

Low-EMI designs for isolated ADC signal-chain solutions

Dr. Ralph Oberhuber

Precision Analog-to-Digital Converters

Introduction

The sheer volume of electronic devices in use today, coupled with the constant reduction in the size of these devices, makes electromagnetic interference (EMI) a major problem for circuit designers. Circuits used for communications, computations and automation need to operate in close proximity [1]. Products must also comply with government electromagnetic compatibility (EMC) regulations. Virtually every country regulates the EMC of electronic products marketed or sold within its borders. In the United States, the Federal Communications Commission (FCC) regulates all commercial (nonmilitary) sources of electromagnetic radiation [2] and defines the radiated and conducted EMI test procedures in standards such as Standard C63.4 [3] from the American National Standards Institute (ANSI). Countries in the European Union (EU) regulate both electromagnetic emissions and the immunity of electronic devices; the Electromagnetic Compatibility Directive [4] basically states that equipment must comply with harmonized standards on EMC and be tested and labeled accordingly.

There are a large number of EMC standards pertaining to various types of equipment. For example, International Electrotechnical Commission (IEC) 61000 standards cover immunity requirements for most commercial products, while the Comité International Spécial des Perturbations Radioélectriques (CISPR) 32 standard specifies limits on conducted and radiated emissions [5]. **Table 1** lists CISPR, European Norm and FCC standards for the relevant product sector. Many other countries outside the U.S. and EU either specify compliance with FCC or EU EMC requirements or have their

own requirements. Regulations in countries outside of the U.S. and Europe often resemble the FCC or EU requirements [6].

Product sector	CISPR standard	EN standard	FCC standard
Automotive	CISPR 25	EN 55025	–
Multimedia	CISPR 32	EN 55032	Part 15
Industrial, scientific, medical	CISPR 11	EN 55011	Part 18
Household appliances, electric tools and similar	CISPR 14-1	EN 55014-1	–
Lighting equipment	CISPR 15	EN 55015	Parts 15 and 18

Table 1. Summary of the main product standards for radiated and conducted emissions [5].

The need for low EMI becomes even more obvious when considering a specific type of equipment, for example in smart metering. Smart electricity meters are a significant part of the future of energy distribution. They provide real time data on usage to both utilities and end users, helping people monitor energy usage and eliminating meter reading visits. The majority of smart meters connect via wireless communications [7], such as Wireless M-Bus or ZigBee, or they connect to the cellular phone network (GSM, LTE cat NB1- NB2, 2G/3G/5G). As illustrated in **Figure 1**, a smart electricity meter contains a radio-frequency (RF) transmitter circuit, usually in the same housing with the energy-metering (metrology) circuit board. It is important to minimize radiated emissions from the metrology circuit in order to not disturb RF communication, which can operate at frequencies such as 800MHz, 900MHz, 1,800MHz, 2,100MHz or 2,700MHz. The metrology circuit also needs to be resistant in terms of electromagnetic

susceptibility (the ability to withstand electromagnetic energy from wireless communication) in order to avoid billing errors from the injection of RF noise into the sensitive energy-measurement front end.

This article explains the sources of EMI – specifically radiated emissions – and present some techniques to minimize EMI for an analog signal chain, including detailed layout examples and measurement results.

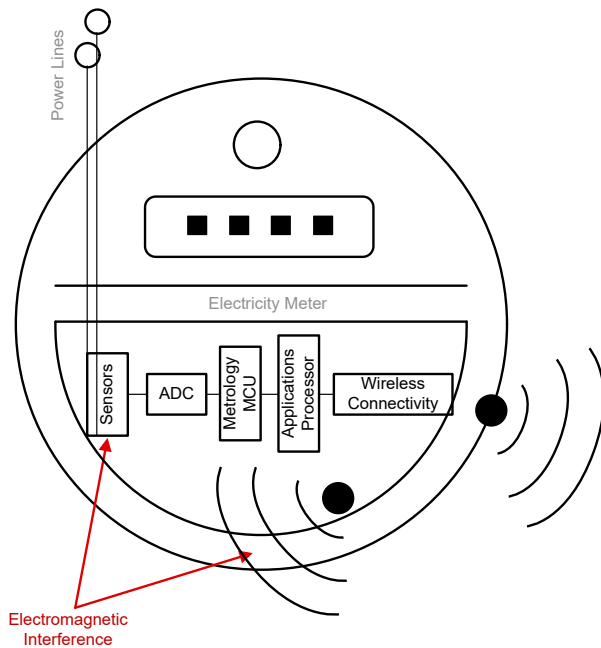


Figure 1. An RF-enabled smart electricity meter.

