High-voltage isolation quality and reliability for AMC130x

TEXAS INSTRUMENTS

Tom Bonifield
HV Isolation Team
Analog Technology Development Department

Texas Instruments

www.ti.com/isolation

Introduction

Isolation products prevent DC and unwanted AC currents between two parts of a system, while allowing signal and power transfer. TI's AMC130x product family is the first generation that is rated for reinforced isolation, i.e., it provides reliability, shock protection and isolation equivalent to two levels of basic isolation in a single package.

High-voltage isolation technology

High-voltage (HV) isolation is achieved using two thick SiO_2 capacitors in series—one on each side of the isolation barrier. SiO_2 is an excellent dielectric with the highest dielectric strength among materials commonly used for HV isolation components and, unlike polyimide and other polymer-based insulators, SiO_2 is void free and the reliability of an SiO_2-insulated capacitor does not degrade with exposure to ambient moisture.

Insulator materials	Dielectric strength
Air	~1 Vrms/µm
Epoxies	~20 Vrms/µm
Silica-filled mold compounds	~100 Vrms/µm
Polyimide	~300 Vrms/µm
SiO_2	~500 Vrms/µm

Table 1: Common insulators used for HV Isolation

The HV caps are manufactured in a high-performance analog CMOS process and packaged in a multi-chip SOIC module. The wafer fab process is a multiple-level metal process with the HV capacitor formed between metals as shown in Figure 1. This structure achieves the SiO_2 thickness needed for HV isolation simply by using standard interlevel dielectric layers. This multi-layered structure improves quality and reliability by reducing the dependence of the HV performance on any single layer.

Manufacturing of the HV capacitors uses the same processes and equipment that are used for high-volume Analog and CMOS production. The SiO_2 films are amorphous and homogeneous, and are deposited by Plasma-Enhanced Chemical Vapor Deposition. Each SiO_2 layer is planarized using Chemical Mechanical Polishing. The final SiO_2 film thicknesses are measured and controlled during process. Using multiple layers reduces dielectric thickness variability for a well-controlled total capacitor dielectric thickness, which is verified by a wafer-level capacitance measurement prior to assembly.

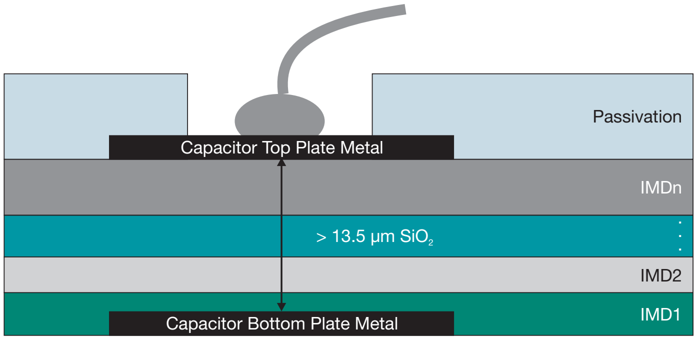


Figure 1: HV capacitor illustration.

An AMC130x multi-chip module using this isolation capacitor technology combined with high-performance analog circuits is shown in Figure 2 on the following page. Both the transmitter and receiver have isolation capacitors to double the high-voltage capability compared to a single capacitor. The die-to-die bond wires' loop heights are controlled for compatibility with HV. A very thick multilayer passivation of planarized

SiO_2, SiON and polyimide protects the HV isolation die from possible breakdown in the mold compound surrounding the die.

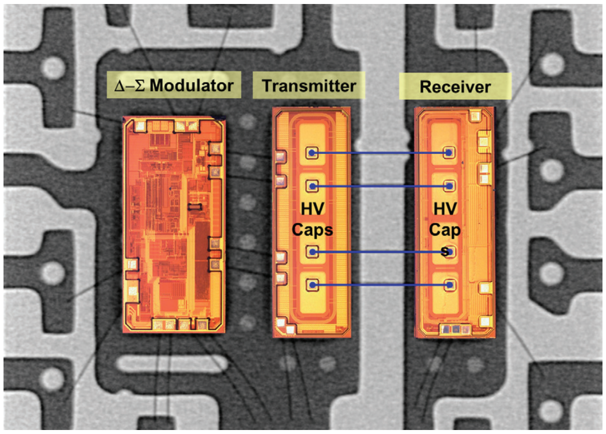


Figure 2: AMC1305 High-voltage isolation multi-chip module with HV capacitors on transmitter and receiver connected in series.

