Practical Papers, Articles and Application Notes

Robert G. Olsen, Technical Editor

In this issue you will find two practical papers that should interest members of the EMC community. The first is entitled "EMC at the South Pole," by H. R. Hofmann. Except for those of you at latitudes closer to the equator or in the parts of the southern hemisphere where it is now really summer and "warm," this is an appropriate article for the "Winter" issue. In this paper, Bob discusses the EMC aspects of a very interesting physics experiment that will soon be started at the South Pole. I think that you will be able to identify a number of familiar and very practical EMC problems. The second paper is entitled, "The Contribution of Asymmetry to Exciting Common-Mode Emissions," by T. A. Jerse, one of the EMC Society's current Distinguished Lecturers. If you don't have a chance to hear one of Tom's lectures, this paper will introduce you to his topic. After reading it, I think that you will find the subject of "common modes excitation" considerably less mysterious than many think.

The purpose of this section is to disseminate practical information to the EMC community. In some cases the material is entirely original. In others, the material is not new but has been made either more understandable or accessible to the community. In others, the material has been previously presented at a conference but has been deemed especially worthy of wider dissemination. Readers wishing to share such information with colleagues in the EMC community are encouraged to submit papers or application notes for this section of the Newsletter. See page 3 for my e-mail, FAX and real mail address. While all material will be reviewed prior to acceptance, the criteria are different from those of Transactions papers. Specifically, while it is not necessary that the paper be archival, it is necessary that the paper be useful and of interest to readers of the Newsletter.

Comments from readers concerning these papers are welcome, either as a letter (or e-mail) to the Associate Editor or directly to the authors.

EMC @ THE SOUTH POLE

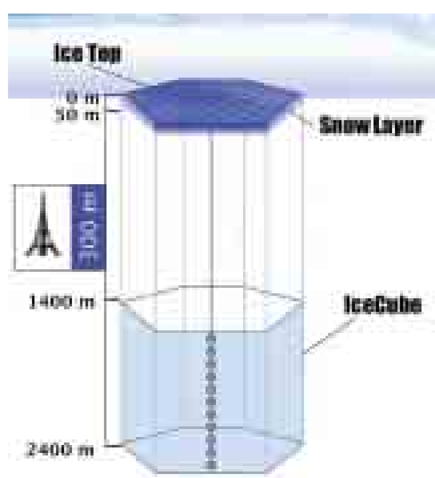
H. R. Hofmann, Hofmann EMC Consulting

If the word "IceCube" means more to you than just a rap singer, or what you find in your freezer, you are among a very select group of people. IceCube is a project involving a matrix of more than 5000 photodetectors imbedded as deep as 2400 meters in the 3000-meter thick Antarctic polar ice cap, within a few hundred meters of the actual South Pole.

IceCube was designed by a worldwide consortium of physicists to study the interaction of subatomic particles, called Neutrinos, within the South Pole ice cap. Neutrinos hitting the ice molecules cause a faint blue glow to occur. Determining the strength of the glow, and the rate at which the different photodetectors in the matrix see the glow, the physicists expect to learn more about Neutrinos. That exhausts my knowledge of the physics of the experiment.

Getting signals from the buried photodetectors to a central computing center on the surface of the ice seems like it should be simple. However, it turns out that there are high-powered transmitters at the South Pole, ranging in frequency from 19 kHz to over 1 GHz, plus a highly noisy AC power source. Add to that many nearby pulse-width modulated motor controllers for high-powered variable speed motors and the fact that the relative humidity at the South Pole is about 5% with a constant wind and temperatures down to -70 C and you come up with a challenging EMC/ESD environment.

One-half meter diameter holes 2400 meters deep are drilled in the ice using a hot water drill that uses several variable-speed motors to control the hose reel with the 2400 meters of hose, water flow and heater operation. These variable speed motors will be located nearby other actual operational photodetector strings. When the hot-water drill hose reaches its final depth of 2400 meters, it is quickly pulled out and 60 in-ice photodetectors strung out every 18 meters along the bottom end of a 2400-meter multiconductor cable are placed into the hole. The cable and detectors must be placed within 30 hours of drilling the



IceCube Layout – Courtesy of the National Science Foundation.

hole, before the ice refreezes. Ultimately, there will be 80 holes drilled, spaced uniformly over a 1 km hexagonal area, centered about 700 meters from the South Pole. That makes 4800 photodetectors arranged in a matrix in the ice. An additional 320 detectors will be located in darkened tubs of ice on the surface, 4 at each of the 80 holes, to serve as reference detectors.

