STATE OF MICHIGAN

BEFORE THE MICHIGAN PUBLIC SERVICE COMMISSION

In the matter of the application of DTE ENERGY COMPANY for authority to increase its rates amend its rate schedules and rules governing the distribution and supply of electric energy, and for miscellaneous accounting authority
______________________________________/

Case No. **U-18255**

DIRECT TESTIMONY AND EXHIBITS OF WILLIAM S. BATHGATE

On Behalf of

Residential Customer Group

August 29, 2017

I. QUALIFICATIONS

Q. Please state your name and address.

A. My name is William S. Bathgate, and my business address is 10909 Monticello Road Pinckney, MI 48169.

Q. Please state your qualifications and background.

A. I am an engineer having significant experience with the technology used in AMI Meters, including the type of AMI Meter that DTE Energy Company and Detroit Energy Company have been installing in their respective service territories. My educational background includes:

> Bachelors of Science, Western, Illinois University, Macomb, IL and Advanced Masters work from Iowa State University. My course of study was in industrial electrical control system and computer engineering controls. My work experience includes:

<u>Professional Work History</u>

<u>2015 - 2017</u> **<u>TATA Consulting, Fiat Chrysler Automotive Account – Current Position</u>**

2015 – 2017 Global Program Manager, Vehicle Systems – Auburn Hills, MI

<u>2009 - 2015</u> **<u>Emerson Electric Corporation, Avocent Division</u>**

2009 – 2015 Global Program Manager, Power Distribution Systems, Emerson Corp., Avocent Div. – Huntsville, AL

<u>1995–2009</u> **<u>Hewlett-Packard Co.</u>**

2005-2009 Managing Director, General Motors Account – Detroit, MI

2003–2005 Director of HP, Information Systems, Audit & Compliance - Americas, CDN, USA, LA

2000-2003 Director of Global Operations, Ford Motors & Visteon Account – Detroit, MI

1998-2000 Director of HP Programs & Data Center Operations - Toronto, Canada

1995-1998 HP Electronic Systems Engineer, Instruments Division – Palo Alto, CA

<u>1983–1995</u> **<u>IBM Co.</u>**

1983-1995 IBM Corporation, Electronic Systems Engineer, Systems Division – Armonk, New York

<u>1977-1983</u> **<u>Textron Corporation</u>**

1977-1983 Textron Corporation, Control Systems Engineer Sundstrand Division – Rockford, IL

<u>Specific Technology Expertise</u>

High tech power management systems, UPS and power distribution
Switched Mode Power Supplies
Electrical and Electronic hardware engineering
Computer systems engineering
Radio Systems design and testing
High Current and High Voltage switches
Internet communications using both wired and wireless technologies
UL, CE (Europe), Africa, Japan, Australia and China product safety certifications
Cyber encryption and protection of Radio Communications using digital signals
RFI/EMI mitigation

My resume is provided as **Exhibit RCG-01** (WSB-01) filed with this testimony.

II. DIRECT TESTIMONY

Q. Please describe the cost impact to residential customers as a result of an AMI smart meter being installed at the homes of residential customers.

A. In contrast to an analog meter, an AMI smart meter itself utilizes significant electric energy, see **Exhibit RCG-02** (WSB-02). Specifically, on average, a smart meter will consume approximately 2.37 kWh per day which equates to approximately 865 kWh per year, at a varying dollar cost depending upon the existence of higher per kWh tariff charges during peak times of the day. The specific costs can range from approximately $0.12135 per kWh inclusive of distribution and fuel optimization charges relative to meter operations during off-peak hours, and approximately $0.19835 for meter consumption occurring during peak hours. For standard flat rates inclusive of distribution and energy optimization charges of approximately $0.13950 @ 2.37 Average kWh per day amounts to approximately $120.674 annual cost borne by the consumer depending on rate tariffs, distribution charges and fuel recovery. These costs were never disclosed in advance to consumers as an outcome of the installation of an AMI Meter on their home. In fact, the consumer was informed this would help them save money. The evidence is to the contrary. If all the consumers in Michigan were told the new AMI would cost them over $120.00 a year in energy costs there would be a large public outcry. The promotional material provisioned by the utilities represented that the AMI would lead to consumer energy savings. This clearly is not the case. The sad part of this story is that this is hitting every low income person and senior citizens the hardest of all. This represents an added $ 253.42 Million in annual revenue from DTE Energy's 2.1 Million customers and 3.924 Billion Tons of CO_2 introduced into the atmosphere just to run the AMI meters. The Analog meters in prior use cost no party any energy either for DTE Energy or the end customer. Just by replacing the Analog Meter with an AMI meter, DTE Energy has obtained a windfall in revenue without a truthful petition to the Commission and is creating more greenhouse CO_2 without obvious notice or disclosure to the public or the FERC.

Q. Please explain why the AMI smart meters consume this amount of energy.

A. The AMI Meter operates continuously measuring voltages and current consumed by the household and EMI/RFI by products from the meter Switched Mode Power Supply (SMPS) which converts the 240 VAC to the various DC voltages. There are current losses in the SMPS operation and there is a 100 ohm resistor shorted across the two 240

VAC line coming into the SMPS. See **Exhibit RCG-04** (WSB-04). This resistor at 240 VAC on its own consumes power in addition to the losses in the SMPS board. There is also the current consumed by the two other circuit boards, the Metrology and RF board which includes a full computer system in the AMI meter. The RF signals transmit throughout the day to pulsate through the surrounding air and the wires of a household to gather specific energy consumption and consumes power constantly. As you can see in the DTE Energy Insight Application it is displaying frequent communications, contrary to all public testimony by DTE. So, it is not unreasonable to conclude that an average of 2.37 kWh per day consumption is a typical average. Actual VOM readings of current draw at the meter in isolation and no other load results in between 90-105 Watts current draw. This current draw increased or decreased based in the measured input voltage and RF pulse quantities and durations which varied in a very unpredictable manner. In tests conducted in contrast, an analog meter incurs no such energy consumption as it is a current measuring meter which records overall energy consumption without utilizing the two-way pulsating capturing of data concerning specific energy consumption throughout the household.

Q. Do you have recommendations concerning how residential customers that want to keep or to have an analog meter should be treated in view of the increased energy consumption caused by smart meters?

A. First, I recommend that the company and the Commission provide customers who want an analog meter to be given that option, whether it involves retaining an existing analog meter, or involves a requirement that the company replace an AMI meter and install an analog meter. Analog Meters are still available in large quantities.

Second, I recommend that the Commission eliminate initial and monthly surcharges for opt-out customers that retain or have analog meters, since the opt-out customers pay for all costs via the electric tariffs of the AMI system whether they opt or not, and because the Analog opt-out customers who have not consented to an AMI meter are not causing the costs on a per-unit basis for the AMI infrastructure and installation and operation of the system. In fact, meter reading can be done without dispatch of a meter reader to customers who choose to retain or have an analog meter by simply taking a photo of their reading each month and communicate their readings to the utility with an annual or semiannual audit by the utility. This was done for many years by the utility with customers and existing phone dial-in meter readings are still available with all the utilities.

Third, I recommend that the increased energy usage that AMI opt-out customers are being charged as I have discussed above be credited against any opt-out surcharges if said surcharges are retained by the Commission. It appears likely that the amount being charged for increased energy consumption caused by the AMI Meters may involve costs which exceed the monthly opt-out surcharges.

Fourth, there should be a full disclosure to the public via an information letter sent via US Mail explaining to consumers that their new AMI Meter is increasing their electric bill to pay for the energy required to run the meter. Otherwise the utility is taking unfair advantage of customers. What I have discovered in AMI meter power consumption is a real condition that can be easily replicated by going to any home, turning off the power breakers off and reading the digital readout on the meter after 24 hours. This is very repeatable.

Q. Are customers with AMI Meters incurring any other costs or risks that should be considered by the Commission?

A. Yes. The customers with smart meters have increased risk of fires, electrical medical equipment damage and appliance damage occurring due to the AMI Meters design creating EMI/RFI effects commonly called conducted emissions and also called EMC. See **Exhibit RCG-05** (WSB-05) A portion of the customers have concerns relating to the operation of the AMI Meters and the resulting electromagnetic infiltration of their homes from Electro-Magnetic and Radio Frequency Interference generated within the unfiltered AMI Meter Switched Mode Power Supply (SMPS), to which some persons also suffer negative health effects from early medical equipment failures. Analog meters have no such EMI/RFI artifacts imposed on the electric wires and only the low frequency sinusoidal wave form shown in the **Exhibit RCG-05** (WSB-05) should be present. The large osculating waveform shown in **Exhibit RCG-06** (WSB-06) is not present with an analog meter.

The Commission should fully consider this information for at least two reasons: (1) these costs and risks should be an additional basis for the Commission to rule that customers should have the option to opt out of having the AMI meter at their home and to have instead an Analog Meter, and without incurring surcharges for exercising this option; and (2) the Commission should utilize its review power on a continuous on-going basis over time regarding health and safety issues relating to electric utility service, including this time.

The fire hazard referenced above can result from the operation of the AMI Meters from several sources:

1. The SMPS circuit board has very limited surge protection resulting from incoming voltage transients. The main component on the SMPS that is vulnerable is called a Varistor, which looks like a small black square on the SMPS board. See **Exhibit RCG-06** (WSB-06). This small electronic part cannot withstand more than a 300 Volts AC surge. The part will explode when a line voltage surge exceeds this limit, such as when a tree branch touches the high voltage lines or lightning strike occurs nearby. Once this Varistor explosion has occurred it permits high voltage transfer to the other circuit board components and the circuit board substrate. This results in the AMI meter literally exploding from the meter socket or in a severe melting of the plastic components, likely leading to a fire and/or severe home damage. Most customers that comment when this occurs say they hear a load pop or a boom, followed by lights flickering, and followed by arcing at the meter housing. This is not how a circuit board should be protected. In series with the Varistor should be a small fuse that would stop voltage progression to the remaining circuit components and interconnections. Every SMPS in the home from a vast array of electronic appliances has a Varistor, such as TV's, PC power supplies, electronically controlled refrigerators, washers, dryers and heating/cooling systems but also has a fuse or fuse-able link that will break the circuit before catastrophic damage progressively results from a surge. There is no sound electronic engineering firm that would permit 240 volts AC to short circuit across the circuit boards due to a component failure such as a Varistor. This is extremely dangerous. Once the progression of the subsequent short circuit begins the line transformer will apply up to 2,000 Amps to the meter

housing until either the feed lines to the home disintegrate and vaporize or the transformer line breaker/fuse trips out after 50 seconds. By this time the damage is so extensive it is jeopardizing human and animal life. No such condition is possible from an Analog Meter. In fact the occurrence of an Analog Meter fire is almost unheard of.

2. There are also unseen dangers from the meter to meter box contacts. At my own home which was built in 2015, the Analog Meter was replaced with an AMI meter installed in October of 2015. In the winter of 2017, I could not get remote electronic readings from my meter to the utility. The result was that I could only get estimated readings for Feb, March, April and May. Numerous attempts to resolve this issue were unsuccessful. Since I have the instrumentation at home I knew that the meter was transmitting. I was told by the utility that the deployment of AMI meters would eliminate estimated readings. This was not true based on my observations. I decided to ask for an Opt-Out meter to be installed so I could get a meter manually read and end the frustration of estimated bills.

When the AMI meter was removed. I discovered that the one set of contacts had all burned up from excessive heat. See **Exhibit RCG-07** (WSB-07). This was a new meter box in 2015 and in use for about 2 years. It could have easily led to a meter fire without warning. If I had not changed my meter, I would never have known there was a problem. How many other meter boxes are at risk with the same conditions today? The only way we will know is when we begin to see more meter fires. Unfortunately once a fire begins at the meter contacts all evidence of the root cause are near impossible to determine. The utility concludes without any evidence that the meter fire occurred due to customer wiring. Had I known that placing an AMI meter on my home would lead to burned contacts on my home, I would never have permitted its installation. There are supposed to be sensors of high heat within the meter, but it did not detect the condition at my home.

3. There are also a serious issue presented in the RF emitting mesh network used by DTE. The use of the unlicensed spectrum of the 33cm frequency band (901 to 928 MHz) is a violation of my FCC privileges as an Amateur Radio operator. Amateur operations is a primary user of this spectrum and cannot be interfered with by unlicensed user equipment. Such as the AMI meter. I run satellite communications and Fast Scan Amateur TV (ATV) on this band. The FCC license used by the AMI is for only one meter, not thousands. Today because of all the AMI meters my ATV transmissions are frequently interrupted suffering from disconnections and poor signal reception. The bandwidth of the ATV signal in use in my station is 6 MHz, the other receiving station also uses 6 MHz so together we use 12 MHz of the 27 MHz spectrum. The AMI meters have caused so much interference that it is making my ATV operation nearly impossible.

In addition my communications with government satellites in this section of the frequency band is severely impacted. I frequently have dropped message streams

With all the AMI meters in use my communications is severely affected. This is a direct violation of FCC rules as specified by law. DTE never did the due diligence about the deployment of AMI meters, they never understood what they were doing with complete saturation of the 33 cm band. It is not a first come first served frequency allocation. It is not the Amateur operator that needs to halt operations it is the unlicensed stations that must not interfere with the licensed operators. With almost a 1,000 AMI meters transmitters near my home these are interfering with my operations and it against the federal law. Please see the following laws that apply. I can make a complaint to the FCC and cause DTE to cease operations of the AMI mesh network.

The Communications Act of 1934

- Section 301 - requires persons operating or using radio transmitters to be licensed or authorized under the Commission's rules (47 U.S.C. § 301)
- Section 302(b) - prohibits the manufacture, importation, marketing, sale or operation of these devices within the United States (47 U.S.C. § 302a(b))
- Section 333 - prohibits willful or malicious interference with the radio communications of any station licensed or authorized under the Act or operated by the U.S. Government (47 U.S.C. § 333)
- Section 503 - allows the FCC to impose forfeitures for willful or repeated violations of the Communications Act, the Commission's rules, regulations, or related orders, as well as for violations of the terms and conditions of any license, certificate, or other Commission authorization, among other things.
- Sections 510 - allows for seizure of unlawful equipment (47 U.S.C. § 510)

The Commission's Rules

- Section 2.803 - prohibits the manufacture, importation, marketing, sale or operation of these devices within the United States (47 C.F.R. § 2.803)
- Section 2.807 - provides for certain limited exceptions, such as the sale to U.S. government users (47 C.F.R. § 2.807)

The Criminal Code (Enforced by the Department of Justice)

- Title 18, Section 1362 **-** prohibits willful or malicious interference to US government communications; subjects the operator to possible fines, imprisonment, or both (18 U.S.C. § 1362)
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- Title 18, Section 1362 **-** prohibits willful or malicious interference to US government communications; subjects the operator to possible fines, imprisonment, or both (18 U.S.C. § 1362)
- Title 18, Section 1367(a) **-** prohibits intentional or malicious interference to satellite communications; subjects the operator to possible fines, imprisonment, or both (18 U.S.C. § 1367(a))

Prior to AMI meters I had no difficulties with communications for any other station on the 33cm band, now it is near impossible.

Q. Does DTE Energy's failure to independently test AMI meters put customers at risk? If so, how?

A. The AMI Meter Switched Mode Power Supply (SMPS) design is lacking what is called a differential voltage and common mode current filter circuit to keep it from back-feeding high frequency voltage transients and magnetic currents as an electrical by-product onto the home primary wiring circuits. See **Exhibit RCG-03** (WSB-03) and **Exhibit RCG-05** (WSB-05). The result is magnetic fields and high frequency radio emissions surrounding every room. This class of emissions is called EMI/RFI (commonly called EMC) and is viewed by the FCC as Conducted Emissions. The FCC has limits for Conducted Emissions (please note not the mesh network RF meter reading emissions) and any electronic device that has Conducted Emissions in excess of 9 KHz switching oscillators must comply with FCC conducted emissions specifications. See **Exhibit RCG-08** (WSB-08). There are two classes of devices, Class A for industrial application and Class B which is more stringent for computer based applications. The AMI meter has a computer CPU and Memory just like any PC has, and therefore FCC Class B regulations apply. No AMI meter used by DTE Energy has been independently tested to ensure compliance with the FCC recommended line impedance stabilization network ("LISN") test equipment. LISN tests are done by third parties on behalf of manufacturers and provide manufacturers public documented assurance their products comply with FCC Conducted Emissions standards. Nor has DTE Energy published any LISN test results for Conducted Emissions from an independent third party. This would be very difficult to achieve because an LISN test setup requires a ground reference. There is no ground connection to the SMPS so it would likely not be able to be tested per FCC Specifications for conducted emissions. It is important to note that these tests must be performed under varying loads and with typical home appliances, not by some backroom lab at idle current, because when current demand is applied the variations in Conducted Emissions are exacerbated.

