system should be able to calculate substance data at the component, assembly, and product level. The system will also enable proper reporting on particular substances (such as SVHC or CMR substances) at the product level or even across different products.

A chemical substance database covering potentially thousands of components is complex and far beyond the limits of a spreadsheet application like Excel. Moreover, entering the data by hand is impractical and will introduce errors.

### Breakdown of all Materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>% Weight</th>
<th>PPM</th>
<th>Where Used</th>
<th>CAS #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al2O3</td>
<td>68.97</td>
<td>68970</td>
<td>substrate</td>
<td>12036-10-1</td>
</tr>
<tr>
<td>SiO2</td>
<td>2.155</td>
<td>21550</td>
<td>substrate</td>
<td>7440-21-3</td>
</tr>
<tr>
<td>MgO</td>
<td>0.575</td>
<td>5750</td>
<td>substrate</td>
<td>1313-13-9</td>
</tr>
<tr>
<td>Ag</td>
<td>3.638</td>
<td>36380</td>
<td>inner electrode top</td>
<td>7440-22-4</td>
</tr>
<tr>
<td>Pd</td>
<td>0.099</td>
<td>990</td>
<td>inner electrode top</td>
<td>1309-60-0</td>
</tr>
<tr>
<td>Pbo</td>
<td>0.08</td>
<td>800</td>
<td>inner electrode top</td>
<td>1303-86-2</td>
</tr>
<tr>
<td>B2O3</td>
<td>0.04</td>
<td>400</td>
<td>inner electrode top</td>
<td>7631-86-9</td>
</tr>
<tr>
<td>SiO2</td>
<td>0.08</td>
<td>800</td>
<td>inner electrode side</td>
<td>7440-02-0</td>
</tr>
<tr>
<td>Ni</td>
<td>0.338</td>
<td>3380</td>
<td>inner electrode side</td>
<td>7440-07-3</td>
</tr>
<tr>
<td>Cr</td>
<td>0.338</td>
<td>3380</td>
<td>inner electrode side</td>
<td>12036-10-1</td>
</tr>
<tr>
<td>RuO2</td>
<td>0.992</td>
<td>9920</td>
<td>Resistive Film</td>
<td>1309-60-0</td>
</tr>
<tr>
<td>Pbo</td>
<td>1.006</td>
<td>10060</td>
<td>Resistive Film</td>
<td>1303-86-2</td>
</tr>
<tr>
<td>SiO2</td>
<td>0.292</td>
<td>2920</td>
<td>Resistive Film</td>
<td>7631-86-9</td>
</tr>
<tr>
<td>Cu0</td>
<td>0.050</td>
<td>500</td>
<td>inner protective coat</td>
<td>129915-35-1</td>
</tr>
<tr>
<td>B2O3</td>
<td>0.277</td>
<td>2770</td>
<td>inner protective coat</td>
<td>7631-86-9</td>
</tr>
<tr>
<td>SiO2</td>
<td>0.419</td>
<td>4190</td>
<td>inner protective coat</td>
<td>1317-38-0</td>
</tr>
<tr>
<td>Epoxy Resin</td>
<td>1.547</td>
<td>15470</td>
<td>outer protective coat</td>
<td>1308-38-9</td>
</tr>
<tr>
<td>SiO2</td>
<td>0.184</td>
<td>1840</td>
<td>outer protective coat</td>
<td>1313-13-9</td>
</tr>
<tr>
<td>Cu0</td>
<td>0.231</td>
<td>2310</td>
<td>outer protective coat</td>
<td>7440-02-0</td>
</tr>
<tr>
<td>Cr2303</td>
<td>0.472</td>
<td>4720</td>
<td>outer protective coat</td>
<td>7440-31-5</td>
</tr>
<tr>
<td>MnO2</td>
<td>0.079</td>
<td>790</td>
<td>outer protective coat</td>
<td>1313-13-9</td>
</tr>
<tr>
<td>Ni</td>
<td>8.85</td>
<td>88500</td>
<td>middle termination</td>
<td>7440-02-0</td>
</tr>
<tr>
<td>Sn</td>
<td>6.929</td>
<td>69260</td>
<td>outer termination</td>
<td>7440-31-5</td>
</tr>
<tr>
<td>Others</td>
<td>1.147</td>
<td>11470</td>
<td>others (all locations)</td>
<td>---</td>
</tr>
</tbody>
</table>

**Figure 1: Correction of CAS number for SiO2 is necessary**
Requesting that suppliers send chemical substance data in a common format that your software is able to import directly is also not feasible in reality. Finding a proper way of entering the chemical substance data to the software system is a challenge.

**Limited Resources**
Most electronics OEMs have no one devoted to or specializing in chemical management. Most likely, the task of REACH compliance will go either to component engineering or the quality group. Designers of products have little need to know the chemical substances used in the components, though they do need to know whether the components they select are REACH-compliant. With limited resources and budget, most companies can only afford to have a few people be responsible for this task and cannot afford to spend several hundreds of thousands of dollars on REACH compliance modules available with ERP or PLM upgrades. Finding a way of implementing REACH compliance management in a limited budget with limited resources is another challenge that most companies have to face.