Each 12-inch diameter photodetector assembly consists of a photomultiplier tube to amplify the weak photons detected from the pale blue glow, a 45V to 2000V DC-DC converter for the photomultiplier high-voltage supply, an analog to digital converter to digitize the photomultiplier output, cable drivers and receivers to facilitate 2-way transmission with the surface, a local oscillator and synchronizing circuitry to put a time stamp on every flash occurrence, a circuit to flash several calibrated leds to check the photomultiplier sensitivity in other nearby photodetectors, and the hardware and software to control all of these functions. All this circuitry is located in a 12" glass sphere that is capable of withstanding pressures of over 10,000 psi, which will eventually occur as the refrozen ice cold-flows under the extreme pressures 2400 meters under the South Pole surface.

Surface cables, varying from 50 meters to 500 meters in length, are connected to the in-ice cables to bring the signals from the 80 holes and the IceTop tanks across the surface of the ice to a central computing building (Counting House) that is being converted from a dormitory to a computer center. A separate Surface Junction Box (SJB) is used to connect each surface cable and its shield to the in-ice and IceTop shielded cables. There are EMC filters in the SJB, which presented some problems that will be discussed later.

Along the way, in some cases, the cables will run parallel to a 19.6 kHz transmitting antenna that is just one of many transmitters located at the South Pole. The entire IceCube complex is adjacent to the skiway used by the C-130 flying boxcars equipped with skis instead of wheels that are used to ferry equipment and personnel from McMurdo Station on the coast of Antarctica. Hence, there are limits on emissions from IceCube to avoid interference to aircraft, in addition to protecting other general radio experiments at the South Pole.

Initial plans for the entire project called for no EMC shielding or ESD treatments in any way, shape or form, to either protect the IceCube equipment from the noisy environment, or to protect the environment from IceCube-generated noise. When some early prototype experiments at the South Pole started experiencing some noise problems, EMC help was sought, and I was recommended. Although retired from Bell Labs for two years, the project was too intriguing to turn down. Also, I was told I would not have to go to the South Pole, but would work instead at the University of Wisconsin - Madison where all the equipment was being assembled before being shipped to the South Pole.

PHOTO BY TERRY HANNAFORD
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Hose Reel for the Enhanced Hot Water Drill at the South Pole.

An examination of the vertical in-ice cable showed that the basic design using separate twisted pairs for each photodetector was sound, but that an external shield around the entire cable would be advisable. A wound copper tape was chosen, as it could easily be removed at each of the breakouts for the connectors to the photodetectors and then be rewound again. This shield is under the exterior polyethylene cable jacket, and is protected at each breakout by a remolding of the sheath over the copper tape after cable conductor connections to the breakout connector have been completed.

An interesting problem regarding the in-ice cable was how to treat the isolated copper pairs remaining in the lower part of the cable, below the breakout point where that particular pair was cut and used to connect to a photodetector. The experience of a number of people had been that isolated segments of copper wire in a cable, with signals on adjacent pairs, could experience buildup of charges on the isolated segments until voltage breakdown would occur. The solution chosen was to have the bottom end of the cable, where all the cable stubs would be accessible, terminated in a resistive epoxy/silicone rubber, which also contacted the external shield. This should bleed off any charges building up on the copper cable stubs.

By the time the digitized photomultiplier output signals of about 2V p-p reach the Counting House, they have traveled as far as 2900 meters and are attenuated to levels of only 50 to 100 millivolts. These signals are in pairs that are adjacent to other pairs in the cable that may be signaling down to the photodetectors with levels of 2V p-p. Thus, there are fairly stringent crosstalk/balance requirements on the in-ice and surface cables, in addition to overall attenuation and impedance requirements. Near-end cross-talk requirements are for 50 dB attenuation at 145 ohm cable impedance up to 1 MHz, decreasing to 30 dB at 100 MHz.

In the Counting House/former dormitory, the decision was made to shield the rebuilt second floor, where the computing equipment will be located, using copper screening on all 6 surfaces of the room. The screening will overlap at the seams and be covered with ordinary sheet-rock. EMC doors will be used at the entrance to the screened area and will be connected to the building shielding.

