# Magnetic-field immunity of digital capacitive isolators

**By Thomas Kugelstadt**
*Senior Applications Engineer*

The application environment of digital capacitive isolators often includes close proximity to large electric motors, generators, and other equipment that generates a large electromagnetic field. Exposure to these fields raises concern about the possibility of data corruption, as the electromotoric force (EMF), the voltage created by these fields, can interfere with the transferred data signal. Due to this potential threat, many users of digital isolators demand proof of an isolator's high magnetic-field immunity (MFI). While many digital-isolator technologies come with claims of having high MFI, capacitive isolators provide an almost infinitely high MFI due to their design and internal construction. This article explains the details of this design.

## Some physical fundamentals

A current-carrying conductor, such as one of the supply lines to an electric motor, is said to be surrounded by a magnetic field created by the current flowing through it. The direction of the magnetic field is easily determined by applying the right-hand rule (see Figure 1). This rule says that when the conductor is grasped with the right hand and the thumb is pointing in the direction of the current, the fingers encircling the conductor indicate the direction of the magnetic field. Thus, the plane of the magnetic flux lines is always perpendicular to the current.

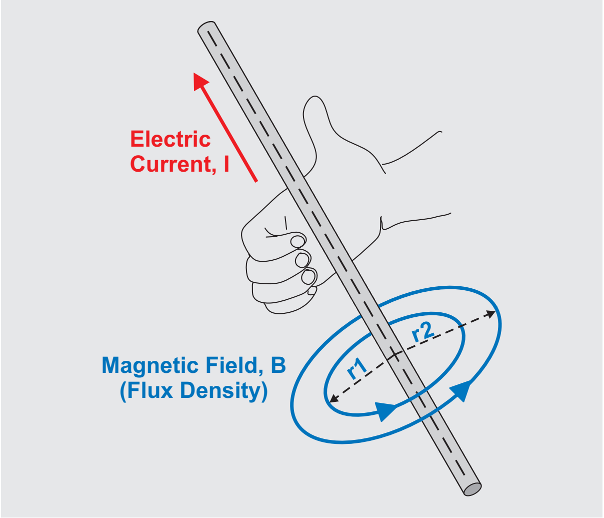
Figure 1 shows the magnetic flux density, B, for a DC current. For an AC current, the right-hand rule is applied in both directions, and the magnetic field changes with the same frequency, f, as the AC current: B(f) ~ I(f). The magnetic field—or, more accurately, the magnetic flux density and its corresponding magnetic-field strength—lessens with increasing distance from the center axis of the conductor. These relations are expressed as

$$B = \frac{\mu_0 I}{2\pi r} \tag{1}$$

and

$$H = \frac{B}{\mu_0} = \frac{I}{2\pi r}, \tag{2}$$

**Figure 1. The right-hand rule**



where B is the magnetic flux density in volt-seconds per square meter ($V{\bullet}s/m^2$), $\mu_0$ is the magnetic permeability in free space (given by $4\pi \times 10^{-7}$ $V{\bullet}s/A{\bullet}m$), I is the current in amperes, r is the distance from the conductor in meters, and H is the magnetic-field strength in amperes per meter (A/m).

When the magnetic-field lines cross a nearby conductor loop, they generate an EMF whose magnitude depends on the loop area and the flux density and frequency of the magnetic field:

$$EMF(f) = B \times 2\pi f \times A, \tag{3}$$

where EMF is the electromotoric force in volts, f is the field frequency, and A is the loop area in square meters ($m^2$).

All isolators possess conducting loops in some shape or form for magnetic-field lines to cross and generate EMF. If large enough, this EMF, which is superimposed onto signal voltages, can lead to erroneous data transmission. In fact, some isolation technologies are highly susceptible to magnetic interference. To understand why capacitive isolators are unaffected by magnetic fields, their internal construction needs to be examined.