Sources of EMI and radiated emissions

EMC is the ability of an electric system to function properly in its intended environment in the presence of EMI, and to not be a source of interference to that electromagnetic environment beyond the limits as specified in the relevant standard [1].

EMI can be either radiated or conducted. Radiated interference travels in the form of radio waves, and is also called RF interference. Conducted interference comes from the magnetic field generated by current flow in cables carrying signals and power.

The focus of this article is on minimizing radiated emissions. On a printed circuit board (PCB) or inside an

integrated circuit (IC) mounted on that PCB, some of the primary sources of radiated emissions include:

- Switching signals such as clocking signals, with rapid changes in voltage levels during digital signal transitions. This occurs because of the high-frequency components in the signals. Switching and clocking signals are essential for synchronizing the operation of various components within and between ICs.
- Switching regulators and other components, which cause rapid changes in current draw through power-supply lines.
- Input/output buffers, especially those associated with high-speed interfaces such as USB, HDMI or Ethernet, because of the high-speed signal transitions they handle.
- Harmonics created by nonlinear behavior in the IC's internal circuits at frequencies higher than the fundamental signals.
- Parasitic capacitance, inductance and resistance in the IC's interconnects and structures.
- Electrostatic discharge (ESD) events that trigger ESD protection circuits.

Figure 2 illustrates TI's **AMC131M03** galvanically isolated analog-to-digital converter (ADC) [8] and the predominant sources of radiated emissions resulting from its internal architecture and connections on the PCB. The ADC is used in a three-phase energy metering application, and **Figure 2** shows the circuitry for one phase (phase A). The signal chain is designed to extract voltage and current measurements for energy monitoring [8]. ADC channel 0 measures the phase current using a shunt resistor, and channel 1 measures the phase voltage through a resistive divider [8]. The most relevant contributor to emissions is the internal switching DC/DC converter (a in **Figure 1**) that generates the isolated power supply on the high-voltage side [8]. The second-highest source of radiated emissions is the digital isolation (b in **Figure 2**), as it is implemented using high-

frequency on/off keying transmission through a stacked capacitor barrier [8], [9]. Furthermore, clock signals emit radiation in a wide frequency range, such as the ADC modulator clock CLKIN (c in Figure 2) as well as the

digital communication interface between the ADC and the microcontroller (d in Figure 2).