Shielding the Counting House and all the cables brought to light an interesting problem, what is the "reference ground" at the South Pole to which the building shielding and any other shielding is to be connected? Real ground is about 3000 meters below the surface of the South Pole, requiring a rather impossible ground rod. Since all AC power at the South Pole comes from a common diesel generator, it was decided to use the ground of the AC power supplied to the Counting House at the point where the power enters the Counting House as the "Reference Ground" to which all other IceCube equipment would be connected.

Unfortunately, there is little control over the quality of the incoming AC power from the diesel generator. Since almost all heat for the various South Pole Station buildings, including the Counting House is resistive, and the heaters have low initial/turn-on resistance, there are large spikes on the incoming and on the local internal building AC power lines that could couple into the computing equipment. There may be some reduction in AC power noise coming in from the incoming power line due to the voltage reduction transformer in the first floor of the Counting House, but that could not be quantified. And, there are several local Counting House resistive heaters located on the first floor of the Counting House adding to the noise, so it was decided to provide power line filtering for all AC power that feeds the second floor, including all of the lighting circuits. There are also filters on all copper communications lines that enter the second floor. Some communications circuits use fiber optics, which will only require checking that there are no metallic reinforcing strands in the fiber cables where they penetrate the screening. Ambient temperatures inside the Counting House computing area are expected to stay above 0 degrees Celsius, well within the normal range of filter specifications. Filter recommendations were made using standard catalog filters provided by ETS-Lindgren.

To ensure computing hardware compatibility, all purchased equipment to be located inside the screened area in the Counting House is required to have either FCC Part 15 Verification or better, and/or CE Class A or Class B marking. This equipment is being housed in standard commercial computing equipment racks, which provide some inter-unit shielding. There will be some added shielding inside the equipment racks around the sensitive cable receivers. Frames will be grounded to the floor screening, which in turn is connected to the "Reference Ground."

Equipment such as the Surface Junction Box (SJB) that are located on the Antarctic ice surface routinely see temperatures colder than -40 degrees C, and a lower temperature of -70 degrees C is possible and was recorded again this past Antarctic winter. The electrical and mechanical engineers on the project were able to find connectors to interconnect the various cables that would function satisfactorily at these temperatures. Finding EMC filters for the SJB that would work at -55 C and survive down to -70 C proved interesting.

Special pumps, heaters, and de-oxygenation filters are used in IceTop to ensure crystal-clear ice in the IceTop reference tanks. The power for this equipment is fed from the Counting House via extra conductors in the surface cables and goes through the SJB before connecting to IceTop. The SJB required a dual section filter for the +/- 52V DC balanced supply. Limiting the voltages to this level provided safety that did not exist with the originally planned +/- 120V AC. Another similar single-section filter is used to provide filtering of the reference ground from the noisy ground of the IceTop equipment. Since we were most concerned with filtering out IceTop pickup from the nearby 19.6 kHz transmitter, a filter with good low-frequency performance was needed.

A search of filter manufacturers' catalogs proved futile. There was a large reputable filter manufacturer located in Milwaukee (Curtis Industries), only one hour from Madison, and so it was decided to work with them to see if a satisfactory filter could be obtained. After listening to the rather unique temperature requirements, Curtis said that they believed they could provide a filter that would meet our needs, basing the design on a telephone DC power supply filter. Special capacitors would be needed to meet the low temperature requirements, but the ferrite core to be used was not expected to present any special problems, especially since there were balanced DC currents, except under trouble conditions. The manufacturer procured components and a sample filter was built and placed in a cold chamber to see if the characteristics were met at -55 C. The test of the chilled filter was a success, with the filter meeting all objectives. On that basis, a total of 50 filters were ordered for use at the South Pole for the first year and for engineering samples. The filters were received on schedule, mounted in the SJB, and are now in transit to the South Pole.

As part of the characterization of the emissions from the IceCube complex, radiated emission measurements were made of the Hot Water Drill operating system while it was undergoing final testing in Madison, WI. The first round of tests showed a very strong and pervasive noise no matter where the measuring antenna was located within the acre or so of ground covered by the hot water drill, hose and cable reels, motor controllers, and other electronic equipment. The noise extended from 100 kHz up to several MHz. After considerable effort, it was discovered that the noise was radiating from the AC power lines that were threaded throughout the complex, fed from a single pole-mounted step-down power transformer. Noise levels were high at all points within the complex.