**BEST PRACTICES OF COMPLIANCE MANAGEMENT IN REACH**

**Scrub your BOMs**
Most BOMs are dirty. Dirty BOMs contain inaccurate manufacturer names and part numbers. Before calling suppliers for chemical substance data, it’s best to start by cleaning up the dirty BOMs stored in the ERP or PLM. You may have done this several years ago while requesting RoHS data from suppliers. If not, now is the time to scrub your BOMs by validating the manufacturer names, manufacturer part numbers and part description on all components in the BOMs. It will save a tremendous amount of time in getting data from your suppliers.

**Collect full-disclosure chemical substance info from suppliers whenever possible**
In order to be REACH-compliant, you need to know the chemical substance composition of the components in your products. This means collecting full-disclosure chemical substance data from your suppliers. If you are an “Article Producer” and only care about REACH SVHC compliance, you should still collect full-disclosure chemical substance data on all parts from suppliers whenever possible. Collecting REACH SVHC certificates from suppliers can only get you through compliance for 6 months to a year. New substances will be added to the SVHC Candidate list regularly. Collect full-disclosure chemical substance information from suppliers whenever possible so you don’t need to recollect the certificates from the same suppliers when the SVHC Candidate list changes. This is the most critical step in compliance management.

It is highly recommended, if financially viable, to outsource the data collection to a 3rd-party solution provider. By tapping into the component chemical substance database established by a 3rd-party solution provider, you may find that data collection is actually cheaper, faster, and more accurate than doing it in-house. In our experience with electronics manufacturers, a typical BOM of 1000 parts will have more than 60% coverage in full-disclosure chemical substance data in our component database. This means the effort of data collection has been reduced to 40%. The challenge of recollecting data from the same suppliers when regulations change has also been reduced. Outsourcing data collection enables your component or quality engineers to focus on their core competencies of completing the product with quality, instead of dealing with mismatched or incorrect part numbers, CAS numbers, substance names, etc.

**Select the proper software tool to help manage REACH compliance**
Once you start collecting chemical substance data from suppliers, a software tool is necessary to help manage collection activities, establish the internal chemical substance database, and analyze the substances used in your products. The tool needs to tell you what has been collected and what has not, and should be able to report the aggregated weight of a substance in a product based on the projected annual shipment to the EU or customers in another region. The tool should also report on any SVHC substance contained in components used in your product in order to communicate
with your suppliers for replacements and to alert your customers to proper usage scenarios. You may need to notify the ECHA on the use of SVHC substances in your products if they account for more than 0.1% of the product weight when more than 1 tonne is shipped to the EU per year. The tool should also be capable of scanning all components for substances in the categories of CMR (Carcinogenic, Mutagenic or Reprotoxic), PBT (Persistent, Bioaccumulative and Toxic) or vPvB (very persistent, very bioaccumulative) for possible violation of SVHCs in the future.

**Enter chemical substance data in the software tool to establish an internal chemical substance database**

In the process of collecting and validating chemical substance data from the components used in your products, you need to establish an internal chemical substance database by entering the substance data to the software tool. Be aware of these issues:

**Data Format:** Suppliers can provide chemical substance data in various formats, including pdf, Excel, html, XML and IPC-1752 forms. These formats need to be consolidated into one standard format in order to import them to the software tool. If you have outsourced the data collection job to a 3rd-party data provider, ask them to provide a common format that can be imported to the software tool.

**Consolidated Substance Master:** Entering substance data into the software tool can reveal several potentially difficult issues:

1. Some substances have a different CAS number but have the same substance name because they actually are the same substance. See Figure 3, an illustration from the SVHC Candidate List. CAS number 7789-12-0 and CAS number 10588-01-9 are both Sodium Dichromate. When a part contains substance 7789-12-0 and substance 10588-01-9, the software tool will need to be able to recognize that these two are actually the same and aggregate them properly.

2. Some substances have different CAS numbers and different substance names, but are in the same group of restricted substances. See Figure 4, again from the SVHC Candidate List. Note that HBCDD could have 2 different CAS numbers: 25637-99-4 or 3194-55-6, an alias CAS number. HBCDD could also have 3 isomeric series: alpha-HBCDD (134237-51-7), beta-HBCDD (134237-50-6), and gamma-HBCDD (134237-52-8). When parts contain any of these substances, the software tool will need to be able to recognize that these actually belong to the same group and aggregate them properly.

3. The software tool should maintain a consolidated substance master that covers all alias substances provided by suppliers and all isomeric series of substances. In reality, it is almost impossible for any software tool to cover all possible substances with their aliases and isomeric relatives. A good way to solve this issue is to make sure the software tool has a substance master that covers almost all substances provided by suppliers and can handle substance aliases and isomeric series. Most important, the tool should receive updates whenever a new substance provided by the supplier is not covered in the substance master. If you have outsourced the data to a 3rd-party data solution provider, make sure they will work with the software vendor so that both will maintain the same substance master and both will update their substance master whenever a new substance is identified.