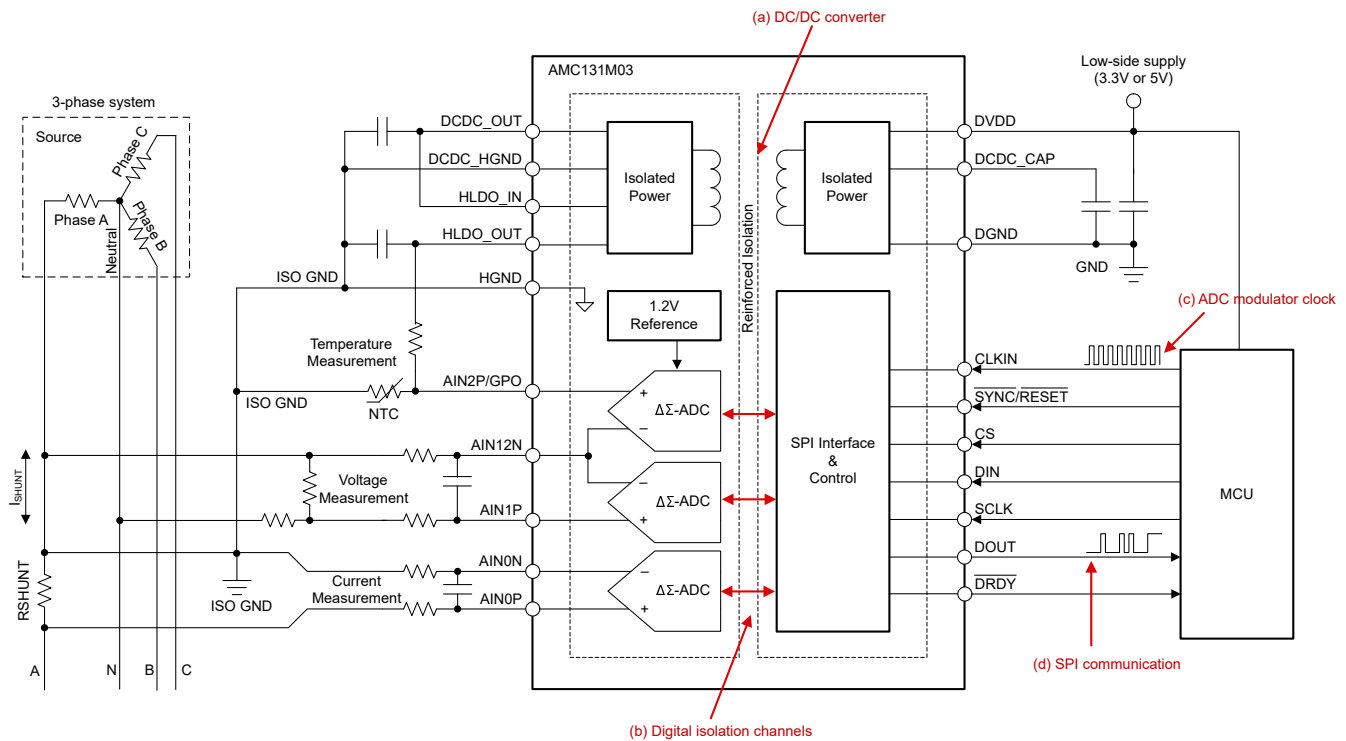


Figure 2. Analog signal chain with an isolated ADC, and sources of radiated emissions.

Techniques to minimize EMI

Several common PCB design techniques minimize EMI, also detailed in references [1], [10], [11]:

- Proper grounding. This is one of the most effective ways to reduce radiated emissions. Careful grounding can avoid ground loops that can act as antennas. Using a ground plane can also help reduce loop areas and provide a return path for signals, reducing the potential for EMI. In other cases, however, ground planes can create antennas on sensitive nodes and increase radiated emissions (see specific example shown in Figure 5).
- Component placement. Place components in a way that minimizes the length of signal traces, particularly for high-speed signals. Keep digital and analog components separate to avoid interference.

- Straight, short trace routing. Routing high-speed traces in a straight line and keeping them as short as possible can minimize the potential for EMI. Also, take care to avoid creating right angles in your trace routes, which can cause reflections and signal losses.
- Using decoupling capacitors. Decoupling capacitors can provide a short return path for high-frequency noise to ground. Place decoupling capacitors as close as possible to the power pins of ICs.
- Controlled impedance. Controlling the impedance of signal traces will match the impedance of the source and load and can help prevent signal reflections that can lead to radiated emissions.
- Shielding. Sometimes, using metal shields or shielding material on certain areas of the PCB can prevent radiated emissions.

- Using filters. Filters can block out certain frequencies that are causing radiated emissions, and are particularly useful in power-supply circuits.
- Layer stacking. In multilayer PCBs, take care to arrange the layers in a way that minimizes EMI. It's generally good practice to alternate between power and ground layers, as this can help reduce loop areas and provide a return path for signals. Top and bottom ground layers can help act as a shield field for internal signal layers such as clocks that generate radiated emissions.

- Avoid clock harmonics. Clock signals can generate harmonics that can interfere with other parts of the circuit. Spread-spectrum techniques can help spread these harmonics out and reduce their impact.
- EMI simulations. Radiated emissions simulation tools can help predict and minimize EMI in the PCB design phase itself [12], [13].

Figure 3 is a detailed schematic of the analog signal chain introduced in Figure 2.