Using a loop antenna, the noise source was finally traced to a 240V AC input Uninterruptible Power Supply (UPS). It was discovered that this was one of two identical UPSs purchased from a name-brand vendor, and that there was no FCC identification/certification/verification information either on the UPS or in the instruction manual. The unit really should have had a transmitter license, as the noise it was feeding back onto the 240V AC input power line was far above the FCC permitted levels for conducted emissions. It appeared there was absolutely no filter on the input of the UPS. Replacing the UPS with a different model from the same manufacturer, with an FCC approval sticker on the new UPS, solved the noise problem, and it was then possible to make some meaningful radiated emission measurements. Those measurements showed a fair amount of radiated noise within the Drill Camp complex, but signals more than 10 meters from the perimeter of the Drill Camp were generally below the FCC levels for Class A equipment. There were no detectable signals at frequencies used by aircraft. This means that the IceCube complex should be a good neighbor at the South Pole, especially to the aircraft using the skiway during the November 15 to March 15 window which is the only time there is any access to the South Pole Station.

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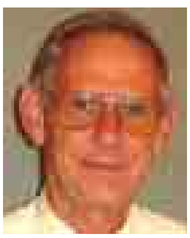
Geodesic Dome at the Amundsen Scott South Pole Station.

The proof of the pudding will start in late January 2005, when the first 4 (out of 80 eventual) holes are expected to be drilled in the polar ice and 4 cables and 240 photodetectors are put into the ice. Four IceTop units will also be put into service. That will be the first time a full cable of 60 detectors will be subjected to the rigors of transportation to the South Pole and the hazards of placing the cable and detectors into the ice, connecting the in-ice and surface cables together, getting signals to travel reliably in both directions along the cables, and getting the software for recognizing and analyzing the signals to work in a real-time environment.

For more information on the IceCube project, see their web site at: http://www.icecube.wisc.edu, or Google on "IceCube". Bob may be contacted at: hrhofmann@att.net. This material is based upon work supported by the National Science Foundation under Grant Nos. OPP-9980474 (AMANDA) and OPP-0236449 (IceCube), University of Wisconsin-Madison.



Biography

***Bob Hofmann** is currently working as an EMC consultant to the University of Wisconsin - Madison on electromagnetic compatibility issues for the South Pole IceCube Neutrino Detector project. He retired from Bell Laboratories/Lucent Technologies after 44 years of service. He has a BSEE degree from the University of Florida and an MSEE degree from New York University. Bob is a past President and a Life Member of the IEEE EMC Society and a Senior Member of the IEEE. He received the Laurence G. Cumming award from the IEEE EMC Society in 1994 and has received numerous other awards. Bob served as chairman of the Information Technologies Industries Council (ITI) TC-5 EMC Committee from 1990 to 1999. He also served as vice-chairman of the ECMA (European Computer Manufacturers Association) TC-20 EMC Committee. He is a NARTE registered engineer. Bob is currently a member of several ANSI ASC C63 subcommittees and working groups. He led the 1987 and 1999 revisions of ANSI/IEEE C63.12 on Electromagnetic Compatibility Limits, and was an active member of the editing committee for the 1991, 1992, 2001, and 2003 revisions of C63.4 on Methods of Measurement of Emissions. He has authored and presented papers on EMC standards and testing in the United States, Europe, and Japan, and has chaired several sessions on International EMC standards and EMC testing at various EMC symposia. Bob has taught a number of courses on EMC measurements and is a reviewer of papers submitted for presentation at the IEEE EMC Symposia and of questions used for the NARTE engineer and technician certification program. For a change from EMC, Bob likes to climb 14,000 foot mountains in Colorado, ski the sides of the same mountains in winter, bike the flat land of Illinois, and run 10 kilometer races. He may be reached at hrhofmann@att.net.*

The Contribution of Asymmetry to Exciting Common-Mode Emissions

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Abstract–Common-mode currents are often the dominant source of radiated emissions from an electronic product. Unlike differential-mode currents, conventional circuit analysis programs do not predict common-mode currents without the inclusion of stray elements that approximate the situation. Hence, the mechanisms that excite common-mode currents are more difficult to visualize and quantify. This article will distinguish the differences between the modes, and then focus on common-mode currents. The production of common-mode currents by the "ground noise" produced by return currents flowing through the impedance of the ground system will be reviewed briefly. The primary focus will be an explanation and demonstration of how asymmetric layouts also induce common-mode currents.