**Figure 2. Simplified diagram of a capacitive isolator's internal construction**

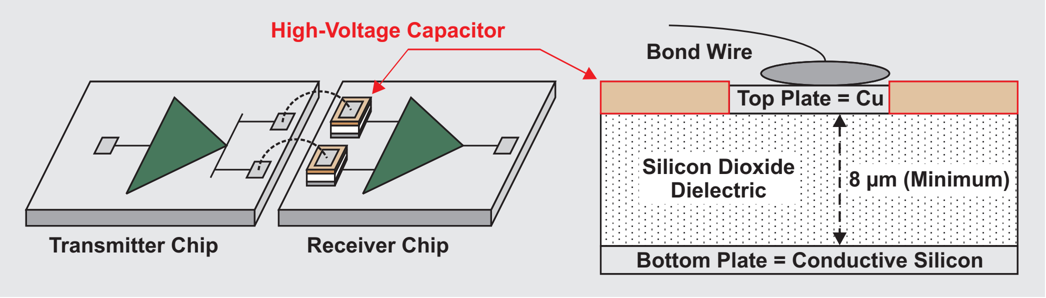
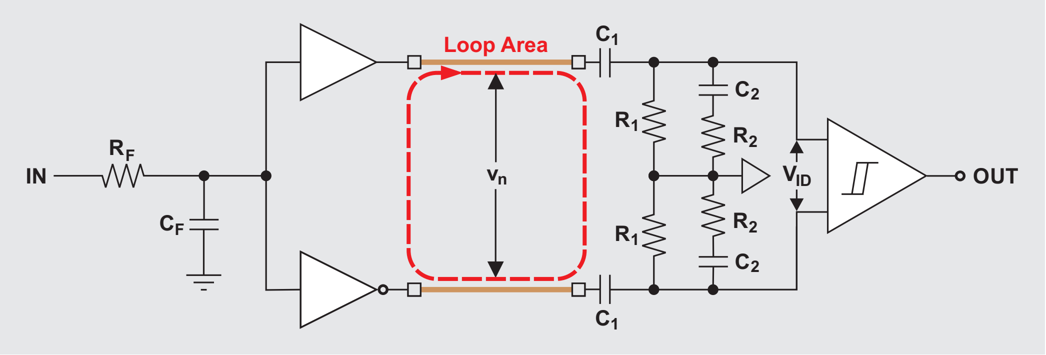


**Figure 3. Equivalent-circuit diagram of the isolation barrier**

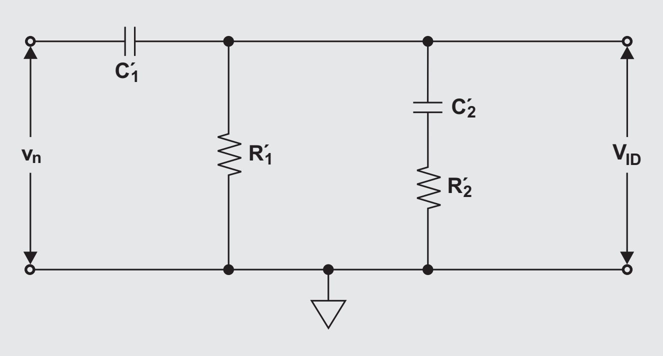


## Construction of capacitive isolators

Capacitive isolators consist of two silicon chips—a transmitter and a receiver (Figure 2). Data transfer occurs across a differential isolation barrier formed by two capacitors, each with a copper top plate and a conductive silicon bottom plate on each side of a silicon dioxide ($SiO_2$) dielectric. The driver outputs of the transmitter chip connect via bond wires to the top plates of the isolation capacitors on the receiver chip. With the bottom plates of the capacitors connecting to the receiver inputs, a conducting loop is created. Figure 3 shows the equivalent-circuit diagram of the isolation barrier and points out the loop area between the gold bond wires. Evidently a magnetic field crossing this loop will generate an EMF that represents input-voltage noise, $v_{n1}$, to the following RC network. A second differential noise component often encountered, $v_{n2}$, is due to the conversion of common-mode noise to differential noise. Both noise components make up the combined noise, $v_n$. If only the effects of EMF are considered, $v_n$ can be conservatively split in half:

$$\text{EMF} = \frac{v_n}{2} \tag{4}$$

**Figure 4. Single-ended RC network**



To trigger the receiver, the output of the RC network must provide a differential input voltage, $V_{ID}$, that exceeds the receiver input thresholds. Whether or not false triggering occurs depends on the gain response, G(f), of the RC network.