Products using this configuration meet the industry standard requirements for reinforced isolation, including:

V_{IOTM} = 5.0 kVrms transient overvoltage
V_{IORM} = 1.0 kVrms 20 yrs reinforced iso working voltage
Surge > 10 kV peak

High-voltage isolation testing

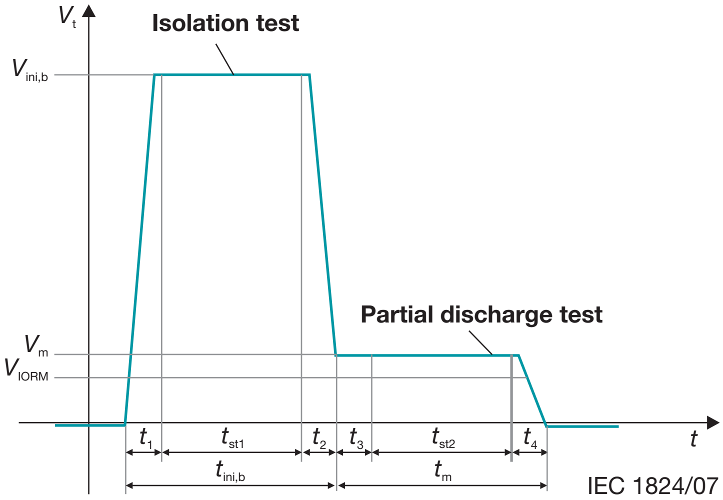
Multiple component-level as well as system- and end-equipment-level standards govern and certify isolation products. Based on real-world operating conditions, various voltage stress profiles are mandated for isolation products which quantify their HV isolation performance.[1] Some of these component-level parameters are working voltage (V_{IOWM}), maximum transient isolation voltage (V_{IOTM}), isolation withstand voltage (V_{ISO}), maximum repetitive peak voltage (V_{IORM}) and maximum surge isolation voltage (V_{IOSM}). These parameters and the tests which are used to verify these capabilities are listed in Table 2.

Parameter	HV tests
V_{IOTM}, V_{ISO}	Method-B1 production screen, Ramp-to-breakdown, Method-A, TDDB
V_{IORM}, V_{IOWM}	Method-B1 production screen, TDDB
V_{IOSM}	Surge, Surge breakpoint

Table 2: HV tests

Routine high-voltage production testing on every part follows Method-B1 as prescribed by IEC 60747-5-5. Method-B1 test conditions are shown in Figure 3. This test has two parts: an isolation test and a partial discharge test. The isolation test is an HV leakage test for 1 sec (t_{st1}) at a stress voltage $V_{ini,b} \geq 120\%$ of V_{IOTM} or V_{ISO}. This part of the test screens out units with defective HV capacitors. The second part of Method-B1 is a 1-sec partial discharge test at "V_m" which is ≥ 1.875× V_{IORM} for reinforced isolation. The partial discharge test screens out units with electrically active voids in the mold compound.

RTB (Ramp-to-Breakdown) test is a destructive test performed on a sample basis as shown in Figure 4. These RTB data show a tight distribution



IEC 1824/07

Figure 3: Method-B1 routine production test performed on all parts

of breakdown voltages with high margin to the Method-B1 leakage test at ≥ 6 kVrms for 1 sec.