THE TWO MODES OF CURRENT FLOW

Because the modes have different causes, radiation mechanisms, and remedies, emissions have traditionally been divided into differential- and common-mode components. In the elementary configuration illustrated in Figure 1a, the current provided by the source flows through the load, and then returns in the adjacent conductor. Without considering the influence of any other structures that may be part of the overall system, the return current will be exactly equal, but opposite in direction, to the outgoing current. This situation defines differential mode current. Each current produces a magnetic field that can be sensed as a radiated emission, but because the currents flow in opposite directions, their magnetic fields also point in opposite directions. An observer located a distance away from the circuit, such as an antenna used for a compliance test, will receive a lower signal than from either of the individual conductors, owing to the significant cancellation of the opposing fields. Because the conductors are not precisely the same distance from most observation points, the cancellation is not perfect. In other words, the phase difference between the fields is not exactly 180°, but the smaller the distance between the conductors is as a fraction of a wavelength, the greater will be the cancellation.

By contrast, common-mode currents flow in the same direction on both of the conductors as shown in Figure 1b. Conventional analysis of the circuit illustrated will not predict such behavior, but there are various mechanisms for producing common-mode current that can be modeled using the techniques of electromagnetics or approximated at lower frequencies by the incorporation of parasitic lumped elements in the model. The excitation mechanisms will be discussed later, but for now, the nature of the emissions generated by common-mode current will be examined. Because the common-mode currents flow in the same direction, their associated magnetic fields also point in the same direction. When, as is typically the case, the conductors are spaced apart by much less than a half of a wavelength, an observer measuring the radiated emissions will see the two magnetic fields reinforce each other to produce a larger field. Hence, a common-mode radiator is substantially more efficient. The relative radiation efficiencies of the differential- and common-mode excitation depend on frequency and the geometry of a particular structure, but it is typical for a common-mode current in a circuit to produce radiation at the same levels as a differential mode current that is two or three orders of magnitude larger.

Most circuits in electronic products carry both common- and differential-mode currents simultaneously. To gain insight into radiated emissions, the measured currents in a circuit are often decomposed into their differential and common-mode compo-

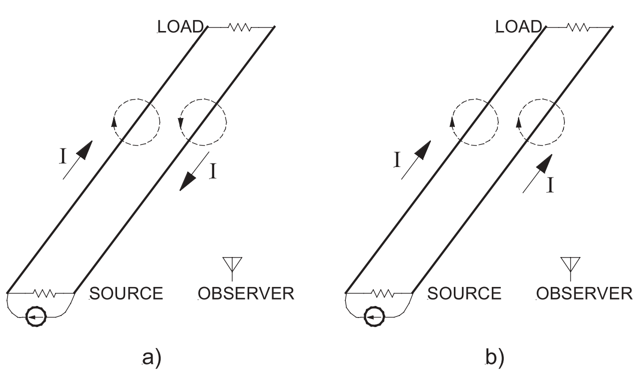

Figure 1 a) Differential-mode current flow and b) common-mode current flow. The orientations of the magnetic field associated with each conductor are shown with the dashed lines.

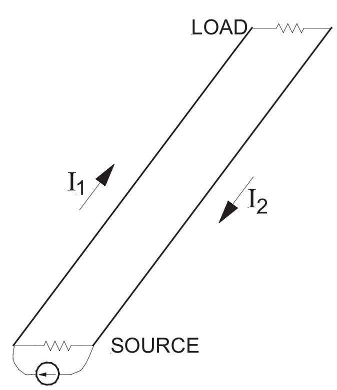

Figure 2 Definition of outbound and return currents, I_1 and I_2, respectively.

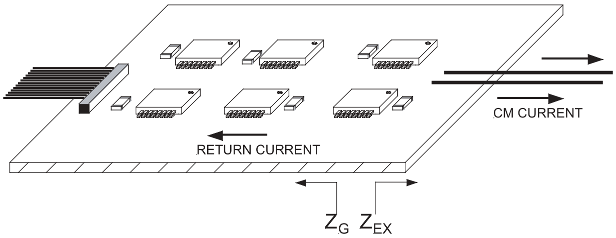

Figure 3 Circuit card example. Return current flowing to the left through a non-zero ground impedance, Z_G, generates a potential that forces some of the current onto the cable pair attached on the right.