My testing has shown that Conducted Emissions far exceed FCC limits with typical peak to peak voltages of 14-19 Volts and at frequencies ranging from 2 KHz to 36 MHz In addition, I have found through testing a home under load that measured in excess of 27 Volts peak-to-peak at frequencies exceeding 40 MHz max. See **Exhibit RCG-08** (WSB-08). The oscilloscope trace I have provided is a typical home with no branch circuits active and only measuring the Conducted Omissions from only the AMI meter. As noted in the oscilloscope trace, the frequency of the emissions varies dramatically in phase with the

60 Cycle AC. This makes it very problematic to state that the emissions are of a certain fixed frequency, because they are constantly varying. This makes mitigating these emissions downstream from the AMI meter (with high amperages in the home requiring multiple low pass limits to allow only the 60 cycle frequency to be present) extremely expensive to procure, exceeding $7,000. All medical facilities and data centers used by the US DoD place these filters in line with the main electric service classified in Mil Spec MIL-STD-461F NCE02 for 10 KHz to 10 MHz (see attached **Exhibit RCG-09** (WSB-09) http://incompliancemag.com/article/design-practices-for-military-emc-and-environmental-compliance/). Based on these standards no AMI meter could ever be directly connected to the primary building wiring of sensitive facilities such as a senior health center, doctors office, hospital or emergency center without an EMC mitigating high voltage and high amperage low pass filter between the utility source and the buildings load panels. Every medical office has many highly sensitive electronic equipment such as EKG and X-ray equipment that are subject to the deleterious effects of these high conducted emissions which can degrade equipment or affect the reading and operational life of this type of equipment. Yet the utility has proceeded to install AMI meters in these facilities and not notified the owners of these businesses of the conducted emissions risks they now are subject to as the result of installing an AMI or Opt-Out meter. Unfortunately the only fix for the conducted emissions from the SMPS is a complete redesign with a connected wire ground reference. This would effectively cause a redesign of the AMI meter. The other option is an Analog Meter.

Q. Are DTE Energy's residential customers similarly at risk, particularly those operating medical equipment?

A. Yes, the same is true for households for residents with life sustaining electronic equipment such as the following:

Tank type Respirator (Iron Lung)

Cuirasses Respirator (Chest Respirator)

Rocking Bed

Electrically operated Respirator

Suction Machine (Pump)

Hemodialysis Equipment (Kidney Machine)

Intermittent Positive Pressure Respirator

Special Air Conditioning (specific humidity control)

Heart Rate Monitor

PD APENA Monitor (Parkinson's disease control)

Diaphragm Stimulator

Oxygen Concentrator

Medical Pump

Press Respirator (for Hypertension treatment)

CP Drum ventilator (for particulate filtering for persons with Cystic Fibrosis lung diseases)

All this essential medical equipment will either unexpectedly fail operation in an unpredictable manner or be unpredictably compromised from normal operation when subjected to the level of Conducted Emissions present in the AMI meter in use by DTE Energy, or any other utility. A person with a sensitive condition could die or suffer a serious degraded health from a critical device failure.

Q. How can the Commission address and alleviate the risks you have described?

A. The only means to prevent harm to the residents of homes and certain medical offices is the elimination of the AMI installation and replacement with an Analog Meter. In fact, National Grid in Massachusetts is trying to address this problem today and has a process in place to assure safe electric service to consumers with this type of medical equipment. See **Exhibit RCG-10** (WSB-10). However, here in Michigan no consideration or accommodation is provided by any utility. Instead, the MPSC until now has approved or acquiesced to the utilities punitive internal polices and directives that a customer must either accept the installation of an AMI type meter or do without electric service and/or to pay opt-out rate surcharges as well. The Commission should undertake actions to reverse and modify these policies. Placing at risk medically vulnerable persons with severe conditions just because the utility wants its way is unconscionable. The current AMI Opt-Out Meter solution provides no protection from harm from Conducted Emissions. The current practice is either accept an AMI which can damage your life sustaining equipment or risk death. The Analog Meter has no electronic components that created Conducted Emission effects. The Commission never provided guidance or conditions applicable to the AMI rollout. The utilities have done this as they willed. Yet, it is the Commission's role to ensure that SAFE reliable electric service is provided. The Commission should provide new guidance to all Utilities that customer accommodation to their wishes should be provided. Today the lack of guidance has caused harm or ongoing risks of harm to thousands of citizens for a program requiring only an Opt-In offering, resulting in a forced AMI technology implementation by DTE Energy and the other major providers such as DTE. Even with the amount of time the utilities have had to educate consumers, most residents do not even know they have an AMI meter on their home. 50% of my neighbors I polled have no any idea what an AMI meter is until it is specifically pointed out to them.

Q. Does this complete your testimony?

A Yes.

William S. Bathgate

Certifications - *PMP, ITIL, COBIT, CISA, CRISC, CISM, CGEIT*
US DOD Top Secret Security Clearance
Bachelors of Sciences, Western Illinois University
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Global Technology Professional

Professional Work History

2015 - 2017 TATA Consulting, Fiat Chrysler Automotive Account – Current Position

2015 – 2017 Global Program Manager – Auburn Hills, MI

Manger of Global Programs for enhancements of systems for MOPAR, Secure Vehicle. U-Connect Radio Systems, Connected Vehicle and Autonomous Vehicles. Reports directly to FCA Director of Systems Planning.

2009 - 2015 Emerson Electric Corporation, Avocent Division

2009 – 2015 Global Program Manager, Emerson Corporation, Avocent Div. – Huntsville, AL

Program Manager of a power distribution products portfolio. Responsible for global engineering development and release of newly developed electrical products engineered in the USA and Germany but built in in Mexico and Czech Republic. This product is called MPH and MPH II. This is a computer network controlled high voltage and high amperage load control device engineered for worldwide installations adapted for each local countries either three phase and single phase AC distribution grid. As Program Manager I also provided direction and oversite of product safety testing and certifications, such as UL, CSA, CE, and PSE for product safety compliance in over 100 countries. So far over 1 Million units of the products I developed are in service. This role reported to the Vice President of Engineering of Emerson's Avocent Division.

1995–2009 Hewlett-Packard Co.

2005-2009 Managing Director, General Motors Account – Detroit, MI

Managed Global infrastructures, Global Data Centers, IT Operations, Global Networks, Network and System Security, disaster recovery preparedness and rehearsals. As Managing Director of a Global Team of 600 support personnel, I successfully directed multiple multi-million dollar complex mission critical projects involving modernizing computing facilities and internal systems for power, cooling, networks and automated SCADA control systems.

2003–2005 Director of HP, Information Systems, Audit & Compliance - Americas, CDN, USA, LA

Managed HP Internal IT infrastructures, Data Centers, IT Operations, Networks, Network and System Security. Ensured US government compliance, managed Information Security Audit function, built Disaster Recovery Centers, managed secure VPN, Secure Information Systems Certificate Encryption Authority (CA), CBX, IVR, VOIP systems, systems and network monitoring, Responsible for and managed the staff of 1,100 IT and Network Security professionals in the disciplines of Networks, UNIX, Linux, VM Ware, MS Exchange, and Web B2B and B2C applications. Responsible for and managed the corporate portfolio of projects and programs for all of HP Internal IT within North America and South America.

2000-2003 Director of Global Operations, Ford Motors & Visteon Account – Detroit, MI

Managed Global Ford applications and infrastructures, Ford Data Centers, IT Operations, WAN Networks, $42M Annual Personnel Budget, Network and System Security, VOIP systems, Ford systems and network monitoring. Built new data centers to host control center operations and service desk. Implemented ITIL processes, workflows and CMDB. Responsible for developing the Visteon Corporation Competency Center, that enabled Mainframe application conversions to SAP.

1998-2000 Director of HP Programs & Data Center Operations - Toronto, Canada

Managed HP Canada and CIBC Bank Tier IV Data Centers, IT Operations, 30,000 Unit ATM Secure Network, Network and System Security, Help Desk. New systems Implementation and Operations. Re-engineered data centers for power, cooling and networking to host Canada Operations center and service desk. Implemented processes, incident, problem, change management process workflows and implemented a comprehensive Configuration Management Data Base (CMDB).

1995-1998 HP Electronic Systems Engineer, Instruments Division – Palo Alto, CA

Now this division is called "Keysight Technologies". Developed new automated instrument calibration systems and new circuit designs for oscilloscopes, high precision DC power supplies, EMI & EMC Measurements, Phase Noise, Physical Layer Test Systems, RF & Microwave Test Accessories, Device Current Waveform Analyzers, AC and DC power analyzers. Network analyzers and vector signal analyzers.

<u>1983–1995</u> <u>IBM Corporation</u>

1983-1995 IBM Corporation, Electronic Systems Engineer, Systems Division – Armonk, New York

Developed Mainframe computer CPU, Memory and Input and Output peripherals for S/370 and S/3090 platforms. Part of the design team for the first IBM PC products, responsible for power supplies, main computer circuit boards and Operating Systems integration. Also assigned to NASA in Houston, Cape Canaveral and Marshall space flight centers for launch control and space vehicle telecommunications using high frequency and microwave RF signals.

<u>1983–1995</u> <u>Textron Corporation</u>

1977-1983 Textron Corporation, Sundstrand Division, Control Systems Engineer – Rockford, IL

Developed Electronic Control Systems for control of Aerospace applications generating power for inflight services, control of engine start, elevators, rudder and aileron controls. Subcontractor to Lockheed Martin for enhancements to the flight data recorder (Black Box) improving circuit mountings for improved crash survival. Developed control systems for off road construction equipment such as cement mixers, combines, bulldozers and high rise cranes.

<u>Industry Certifications & Expertise</u>

Certified Project Management Professional (PMI/PMP)
Certified in Governance of Enterprise IT (CGEIT)
Certified in Risk and Information Systems Control (CRISC)
Certified Information Systems Auditor (CISA)
Certified Information Security Manager (CISM)
Certified in Control Objectives of IT (COBIT)
Certified in Information Systems IT Infrastructure Library (ITIL) for Operations, Design and Configuration

FCC Amateur Extra Class License Holder
FCC Land Mobile License Holder
FCC Marine Mobile License Holder

High tech power management systems, UPS and power distribution
Switched Mode Power Supplies
Electrical and Electronic hardware engineering
Computer systems engineering
Radio Systems design and testing
High Current and High Voltage switches
Internet communications using both wired and wireless technologies
UL, CE (Europe), Africa, Japan, Australia and China product safety certifications
Cyber encryption and protection of Radio Communications using digital signals
RFI/EMI mitigation

Hold a US DOD Top Secret Clearance and am an instructor of information security encryption control and compliance to the US Missile Defense Agency, NASA, and US Department of Homeland Security.

My Energy Readings

William S. Bathgate

The following information is to support the testimony found in Exhibit RCG-3 (WSB-3)

The first page shows the AMI meter SMPS board noting the location of the 100 ohm resorts that draws 1.3 kWh per day.

The purpose of this second page of this exhibit is to document the energy consumed by the AMI meter at idle on a home with no power breakers on. No branch circuit breakers were turned on and exterior temperatures were in 60's during daylight hours and 45 degrees overnight.

The third page of this exhibit shows the cost per kWh are based on current rates inclusive of distribution charges and fuel optimization costs. The costs can vary based on time of year or tariff effective dates, but are mathematically sound determination of cost factors. Also is the environmental impact of this added energy in CO2

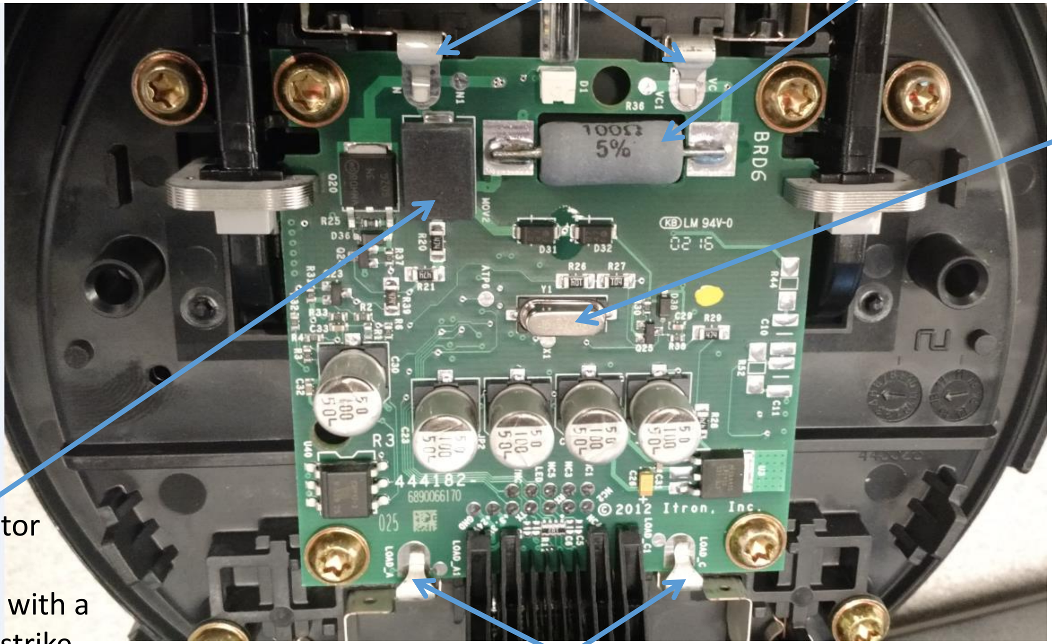
The ITRON Meter SMPS Board

240 Volts IN

<u>100 ohm resistor @5% accuracy, draws 1.3 kWh a day</u>

Current – KW measurement

16 MHz Oscillator



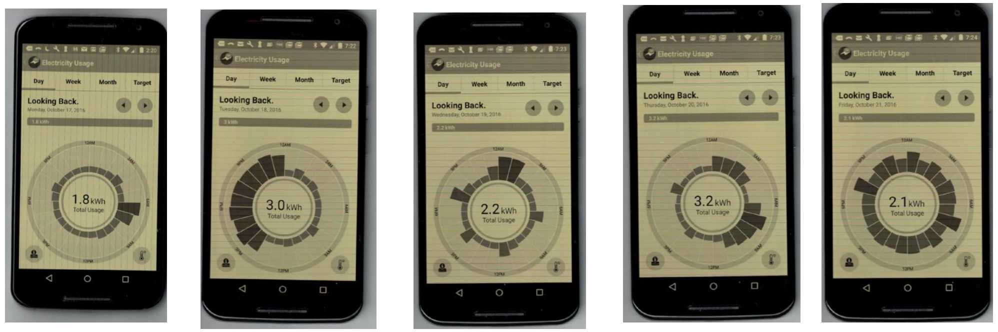
Thermistor that will explode with a lighting strike or power surge

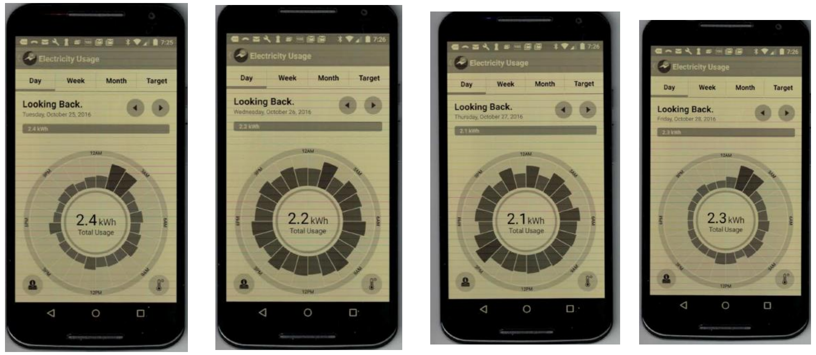
240 Volts OUT

You will notice that there is no Common & Differential mode filter circuit at all, no coil, no fuse and no differential capacitor filter

My Energy Readings

Avg. Daily AMI kWh Use 2.37 kWh @ 0.139 per kWh = $0.319 x (865 kWh/Yr.)





As you can see this is not just simply reading power consumption once a day, but is done many times, all day

Note – No breakers were on and the time and reading of the meter is not a simple “Text” message

Impact to the Environment

Annual Cost per Customer	Rev $ for DTE	Rev $ for CE	kWh per DTE	kWh per CE	CO^2 Per DTE	CO^2 Per CE
$120.67/Yr.	$253.42M	$217.21M	1.816B	1.521B	3.924BT	3.879BT

Total Consumer Costs Yr.	Total kWh Consumed Yr.	Total CO^2 Per Yr. (Coal @ 2.16 lbs kWh)
$470.63M	3.337B	7.803BT

Conclusion: There is absolutely NO evidence the AMI Meter program saves CO^2, energy in kWh or money, in fact it only drains the bank accounts of the consumer, pads utility revenue and adds to Global Warming.

The only way the AMI program will save kWh's is to use it to aggressively ration power to consumers via Demand Response/Time of Use rate structures at 4-10 X normal rates where the elderly, disabled and young families with a parent and small children at home can least afford it or do without power during the Demand Response/Time of Use period. Under this scenario the AMI program is the largest fleecing of the consumer to ever exist and a deception to our citizens regarding reducing costs, CO^2 and protecting our environment.