The conversion from a differential to a single-ended network (Figure 4) simplifies the derivation of G(f) but requires that $C_1' = 2C_1$, $R_1' = R_1/2$, $C_2' = 2C_2$, and $R_2' = R_2/2$.

A circuit simulation confirmed that the RC network is a first-order high-pass filter, with $C_1'$ and $R_1'$ being the dominant components up to 100 MHz (see the blue curve in Figure 5). Beyond this frequency, the parasitic components $C_2'$ and $R_2'$ become effective, causing a slight deviation from the linear slope. For up to 100 MHz, therefore, the gain response can be expressed as a ratio of $V_{ID}/v_n$:

$$\frac{V_{ID}}{v_n}(f) = |G(f)| = \frac{2\pi f}{\sqrt{(2\pi f)^2 + \left(\frac{1}{R_1' \times C_1'}\right)^2}} \qquad \textbf{(5)}$$

Determining the maximum noise allowed that does not cause false receiver triggering requires Equation 5 to be solved for $v_n$:

$$v_n(f) < \frac{V_{ID}\sqrt{(2\pi f)^2 + \left(\frac{1}{R_1' \times C_1'}\right)^2}}{2\pi f} \qquad \textbf{(6)}$$

Then, substituting $v_n$ into Equation 4 provides the maximum tolerable EMF in volts:

$$\mathrm{EMF}(f) < \frac{V_{ID}\sqrt{(2\pi f)^2 + \left(\frac{1}{R_1' \times C_1'}\right)^2}}{4\pi f} \qquad \textbf{(7)}$$

Substituting EMF into Equation 3 then yields the maximum possible magnetic flux density:

$$B(f) < \frac{V_{ID}\sqrt{1 + \left(\frac{1}{2\pi f \times R_1' \times C_1'}\right)^2}}{4\pi f \times A} \qquad \textbf{(8)}$$

**Table 1. Current and magnetic values for a conductor that is 0.1 m from a capacitive isolator**

| FREQUENCY, f | MAGNETIC FLUX DENSITY, B (V•s/m$^2$) | EMF (V) | MAGNETIC-FIELD STRENGTH, H (A/m) | CURRENT, I (A) |
|---|---|---|---|---|
| 1 kHz | $1.07 \times 10^7$ | 63738.5 | $8.55 \times 10^{12}$ | $5.37 \times 10^{12}$ |
| 10 kHz | $1.07 \times 10^5$ | 6373.8 | $8.55 \times 10^{10}$ | $5.37 \times 10^{10}$ |
| 100 kHz | $1.07 \times 10^3$ | 637.4 | $8.55 \times 10^8$ | $5.37 \times 10^8$ |
| 1 MHz | $1.07 \times 10$ | 63.7 | $8.55 \times 10^6$ | $5.37 \times 10^6$ |
| 10 MHz | $1.07 \times 10^{-1}$ | 6.4 | $8.55 \times 10^4$ | $5.37 \times 10^4$ |
| 100 MHz | $1.07 \times 10^{-3}$ | 0.6 | $8.55 \times 10^2$ | $5.37 \times 10^2$ |

The frequency-dependent values listed in Table 1 for the magnetic flux density were derived by inserting the following numerical values into Equation 8:

$V_{ID}$ = 10 mV (magnitude of the receiver's input thresholds)

$R_1' \times C_1'$ = 25 ps (effective time constant)