4. Almost all software vendors claim to be able to import substance data in IPC-1752 format, but this format has limitations. IPC-1752’s substance master is based on JIG specifications, so only about 300 substances are covered. Substances beyond JIG will be tagged as either Supplier Specific or Requester Specific. You will almost certainly

<table>
<thead>
<tr>
<th>Substance name</th>
<th>CAS number</th>
<th>EC number</th>
<th>Basis for Identification as SVHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diarsenic pentoxide</td>
<td>1303-28-2</td>
<td>215-116-9</td>
<td>Carcinogen, cat. 1</td>
</tr>
<tr>
<td>Diarsenic trioxide</td>
<td>1327-53-3</td>
<td>215-481-4</td>
<td>Carcinogen, cat. 1</td>
</tr>
<tr>
<td>Sodium dichromate</td>
<td>7789-12-0</td>
<td>234-190-3</td>
<td>Carcinogen, cat. 2</td>
</tr>
<tr>
<td></td>
<td>10588-01-9</td>
<td></td>
<td>Mutagen, cat. 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Toxic for reproduction, cat. 2</td>
</tr>
</tbody>
</table>

**Figure 3: Substance aliasing between 7789-12-0 and 10588-01-9**

<table>
<thead>
<tr>
<th>Substance name</th>
<th>CAS number</th>
<th>EC number</th>
<th>Basis for Identification as SVHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexabromocyclododecane (HBCDD) and all</td>
<td>25637-99-4</td>
<td>247-148-4</td>
<td>Persistent, bioaccumulative and toxic</td>
</tr>
<tr>
<td>major diastereoisomers identified</td>
<td>and 3194-55-6</td>
<td>221-695-9</td>
<td></td>
</tr>
<tr>
<td>(α – HBCDD, β – HBCDD, γ – HBCDD)</td>
<td>(134237-51-7, 134237-50-6, 134237-52-8)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4: Substance grouping of 5 CAS numbers**
see suppliers submit substance data and tag it Supplier Specific. If you are working with a data vendor to perform data collection, make sure to ask that they consolidate the substances so that all Supplier Specific substances or Requester Specific substances be grouped so that they can be aggregated in the software.

5. One recommendation is to find a 3rd-party solution provider that both collects data and provides the software tool. This is the preferred solution because the substance master for both the data service and the software tool are the same and synched for updates and aliases. This eliminates the issue of consolidated substances and substance maintenance, and reduces management of two vendors (or more) to one.

**Make sound decision on change of parts or change of suppliers based on REACH compliance performance**

Should you discover that components used in your BOMs contain certain regulated substances (from SVHC, CMR, PBT or vPvB), communicate with your suppliers for replacements. If the supplier fails to provide a plan for replacement, you may need to consider changing the suppliers. Based on the analysis from the tool, you should be able to make such decision quickly in order to avoid any disruption in businesses.

**CONCLUSION**

Compliance with REACH demands thorough and accurate data and an efficient way to analyze and manage the data. Companies throughout the supply chain will be feeling the impact of REACH and need to develop strategies to ensure that disruptions are minimized. These strategies include:

1. Clean the data you already have by scrubbing your BOMs.
2. Collect full-disclosure chemical data for all your components if it is available. A third-party solution provider may save you time and money.
3. Find a software tool to manage REACH compliance, including reporting on data collection, and chemical analysis at the component, subassembly, and product level.

Applying these strategies will help prevent product delays, redesigns, and supply chain disruptions.

Larry Yen is president and CEO of GreenSoft Technology, Inc., a data services provider and developer of software solutions for environmental compliance regulations such as RoHS and REACH.
EU REACH: The Continued March of Candidate SVHC Lists and the Authorization Process – What’s Next?

by Michael Kirschner
Design Chain Associates, LLC

While the European Union’s REACH regulation (formally, Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals) has been in force for nearly two years, it is rolling out in a slow and determined fashion. In October 2008 the European Chemicals Agency (ECHA) produced the first candidate list of 15 substances of very high concern (SVHCs). Last spring, in early June, seven of those substances were prioritized to be the first to go through the authorization process. This is the next step towards possible future restrictions for these substances. Then, in early September the second list of 15 proposed candidate SVHCs was issued and 14 of these substances were then added to the candidate list of SVHCs in mid-January this year. What is next and what does all this mean to manufacturers of electronic components and products?

The key concerns for non-EU-based manufacturers of components and discrete products – termed “article manufacturers” in REACH – are twofold:

1. Understanding which substances must be disclosed to customers downstream in the supply chain if they are present in the product you are selling in amounts greater than 0.1% by weight (of the entire article), and
2. Knowing when restrictions come in to play

EU-based manufacturers must also be concerned with substances that are going through the authorization process and whether their supply chains must replace these substances or should apply for an authorization to allow continued use.