EMI/RFI from the AMI Meter

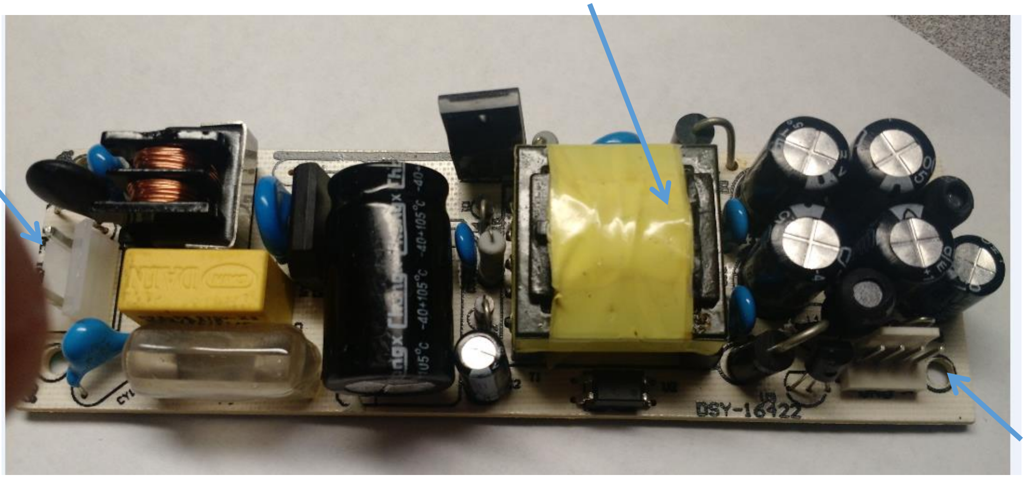
This set of pages shows what a proper UL approved 240 Volt AC to 12 Volt DC Switched Mode Power Supply versus the AMI Meter

SMPS with Proper differential and Common Mode Filter – UL Approved Example

Please note this is an example of a UL approved 240 Volt AC to 12 Volt DC SMPS
This design does not inject high frequency oscillations onto the incoming AC line because it has a common mode & differential filter circuit (left hand side of the circuit board)

Transformer that converts 240 volts to 12 volts

AC In



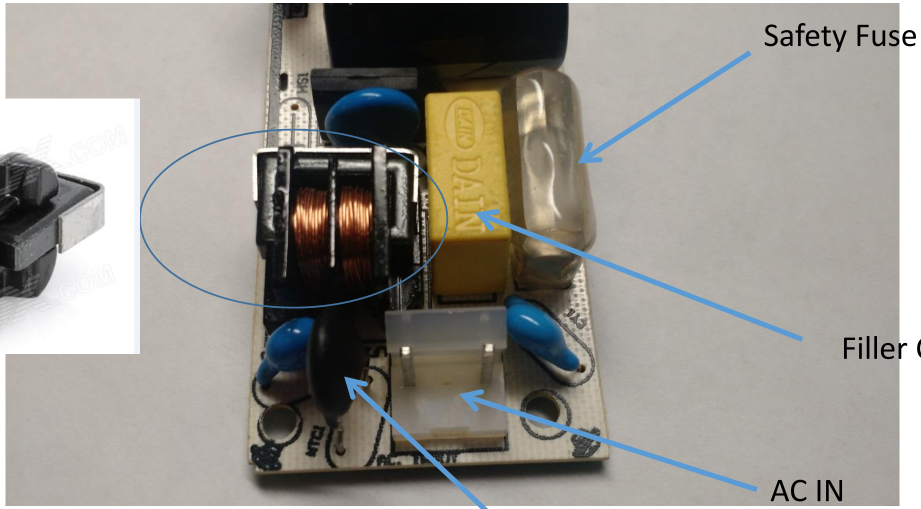
DC Out

Note the DC Out has + - and a ground lead (center) which is connected to a true ground

Common Mode Filter - Sample

Please note this is an example of the Common Mode Filter in the design example

Common Mode Filter



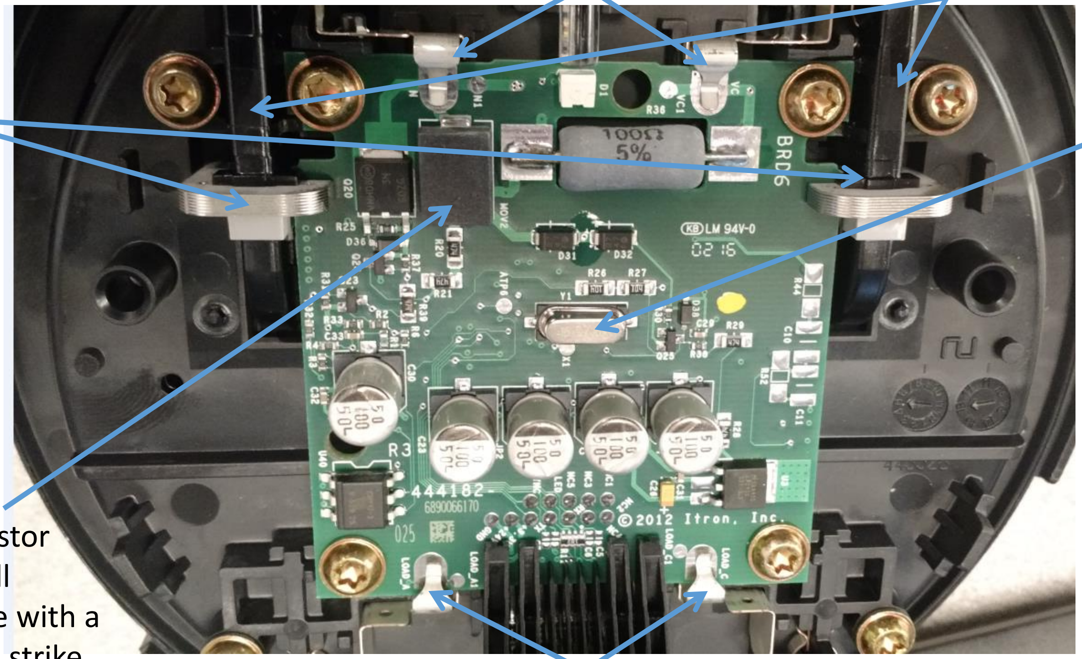
The ITRON Meter SMPS Board

240 Volts IN

Note under this plastic is the current carrying tab, if this gets hot it melts

Current – KW measurement

16 MHz Oscillator

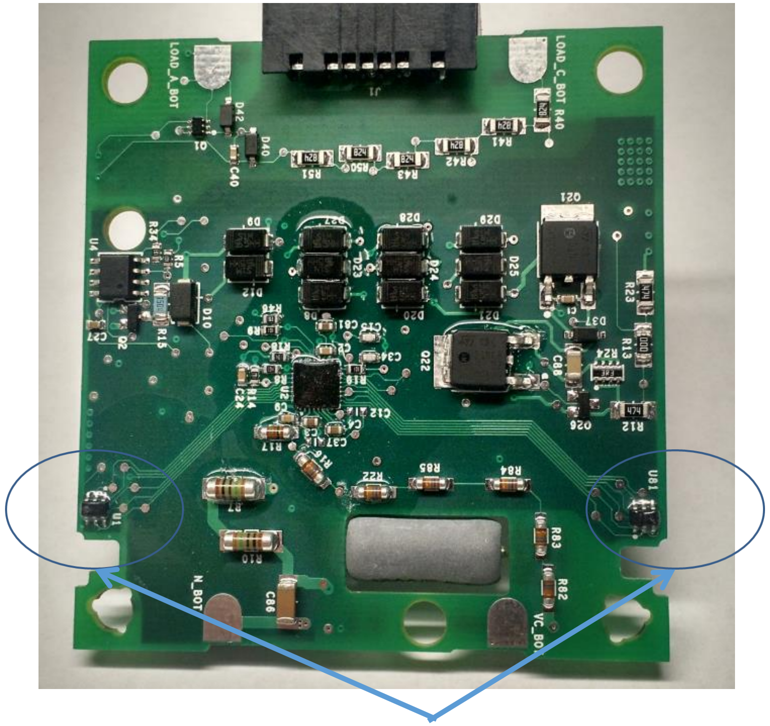


Thermistor that will explode with a lighting strike or power surge

240 Volts OUT

You will notice that there is no Common & Differential mode filter circuit at all, no coil, no fuse and no differential capacitor filter

The ITRON Meter SMPS Board – Back Side of Board

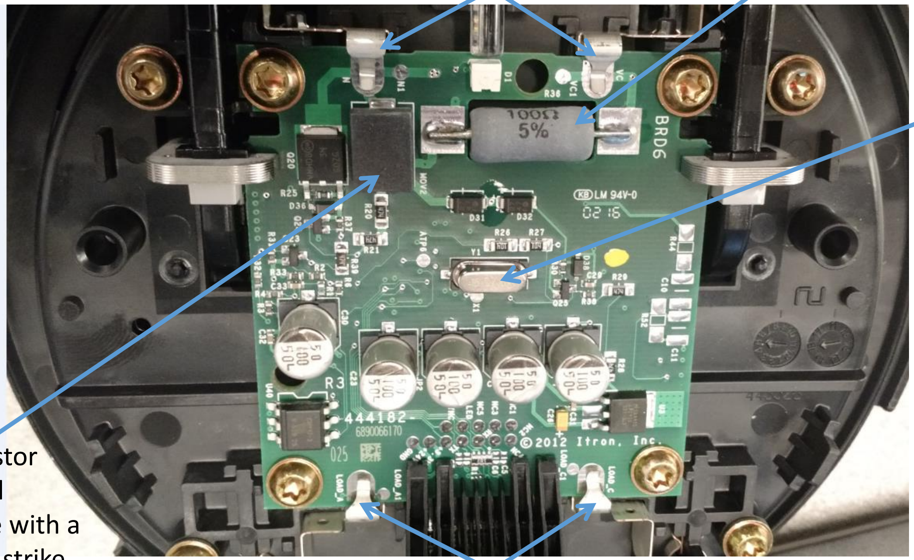


Here are the hall effect sensors that are used to measure Current/kWh

The Power to Run the AMI meter

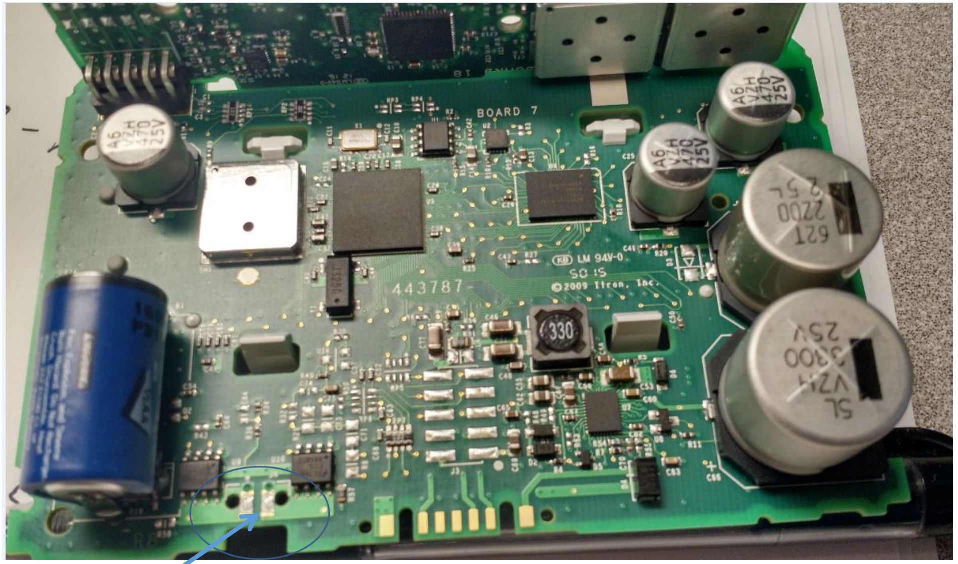
This next page shows the location of the 100 ohm resistor that consume 1.3 kWh and is a large part of the total 2.37 kWh required to run the meter by itself. The balance of the power 1.07 kWh to make up the total is consumed within the other two remaining boards.

The ITRON Meter SMPS Board



You will notice that there is no Common & Differential mode filter circuit at all, no coil, no

The ITRON Meter System Board



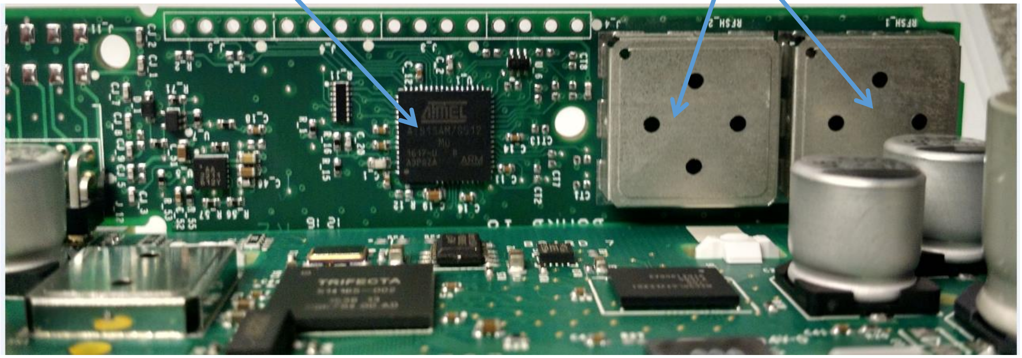
To the disconnect solenoid (24 V)

In this photo is the metrology memory board and additional voltages for the disconnect solenoid (24 V) and is used for the LCD display (on Back of this board)

The ITRON Meter Computer and RF Transceiver Board

The ARM Computer Chip

The two transceivers 900 MHz and 2.4 GHz



In this photo is the computer chip (ARM Chip) board and the two transceivers

My Energy Readings

William S. Bathgate

The following information is to support the testimony found in Exhibit RCG-3 (WSB-3)

The first page shows the AMI meter SMPS board noting the location of the 100 ohm resorts that draws 1.3 kWh per day.

The purpose of this second page of this exhibit is to document the energy consumed by the AMI meter at idle on a home with no power breakers on. No branch circuit breakers were turned on and exterior temperatures were in 60's during daylight hours and 45 degrees overnight.

The third page of this exhibit shows the cost per kWh are based on current rates inclusive of distribution charges and fuel optimization costs. The costs can vary based on time of year or tariff effective dates, but are mathematically sound determination of cost factors. Also is the environmental impact of this added energy in $CO2$