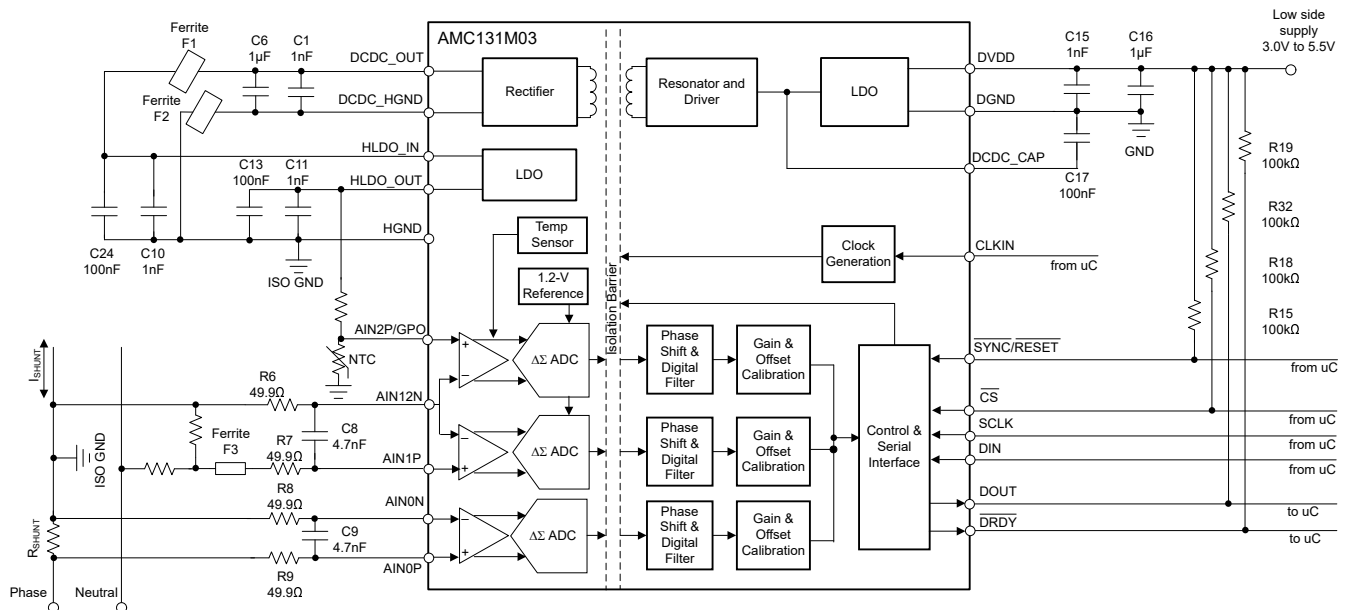


Figure 3. Detailed schematic of the analog signal chain from Figure 2.

Figure 4 and Figure 5 illustrate the application of radiated emissions reduction techniques to the corresponding PCB layout for the AMC131M03. Figure 4 shows a “good” layout, keeping traces short for ADC inputs and power routes in the high-voltage domain (PCB area to the left of the AMC131M03 placement) and placing bypass capacitors C1, C6, C8, C9, C11, C13, C14 and C24 close to the IC.

An important aspect when mitigating EMI is the grounding scheme of the isolated ground node

ISO_GND. Minimizing trace lengths and not placing a ground plane in the high-voltage domain minimizes the antenna on this node, and thus minimize radiated emissions [14]. Ferrite beads F1 and F2 are inserted into power connections DCDC_OUT and DCDC_HGND to block out high-frequency noise. You can also place an additional ferrite bead (F3) with high impedance at the frequency of excessive radiated emissions (which will depend on the PCB design) in series with the resistive divider for the voltage measurement.