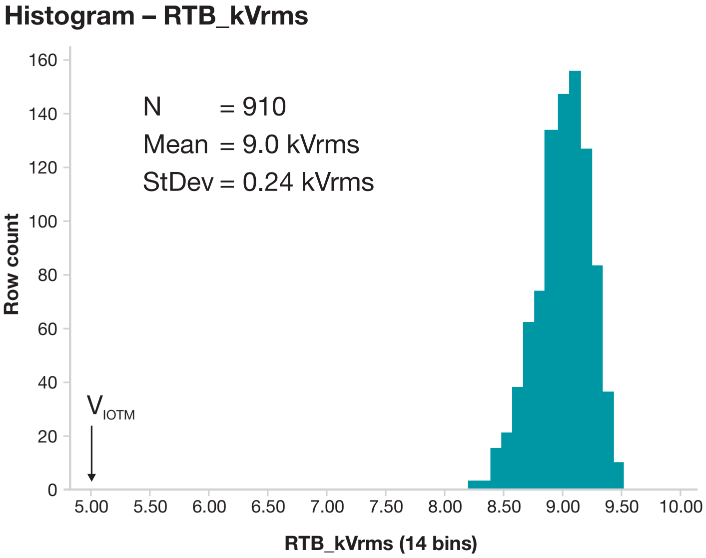


Figure 4: RTB voltage distribution, with1kVrms/sec ramp rate

Time Dependent Dielectric Breakdown (TDDB) is the standard test method to verify the lifetime of any dielectric[2], [3], [4]. It is a key test of the high-voltage isolation barrier. TDDB can be performed on final packaged product parts because the isolation insulator is directly accessible by testing between the two isolated voltage domains. TDDB is performed by stressing parts at a constant high AC or DC voltage for a long time until the insulator wears out and fails by electrical short. By testing TDDB at multiple voltages, the product lifetime at the working voltage is determined by extrapolation as shown in Figure 5.

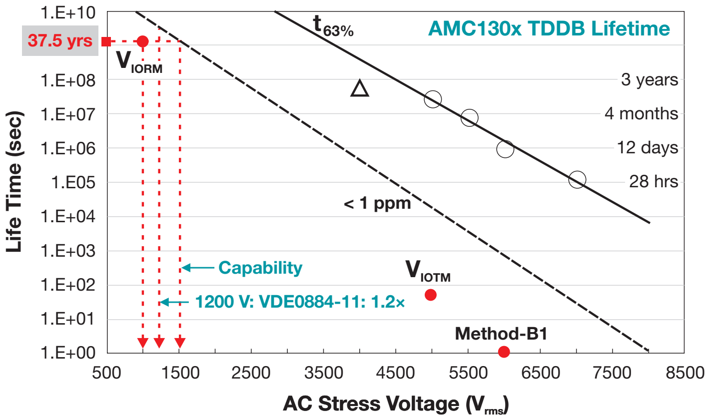


Figure 5: Time Dependent Dielectric Breakdown (TDDB). Circles are the time for 63% of units to break down. The triangle is on-going TDDB testing at 4 kVrms with no units failed as of 17,000 hours

The breakdown times at each TDDB test voltage are analyzed by the Weibull method to determine an average fail time $t_{63\%}$ and extrapolation to 1 ppm failure probability. The TDDB breakdown times follow the commonly used model:

$$\text{Time-to-fail} = A * \exp^{(-\gamma * E)}$$

where γ is the field acceleration factor and E is electric field.

Margins for establishing the lifetime of a reinforced isolation part using HV capacitors, such as AMC130x, are covered in VDE884-11 spec. These include 20% margin in working voltage and 87.5% margin in lifetime; i.e., a 1 kVrms working voltage with 20-year lifetime must demonstrate < 1 ppm failure probability at 1.2 kVrms for 37.5 years. Figure 5 demonstrates a good fit to the model and very high isolation barrier lifetimes for this technology at the maximum use condition or working voltage (V_{IORM}, V_{IOWM}) of 1.0 kVrms.

Method-A test is prescribed by IEC to directly confirm V_{IOTM} on a sample basis. Method-A test includes a 60-sec leakage test at V_{IOTM}, which is 5.0 kVrms for this technology. TDDB is the best means to determine the quality of the actual distributions relative to the V_{IOTM} spec. Figure 5 shows the average time to breakdown is over 5 orders of magnitude higher than V_{IOTM}.