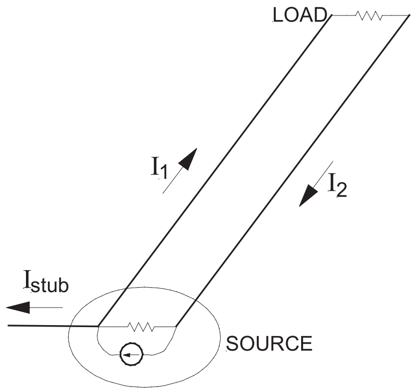

Figure 4 Example of an asymmetric circuit with a stub that unbalances I_1 and I_2.

nents. As depicted in Figure 2, let the current outbound to the load be denoted as I_1, and the return current from the load flowing back in the opposite direction be represented by I_2. The differential mode current can be computed from

$$I_{DM} = \frac{I_1 + I_2}{2} \tag{1}$$

and the common-mode current is extracted using

$$I_{CM} = \frac{I_1 - I_2}{2} \tag{2}$$

In the desirable case of exactly equal but opposite currents, $I_{DM} = I_1 = I_2$ and $I_{CM} = 0$ as expected. A more typical example is a situation such as $I_1 = 1\ mA$ and $I_2 = 0.98\ mA$. In this case, $I_{DM} = 0.99\ mA$ and $I_{CM} = 10\ \mu A$. Such a small disparity between the conductor currents would be difficult to discern using conventional circuit measurement techniques, but may result in radiated emissions noticeably larger than the consideration of only the differential-mode currents would predict.

EXCITATION OF COMMON-MODE CURRENT

A frequent excitation source for common-mode currents is the "ground noise" produced on a circuit card by currents returning from the myriad of circuits located there. These currents flow through the impedances presented by the ground system, generating voltages that raise the potential of all conductors that are connected to the ground system. Ground impedances typically exhibit both resistive and inductive components; the latter produces broadband voltage spikes by differentiating the edges of the current pulses that flow in a digital system. Common-mode current is induced in cables that are connected to the "noisy" ground on a circuit board. Consider the circuit board illustrated in Figure 3 that uses a ribbon cable on the left to carry power and ground from the system and has a two-wire interconnect cable attached on the right for carrying a signal. The return currents from the integrated circuits flowing through the impedance of the ground system (Z_G) generate a voltage, which in turn can excite current both the signal and return leads of the cable leading off the board to the right.

A more literal way to characterize this phenomenon is as a current divider. Let I_{RTN} represent the current returning from a particular circuit and I_{EX} be the total common-mode current induced in the cable conductors by that circuit.

$$I_{EX} = I_{RTN} \frac{Z_G}{Z_G + Z_{EX}} \tag{3}$$

where Z_{EX} is the impedance looking down the cable from the point of current division. Equation 3 highlights the two degrees of freedom available to a designer to minimize I_{EX} the

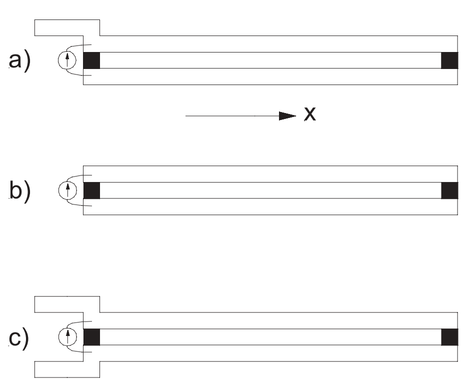

Figure 5 Three example layouts to demonstrate the effect of symmetry. The solid black squares represent terminating resistors.

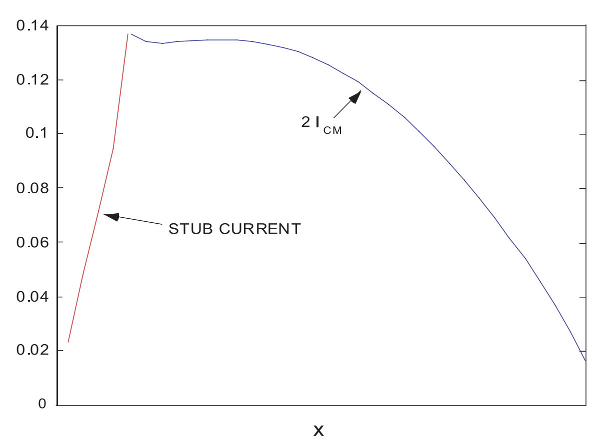

Figure 6 Current distribution along the circuit of Figure 5a.