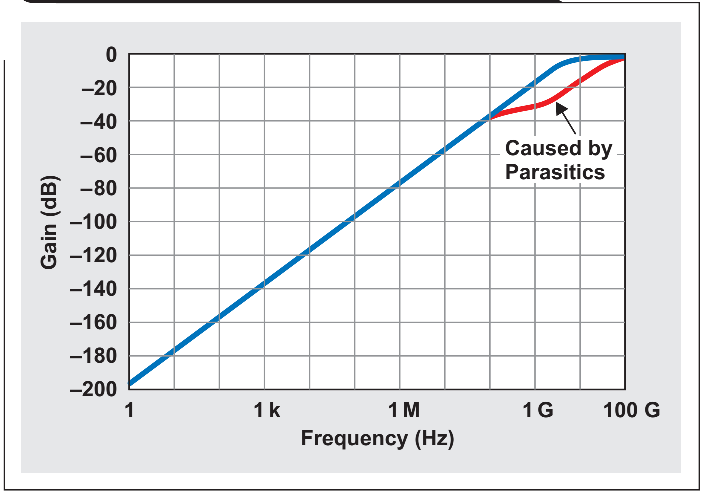
A = 944 × $10^{-9}$ m$^2$ (effective loop area)

f = 1 kHz to 100 MHz (frequency range of interest)

Using Equations 2 and 3 also provides the EMF, the magnetic-field strength (H), and the corresponding current (I) for a conductor here assumed to be 0.1 m from a prospective isolator.

From the enormously high values in Table 1, it is evident that neither a low-frequency current of 5 trillion amperes nor 500 A at 100 MHz is capable of stopping this isolator

**Figure 5. Frequency response of the gain magnitude, |G(f)|**



from working correctly. The reason for this almost infinite MFI lies in the location of the isolation capacitors. If these capacitors reside on the transmitter chip, any generated EMF in the bond wires reaches the receiver inputs undisturbed.

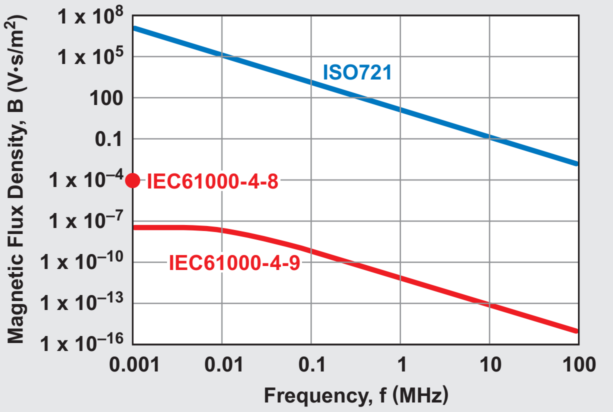
Evidently such high MFI values are impossible to test in practice. The data sheets of capacitive isolators therefore show the modest value of only 1000 A/m as the practical test field. However, unshielded capacitive isolators easily pass the Class 5 MFI requirements of the IEC61000-4-8 and IEC61000-4-9 standards. These standards respectively describe the application of power-frequency fields of up to 100 A/m and pulsed fields of up to 1000 A/m. Class 5 defines severe industrial environments with conductors, bus bars, or medium- or high-voltage lines, all of which carry tens of kiloamperes. Also included are the ground conductors of a lightning-protection system and high structures (such as line towers) carrying the whole lightning current. Switchyards of heavy industrial plants and power stations also represent this type of environment.

Figure 6 compares the calculated MFI thresholds of a capacitive isolator with the Class 5 (highest) test levels of IEC 61000-4-8 and IEC 61000-4-9.

## Conclusion

Magnetic coupling exceeding the noise budget in the differential circuit of a capacitive isolator requires a magnetic flux density greater than 11.7 V•s/m$^2$ (117 kilogauss) at 1 MHz. This would be the field generated by over 5 million amperes in a conductor that is 0.1 m away from the device. It is unlikely that this will occur in nature or any manufactured equipment. If it does, the designer can assume that surrounding circuitry will fail before the isolation barrier does.