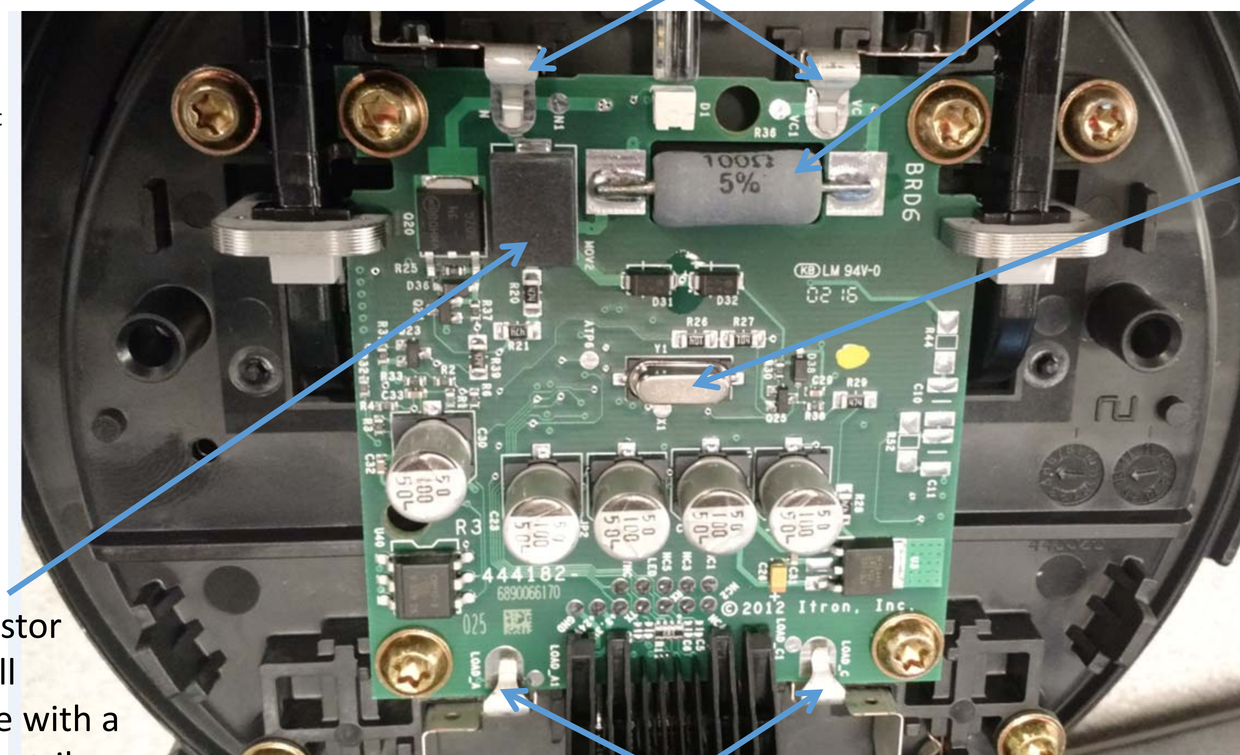
The ITRON Meter SMPS Board

240 Volts IN

<u>100 ohm resistor @5% accuracy, draws current</u>

Current – KW measurement

16 MHz Oscillator



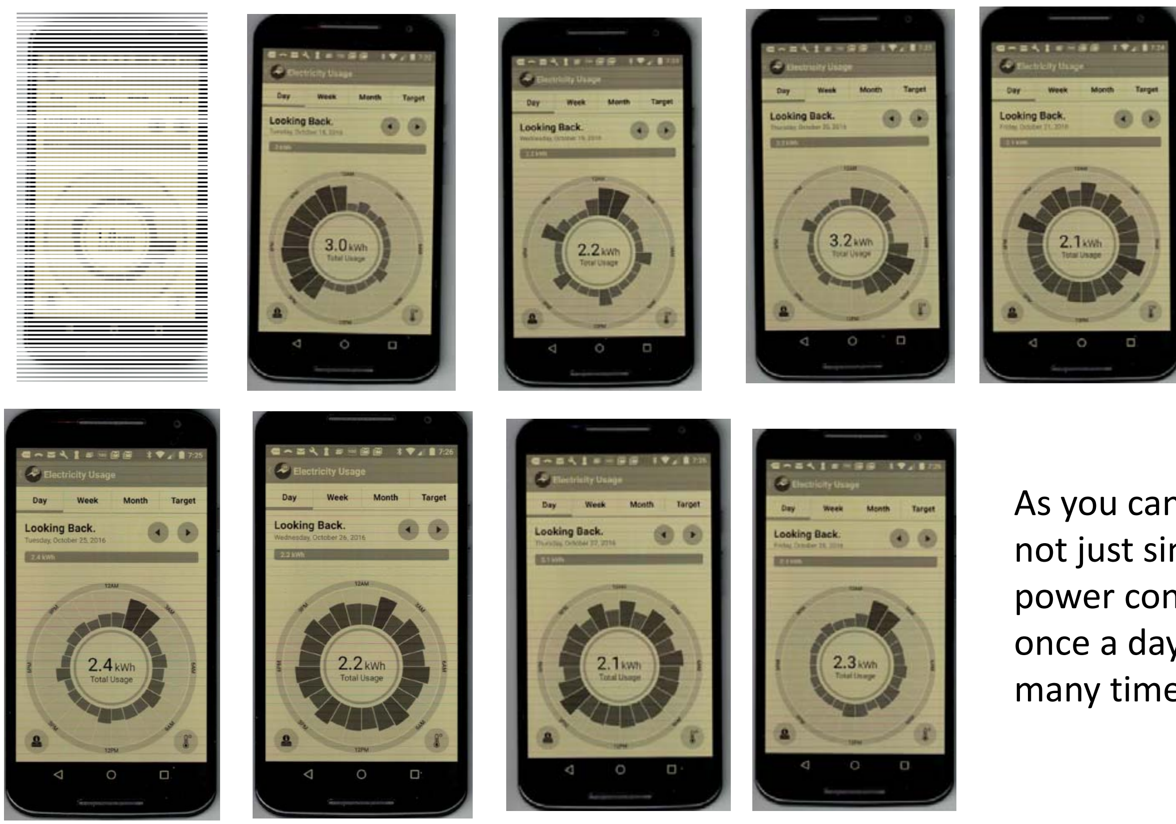
Thermistor that will explode with a lighting strike or power surge

240 Volts OUT

You will notice that there is no Common & Differential mode filter circuit at all, no coil, no fuse and no differential capacitor filter

My Energy Readings

Avg. Daily AMI kWh Use 2.37 kWh @ 0.139 per kWh = $0.319 x (865 kWh/Yr.)



As you can see this is not just simply reading power consumption once a day, but is done many times, all day

Note – No breakers were on and the time and reading of the meter is not a simple "Text" message

Impact to the Environment

Annual Cost per Customer	Rev $ for DTE	Rev $ for CE	kWh per DTE	kWh per CE	CO^2 Per DTE	CO^2 Per CE
$120.67/Yr.	$253.42M	$217.21M	1.816B	1.521B	3.924BT	3.879BT

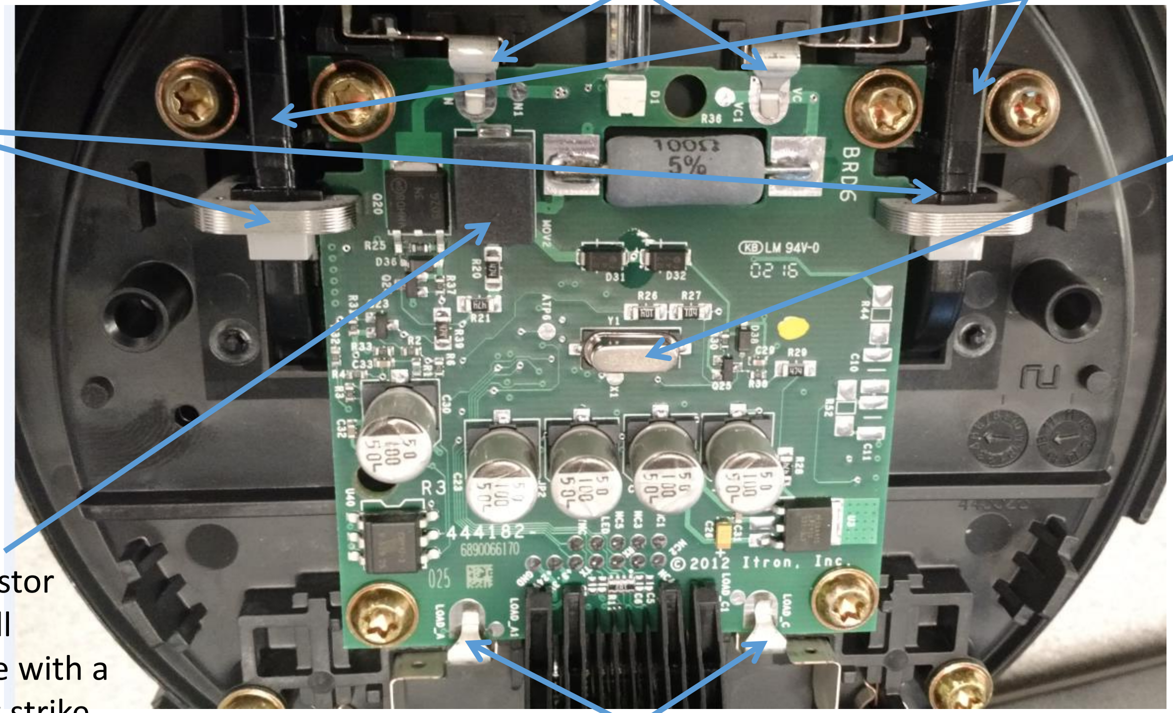
Total Consumer Costs Yr.	Total kWh Consumed Yr.	Total CO^2 Per Yr. (Coal @ 2.16 lbs kWh)
$470.63M	3.337B	7.803BT

Conclusion: There is absolutely NO evidence the AMI Meter program saves CO^2, energy in kWh or money, in fact it only drains the bank accounts of the consumer, pads utility revenue and adds to Global Warming.

The only way the AMI program will save kWh's is to use it to aggressively ration power to consumers via Demand Response/Time of Use rate structures at 4-10 X normal rates where the elderly, disabled and young families with a parent and small children at home can least afford it or do without power during the Demand Response/Time of Use period. Under this scenario the AMI program is the largest fleecing of the consumer to ever exist and a deception to our citizens regarding reducing costs, CO^2 and protecting our environment.

Explosive Parts in an AMI meter

The ITRON Meter SMPS Board



You will notice that there is no Common & Differential mode filter circuit at all, no coil, no fuse and no differential capacitor filter

Bad Contacts from AMI meter installed

Module 8:

EMC Regulations

Introduction

The goal of electromagnetic compatibility, or EMC, is to design electronic systems that are electromagnetically compatible with their environment. EMC requirements exist so that electronic systems designers have a set of guidelines that explain the limits of what is considered electromagnetically compatible. There is not, however, one all-encompassing set of EMC guidelines. Instead, EMC guidelines are created by individual product manufacturers, and by the government. Requirements set forth by the government are legal requirements that products must meet, while the requirements set forth by the manufacturer are self-imposed and often more stringent than those set forth by the government.

Government Requirements

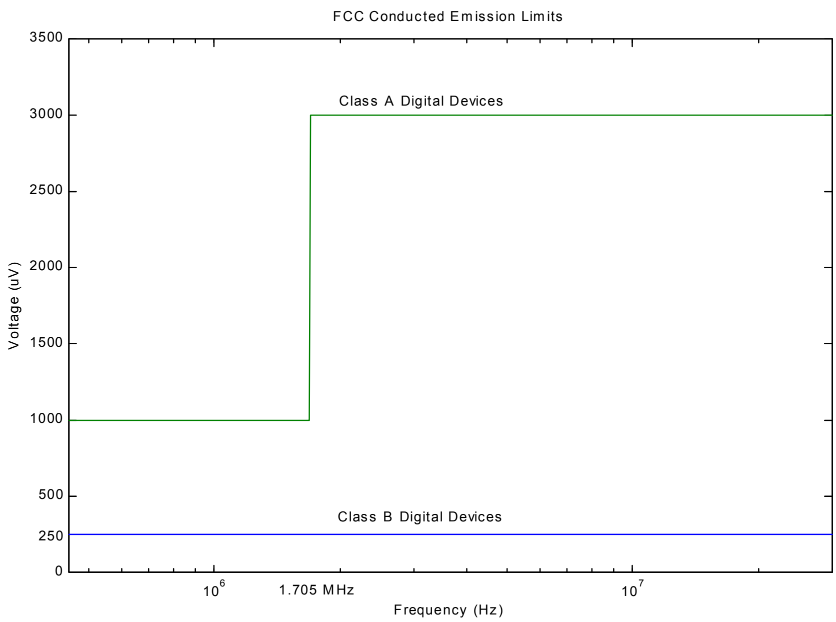
Not all countries have the same EMC requirements. In fact, each country is responsible to enforce their own set of requirements. This does not, however, mean that each country has a unique set of EMC requirements. In fact, the various EMC requirements set forth by all the countries of the world are very similar, and many countries are moving toward accepting an international standard for EMC requirements know as the CISPR 22 standards. These standards have been adopted throughout much of Europe and were developed in 1985 by CISPR (the French translation meaning International Special Committee on Radio Interference).

In the United States the Federal Communications Commission (FCC) is charged with the regulation of radio and wire communication. Radio frequency devices are the primary concern in EMC. A radio frequency device is defined by the FCC as any device that is capable of emitting radio frequency energy by radiation, conduction or other means whether intentionally or not. Radio frequencies are defined by the FCC to be the range of frequencies extending from 9 kHz to 3000 GHz. Some examples of radio frequency devices are digital computers whose clock signals generate radiated emissions, blenders that have dc motors where arcing at the brushes generates energy in this frequency range, and televisions that employ digital circuitry. In fact nearly all digital devices are considered radio frequency devices.

With the advent of computers and other digital devices becoming popular, the FCC realized that it was necessary to impose limits on the electromagnetic emissions of these devices in order to minimize the potential that they would interfere with radio and wire communications. As a result the FCC set limits on the radiated and conducted emissions of digital devices. Digital devices are defined by the FCC as any unintentional radiator (device or system) that generates and uses timing pulses at a rate in excess of 9000 pulses (cycles) per second and uses digital techniques… . All electronic devices with digital circuitry and a clock signal in excess of 9 kHz are covered under this rule, although there are a few exceptions.

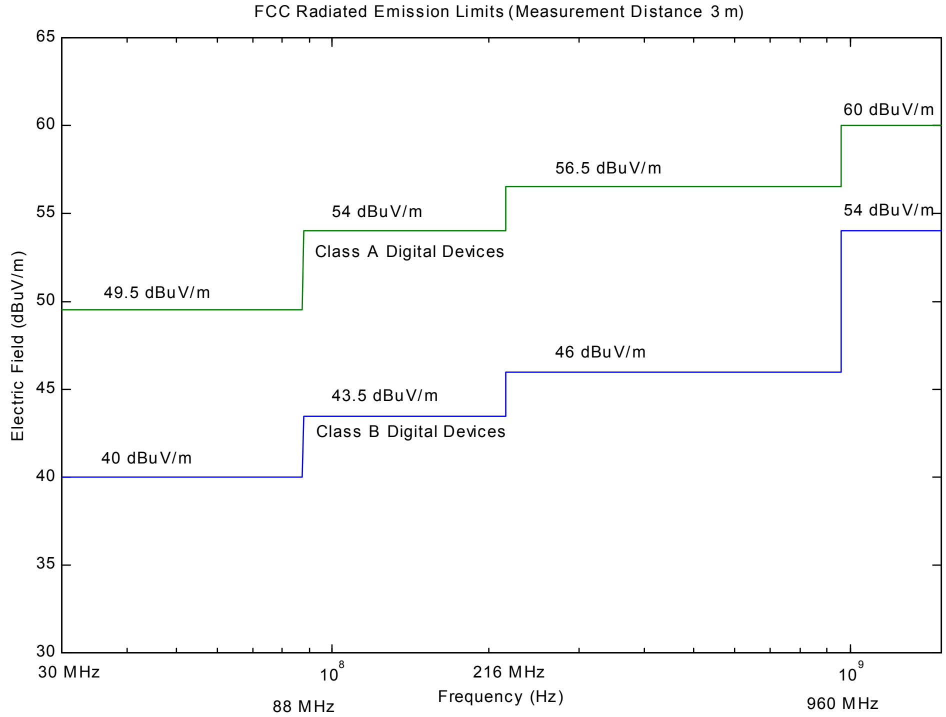
The law makes it illegal to market digital devices that have not had their conducted and radiated emissions measured and verified to be within the limits set for by the FCC regulations. This means that digital devices that have not been measured to pass the requirements can not be sold, marketed, shipped, or even be offered for sale. Although the penalties for violating these regulations include fines and or jail time, companies are more concerned with the negative publicity that would ensue once it became known that they had marketed a product that fails to meet FCC regulations. Furthermore, if the product in question were already made available to the public, the company would be forced to recall the product. Thus it is important that every unit that a company produces is FCC compliant. Although the FCC does not test each and every module, they do perform random tests on products and if a single unit fails to comply, the entire product line can be recalled.

The FCC has different sets of regulations for different types of digital devices. Devices that are marketed for use in commercial, industrial or business environments are classified as Class A digital devices. Devices that are marketed for us in residential environments, notwithstanding their use in commercial, industrial, or business environments are classified as Class B digital devices. In general the regulations for Class B devices are more stringent than those for Class A devices. This is because in general digital devices are in closer proximity in residential environments, and the owners of the devices are less likely to have the abilities and or resources to correct potential problems. The following table shows a comparison of the Class A and Class B conducted emissions limits, where you can clearly see that the regulation for Class B devices are more strict than those for Class A devices. A comparison for radiated emissions will be shown later. Personal computers are a subcategory of Class B devices and are regulated more strictly than other digital devices. Computer manufacturers must test their devices and submit their test results to the FCC. No other digital devices require that test data be sent to the FCC, rather the manufacturer is expected to test their own devices to be sure they are electromagnetically compatible and the FCC will police the industry through testing of random product samples.



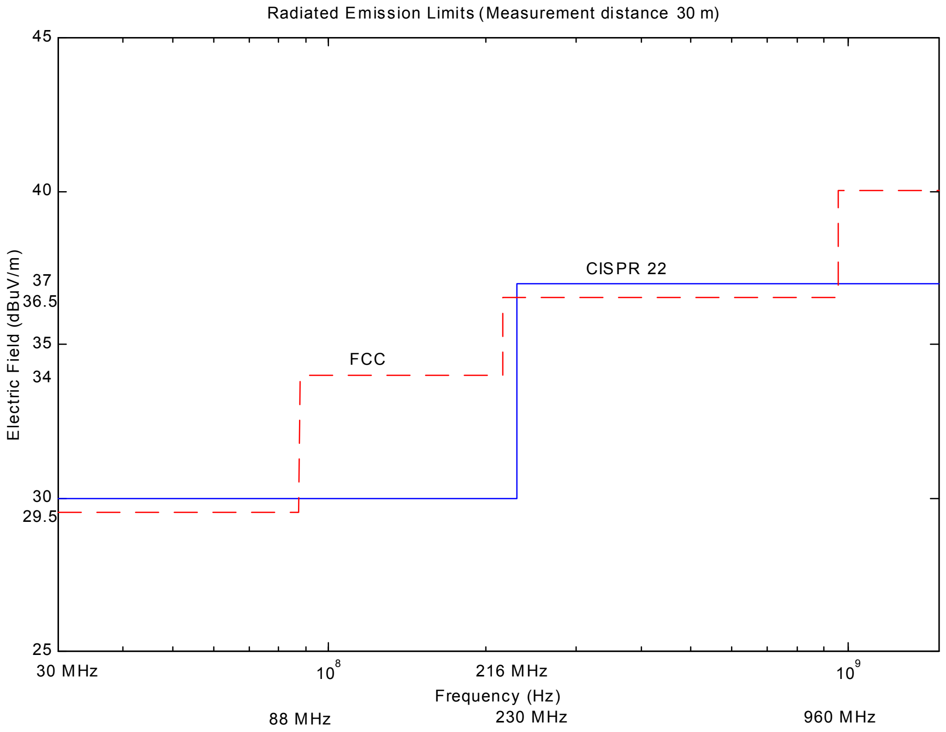
Since the FCC regulations are concerned with radiated and conducted emissions of digital products, it is useful to understand what these emissions are. Conducted emissions are the currents that are passed out through the unit's AC power cord and placed on the common power net. Conducted emissions are undesirable because once these currents are onto the building wiring they radiate very efficiently as the network of wires acts like a large antenna. The frequency range of conducted emissions extends from 450 kHz to 30 MHz. Devices are tested for compliance with conducted emissions regulations by inserting a line impedance stabilization network (LISN) into the unit's AC power cord. Current passes through the AC power line and into the LISN, which measures the interference current and outputs a voltage for measurement purposes. The actual FCC regulations set limits on these output voltages from the LISN even though the current is what is truly being regulated. Radiated emissions are the electric and magnetic fields radiated by the device that may be received by other devices, and cause interference in those devices. Although radiated emissions are both electric and magnetic fields, the FCC and other regulatory agencies only require that electric fields be measured for certification. The magnitudes of these fields are measured in dBμV/m and the frequency range for radiated emissions extends from 30 MHz to 40 GHz. Radiated field measurements for FCC compliance are done in either a semianechoic chamber or at an open field test site. The product under test must be rotated so that the maximum radiation will be achieved and measurements must be made both with the measurement antenna in vertical and horizontal polarizations with respect to the ground plane.