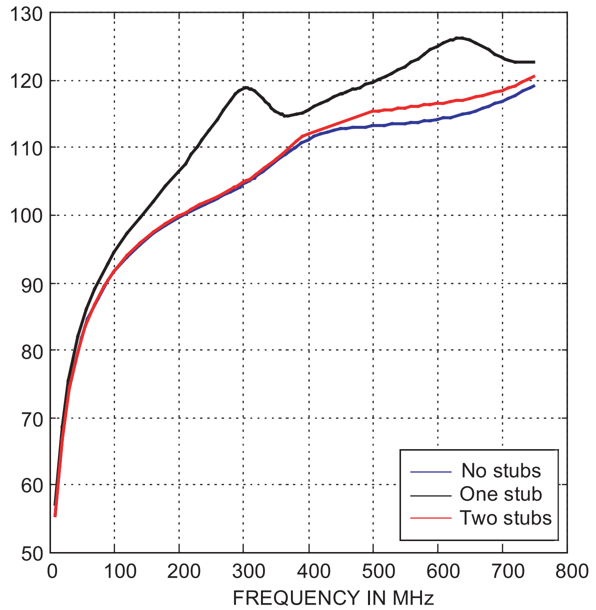

Figure 7 Radiated emissions from the three configurations of Figure 5.

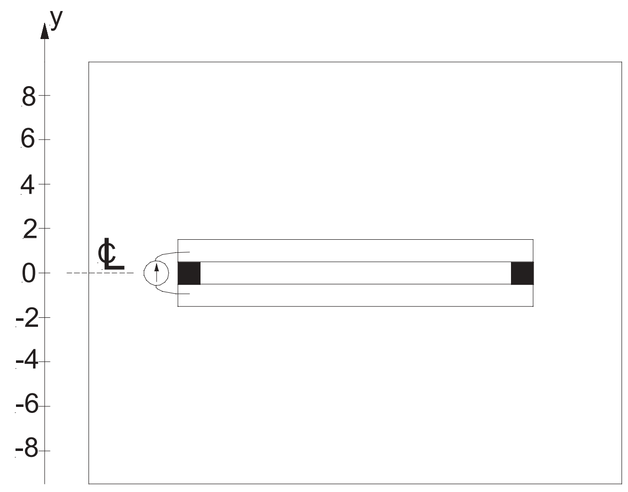

Figure 8 Circuit above a ground plane that is moved vertically to demonstrate the induction of common-mode current by asymmetry.

ground impedance Z_G can be made small, and/or Z_{EX}can be made large. In modern designs, careful layout techniques most often employing ground planes along with short, low-impedance connections back to the ground of the system decrease ZG. The equivalent value of Z_G seen from the point of current division can also be reduced by attaching the cable at points near the system ground connection for the board.

Impedance Z_{EX} depends on the cable routing and its termination at the other end. Because the routing of cables between devices in a system is often not well controlled, the common-mode impedance looking up the cable and is often raised by applying ferrite material around a segment of the cable to form a common-mode choke. Ferrite material also has the ability to dampen the resonances that exist in Z_{EX}.

When the cable attached on the right of the board comprises parallel lines such as in a ribbon cable, the conductors carry similar currents excited by the ground noise in the same direction. In the case of a shielded cable, the current excited by the ground noise on the shield conductor flows on its outer surface, owing to skin effect. Hence, instead of protecting against common-mode radiation, the shield serves as an efficient vehicle for its generation.

THE ROLE OF SYMMETRY

Asymmetric layouts can be another cause of common-mode currents [1,2]. Consider the circuit layout in Figure 4 where a source drives a load connected by two conductors. As an example of asymmetry, a small, open-circuited stub is also connected at the source. The stub serves as a small antenna and draws current, I_{stub}, away from the circuit. Applying Kirchhoff's current law (KCL) to the supernode circled on the drawing with a dotted line shows two outbound currents, I_1 and I_{stub}, that must balance with the lone inbound current, I_2. The resulting KCL equation can be written

$$I_{stub} = I_2 - I_1 \qquad (4)$$

Comparing this result with Equation 2 reveals that the stub current is equal to twice the magnitude of the common-mode current (I_{CM}). If the stub were not present, the common-mode current would be zero.

To demonstrate the induction of common-mode current by the stub, a full-wave analysis using the Partial-Element Equivalent Circuit (PEEC) method [3] was performed on the single-stub circuit of Figure 5a. Figure 6 plots the stub current and twice the common-mode current as function of horizontal position, x, along the structure. The loci show the satisfaction of KCL at the source end where the stub is attached. As expected, the current goes toward zero at the end of the stub, and the common-mode current also goes toward zero at the load end, enforced by the symmetry there. In lumped element terms, the reduction in stub current from a maximum value at the stub attachment point to zero at its end can be visualized as the current exiting the stub via the mutual (or stray) capacitance that exists between the stub and the rest of the circuit.