Surge is an IEC sample test to check immunity to very high voltage, very short time events (such as lightning strikes). The surge pulse waveform is specified by IEC 61000-4-5, as shown in Figure 6. Reinforced isolation requires passing a surge test with a minimum of 50 pulses of 10 kV peak voltage.

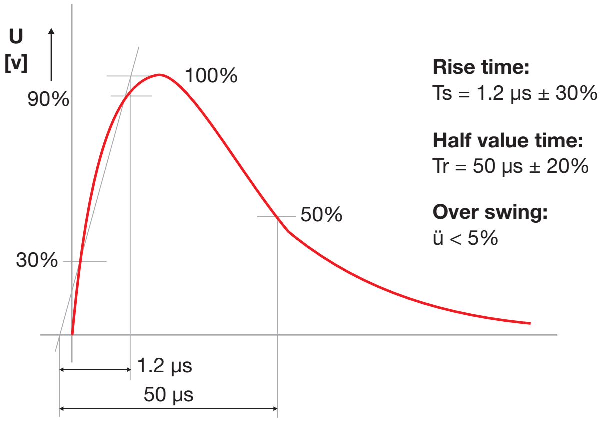


Figure 6: Surge test waveform

Surge testing is performed periodically on production samples to verify they meet the requirement for reinforced isolation.

To assess the actual surge capability, the surge fail rate is measured as a function of the surge peak voltage. Many units are tested at each voltage. Two different surge test methods are assessed: "unipolar" where all pulses are in the same polarity, and "bipolar" where half of the pulses are one polarity and the other half are the opposite polarity.

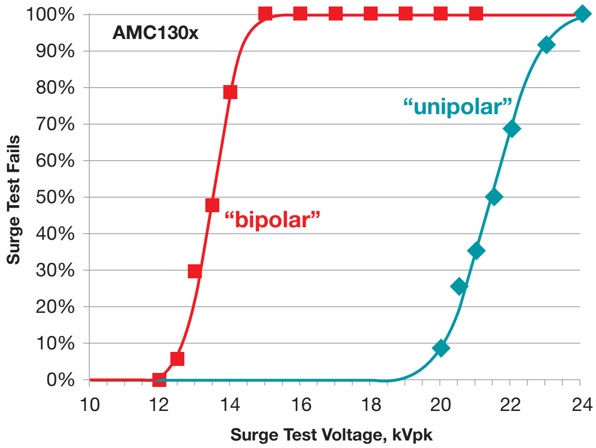


Figure 7: Surge breakpoint statistical assessment, by both "unipolar" and "bipolar" surge test methods

The actual surge breakpoint distributions are shown in Figure 7.

Both "unipolar" and "bipolar" surge breakpoints exceed the 10 kV surge requirement for reinforced isolation. The lower surge breakpoints for "bipolar" surge are a temporary hysteresis effect. The "unipolar" surge distribution is representative of single surge events.

Conclusion

The AMC130x family of products has high-voltage capability that exceeds the requirements for reinforced isolation. The quality of HV isolation is demonstrated by substantial margins using statistical test methods. The reliability of the AMC130x HV isolation system is proven with high margin by TDDB, which is the industry standard method of proving lifetime at use conditions.

References

[1] High-voltage reinforced isolation: Definitions and test methodologies: **http://www.ti.com/lit/wp/slyy063/slyy063.pdf**.

[2] J. W. McPherson, "Time dependent dielectric breakdown physics—Models revisited," in *Microelectronics Reliability* 52, 2012, p. 1753–1760.

[3] I. C. Chen, E. Holland, and C. A. Hu, "A quantitative physical model for time-dependent breakdown in SiO_2," in *Proc. Int. Reliab. Phys. Symp.*, 1985, p. 24.

[4] J. W. McPherson, V. Reddy, K. Banerjee, and L. Huy, "Comparison of E and 1/E TDDB models for SiO_2 under long-term/low-field test conditions," in *IEDM Tech. Dig.*, 1998, p. 171.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

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

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license 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 significant portions 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. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

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

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2016, Texas Instruments Incorporated