The method for measuring radiated emissions varies depending on the type of device being measured. Class A digital devices must be measured at a distance of 10 m from the product and Class B devices are to be measured at a distance of 3 m from the product. As explained earlier, the Class B devices, which are marketed for residential use, have stricter regulations and thus must be measured in closer proximity than Class A devices. The following graph displays the radiated emission limits that are defined by the FCC for Class A and Class B digital devices. Because the measurement distances defined by the two requirements are different, we must scale the measurement distances so that they are both at the same distances in order to achieve an accurate comparison. One way to do this is with the inverse distance method, which assumes that emissions fall off linearly with increasing distance to the measurement antenna. Thus emissions at 3 m are assumed to be reduced by 3/10 if the antenna is moved out to a distance of 10 m. So, to translate Class A limits from a distance of 10 m to 3 m , we add $20\log_{10}(3/10) = 10.46$ dB to the Class A limits. This approximation is only valid, however, if the measurements are taken in the far field of the emitter. We can assume that the far field boundary is three wavelengths from the emitter, and with the radiated emissions frequency range defined as 30 MHz to 40 GHz, the maximum distance from the emitter that the measurements will be in the far field is 30 m. Thus, at 10 m not all measurements will be in the far field. At 10 m frequencies of 90 MHz and higher will be in the far zone. So, for the case of this plot, the inverse distance method can be assumed to be accurate for frequencies above 90 MHz, but begins to break down at lower frequencies. However, this comparison still nicely demonstrated how Class B limits tend to be roughly 10 dB more strict than Class A radiated emission requirements.

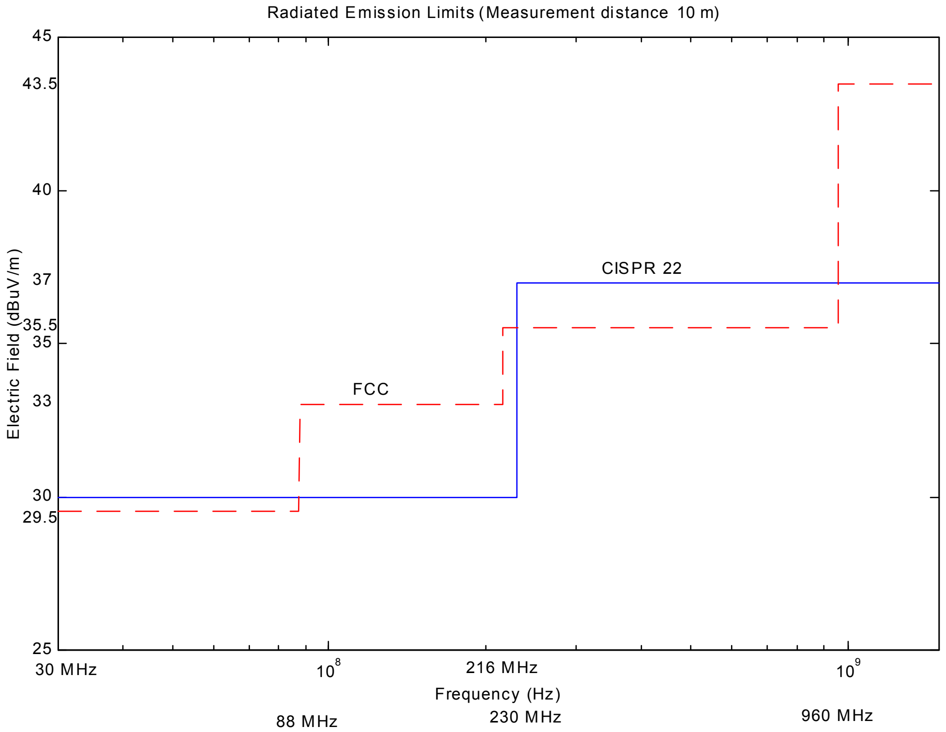


Internationally EMC requirements differ from those in the United States. As discussed earlier, each country is responsible for its own set of EMC regulations. Since the CISPR 22 regulations have been adopted by several countries we will examine them and compare them to the FCC regulations in the United States. CISPR 22 regulations require that radiated emissions measurements for Class A devices be measured at a distance of 30 m and Class B devices be measured at a distance of 10 m. Again using the inverse distance method, we can scale the measurement limits to a common distance and plot the CISPR 22 and FCC regulations together to compare them. As you can see, although the regulations vary slightly in different frequency ranges, there isn't much difference between the FCC and CISPR 22 regulations for radiated emissions.

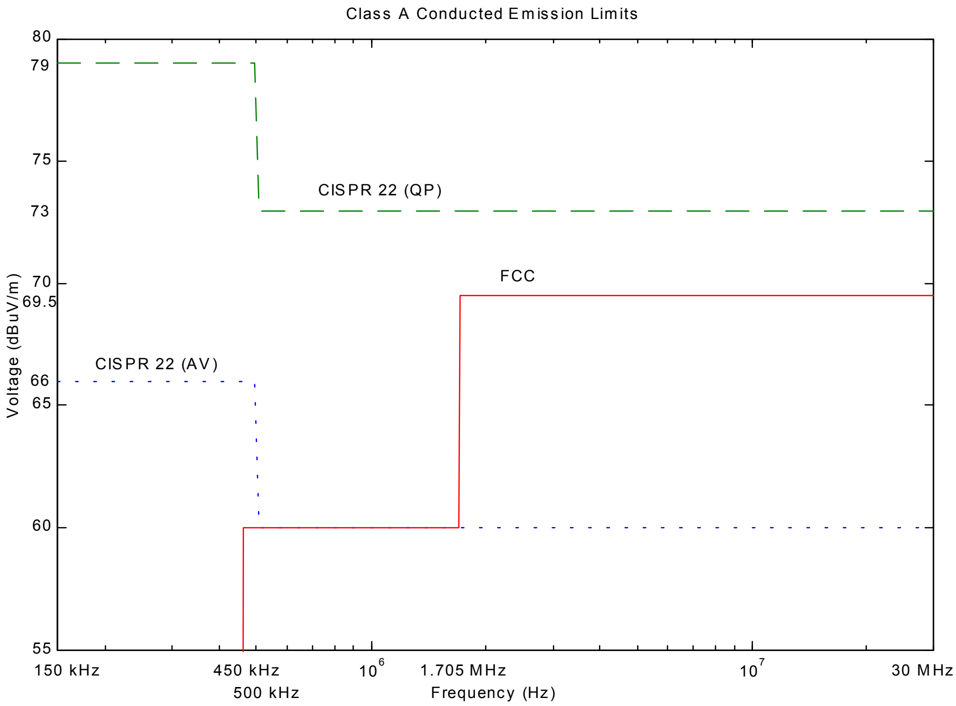
Radiated Emissions Limits for Class A Digital Devices

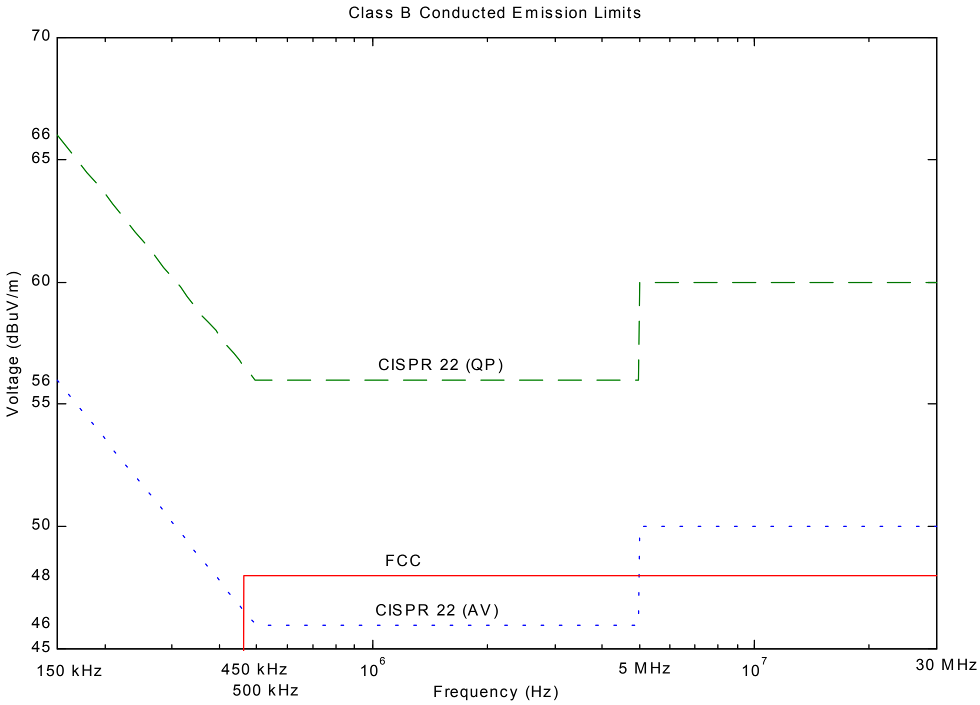


Radiated Emissions Limits for Class B Digital Devices



The differences in the FCC and CISPR 22 regulations become much more obvious when looking at the conducted emissions limits. The most notable difference is the frequency range that is regulated for conducted emissions. While they both have a maximum frequency of 30 MHz, the CISPR 22 regulations extend down to 150 kHz, while the FCC regulations only extend down to 450 kHz. You can see that the CISPR 22 limit for class B devices rises for frequencies below 500 kHz. This extension was put in place to cover the emissions of switching power supplies, which are growing in importance over linear power supplies due to their efficiency and light weight. Another difference is that the CISPR 22 regulations for conducted emissions are given for when the receiver uses a quasi-peak detector (QP) and when the receiver uses an average detector (AV). FCC conducted emissions limits and CISPR 22 and FCC conducted emissions limits all apply to the use of a quasi-peak detector.



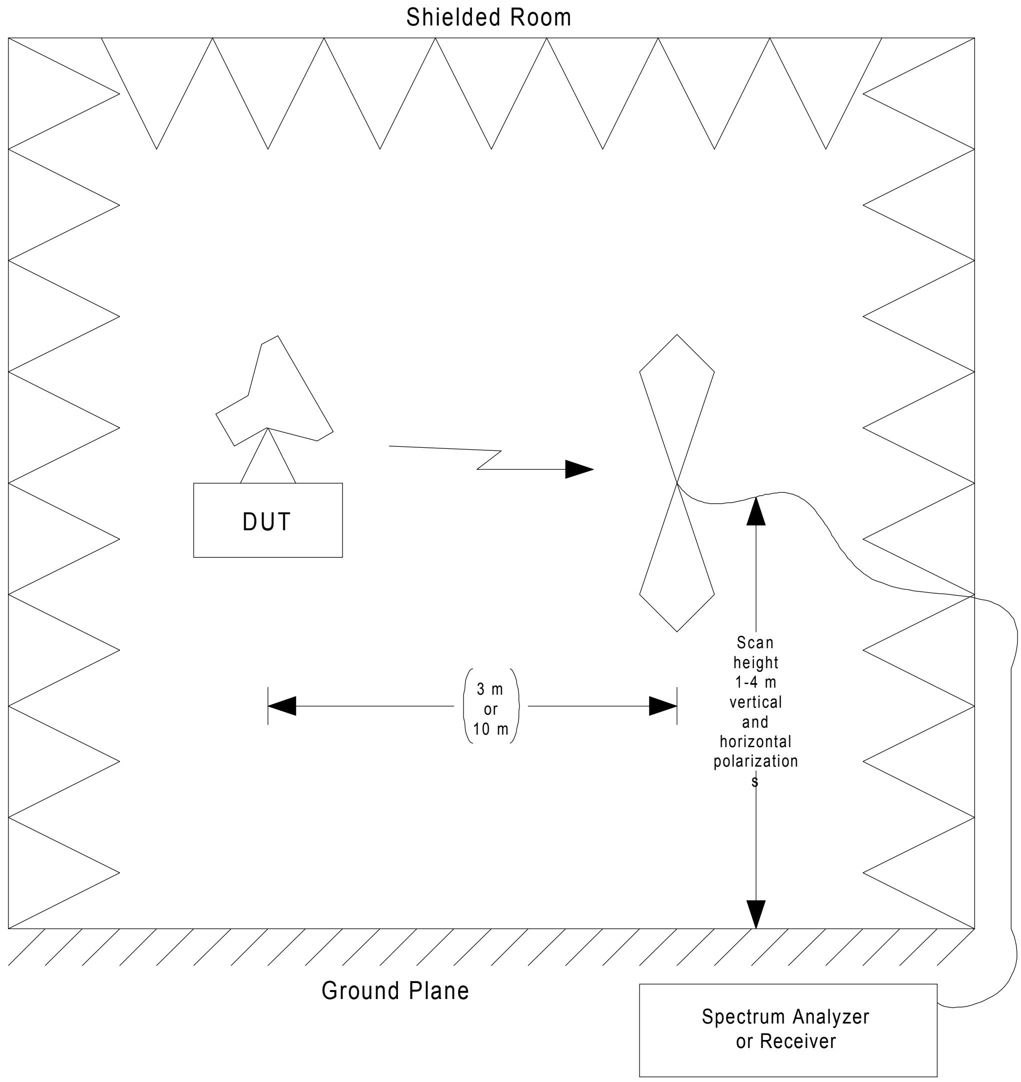


Military EMC regulations also exist. As you would expect, EMC issues are very important in military applications so that missions will not be compromised. Along with conducted and radiated emissions, the military also regulates susceptibility. This is very important in military applications, as it is vital that military equipment is immune to outside interference. The military is more strict in its regulations than the FCC or CISPR and it also has a much larger frequency range that is regulated and has several subdivisions within that frequency range. Additionally, the military may deem to have the EMC requirements waived for certain applications if it is judged that it is necessary to mission success. CISPR and FCC regulations cannot be waived for commercial products.

Measuring Radiated Emissions

In order to ensure that testing for radiated emissions are accurate, the FCC and CISPR have testing standards that explain how testing must be done. This ensures that the testing is accurate and repeatable. For radiated emissions the FCC specifies that the measurements of radiated and conducted emissions must be performed on the complete system. All interconnect cables to peripheral equipment must be connected and the system must be in a typical configuration. The cables and the system must also be configured in a representative way such that the emissions are maximized. For instance, a unit with interior wire harnesses must have the harnesses configured in such that for all possible ways the unit can be assembled with those wire harnesses, the way with the most radiated emissions must be tested. This ensures that for mass production of a unit, the worst case scenario is taken into consideration.

The testing standards set forth by the FCC for radiated emissions testing are very specific and difficult to automate. Radiated emissions are to be measured at a distance of 10 m for Class A devices and at a distance of 3 m for Class B devices. These measurements are to be made over a ground plane using a tuned dipole antenna at an open field test site. Additionally, the tests are to be made with the measurement antenna in both the vertical and horizontal positions. During development of products, however, most companies test their products in a semianechoic chamber, which is a shielded room with radio frequency absorbing cones on the walls and ceiling. This semianechoic chamber simulates an open field test site, and eliminates any ambientambient signals that may be present in an open field environment. An example of this setup can be seen in the following figure.



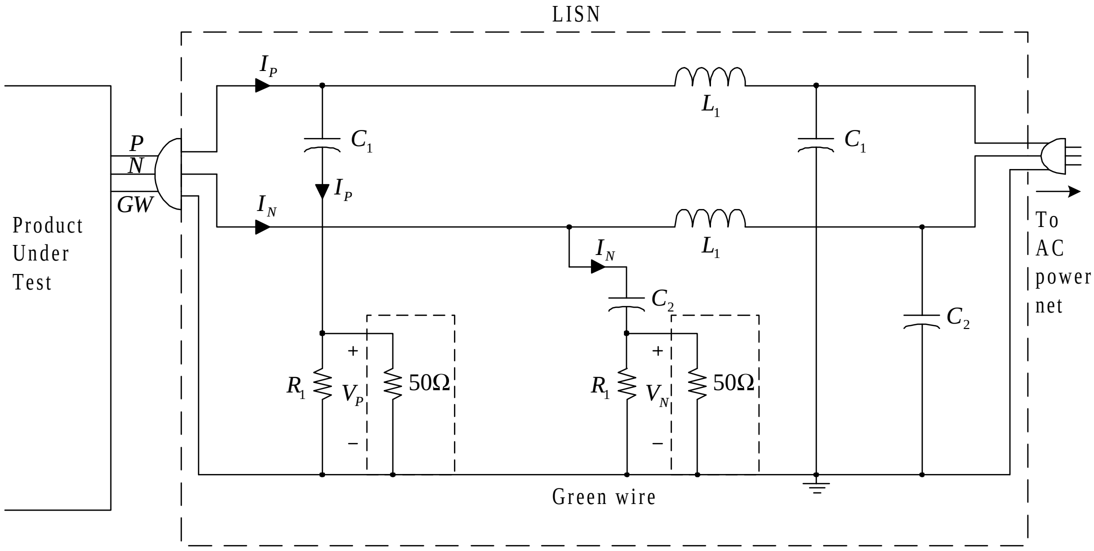
Another way that companies simplify the FCC test procedure is by using a broadband antenna such as a log-periodic or discone antenna. Such antennas are desireable since, unlike a tuned dipole, their length does not need to be adjusted with each frequency change. This allows companies to test their products using a frequency sweep rather than having to do each frequency separately and adjusting the dipole lengths with each measurement.