All substances on the candidate list that meet the concentration requirement described above must be disclosed directly to your immediate customer in the EU, unless that customer is an end-user/consumer. Today there are 29 substances (some have more than one CAS number; for instance, hexabromocyclododecane has several “diastereoisomers” – certain atoms, in this case bromine, can have different sets of locations on the molecule, resulting in different configurations1 and therefore different CAS numbers) you will have to disclose the presence of those substances in your products per article 33(1) of the REACH regulation.

ECHA has said it intends to produce new candidate lists of SVHCs twice a year from now on, with the next proposal coming out in the February/March timeframe – it may in fact be published by the time you read this. It will then go through a 45-day stakeholder consultation process where

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1 See, for example, Heeb, et al., Structure elucidation of hexabromocyclododecanes — a class of compounds with a complex stereochemistry, Chemosphere 61 (2005) 65-73, at http://www.empa.ch/plugin/template/empa/*/54786/---/l=2
you can provide technical – not editorial – comments on why substances should or should not be considered for the actual list. Some time after that, some or all of the proposed substances will again be added to the candidate list of SVHCs.

The candidate list of SVHCs identifies candidates for the Authorization process. The authorization process defines a timeline for prioritized SVHCs to be “sunsetted”, or restricted. If a (EU-based) manufacturer wants to continue to use a prioritized SVHC beyond the sunset date, they must identify the source of the substance that (pre)registered it in their supply chain, and have them apply for an authorization for your (and all their other customers’) specific use. The authorization process will not be easy; it will require a fee to be paid, and justifications based either on socio-economic impact (e.g. replacement substance is too expensive or unavailable) or adequate control of exposure during the substance’s lifetime, including and after disposal. Suppliers may decide not to apply in which case the manufacturer may have to find another source or reformulate the product, or move production outside of the EU (though, as pointed out above, that might only delay the inevitable). As I write this in late January we are awaiting both guidance documents for industry on the authorization process, and the Commission’s documentation officially modifying REACH Annex XIV to officially include some or all seven SVHC substances as proposed by ECHA.

Note that importers of articles (functional components, electronics, wires, cables, connectors, etc…nearly everything in the electronics world except individual chemical substances like pure solvents, or formulations such as adhesives, solder, or bar stock) are effectively exempt from the authorization process, so they can still export product to their EU markets that contain sunsettled substances after the sunset date. However, don’t expect this “loophole” to provide indefinite freedom to continue shipping. Article 69 of REACH allows ECHA and the EU Member States to directly apply restrictions to imported articles, so expect that process to be started soon after the sunset dates start occurring.

While this new, and very different, chemical policy might seem to be slow in rolling out, do not expect it to stay that way. These are new processes that the ECHA and the EU Member State chemical and enforcement agencies are essentially running through their paces. Once they better understand the resource requirements and work out any kinks in the processes of candidate list definition, substance authorization and restriction, and enforcement, expect the lists of candidate SVHCs and prioritized SVHCs to rapidly become more voluminous. This does today, and will tomorrow. require a deeper understanding by manufacturers of what substances are in your products, in what quantities, and what their toxicity profiles are. If they meet the definition of SVHCs (see article 57 in REACH) and are generally used in high volume (since it’s likely these will get ECHA’s attention more quickly than low volume SVHCs), you may consider getting ahead of the process by prioritizing these substances (based, for instance, on relative toxicity), and reformulating products or designing out offending components as soon as is practical. In addition to reducing business and fiduciary risk, you may also gain a marketing advantage by doing so.

DCA produced an in-depth, 2 ½ hour webinar on REACH for article manufacturers on December 16, 2009. You can gain a deeper understanding by viewing this webinar and downloading the associated slide set. Please visit the DCA website for more information.

Michael Kirschner is president of Design Chain Associates, LLC, a consultancy that provides services that help Electronics OEMs and other product manufacturers increase engineering, procurement, and production efficiency, product and operational environmental performance, and corporate profitability by ensuring that the right decisions about supply base and the environment are made during the earliest stages of the product lifecycle, and are built-in to corporate strategies and tactics. Contact Mike at (415) 904-8330 or mike@designchainassociates.com.
“battery” is the generic term for an electrochemical source of electricity, which stores energy in a chemically bound form, and which can convert this directly into electric power. A battery cell consists of two electrodes, called the anode (+ pole) and cathode (- pole), separated by a fluid or solid electrolyte, and conductors. Batteries can be divided into primary and secondary systems. Primary batteries are disposable batteries, i.e. batteries that cannot be recharged, and their conversion of chemical energy into electrical energy is irreversible, which means that the chemicals are consumed while the battery discharges. Secondary batteries can be recharged, and the electrode material is reconstituted using an electric charge, so that discharge process can be repeated a multitude of times during the lifecycle of the battery.

WHEN SELECTING A BATTERY, TECHNICAL REQUIREMENTS AND COST ARE KEY
The choice of primary or secondary batteries depends on financial factors and the technical requirements imposed by its intended use. In general, primary batteries are principally used for applications with low energy consumption, in which there is a long storage time between use, or where it is difficult or inconvenient to charge the battery. Secondary batteries are primarily used when there is a need for high levels of energy or large load currents, at low temperature and where it is convenient to charge the batteries.