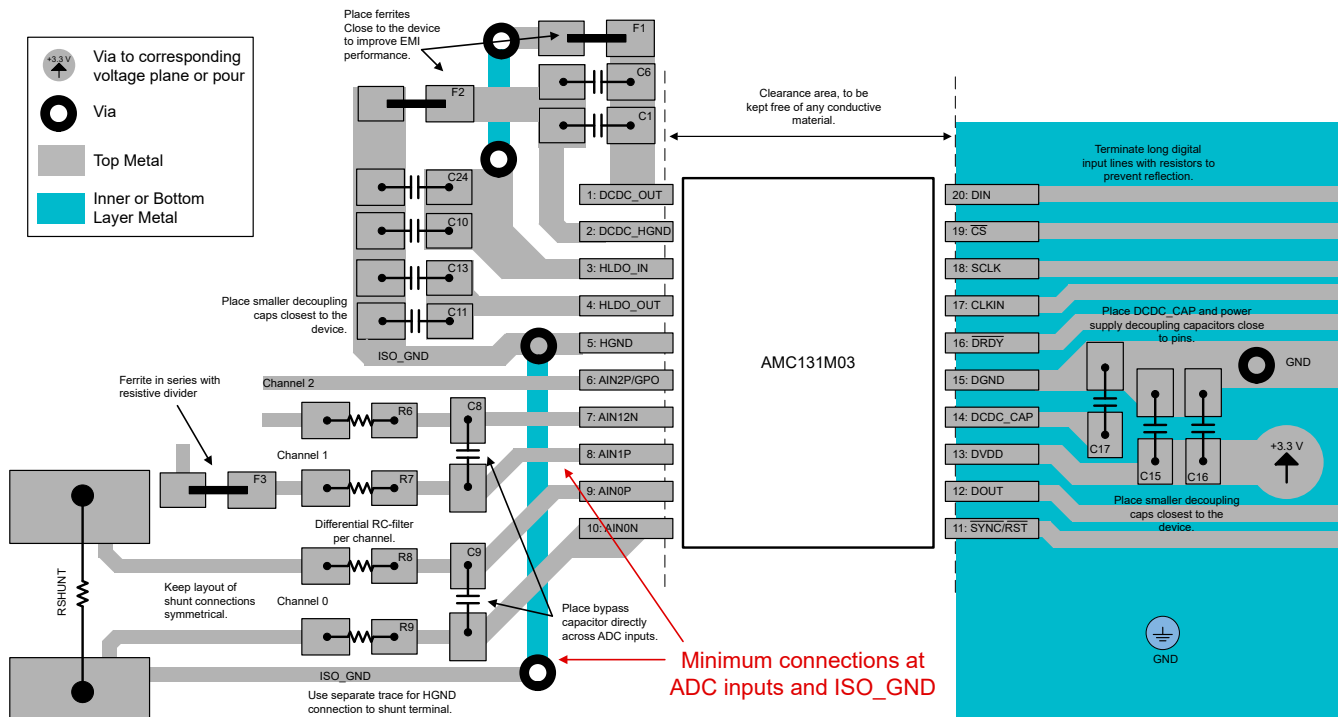


Figure 4. Good PCB layout (low EMI).

Figure 5 illustrates a “bad” layout, showing a ground plane connected to the ISO_GND node, which acts as an antenna and can increase radiated emissions significantly [14].