One last test requirement for radiated emissions testing is the bandwidth of the receiver being used to measure the signal must be at least 100 kHz. By having such a large bandwidth, the test will not pick up intended narrowband signals such as clock signals, but it will detect emissions from broadband sources such as the arcing at the brushes of a dc motor. A related issue is the detector used in the output stage of the receiver. Although typical spectrum analyzers us peak detectors, the FCC and CISPR test procedures require that the receiver use a quasi-peak detector. This ensures that fast changing, momentary signals such as randomly occurring spikes will not charge up the quasi-peak detector to as high a level as periodic signals. After all, the FCC is not concerned with randomly occurring one time signals. Rather, they are concerned with more significant and frequent emissions that would cause interference with radio and wire communications.

Measurement Requirements for Conducted Emissions

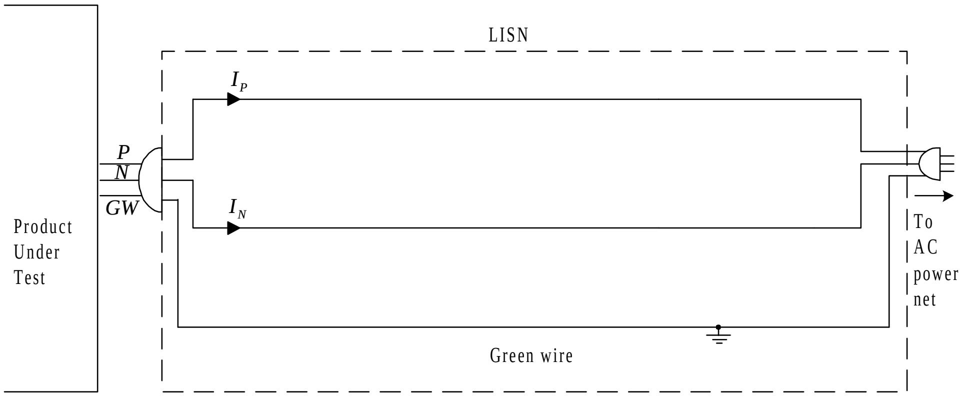
The intent of conducted emissions limits is to prevent noise currents from passing out through the AC power cord of the device onto the common power net of the installation. The common power net of an installation is an array of interconnected wires in the installation walls, and can be seen as a large antenna. Noise currents placed onto the common power net will consequently radiate very efficiently. An example of this is the interference that occurs on your television or radio when you use the blender. The arcing of the brushes of the dc motor in the blender causes noise currents that pass out through the power cord of the blender and into the common power net of your house. The wiring in the house acts as an antenna and radiates the noise, which is picked up as interference in your television and radio.

Therefore, conducted emissions are concerned with the current that is passed out through the power cord of the device. However, the FCC and CISPR 22 conducted emission limits are given in units of volts. This is because the LISN, which is used to measure conducted emissions converts the noise currents to voltage. In order to understand the function of the LISN it is important to understand the standard ac power distribution system. In the United States, AC voltage used in residential and business environments has a frequency of 60 Hz and an RMS voltage of 120 V. The power wires in a home consist of 3 wires, a phase wire, a neutral wire, and the green wire. Both the phase and neutral wires carry the 60 Hz power and the potential between each wire and ground is 120 V. The currents that need to be measured for conducted emissions tests are the currents that occur on the phase and neutral wires.

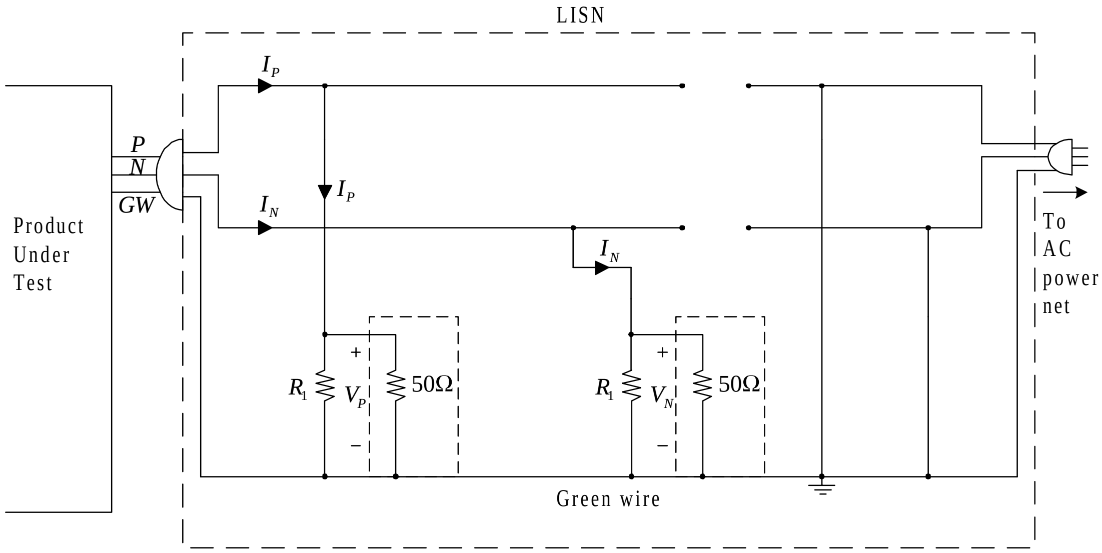


The above figure shows the LISN used for FCC conducted emissions tests. A similar LISN is used for CISPR 22 conducted emissions testing, but the component values are different due to the different frequency range defined by CISPR for conducted emissions testing. The LISN has two functions. The first function is to isolate external noise from the common ac net from contaminating the measurement. The second purpose of the LISN is to present a constant impedance in frequency from site to site to the product between phase and ground and between neutral and ground.

Following is an explanation of how the LISN works. First, one of the 50 Ω resistors represents the input impedance of the spectrum analyzer, and the other 50 Ω resistor is a dummy load. The capacitors C_1 =0.1 μF is in place to prevent any dc from overloading the test receiver and the resistors R_1=1kW are in place to provide a path an path for C_1 to discharge in the event the 50 Ω resistors are disconnected. The product under test should operate normally at 60 Hz power frequencies. Thus, at 60 Hz the capacitors will look like open circuits and the inductors will look like short circuits, and the equivalent circuit will look like this:



Thus the product under test will operate as if there were nothing between it and the ac power net at 60 Hz. In the frequency range of conducted emissions (450 kHz-30 MHz), however, the conductors will look like short circuits and the inductors will look like open circuits. The equivalent circuit will look like this:



Thus, the currents on the neutral and phase lines can be isolated and measured at the 50 Ω resistors. Notice that the currents on the phase and neutral lines have no path that they can get onto the ac power net with.

Additional Product Requirements

As stated earlier, the FCC and CISPR 22 regulations are requirements set forth by law to regulate digital devices. Individual companies, however, self impose their own set of regulations on their products, which are often much more stringent than the required regulations. The automobile industry, for example is exempt from FCC requirements, yet their self-imposed regulations far exceed those that the FCC sets forth for normal digital devices. This is because companies stand to lose far more money as a result of a faulty or poorly designed product, than they would by investing to make sure their product is safe and well designed. After all, people put their lives in the hands of auto manufacturers every time they drive a vehicle, and auto manufacturers cannot afford to have lax standards.

Aside from imposing stricter versions of government regulations on themselves, many companies also impose design constraints on their products that protect against, radiated immunity, conducted immunity, and electrostatic discharge (ESD). The FCC does not regulate these areas because they do not pose a threat to radio or wire communications, so individual manufacturers are left to create their own standards. Furthermore, as each of these categories pertains to a products ability to function despite outside interference, they are of the utmost importance for manufacturers to guard against. Radiated immunity is a products ability to operate in the face of high power transmitters, such as AM and FM transmitters and airport surveillance radars. Manufacturers test their products by illuminating their product with typical waveforms and signal strengths that simulate worst case exposure that the product could encounter. Conducted immunity is the ability of a product to operate despite a variety of interferences that enter the device via the ac power cord. An obvious example of such interference would be a power surge caused by lightning strike. Manufacturers must design tests that would simulate the effect of lightning induced transients and design their product to resist such interference accordingly. Electrostatic discharge is when static charge builds up on the human body or furniture and is subsequently discharged to the product when the person or furniture comes in contact with the product. Such static voltage can approach 25 kV in magnitude. When the discharge through the product occurs, large currents momentarily coarse through the product. These currents can cause machines to reset, IC memories to clear, etc. Manufacturers test their products by subjecting them to controlled ESD events and design their product to operate successfully in the event of such ESD occurances.

References

1. Paul, C. Introduction to Electromagnetic Compatibility, John Wiley & Sons, 1992

Design Practices for Military EMC and Environmental Compliance

BY MILITARY EMC STAFF, INTERTEK

The reliable operation of complex electronic communications, control and armament systems in extreme environments demands stringent design criteria and careful validation. Severe shock, vibration, heat, humidity and airborne contaminants are common in land, sea and air platforms.

Coupled with dense packaging, high-power radio and radar illumination, Hazards of Electromagnetic Radiation to Ordnance (HERO), and a possible electromagnetic pulse (EMP), the military equipment environmental requirements can be extreme indeed.

In order to expedite equipment availability and reduce cost, the acquisition of commercial-off-the-shelf (COTS) equipment for US military applications is an attractive consideration. But many types of commercial equipment are unlikely to meet all military environmental requirements as manufactured, so some modification or re-design is usually needed. Defining the gap between the commercial equipment's environmental performance and its military expectations is a first step in determining its potential suitability.

The full cycle of US military product development from environmental assessment, to definition of requirements, to test reports, is carefully spelled out in the relevant military standards or ancillary documents for the applicable physical and electromagnetic environments. These provide the design guidance, along with competent engineering practices, for a cost-effective and robust military product design.

THE ELECTROMAGNETIC ENVIRONMENT

Electromagnetic compatibility (EMC) requires the component, equipment or system to perform its designed functions without causing or suffering unacceptable degradation due to electromagnetic interference to or from other equipment. The starting point for EMC is self-compatibility, where the final product or system does not interfere with its own operation. This is a basic requirement in military EMC standards; for example, in MIL-STD-461F clause 4.2.3:

> *The operational performance of an equipment or subsystem shall not be degraded, nor shall it malfunction, when all of the units or devices in the equipment or subsystem are operating together at their designed levels of efficiency or their design capability.*

As we shall see, this is the modest starting point for military EMC, which extends to both lower and higher frequencies than most commercial EMC standards and to both lower emission limits and much higher susceptibility requirements. Test methods generally differ from their commercial counterparts in both setup and detail.

History of Military EMC

EMC problems in commercial applications were first noted worldwide in the 1930s, when early broadcast radios were being installed in automobiles. Reception was degraded by ignition noise and electrostatic buildup caused by non-conductive rubber tires.

The first US military specification on EMC also addressed this problem. It was published by the US Army Signal Corps in 1934 as SCL-49, "Electrical Shielding and Radio Power Supply in Vehicles". It required shielding of the vehicle ignition system, regulator and generator. With the increased use of mobile military radio communications, SCL-49 became inadequate. In 1942 it was superseded by specification 71-1303, "Vehicular Radio Noise Suppression."

In the period 1950 - 1965, each major military agency imposed its own EMC specifications. The Air Force used MIL-I-6181 and MIL-I-26600; the Navy used MIL-I-16910; the Army used MIL-I-11748 and MIL-E-55301(EL). These specifications limited the levels of conducted and radiated emissions, and they set susceptibility levels which systems and equipment must reject. These specifications also detailed the test configurations and methods for demonstrating compliance.

Unfortunately, over this period of time the various military EMC standards diverged from each other in test frequency ranges, limits and required test equipment. The differences made it quite expensive for a test lab or manufacturer to be fully equipped to test to all EMC specifications.

In 1960 the US Department of Defense enacted a comprehensive electromagnetic compatibility program that charged the military services to build EMC into all of their communications and electronics equipment. In 1966, EMC personnel of the three military departments jointly drafted standards addressing the overall EMC needs of the Department of Defense. That program resulted in 1967 in military standards 461 (requirements), 462 (methods) and 463 (definitions and acronyms). After revision, MIL-STD-461A was issued in August 1968. Subsequent revisions were designated B, C, and D. MIL-STD-463 was withdrawn after 1990.

In 1999 the 461D and 462D standards were merged into one document, MIL-STD-461E. The current version is MIL-STD-461F (2007), and updates to it are in the planning stage. Prior revision levels A-E may still be specified for testing.

USA: Supporting Documentation

The designer of military electronic equipment has an abundance of guidance available for successfully meeting the EMC demands of the intended operating environments.

Standards

Active military standards (Table 1) specify a variety of scopes, environmental sub-categories, limits and test methods clearly and in great detail.

The most commonly-used MIL standards are 461 (subsystems and equipment) and 464 (systems), and they apply to ground-based, shipboard and airborne applications. Other

Reference	Title
MIL-STD-188-124	Grounding, Bonding and Shielding for Common Long Haul/Tactical Communications Systems Including Ground Based Communication-Electronics Facilities and Equipments
MIL-STD-188-125-1	High-Altitude Electromagnetic Pulse (HEMP) Protection For Ground-Based C41 Facilities Performing Critical, Time-Urgent Missions - Part 1 - Fixed Facilities
MIL-STD-188-125-2	High-Altitude Electromagnetic Pulse (HEMP) Protection For Ground-Based C4I Facilities Performing Critical, Time-Urgent Missions - Part 2 - TransporTable Systems
MIL-STD-331C	Environmental and Performance Tests for Fuze and Fuze Components
MIL-STD-449D	Measurement of Radio Frequency Spectrum Characteristics
MIL-STD-461F	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-464A	Electromagnetic Environmental Effects – Requirements for Systems
MIL-STD-704F	Aircraft electric Power Characteristics
MIL-STD-1310H	Shipboard Bonding, Grounding, and other Techniques for Electromagnetic Compatibility, Electromagnetic Pulse (EMP) Mitigation, and Safety
MIL-STD-1377	Measurement of effectiveness of cable, connector, and weapons enclosure shielding and filters in precluding Hazards of electromagnetic radiation to ordnance
DOD-STD-1399-70-1	Interface Standard for Shipboard Systems – Section 070 – Part 1 – DC Magnetic Field Environment
MIL-STD-1399-300B	Interface Standard for Shipboard Systems – Section 300 - Electric Power, Alternating Current
MIL-STD-1541A	Electromagnetic Compatibility Requirements for Space Systems
MIL-STD-1542B	Electromagnetic Compatibility and Grounding Requirements for Space System Facilities
MIL-STD-1576	Electroexplosive Subsystem Safety Requirements and Test Methods for Space Systems
MIL-STD-1605A	Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ship)
MIL-STD-2169B	High Altitude Electromagnetic Pulse (HEMP) Environment.

Table 1: Active US military EMC standards for equipment, systems and facilities

government documents may apply to a specific platform or application, and some of these are listed in the standards such as MIL-STD-461 and -464.

Handbooks

In addition to the EMC standards listed in Table 1, there are a number of handbooks available that provide procedural, EMC assessment and design guidance for specific military applications. These provide guidance only, and are not to be construed as requirements. A list of relevant handbooks is given in Table 2.

Generally these handbooks are tutorial in nature, clearly written, and with explanations of the underlying physical principles. They provide invaluable assistance to the equipment or systems designer.

Data Item Descriptions

Finally, there are very detailed documentation specifications associated with military EMC standards. In some cases the required documentation is described in separate Data Item Descriptions (DIDs) or Test Operational Procedures (TOPs). These Data Item Descriptions cover EMC design procedures, test and verification procedures, and test reports. Table 3 contains a list of Data Item Descriptions and TOPs and the military standards with which they are associated.