There is a wide range of primary and secondary batteries. The most common primary systems are alkaline, lithium and metal/air batteries. Among secondary batteries, lead acid, nickel/cadmium (NiCd), nickel/metal hybrid (NiMH) and Lithium-ion (Li-ion)/Lithium-polymer (Li-polymer) batteries dominate, but efforts are being made continuously to find new systems that can match or exceed the performance of existing systems, improve their safety and reduce their cost.

PRIMARY SYSTEMS
The most popular primary battery used in portable consumer products is the alkaline battery. There are many different types of primary lithium batteries. Lithium/manganese dioxide batteries (Li/MnO2) are the best sellers by far, and are primarily used for memory backup and in consumer products such as cameras and toys. Despite their better performance, Li/MnO2 batteries have great difficulty in competing with alkaline batteries in many consumer products because of their price.

Metal/air batteries exploit the oxygen in the air as an active cathode material, which means that the air electrode, on which the oxygen will react, makes up only a marginal part of the volume of the battery. The metal anode occupies a far greater space than in a conventional primary battery, which consequently results in a very high energy content. A number of different metal/air systems have been the subject of research, but only the zinc/air battery has achieved extensive use, and then only in the button cell design.

STRicter Environmental Legislation Will Phase Out Some Battery Technologies
The use of lead-acid batteries began in the nineteenth century. Because of low manufacturing costs, good performance and long life, the lead-acid battery is, in spite
of its respectable age, still the most common battery in the entire world, with a market share of as much as 40 – 45%. New manufacturing methods, cell designs and application areas are still introduced. The lead-acid battery has a wide field of applications. The most common use is as a starter battery in cars, with additional applications in industrial trucks and as reserve power.

NiCd batteries are a mature and thoroughly tested battery technology that was patented in 1899 by Waldemar Jungner. NiCd batteries are used in a huge variety of stationary, mobile and portable applications, ranging from large-scale backup power and start batteries for aircraft to handheld power tools and toys. NiCd batteries have no future in Europe, due to strict EU environmental legislation. Over the next twenty years, NiCd batteries are expected to be phased out in Europe and the rest of the industrialized world, at least in consumer electronics applications.

The NiMH battery exploits relatively new battery technology, which began to be used more at the beginning of the 1990s. NiMH batteries offer the same cell voltage as NiCd batteries, and can therefore replace them in many applications without special modifications being necessary. The cell voltage, combined with higher energy density and better environmental properties, are the driving forces that enabled NiMH batteries to win market share from NiCd during the 1990s in consumer electronic products, such as computers and mobile phones. Currently, NiMH batteries are being replaced in turn by the significantly more energy-dense Li-ion batteries. The portable NiMH batteries are, however, still expected to remain on the market in the near future as a low-cost alternative to lithium batteries. With their relatively high energy density, and their good cyclic properties, NiMH batteries have also found applications in electric and hybrid vehicles.

ENERGY-DENSE LITHIUM-ION BATTERIES

Li-ion batteries were introduced onto the market in the mid 1990s and then began, as previously stated, to replace the NiMH batteries in mobile phones and other portable electronic items. At the present time, use of lithium batteries has spread to other and cheaper consumer products. It is important to remember that Li-ion batteries are a generic name for a large number of different battery chemistries with varying properties and performance. At present, their low weight, coupled with excellent power delivery, means that the automotive industry is in the driver’s seat for the development of lithium-ion batteries.

Manufacture of lithium-ion batteries is primarily dominated by Japanese companies, and a few manufacturers in Europe and North America, with Korea and China gaining momentum. Li-ion batteries are still in an early phase of development, seen in terms of the battery industry, and have only been available for 15 years in the commercial market. This means that there is a potential for both comprehensive technical development and price reductions.

SELECTING THE MOST SUITABLE BATTERY FOR THE APPLICATION

There are a number of factors that must be considered in selecting the most suitable battery for a particular application. The characteristics of available battery types must be weighted against the equipment requirements. The most important considerations include:

- Operating voltage level
- Load current and profile
- Duty cycle – continuous or intermittent
- Service life
- Physical requirement
  - Size
  - Shape
  - Weight
- Environmental conditions
  - Temperature
  - Pressure
  - Humidity
  - Vibration
  - Shock
- Safety and reliability
- Shelf life
- Maintenance and replacement
- Environmental impact and recycling capability
- Cost

The ideal battery is obviously one that is inexpensive, has infinite energy, can handle all power levels, can operate over the full range of environmental conditions, has unlimited shelf life and is completely safe.

In summary, lithium batteries are expected, over the next 20 years, to dominate the market for rechargeable batteries, while NiCd batteries will have been phased out in the industrialized countries. NiMH batteries will still be used in some niche applications.

This report was authored by Dr Annika Ahlberg Tidblad, Intertek’s resident expert in battery testing. Her background is in research at KTH, the Swedish Royal Institute of Technology, with PhDs in applied electrochemistry and corrosion science, along with ten years of experience in battery technology.
Internal Audits: Auditing a Process Based QMS

by Andy Nichols
NQA

As with any change to the international standard ISO 9001, or one of its “cousins,” like ISO/TS 16949, AS 9100 there’s an opportunity to review and improve the way an organization implements these requirements.