**Figure 6. MFI test thresholds**



## References

1. Donald G. Fink, *Electronic Engineers' Handbook*, 1st ed. New York: McGraw-Hill, 1975.
2. William Hart Hayt, *Engineering Electromagnetics*, 3rd ed. New York: McGraw-Hill, 1974.
3. Clare D. McGillem and George R. Cooper, *Continuous and Discrete Signal and System Analysis*. New York: Holt, Rinehart and Winston, 1974.
4. "Electromagnetic interference test report for the ISO721 high-speed digital isolator," Southwest Research Inst., Document No. EMCR 05/019 rev. 00, August 2005.

## Related Web site

**interface.ti.com**

# *TI Worldwide Technical Support*

## Internet

### TI Semiconductor Product Information Center Home Page

support.ti.com

### TI E2E™ Community Home Page

e2e.ti.com

## Product Information Centers

| | | |
|---|---|---|
| **Americas** | Phone | +1(972) 644-5580 |
| **Brazil** | Phone | 0800-891-2616 |
| **Mexico** | Phone | 0800-670-7544 |
| | Fax | +1(972) 927-6377 |
| | Internet/Email | support.ti.com/sc/pic/americas.htm |

### Europe, Middle East, and Africa

Phone

| | |
|---|---|
| European Free Call | 00800-ASK-TEXAS<br>(00800 275 83927) |
| International | +49 (0) 8161 80 2121 |
| Russian Support | +7 (4) 95 98 10 701 |

**Note:** The European Free Call (Toll Free) number is not active in all countries. If you have technical difficulty calling the free call number, please use the international number above.

| | |
|---|---|
| Fax | +(49) (0) 8161 80 2045 |
| Internet | support.ti.com/sc/pic/euro.htm |

### Japan

| | | |
|---|---|---|
| Phone | Domestic | 0120-92-3326 |
| Fax | International | +81-3-3344-5317 |
| | Domestic | 0120-81-0036 |
| Internet/Email | International | support.ti.com/sc/pic/japan.htm |
| | Domestic | www.tij.co.jp/pic |

### Asia

Phone

| | |
|---|---|
| International | +91-80-41381665 |
| Domestic | Toll-Free Number |
| Australia | 1-800-999-084 |
| China | 800-820-8682 |
| Hong Kong | 800-96-5941 |
| India | 1-800-425-7888 |
| Indonesia | 001-803-8861-1006 |
| Korea | 080-551-2804 |
| Malaysia | 1-800-80-3973 |
| New Zealand | 0800-446-934 |
| Philippines | 1-800-765-7404 |
| Singapore | 800-886-1028 |
| Taiwan | 0800-006800 |
| Thailand | 001-800-886-0010 |

| | |
|---|---|
| Fax | +886-2-2378-6808 |
| Email | tiasia@ti.com or ti-china@ti.com |
| Internet | support.ti.com/sc/pic/asia.htm |

**A042210**

# IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

| **Products** | | **Applications** | |
|---|---|---|---|
| Amplifiers | amplifier.ti.com | Audio | www.ti.com/audio |
| Data Converters | dataconverter.ti.com | Automotive | www.ti.com/automotive |
| DLP® Products | www.dlp.com | Communications and Telecom | www.ti.com/communications |
| DSP | dsp.ti.com | Computers and Peripherals | www.ti.com/computers |
| Clocks and Timers | www.ti.com/clocks | Consumer Electronics | www.ti.com/consumer-apps |
| Interface | interface.ti.com | Energy | www.ti.com/energy |
| Logic | logic.ti.com | Industrial | www.ti.com/industrial |
| Power Mgmt | power.ti.com | Medical | www.ti.com/medical |
| Microcontrollers | microcontroller.ti.com | Security | www.ti.com/security |
| RFID | www.ti-rfid.com | Space, Avionics & Defense | www.ti.com/space-avionics-defense |
| RF/IF and ZigBee® Solutions | www.ti.com/lprf | Video and Imaging | www.ti.com/video |
| | | Wireless | www.ti.com/wireless-apps |

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265