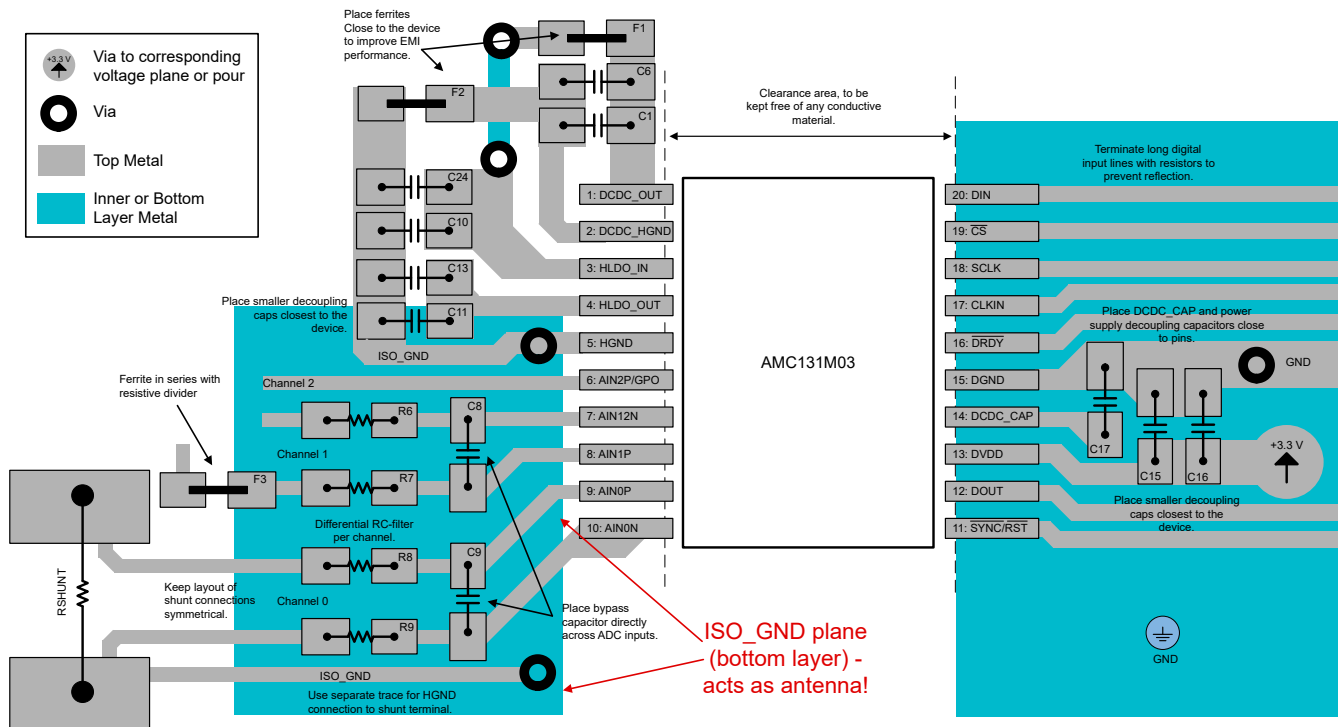


Figure 5. Bad PCB layout (high EMI).

Figure 6 and **Figure 7** show the radiated emissions measurement for the **AMC131M03** PCB using the layout implementation depicted in **Figure 4**. The measurements follow CISPR 11 requirements in a semianechoic chamber using a broadband antenna configured for horizontal and vertical polarizations with a 3m distance. The ADC is receiving a continuous clock at the CLKIN pin and is generating conversion results. However, there is no Serial Peripheral Interface communication while the emission profile is characterized. This design meets CISPR 11 Class A and Class B standards with 13dB of margin, offering the lowest radiated emissions performance on the market for an ADC with reinforced isolation for both data and power.

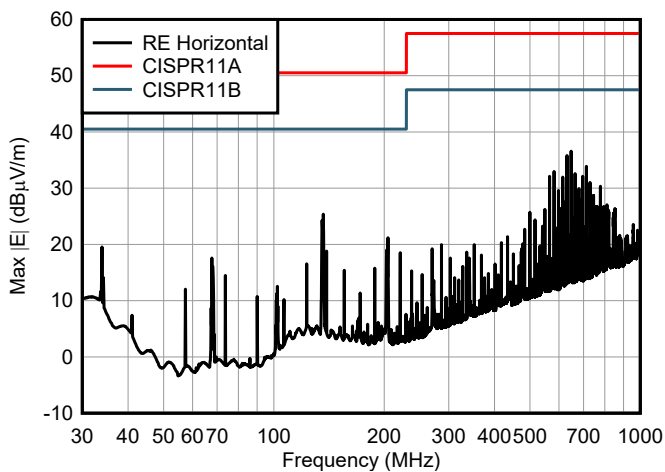


Figure 6. Horizontal radiated emissions CISPR 11 measurement.

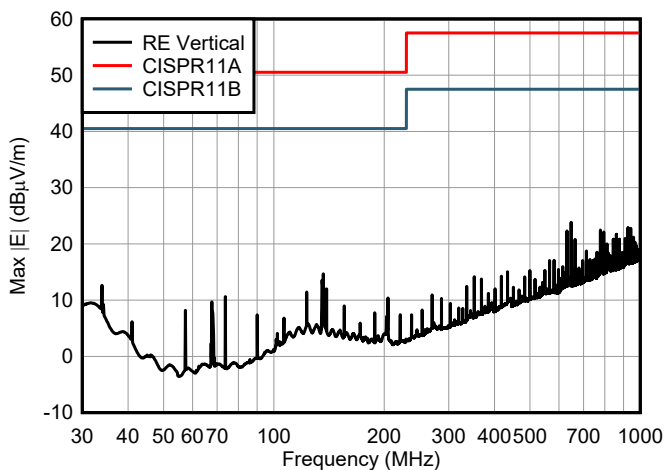


Figure 7. Vertical radiated emissions CISPR 11 measurement.

Conclusion

To ensure that the electronic circuits perform as designed, they must be protected from EMI. At the same time, the circuits themselves must not radiate emissions that can threaten or degrade the performance of other equipment. Compliance with EMC standards requires EMI protection at four levels: the component level, board level, system level and overall system level [15].

The techniques presented here minimize EMI at the PCB (board) design level and are easily applicable to a practical example, a best-in-class precision ADC signal chain with reinforced isolation [16] used for electricity metering. With careful design using the proposed EMI reduction techniques, the design achieves sufficient margin [17] for the relevant EMC standards.

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