For example, the Data Item Description DI-EMCS-80199C associated with standard MIL-STD-461F is very explicit in the level of detail to be provided regarding equipment design procedures:

*3.2. **Design techniques and procedures**. The EMICP [Electromagnetic Interference Control Procedures] shall describe the specific design techniques and procedures used to meet each emission and susceptibility requirement, including the following:*

a. Spectrum management techniques.

b. EMI mechanical design, including the following:

Reference	Title
MIL-HDBK-235B	Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment, Subsystems and systems
MIL-HDBK-237D	Electromagnetic Environmental Effects and Spectrum Supportability Guidance for the Acquisition Process
MIL-HDBK-240	Hazards of Electromagnetic Radiation to Ordnance (HERO) Test Guide
MIL-HDBK-274	Electrical Grounding for Aircraft safety
MIL-HDBK-419A	Grounding, Bonding and Shielding for Electronic Equipments and Facilities, Volume 1 of 2 Basic Theory
MIL-HDBK-423	High-Altitude Electromagnetic Pulse (HEMP) Protection for Fixed and TransporTable Ground-Based C4 1 Facilities – Volume 1 – Fixed Facilities
MIL-HDBK-454B	General Guidelines for Electronic Equipment
MIL-HDBK-83575	General Handbook for Space Vehicle Wiring Harness Design and Testing
MIL-HDBK-83578	Criteria for Explosive Systems and Devices used on Space Vehicles

Table 2: Active US military handbooks relating to EMC

Reference	Title	Associated with
DI-EMCS-80199C	Electromagnetic Interference Control Procedures (EMICP)	MIL-STD-461F
DI-EMCS-80200C	Electromagnetic Interference Test Report (EMITR)	MIL-STD-461F
DI-EMCS-80201C	Electromagnetic Interference Test Procedures (EMITP)	MIL-STD-461F
DI-EMCS-81295A	Electromagnetic Effects Verification Procedures (EMEVP)	Engineering/manufacturing development phase - any
DI-EMCS-81528	Electromagnetic Compatibility Program Procedures	Demo of life cycle EMC compliance - any
DI-EMCS-81540A	Electromagnetic Environmental Effects (E3) Integration and Analysis Report (E31AR)	MIL-STD-464A
DI-EMCS-81541A	Electromagnetic Environmental Effects (E3) Verification Procedures (E3VP)	MIL-STD-464A
DI-EMCS-81542A	Electromagnetic Environmental Effects (E3) Verification Report (E3VR)	MIL-STD-464A
DI-EMCS-81777	Electromagnetic Interference Survey (EMIS) Test Report	MIL-STD-1605A
DI-EMCS-81782	Electromagnetic Interference Survey (EMIS) Test Procedures	MIL-STD-1605A
TOP-1-2-511	Electromagnetic Environmental Effects System Testing	MIL-STD-464A
TOP 1-2-622	Vertical Electromagnetic Pulse (VEMP) Testing	MIL-STD-464A and MIL-STD-2169B

Table 3: EMC Data Item Descriptions and Test Operational Procedures

(1) *Type of metals, casting, finishes, and hardware employed in the design.*

(2) *Construction techniques, such as isolated compartments; filter mounting, isolation of other parts; treatment of openings (ventilation ports, access hatches, windows, metal faces and control shafts), and attenuation characteristics of Radio Frequency (RF) gaskets used on mating surfaces.*

(3) *Shielding provisions and techniques used for determining shielding effectiveness.*

(4) *Corrosion control procedures.*

(5) *Methods of bonding mating surfaces, such as surface preparation and gaskets.*

c. *Electrical wiring design, including cable types or characteristics, cable routing, cable separation, grounding philosophy, and cable shielding types and termination methods.*

d. *Electrical and electronic circuit design, including the following:*

(1) *Filtering techniques, technical reasons for selecting types of filters, and associated filter characteristics, including attenuation and line-to-ground capacitance values of AC and DC power line filters.*

(2) *Part location and separation for reducing EMI.*

(3) *Location, shielding, and isolation of critical circuits.*

MIL-STD-461A			MIL-STD-461B/C			
Test	Description	Frequency	Test	Description	Frequency	
CE01	Power Leads	30 Hz-20 kHz	CE01	Power / Signal Leads	30 Hz-15 kHz	
CE02	Control / Signal Leads	30 Hz-20 kHz	CE02	N/A		
CE03	Power Leads	20 kHz-50 MHz	CE03	Power/Signal Leads	15 kHz-50 MHz	
CE04	Control / Signal Leads	20 kHz-50 MHz	CE04	N/A		
CE05	Inverse Filter Method	30 Hz-50 MHz	CE05	N/A		
CE06	Antenna Terminal	10 kHz-10 GHz	CE06	Antenna Terminal	10 kHz-26 GHz	
CE07	N/A		CE07	Power Leads	Spikes / Time Domain	
CS01	Power Leads	20 Hz-50 kHz	CS01	Power Leads	30 Hz-50 kHz	
CS02	Power Leads	50 kHz-400 MHz	CS02	Power Leads	50 kHz-400 MHz	
CS03	Intermodulation	15 kHz-10 GHz	CS03	Intermodulation	15 kHz-10 GHz	
CS04	Undesired Signal Rejection	15 kHz-10 GHz	CS04	Undesired Sig. Rejection	30 kHz-20 GHz	
CS05	Cross Modulation	15 kHz - 10 GHz	CS05	Cross Modulation	30 kHz - 20 GHz	
CS06	Spikes, Power Leads		CS06	Spikes, Power Leads		
CS07	Squelch Circuits		CS07	Squelch Circuits		
CS08	Undesired Sig. Rejection	30 Hz-10 GHz	CS08	N/A		
CS09	N/A		CS09	Structure Common Mode Current	60 Hz-100 kHz	
CS10	N/A		CS10	Damped Sinusoidal Transients (terminals)	10 kHz-100 MHz	
RE01	Magnetic Field	30 Hz-50 kHz	RE01	Magnetic Field	30 Hz-50 kHz	
RE02	Electric Field	14 kHz-10 GHz	RE02	Electric Field	14 kHz-10 GHz	
RE03	Spurious & Harmonic	10 kHz-40 GHz	RE03	Spurious & Harmonic	10 kHz-40 GHz	
RE04	Magnetic Field	20 Hz-15 kHz	RE04	N/A		
RE05	Vehicle & Eng. Equipment	150 kHz-1 GHz	RE05	N/A		
RE06	Overhead Powerlines	14 kHz-1 GHz	RE06	N/A		
RS01	Magnetic Field	30 Hz-30 kHz	RS01	Magnetic Field, Equipment and Cables	30 Hz-50 kHz	
RS02	Magnetic Induction	Powerline & Spike	RS02	Magnetic Induction, Equipment and Cables	Powerline & Spike	
RS03	Electric Field	14 kHz-10 GHz	RS03	Electric Field, Equipment and Cables	14 kHz-40 GHz	
RS04	Parallel Line Fields	14 kHz-30 MHz	RS04	N/A		
RS05	N/A		RS05	Electromag Pulse Field	Transients	

Table 4: MIL-STD-461 requirement changes, versions A – E

This DID also requires, among other items, *analysis* (results demonstrating how each applicable requirement is going to be met) and *developmental testing* (testing to be performed during development such as evaluations of breadboards, prototypes, and engineering models). For the equipment designer, these points to be documented constitute a virtual punch list of EMC design attributes.

MIL-STD-461F – EMC for Subsystems and Equipment

This is no doubt the most widely-used standard for US military EMC assessment. Specific test requirements are grouped according to conducted (C) or radiated (R) coupling, and emissions (E) or susceptibility (S). Thus the tests are designated:

Conducted emissions: CE---
Radiated emissions: RE---
Conducted susceptibility: CS---
Radiated susceptibility: RS---

The dashes are replaced by the test reference number. Over time, the numerical test designations have transitioned from 01 to 101, 02 to 102, etc., but the prefixes have remained constant. Table 4 indicates the changes in MIL-STD-461 test requirements from versions A through E, and Table 5 (page 40) reflects the present version F requirements.

	MIL-STD-461D			MIL-STD-461E		
	Test	Description	Frequency	Test	Description	Frequency
	CE101	Power Leads	30 Hz-10 kHz	CE101	Power Leads	30 Hz-10 kHz
	CE102	Power Leads	10 kHz-10 MHz	CE102	Power Leads	10 kHz-10 MHz
	CE106	Antenna Terminal	10 kHz-40GHz	CE106	Antenna Terminal	10 kHz-40GHz
	CS101	Power Leads	30 Hz-50 kHz	CS101	Power Leads	30 Hz-150 kHz
	CS103	Antenna Port-Intermod	15 kHz-10 GHz	CS103	Antenna Port-Intermod	15 kHz-10 GHz
	CS104	Antenna Port-Rejection of Undesired Signals	30 Hz -20 GHz	CS104	Antenna Port-Rejection. of Undesired Signals	30 Hz -20 GHz
	CS105	Antenna Port-Cross Modulation	30 Hz-20 GHz	CS105	Antenna Port-Cross Mod.	30 Hz-20 GHz
	RE101	Magnetic Field	30 Hz-100 kHz	RE101	Magnetic Field	30 Hz-100 kHz
	RE102	Electric Field	10 kHz-18 GHz	RE102	Electric Field	10 kHz-18 GHz
	RE103	Antenna Spurious & Harmonics	10 kHz-40 GHz	RE103	Antenna Spurious & Harmonics	10 kHz-40 GHz
	RS101	Magnetic Field, Equipment and Cables	30 Hz-100 kHz	RS101	Magnetic Field, Equipment and Cables	30 Hz-100 kHz
	RS103	Electric Field, Equipment and Cables	10 kHz-40 GHz	RS103	Electric Field, Equipment and Cables	2 MHz-40 GHz
	RS105	Transient Electromagnetic Field	Transients	RS105	Transient Electromanetic Field	Transients
	CS109	Structure Current	60 Hz-100 kHz	CS109	Structure Current	60 Hz-100 kHz
	CS114	Bulk Cable Injection	10 kHz-400 MHz	CS114	Bulk Cable Injection	10 kHz-200 MHz
	CS115	Bulk Cable Injection	Impulse	CS115	Bulk Cable Injection	Impulse
	CS116	Sine Transients - Cables, and Power Leads	10 kHz-100 MHz	CS116	Sine Transients - Cables, and Power Leads	10 kHz-100 MHz

ESD and lightning effects are not included in MIL-STD-461F, although they are being discussed for inclusion in the next (G) version which is currently in draft to be released in 2014. ESD and lightning protection *are* covered in MIL-STD-464A, and in the current US standard for commercial aircraft equipment DO-160G, “Environmental Conditions and Test Procedures for Airborne Equipment.” DO-160G contains a number of non-EMC environmental requirements, and equipment qualified to revisions C – F of RTCA DO-160 is often suitable for military aircraft applications. A summary of DO-160G test categories is given in Table 6.

The military electronic equipment designer needs to know the types of EMC tests that will be applied to the equipment, the magnitudes or limits of the tests, and the frequency ranges of the tests, in order to design for compliance. The designer also needs to know that, where the equipment will be used in more than one environment, the most stringent requirements apply. Generally of secondary importance to the designer are the test configuration details, which are amply documented in MIL-STD-461F. These test details are of course essential to the testing personnel.

What is important to the equipment designer, for the purpose of understanding the limits, are the radiated emissions test distances – which differ from the normal commercial separations of 3m or 10m. MIL-STD-461F is almost unique among EMC standards in requiring a 1m distance between the electric field antenna and the test setup boundary (RE102). Only DO-160G and CISPR 25 (Automotive) has a similar radiated

Test	Description	Lowest Emission or Highest Susceptibility	Changes from 461E version
CE101	Conducted Emissions, Power Leads, 30 Hz to 10 kHz	76 dBµA	-
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz	60 dBµV	-
CE106	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz	34 dBµV	-
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz	136 dBµV	Applicability added for surface ships; setup modifications suggested.
CS103	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz	Per procurement specification	-
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz	Per procurement specification	-
CS105	Conducted Susceptibility, Antenna Port, Cross-Modulation, 30 Hz to 20 GHz	Per procurement specification	-
CS106	Conducted Susceptibility, Transients, Power Leads	400 V peak	CS06 absent from E, added back.
CS109	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz	120 dBµA	-
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz	109 dBµA	Adds common mode test for some applications.
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation	5A x 30 ns	-
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz	10 A peak	Testing with power off is deleted; procedure allows reduction of calibrated test signal if necessary.
RE101	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz	76 dBpT @ 7 cm	Test procedure is modified to allow separations > 7cm where non-compliances are noted.
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz	24 dBµV/m @ 1m	Applicability and frequency ranges modified. Rod antenna methods modified.
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz	-80 dBc, far field	Minor test procedure changes.
RS101	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz	180 dBpT	Scan rate is reduced.
RS103	Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz	200 V/m	Sensor placement clarified; radiating antenna distance limited to $\geq$ 1m.
RS105	Radiated Susceptibility, Transient Electromagnetic Field	50 kV/m peak	-

Table 5: MIL-STD-461F requirement changes from versions E to F (2007).

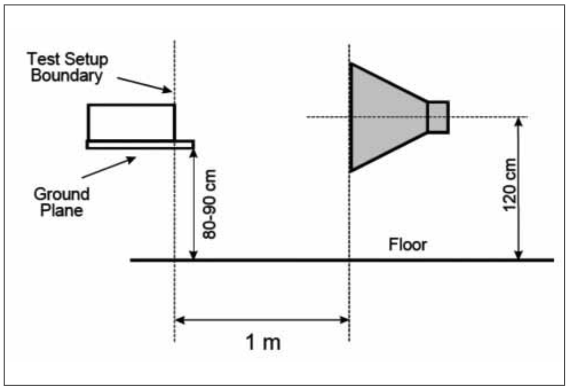


Figure 1: RE102 test setup showing 1m antenna distance, from MIL-STD-461F

General	
Section 1.0	Purpose and Applicability
Section 2.0	Definition of Terms - General
Section 3.0	Conditions of Tests
Environmental Requirements	
Section 4.0	Temperature and Altitude
Section 5.0	Temperature Variation
Section 6.0	Humidity
Section 7.0	Operational Shocks and Crash Safety
Section 8.0	Vibration
Section 9.0	Explosion Proofness
Section 10.0	Waterproofness
Section 11.0	Fluids Susceptibility
Section 12.0	Sand and Dust
Section 13.0	Fungus Resistance
Section 14.0	Salt Spray
Section 24.0	Icing
Section 26.0	Fire, Flammability
EMC Requirements	
Section 15.0	Magnetic Effect
Section 16.0	Power Input
Section 17.0	Voltage Spike
Section 18.0	Audio Frequency Conducted Susceptibility – Power Inputs
Section 19.0	Induced Signal Susceptibility
Section 20.0	Radio Frequency Susceptibility (Radiated and Conducted)
Section 21.0	Emission of Radio Frequency Energy
Section 22.0	Lightning Induced Transient Susceptibility
Section 23.0	Lightning Direct Effects
Section 25.0	Electrostatic Discharge

Table 6: EMC and environmental requirements in RTCA DO-160G

emissions test distance. The magnetic field measurement distance in RE101 is 7 cm.

Radiated Susceptibility (RS 103) also has a 1m separation distance and typically requires a field strength of 200V/m in contrast to the 3V/m and 10V/m commonly encountered with commercial product standards such as EN61000-4-3. This higher field strength requirement can often be a hurdle for many designers involved with COTS or used to working on products intended for the commercial market.

In addition to the changes noted in Table 5, MIL-STD-461F addresses several topics of general applicability:

- The requirement to qualify "Line-Replaceable Modules (LRMs)" is added;
- Restricts the testing of shielded power cables;
- Includes software in the requirement to verify test procedures;
- Frequency step size above 1 GHz has been increased for susceptibility testing.

Simultaneously with the publication of the F version of MIL-STD-461 (December 2007), the F version of RTCA DO-160 was published. DO-160F also included, for the first time, the CS106 test that was originally in MIL-STD-461 but later deleted only to be restored in the latest version. Since that time DO-160G has been released (December 2010), bringing more clarifications and updates.

RTCA DO-160F and G include the ESD and lightning requirements currently absent from MIL-STD-461F, and it includes the environmental requirements which are found in separate MIL documents discussed below. The European Union version of DO-160G is EUROCAE/ED-14G, which is identically worded.

MIL-STD-464A – EMC Requirements for Systems

This standard establishes electromagnetic environmental effects (E3), interface requirements and verification criteria for airborne, sea, space, and ground systems, including associated ordnance. MIL-STD-464A contains two sections, the main body and an appendix. The main body of the standard specifies a baseline set of requirements. The appendix portion provides a detailed rationale and guidance, so that the baseline requirements can be tailored for a particular application.

Verification is intended to cover all life cycle aspects of the system. This includes (as applicable) normal in-service operation, checkout, storage, transportation, handling, packaging, loading, unloading, launch, and the normal operating procedures associated with each aspect.

The scope of E3 as used in this standard is very broad: all electromagnetic disciplines, including electromagnetic compatibility; electromagnetic interference; electromagnetic vulnerability; electromagnetic pulse; hazards of electromagnetic radiation to personnel, ordnance, and volatile materials; and natural phenomena effects of lightning and static.