One important requirement, the internal audits, should be focused on the processes of the quality management system and recurring questions auditors have include; “How do I audit a process?” “Which processes should I start with?” and “How will I know if the process is effective?”

In the coming issues, we’ll be taking a look at practical answers to these questions and more. To start with, we’ll investigate how to get organized when planning and preparing to audit a business process.

A process can be defined as “activities which transform inputs into outputs”. One might add, “under controlled conditions,” since we usually want to be able to predict a (good) result! From this definition, we know a number of things already about any process, they have:

- Input(s)
- Output(s)
- Activities
- Controls

This is helpful, but heading off to do an internal audit with 4 topics on our checklist is unlikely to help us reveal if the process is working as intended. As auditors, we have to develop a better understanding of what an effective process requires to deliver a satisfactory outcome for the organization and its customers.

Most business processes have some form of goal or objective assigned to them, so that performance can be determined. This might be focused externally on customers’ needs or internally to the organization. And it’s usual that these goals and objectives have a measurement associated with them. If the process is working effectively, it’s by these performance criteria that an auditor can tell what’s being achieved.

In addition, it’s desirable to produce a consistent result; therefore, the process must be under control. Most of us know the wailing sound (output) made by a loudspeaker, when the microphone (input) is placed too close to that speaker – it’s called feedback! You can certainly measure the sound level, but the process is out of control! Our business processes need controls to ensure that things don’t get out of hand.

Process controls for the activities are accomplished many ways;

- People – competent, aware and trained
- Equipment – maintained, (calibrated, if necessary for measurement)
- Methods – procedures, work instructions, (as necessary, under document control)
- Materials – approved, available, identified, etc.
In listing these control criteria, our list of audit topics has grown quickly, and we must also consider some other controls which must be in place; – documentation controls, non-conformance, records generated from the process, corrective/preventive actions and improvements.

The challenge of preparing for any audit is the sequence in which to place these, so that we can gather useful information about the process, rather than just a number of facts, since creating a simple list of these topics is not as helpful. There are a number of “visual metaphors” which have been used as tools to assist auditors. One unique approach has proven successful in helping auditors to organize these topics in an appropriate sequence – the “Football®” (Figure 1).

The use of this tool to “visualize” the path an internal auditor should take when auditing a process has a number of advantages;

- Comprehensive planning - so that all relevant controls are considered, in their correct sequence (the above is an example applicable to a manufacturing process). Structure to audit checklists or questions – they follow the appropriate process flow. This allows information to be gathered and used later to verify performance.

- It can assist an audit manager with ensuring the assigned auditor (s) do the relevant research of those requirements and controls, so that they develop better understanding of them, before the audit interviews. The auditor has a “bigger picture” to audit and is therefore more likely to see systematic issues.

- Evaluation of actual process performance to the objective(s) as well as compliance of the QMS.

- Better time management, adherence to audit scope etc.

- By populating the various “bubbles” (in the example) with the details of the organization’s management system and/or customer requirements etc., the auditor is able to get a clearer understanding of the expected outcomes. They are better able to identify opportunities within the management systems, as a result.

It is often easy for an internal auditor to be “drawn off track” when evaluating the other criteria and controls (depicted by the football’s “laces”) which can affect a process – calibration for example – and the football assists the auditor in defining the “boundaries” at which point they must decide to return to the normal process flow.

In review, conducting process based internal quality management system audits can be an overwhelming task leading only to a report based on compliance only. The use of a planning tool like the football, to map out an auditor’s strategy, leads to far more effective and efficient audits and focuses the auditor on validating the results of the process, to the plan.

This report was authored by Andy Nichols, a Regional Sales Manager for NQA USA. Mr. Nichols has an extensive background in the Development of Management Systems, Training, Course Development, Consulting and Management Systems Certification, and ISO 9000 in multiple industries including automotive, manufacturing and engineering organizations. Mr. Nichols can be reached at andrew.nichols@nqa.usa.com.

Figure 1
AK-40G Antenna Kit

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- **Captor Corporation** 937-667-8484
- **Oak-Mitsui Technologies** 518-686-4961
- **TDK Corporation** 972-409-4519

#### Filters, Third-Party Approved, EU
- **LCR Electronics** 610-278-0840
- **Oak-Mitsui Technologies** 518-686-4961
- **TDK Corporation** 972-409-4519

#### Filters, Third-Party Approved, US/Canada
- **LCR Electronics** 610-278-0840
- **Oak-Mitsui Technologies** 518-686-4961
- **TDK Corporation** 972-409-4519

#### Foils, Shield Tape
- **East Coast Shielding** 908-852-9160
- **Parker Hannifin, Chomerics Div** 781-935-4850

#### Gaskets
- **East Coast Shielding** 908-852-9160
- **Parker Hannifin, Chomerics Div** 781-935-4850
- **Spira Manufacturing Corporation** 818-764-8222
- **Tech-Etch** 508-747-0300