To show the ability of this asymmetry to raise the level of radiated emissions, the PEEC program was used to compute the emissions in the plane of circuit measured in the far field. The top locus in Figure 7 displays the level of the strongest emission found in the pattern versus frequency. Resonant peaking is observed at frequencies where the primarily reactive impedance of the stub is equal but opposite to the common-mode impedance looking down the conductors used to connect the load.

To demonstrate that the increase in radiated emissions is due to the common-mode current, and not the sole result of direct radiation by the stub, the radiation from two other structures was computed. First the symmetric case with no stubs as depicted in Figure 5b was modeled. Next the structure was modified to include a second stub at the source to realize symmetry (see Figure 5c). The far-field emissions were computed across the same frequency range. The corresponding locus, displayed in Figure 7, of the two-stub circuit exhibits no resonances and only a small increase in radiated emissions over the case of no stubs.

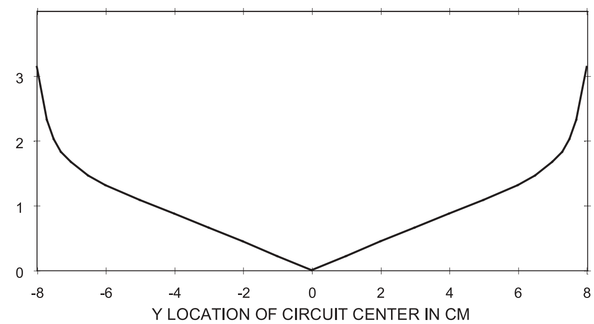

Figure 9 Common-mode current induced as the circuit of Figure 8 is moved off-center.

Many examples have been given in the literature of the increase of radiation as a circuit is moved toward the edge of a circuit card. There are various ways to explain this behavior, but one approach is to think about the unbalance in currents that appears due to an asymmetric configuration. As an example, consider the circuit in Figure 8 where a circuit is placed above a conductive plane. In this experiment, the position of the circuit is varied vertically (in y) from its centered (symmetric) location in both directions so that at the extremes the outer edge of a circuit conductor aligns with the edge of the plane. Figure 9 displays the computed common-mode current as a function of the vertical position of its center, with $y=0$ marking a symmetric layout.

SUMMARY COMMENTS

An asymmetrical layout induces unequal currents in the source and return leads of a circuit—an undesirable situation that stimulates common-mode emissions. The greater radiation efficiency of common-mode currents suggests that a relatively small amount of common-mode current can generate excessive emissions. Methods exist such as ferrite-core common-mode chokes and shielded enclosures with bulkhead connectors to mitigate such emissions, but attention to symmetry may reduce the need for these additional devices. A real circuit board layout involves hundreds if not thousands of circuits, and naturally, not every circuit or even most of the circuits can be made perfectly symmetric. However, it can be helpful for a designer to have an understanding of the benefits of symmetry in order to strive for as much symmetry as practical, particularly in situating circuits that carry coherent spectra with significant high-frequency energy.

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Biography

***Dr. Thomas Jerse** is an Associate Professor of Electrical and Computer Engineering at The Citadel in Charleston, South Carolina. Tom also keeps busy in the military aerospace world by serving as an Associate Technical Fellow of Boeing. He has over 24 years of industry experience and nine years teaching experience in academia. He has been giving EMC lectures in industry since 1981. Prior to his teaching and research at The Citadel, Tom earned his PhD under Dr. Clayton Paul at the University of Kentucky at Lexington. Tom has extensive experience in EMC, both through his work at Boeing and as an R&D Project Manager at Hewlett Packard. While at HP, Tom led a team responsible for the development of high performance spectrum analyzers, and in his spare time developed HP's Design for Electromagnetic Compatibility and its accompanying full prose textbook. Tom also is an accomplished musician, music teacher, and broadcast engineer! He holds one patent, and is a member of the IEEE EMC and Microwave Theory and Techniques Societies, Eta Kappa Nu, Tau Beta Pi, and the ASEE. Tom was awarded the 1992 IEEE EMC Society's President's Memorial Award. He may be reached at jerset@citadel.edu.*