Margin requirements apply to all EMC related tests performed in a 464A verification exercise. The intent is to account for manufacturing variations, aging and maintenance to assure that all equipment, not just test samples, will be compliant in the field over the equipment lifetime. Additional compliance margins to the limits specified in the standard are required for safety-critical, mission-critical and electrically-initiated devices (EIDs) such as electroexplosive devices and fusible links. The additional margins are:

- ≥ 6 dB for safety critical and mission critical system functions;
- ≥ 16.5 dB of maximum no-fire stimulus for safety assurances;

Clause	Parameter	Lowest Emission or Highest Susceptibility
5.2	Intra-system EMC (see also MIL-STD-461F clause 4.2.3)	Self-compatibility
5.2.1	Hull-generated intermodulation interference (IMI)	Not detecTable by onboard receivers
5.2.2	Shipboard internal electromagnetic environment (EME).	50 V/m
5.2.3	Multipaction, space applications, equipment and subsystems	No effect
5.3	External RF electromagnetic environment (EME) Flight deck, ships Weather deck, ships Main beam of transmitter, ships Space and launch vehicle systems Ground systems Army rotary wing aircraft Fixed wing aircraft, excluding shipboard	 2030 V/m peak, 200 V/m average 2030 V/m peak, 200 V/m average 27460 V/m peak, 2620 V/m average 200 V/m peak, 200 V/m average 2500 V/m peak, 50 V/m average 27460 V/m peak, 3120 V/m average 7200 V/m peak, 1050 V/m average
5.4	Lightning Severe stroke Near strike	 200kA strike, 100 kA restrike 2.2×10^9 A/m/s @ 10m
5.5	Electromagnetic pulse (EMP) per MIL-STD-2169B	classified
5.6	Subsystems and equipment EMI	Per MIL-STD-461F
5.6.1	Non-developmental items (NDI) and commercial items	System operational performance requirements shall be met.
5.6.2	Shipboard DC magnetic field environment.	See MIL-STD-1399, Section 070
5.7	Electrostatic charge control. Vertical lift and in-flight refueling. Precipitation static (p-static) control Ordnance subsystems.	 300 kV discharge Meet operational requirements 25 kV discharge
5.8	Electromagnetic radiation hazards (EMRADHAZ) Hazards of electromagnetic radiation to personnel (HERP). Hazards of electromagnetic radiation to fuel (HERF) Hazards of electromagnetic radiation to ordnance (HERO).	 See DoDI 6055.11 No inadvertent ignition 27460 V/m peak, 2620 V/m average
5.10.3	Mechanical interfaces – DC bonding levels	2.5 – 15 mΩ
5.11.1	Aircraft grounding jacks – resistance between the mating plug and the system ground reference.	≤ 1 Ω
5.13	Emissions control (EMCON)	≤ 105 dBm/m² @ 1 km, 500 kHz – 40 GHz

Table 7: Summary of MIL-STD-464A requirements. The high field strength susceptibility values occur in radar bands.

- ≥ 6dB of maximum no-fire stimulus for other purposes.

The worst-case (lowest emission limit or highest susceptibility requirement) for the environments categorized in MIL-STD-464A are summarized in Table 7. In many cases the requirements are frequency-dependent, and are much lower than worst-case over much of the frequency range. The standard should be consulted for details and definitions.

MIL-STD-1310H – Shipboard Bonding, Grounding and Other Techniques for EMC

This document specifies standard practices in wiring, bonding, grounding and shielding to facilitate achievement of the intra-ship and inter-ship electromagnetic compatibility (EMC), electromagnetic pulse (EMP), bonding, and intermodulation interference (IMI) requirements of MIL-STD-464A. It applies to metal and nonmetallic hull ships and is applicable during ship construction, overhaul, alteration, and repair. MIL-STD-1310H is not a typical EMC standard, but it provides the methods guidance appropriate to obtaining EMC in the shipboard environment.

This revision of MIL-STD-1310 has been expanded to include procedures for Electromagnetic Pulse (EMP) hardening. It also provides procedures and guidance to more easily address MIL-STD-464A requirements in relationship to intra- and inter-ship EMC, hull-generated IMI, lifecycle electromagnetic environmental effects (E3) hardness, EMP, and electrical bonding. A separate appendix is included, with procedures to identify whether commercial-off-the-shelf equipment (COTS) or non-developmental items (NDI) meets appropriate safety requirements before use, and to provide direction to bring them into conformance when necessary.

MIL-STD-1541A – Space Systems

The requirements covered by this standard apply to launch and space vehicles plus the associated grounds airborne, or spaceborne operational and support elements of the space system. It applies to new and modified or redesigned equipment or systems, and to existing equipment used in new applications.

MIL-STD-1541A establishes the electromagnetic compatibility requirements for space systems, including frequency management, and the related requirements for the electrical and electronic equipment used in space systems. It also includes requirements designed to establish an effective ground reference for the installed equipment and designed to inhibit adverse electrostatic effects. Bonding and prevention of electrostatic buildup are covered in detail.

As with MIL-STD-464A, this standard imposes additional compliance margin requirements in critical situations:

Category I: Serious injury or loss of life, damage to property, or major loss or delay of mission capability; 12 dB for qualification; 6 dB for acceptance

Category II: Degradation of mission capability, including any loss of autonomous operational capability; 6 dB

Category III: Loss of functions not essential to mission; 0 dB

Intersystem and intrasystem analysis is required by the standard, which also references all emission and susceptibility requirements in MIL-STD-461 (as modified by MIL-STD-1541A) for the relevant class of equipment. Some of the specific requirements of this standard not covered in MIL-STD-461 are summarized in Table 8. Thorough qualification testing is emphasized in the standard.

MIL-STD-1542B – Space System Facilities

This standard is intended for selected space system facilities. The requirements are applicable to all related facilities including, but not limited to, launch complexes, tracking stations, data processing rooms, satellite control centers, checkout stations, spacecraft or booster assembly buildings, and any associated stationary or mobile structures that house electrical and electronic equipment.

MIL-STD-1542B addresses in detail the appropriate bonding, shielding, electrical power and ground network for space system facilities. The facility ground network consists of the following electrically interconnected subsystems:

Section	Test	Limit
5.2.5	Lightning protection	200 kA peak
5.2.6	Outer surface resistivity of ESD control Grounded semiconductive coating over insulating material Painted surface over grounded semiconductive material-over dielectric Volume resistivity of a coating(t, cm) over a grounded metal conductor	 $\leq 10^8$ Ω/square $\leq 4.6 \times 10^7$ Ω/square $(2.5/t) \times 10^{10}$ Ω-cm
5.2.10	Electrical power quality Voltage ripple Spikes Surges Load switching and load faults Power subsystem faults – surge amplitude Vehicle power output ground isolation	 ≤ 500 mV peak-to-peak < 3 times nominal load, $< 0.14 \times 10^{-3}$ V-s Return to steady-state in 5 ms (+) and 100 ms (-) Remain within 65% to 130% of nominal Remain within 0% to 175% of nominal ≥ 1 MΩ
5.3.3	Performance criteria – MIL-STD-461 applies as noted CE01 applies CE06 and RE03 apply CS01 limit applies CS02 and RS03 apply CS06 limits	 Frequency extended to 30th harmonic or 100 GHz Test under maximum and minimum supply Susceptibility signals chosen for max. effect 200 V x 10µs pulse

Table 8: Some requirements in MIL-STD-1541A

Reference	Title
Def Stan 59-188-1 (2009)	High Altitude Electromagnetic Pulse (HEMP) Protection for Ground Based Communication Facilities Performing Critical, Time-Urgent Missions - Part No: 1: Fixed Facilities.
Def Stan 59-411-1 (2007)	Electromagnetic Compatibility - Part No: 1: Management & Planning
Def Stan 59-411-2 (2007)	Electromagnetic Compatibility - Part No: 2: The Electric, Magnetic and Electromagnetic Environment
Def Stan 59-411-3 (2007)	Electromagnetic Compatibility - Part No: 3: Test Methods and Limits for Equipment and Sub Systems
Def Stan 59-411-4 (2007)	Electromagnetic Compatibility - Part No: 4: Platform and System Tests and Trials
Def Stan 59-411-5 (2007)	Electromagnetic Compatibility - Part No: 5: Code of Practice for Tri-Service Design and Installation

Table 9: UK Ministry of Defence EMC standards

Reference	Title
STANAG 3516	Electromagnetic Interference and Test Methods for Aircraft
STANAG 3614	Electromagnetic Compatibility (EMC) of Aircraft Systems
STANAG 4234	Electromagnetic Radiation (Radio Frequency) - 200 kHz to 40 GHz Environment - Affecting the Design of Materiel for Use by NATO Forces
STANAG 4239	Electrostatic Discharge, Munitions Test Procedures
STANAG 4327	Lightning, Munition Assessment and Test Procedures
STANAG 4370	Environmental testing
STANAG 4416	Nuclear Electromagnetic Pulse Testing of Munitions Containing Electro-Explosive Devices
STANAG 4437	Electromagnetic Compatibility Testing Procedure and Requirements for Naval Electrical and Electronic Equipment (Submarines)

Table 10: Some NATO STANAGs relating to EMC.

a. The earth electrode subsystem.
b. The lightning protection subsystem.
c. The equipment fault protection subsystem.
d. The signal reference (technical ground) subsystem.

EMC performance for equipment installed in space system facilities is referenced to MIL-STD-461. COTS (commercial-off-the-shelf) equipment installed in these facilities shall also meet the requirements of MIL-STD-461.

As with the other military EMC standards discussed here, MIL-STD-1542B requires electromagnetic self-compatibility of equipment and systems. Clause 4.2 stipulates:

> *Facility electrical and electronic subsystems and equipment shall be compatible with each other as well as with the technical equipment installed in the facility for support of space system operations.*

UK: DefStan Documents

Equipment procured for military purposes by the UK's Ministry of Defence must meet their defence standards (DefStan). Non-military equipment must meet the essential requirements of the EMC Directive 2004/108/EC. Ministry of Defence EMC standards are listed in Table 9.

Collectively the UK DefStan documents cover the same concerns as UK military standards. Specifically, DefStan 59-411-3 (Part 3) corresponds closely to MIL-STD-461F in methods, limits and frequency ranges. For example, Magnetic emissions are measured at 70 cm in both standards, and high-frequency radiated emissions are measured at 1m in both standards. However there are structural and content differences between the two standards:

- Individual EMC tests in 59-411-3 are denoted DCS---, DCE---, DRE---, DRS--- where the "D" denotes "Defence" and is absent from -461 test references.
- DefStan 59-411-3 uses susceptibility criteria A…D, which are familiar to users of commercial IEC and EU EMC standards. Default performance criteria are defined for each susceptibility test in terms of safety-critical or safety-related function, mission-critical function, or non-safety-critical or non-essential function.
- "Man worn" and "man portable" categories and test requirements are specified in detail in DefStan 59-411-3. Testing for man-worn applications requires the use of a non-conductive dummy approximating the shape

NATO: STANAG documents

The term "STANAG" stands for "Standardization Agreement" among the NATO member countries. There are literally hundreds of active agreements in place, usually drawing from one or more countries' existing standards. Some of the STANAG agreements relating to EMC are summarized in Table 10.

Both environmental considerations and EMC are covered under STANAG 4370. It references several separate documents termed "Allied

Design for EMC Compliance

Military product development follows well-defined program steps. MIL-HDBK-237D defines these steps clearly – including tailoring of requirements - as well as providing useful information on potentially applicable commercial standards plus standards from all branches of the US military, and NATO. An extensive list of acronyms is also included.

Definition and refinement of the product EMC environment occurs during the course of program progress. Initial EMC testing in the laboratory is only the first step toward full qualification. MIL-235B provides information on the likely levels of RF field exposure in various stages of deployment to land-based and shipboard locations.

Generally, EMC test requirements will have been fully defined before the product reaches the test laboratory, although modules or subsystems may have been previously tested. The relevant parts of MIL-STD-461F (typically) will be stipulated, and it will be up to the manufacturer to have used prudent design techniques to meet the designated requirements.

As the EMC requirements in MIL-STD-461F are generally more stringent than commercial standards, designing for successful compliance involves careful review of each level of product integration. Can the designer support each of the design criteria in Data Item Description DI-EMCS-80199C, and summarized in this review? These criteria include PC layout, wiring, shielding, filtering and enclosure design. Designers familiar largely with commercial environments will need to review and enhance the use of EMC control techniques to meet military EMC requirements. Later qualification tests may require control enhancements.

Environmental Conditions and Test Publication" (AECPT). We will explore the environmental aspects later, but we will look at EMC first.

STANAG 4370 references AECPT-500 (Edition 3, 2009), "Electromagnetic Environmental Effects Test and Verification." AECPT-500 draws for its tests and methods both from MIL-STD-461 and DefStan 59-411, as shown in Table 11. Individual EMC tests in AECPT-500 are denoted NCS---, NCE---, NRE---, NRS--- where the "N" denotes "NATO" and is absent from -461 test references.

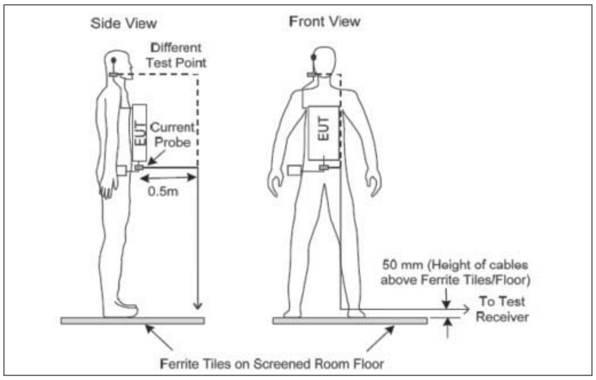


Figure 2: Man worn test configuration from DefStan 59-411-3, DCE02

AECPT-500 also contains a flow chart to guide the gap analysis between commercial and military EMC requirements, when COTS (commercial-off-the-shelf) or MOTS (military-off-the-shelf) acquisitions are being considered.

Look for Part 2 of this article in the April 2014 issue of In Compliance.

This paper was authored by Intertek. Currently Intertek sits on more than 70 SAE standards committees to help draft the test and certifications necessary to keep people safe. Find more articles on EMC issues at www.interk.com. For more information on this topic or to find an Intertek EMC testing lab near you contact icenter@intertek.com or 1-800-WORLDLAB.

Reference	Description	Test Derived from
NCE01	Conducted Emissions, Power Leads, 30 Hz to 10 kHz	MIL-STD-461F
NCE02	Conducted Emissions, Power Leads, 10 kHz to 10 MHz	MIL-STD-461F
NCE03	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz	MIL-STD-461F
NCE04	Conducted Emissions, Exported Transients on Power Leads	Def Stan 59-411
NCE05	Conducted Emissions, Power, Control & Signal Leads, 30 Hz to 150 MHz	Def Stan 59-411
NCS01	Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz	MIL-STD-461F
NCS02	Conducted Susceptibility, Control & Signal Leads, 20 Hz to 50 kHz	Def Stan 59-411
NCS03	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz	MIL-STD-461F
NCS04	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz	MIL-STD-461F
NCS05	Conducted Susceptibility, Antenna Port, Cross Modulation, 30 Hz to 20 GHz	MIL-STD-461F
NCS06	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz	MIL-STD-461F
NCS07	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz	MIL-STD-461F
NCS08	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation	MIL-STD-461F
NCS09	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz	MIL-STD-461F
NCS10	Conducted Susceptibility, Imported Lightning Transient (Aircraft/Weapons)	Def Stan 59-411
NCS11	Conducted Susceptibility, Imported Low Frequency on Power Leads (Ships)	Def Stan 59-411
NCS12	Conducted Susceptibility, Electrostatic Discharge	Def Stan 59-411
NCS13	Conducted Susceptibility, Transient Power Leads	MIL-STD-461F
NRE01	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz	MIL-STD-461F
NRE02	Radiated Emissions, Electric Field, 10 kHz to 18 GHz	MIL-STD-461F
NRE03	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz	MIL-STD-461F
NRS01	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz	MIL-STD-461F
NRS02	Radiated Susceptibility, Electric Field, 50 kHz to 40 GHz	MIL-STD-461F / Def Stan 59-411
NRS03	Radiated Susceptibility, Transient Electromagnetic Field	MIL-STD-461F
NRS04	Radiated Susceptibility, Magnetic Field, (DC)	Def Stan 59-411

Table 11: Cross-reference between NATO EMC test references, MIL-STD-461 and DefStan 59-411

National Grid

Notice of Life-Sustaining Equipment

Account Number: ______________________

Customer Name: ______________________

Service Address: ______________________

City/Town, Zip: ______________________

Telephone Number: ______________________

The following life-sustaining equipment is in my home:

- ☐ Tank-type Respirator (Iron Lung)
- ☐ Heart Rate Monitor
- ☐ Curaisse-type Respirator (Chest)
- ☐ PD APNEA Monitor
- ☐ Rocking Bed
- ☐ Diaphragm Stimulator
- ☐ Electrically operated Respirator
- ☐ Oxygen Concentrator
- ☐ Suction Machine (Pump)
- ☐ Medical Pump
- ☐ Hemodialysis Equipment (Kidney Machine)
- ☐ Press Respirator
- ☐ Intermittent Positive Pressure Respirator
- ☐ CPM Drum ventilator
- ☐ Special Air Conditioner *(Please explain why you need this)*

____

- ☐ Other types of life-sustaining equipment or medical condition *(Please be specific)*

____

If you would like to authorize someone that we may discuss your account with other than yourself, please provide that party's information below.

Third Party Name: ______________________

Third Party Address: ______________________

Third Party City, State, Zip: ______________________

Third Party Telephone: ______________________

STATE OF MICHIGAN

BEFORE THE MICHIGAN PUBLIC SERVICE COMMISSION

In the matter of the Application of DTE Electric Company for authority to increase its rates, amend its rate schedules and rules governing the distribution and supply of electric energy, and for miscellaneous accounting authority _____________________________________/	Case No. **U-18255**

PROOF OF SERVICE

On **August 29, 2017**, an electronic copy of the **Direct Testimony and Exhibits of William S. Bathgate** was served on the following:

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The statements above are true to the best of my knowledge, information and belief.

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