#### Shielding Coatings
- **Magnetic Shield Corporation** 630-766-7800

#### Shielding Material
- **Shielding Material, EMI/RFI**
  - **East Coast Shielding** 908-852-9160
  - **FerriShield** 813-855-6921
- **Magnetic Shield Corporation** 630-766-7800
- **Panashield, Inc.** 203-866-5888
- **Spira Manufacturing Corporation** 818-764-8222
- **Tech-Etch** 508-747-0300

#### Shielding Material, Magnetic Field
- **FerriShield** 813-855-6921
- **Magnetic Shield Corporation** 630-766-7800
- **Panashield, Inc.** 203-866-5888

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- **Captor Corporation** 937-667-8484
- **Okaya Electric America, Inc.** 219-477-4488

#### ESD Equipment & Products
- **Air Ionizers**
  - **3M Electronic Solutions** 512-984-6747
  - **Mks ion Systems** 510-217-0600
- **ESD Tape**
  - **Parker Hannifin, Chomerics Div** 781-935-4850

#### Meters
- **Meters, Static Charge**
  - **Mks ion Systems** 510-217-0600
  - **Prostat Corporation** 630-238-8883

#### Simulators
- **Simulators, EMP**
  - **Teseq Inc.** 978-764-7358

#### Simulators, ESD
- **Advanced Test Equipment Rental** 888-554-ATEC
- **Haefely EMC Technology** 845-279-3644
- **HV TECHNOLOGIES, Inc.** 703-365-2330
- **Teseq Inc.** 978-764-7358
- **Thermo Fisher Scientific** 678-546-8344

#### Simulators, Lightning
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- **HV TECHNOLOGIES, Inc.** 703-365-2330
- **Teseq Inc.** 978-764-7358
- **Thermo Fisher Scientific** 678-546-8344

#### Static Control
- **Static Control, Containers**
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#### Static Control, Garments
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#### Static Control, Mats
- **3M Electronic Solutions** 512-984-6747

#### Static Control, Monitoring Equipment
- **3M Electronic Solutions** 512-984-6747
- **Prostat Corporation** 630-238-8883

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#### Static Control, Workstations
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Materials, Adhesives & Coatings
Absorbing Materials
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Alloys
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Magnetic Shield Corporation . . . 630-766-7800
The MuShield Company Inc. . . . 603-666-4433

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Lubrizol Conductive Polymers . . . 866-680-1555

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Thermoplastic Components
Lubrizol Conductive Polymers . . . 866-680-1555

Thermoplastics and Thermoplastic Materials
Lubrizol Conductive Polymers . . . 866-680-1555
Oak-Mitsui Technologies . . . . 518-686-4961

Power & Power Management
Constant Voltage Regulators
OPHIR RF . . . . . . . . . . . . . . . . . . . . 310-306-5556

Converters
Murata Electronics . . . . . . . . . 770-433-5782
OPHIR RF . . . . . . . . . . . . . . . . . . . . 310-306-5556

Cord Sets
HM Cragg . . . . . . . . . . . . . . . . . . . . 952-884-7775
Power Dynamics, Inc. . . . . . . . 973-560-0019
Schurter Inc. . . . . . . . . . . . . . . . . 707-636-3000

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Isolators, Power/Signal Line
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Line Cords
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Motors
The MuShield Company Inc. . . . 603-666-4433

Multiple Outlet Strips
HM Cragg . . . . . . . . . . . . . . . . . . . . 952-884-7775

Overcurrent Protection
Okaya Electric America, Inc. . . . 219-477-4488

Overvoltage Protection
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Power Amplifier
AE Techron, Inc. . . . . . . . . . . . . . . . . 574-295-9495
The MuShield Company Inc. . . . 603-666-4433
OPHIR RF . . . . . . . . . . . . . . . . . . . . 310-306-5556

Power Cords
HM Cragg . . . . . . . . . . . . . . . . . . . . 952-884-7775
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Power Distribution Systems
Captor Corporation . . . . 937-667-8484
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Schurter Inc. . . . . . . . . . . . . . . . . 707-636-3000

Power Entry Modules
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OPHIR RF . . . . . . . . . . . . . . . . . . . . 310-306-5556
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Schurter Inc. . . . . . . . . . . . . . . . . 707-636-3000

Power Generators
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Power Line Conditioning Equipment
Okaya Electric America, Inc. . . . 219-477-4488
WEMS Electronics . . . . . . . . . . . . . . 310-962-4410

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Power Supplies
AE Techron, Inc. . . . . . . . . . . . . . . . . 574-295-9495
Associated Power Technologies . . . . . 909-860-1646
HM Cragg . . . . . . . . . . . . . . . . . . . . 952-884-7775
Murata Electronics . . . . . . . . . . . . . . 770-433-5782
QuadTech . . . . . . . . . . . . . . . . . . . . 978-461-2100

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Associated Power Technologies . . . . . 909-860-1646

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- Dielectric Bodies
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- Stripline & Circuits
- Waveguide Components

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Anechoic Chamber Software
EM Software & Systems(USA) Inc . . . . . . . 757-224-0548
## Product Directory

### EMC Simulation Software
- **EM Software & Systems (USA) Inc.** 757-224-0548
- **OPHIR RF.** 310-306-5556
- **Instruments for Industry, Inc.** 631-467-8400
- **MetaGeek.** 208-639-3140
- **MILMEGA Ltd.** +44 (0) 1983 618004
- **OPHIR RF.** 310-306-5556
- **Rohde & Schwarz, Inc.** 410-910-7800

### Analyzers
#### Analyzers, EMI/EMC Spectrum
- **Advanced Test Equipment Rental** 888-554-ATEC
- **MetaGeek.** 208-639-3140
- **Rohde & Schwarz, Inc.** 410-910-7800
- **Teseq Inc.** 978-764-7358

#### Analyzers, Flicker
- **Advanced Test Equipment Rental** 888-554-ATEC

#### Analyzers, Network
- **Advanced Test Equipment Rental** 888-554-ATEC
- **Giga-tronics Incorporated.** 925-328-4650
- **Rohde & Schwarz, Inc.** 410-910-7800

#### Analyzers, Power Quality
- **Advanced Test Equipment Rental** 888-554-ATEC

#### Analyzers, Telecom
- **Advanced Test Equipment Rental** 888-554-ATEC
- **MetaGeek.** 208-639-3140

### Automatic Test Sets
- **Teseq Inc.** 978-764-7358
- **Thermo Fisher Scientific.** 678-546-8344

### Avionics Test Equipment
- **Dayton T. Brown, Inc.** 631-589-6300
- **HV TECHNOLOGIES, Inc.** 703-365-2330
- **Thermo Fisher Scientific.** 678-546-8344

### Current Leakage Testers
- **Advanced Test Equipment Rental** 888-554-ATEC
- **ED&D Inc.** 919-469-9434
- **QuadTech.** 978-461-2100

### Data Acquisition Monitoring Systems
- **Advanced Test Equipment Rental** 888-554-ATEC
- **NTS Test Systems Engineering** 505-345-9499
- **Mks ion Systems.** 510-217-0600

### Dielectric Strength Testers
- **Advanced Test Equipment Rental** 888-554-ATEC
- **Associated Research, Inc.** 847-367-4077
- **ED&D Inc.** 919-469-9434
- **QuadTech.** 978-461-2100
- **Slaughter Company, Inc.** 847-932-3662

### Electrical Safety Testers
- **Advanced Test Equipment Rental** 888-554-ATEC
- **EMSCAN Corporation.** 403-291-0313
- **Haeley EMC Technology.** 845-279-3644
- **HV TECHNOLOGIES, Inc.** 703-365-2330
- **Thermo Fisher Scientific.** 678-546-8344
- **TÜV SÜD America Inc.** 978-573-2500

### EMC Testers
- **Advanced Test Equipment Rental** 888-554-ATEC
- **EMSCAN Corporation.** 403-291-0313
- **Haeley EMC Technology.** 845-279-3644
- **HV TECHNOLOGIES, Inc.** 703-365-2330
- **Thermo Fisher Scientific.** 678-546-8344
- **TÜV SÜD America Inc.** 978-573-2500

### EMP Simulators
- **Teseq Inc.** 978-764-7358

### Environmental Chambers
- **Advanced Test Equipment Rental** 888-554-ATEC
- **ED&D Inc.** 919-469-9434
- **TÜV SÜD America Inc.** 978-573-2500

### Gaussmeters
- **Magnetic Shield Corporation.** 630-766-7800

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**Test & Measurement Equipment**

#### Amplifiers, Low Noise
- **A.H. Systems, Inc.** 818-998-0223
- **Advanced Test Equipment Rental** 888-554-ATEC
- **AE Technor, Inc.** 574-295-9495
- **AR.** 215-723-8181
- **Giga-tronics Incorporated.** 925-328-4650
- **Instruments for Industry, Inc.** 631-467-8400
- **OPHIR RF.** 310-306-5556
- **Teseq Inc.** 978-764-7358

#### Amplifiers, Power
- **Advanced Test Equipment Rental** 888-554-ATEC
- **AE Technor, Inc.** 574-295-9495
- **AR.** 215-723-8181
- **CPI, Inc.** 905-877-0161
- **Giga-tronics Incorporated.** 925-328-4650
- **Instruments for Industry, Inc.** 631-467-8400
- **MILMEGA Ltd.** +44 (0) 1983 618004
- **OPHIR RF.** 310-306-5556
- **Rohde & Schwarz, Inc.** 410-910-7800

#### Amplifiers, RF
- **Advanced Test Equipment Rental** 888-554-ATEC
- **AR.** 215-723-8181
- **Com-Power Corporation.** 714-528-8800

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**Standards Suppliers**

- **EMC Compliance.** 256-650-5261
- **ESD Association.** 315-339-6937
- **Hoolihan EMC Consulting.** 651-213-0966

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