

High-voltage isolation quality and reliability for AMC130x



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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 SiO₂ capacitors in series—one on each side of the isolation barrier. SiO₂ 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, SiO₂ is void free and the reliability of an SiO₂-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 SiO₂ 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 SiO₂ films are amorphous and homogeneous, and are deposited by Plasma-Enhanced Chemical Vapor Deposition. Each SiO₂ layer is planarized using Chemical Mechanical Polishing. The final SiO₂ 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.

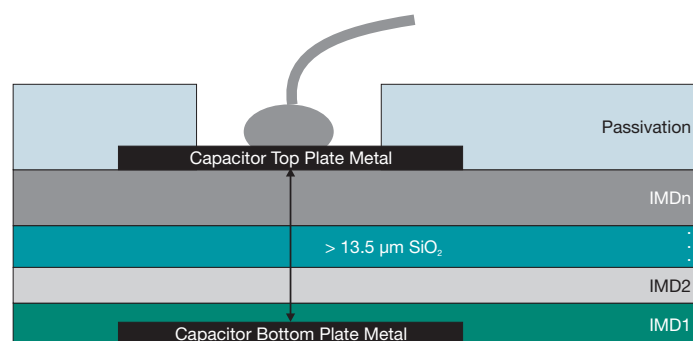


Figure 1: HV capacitor illustration.

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

SiO₂, SiON and polyimide protects the HV isolation die from possible breakdown in the mold compound surrounding the die.

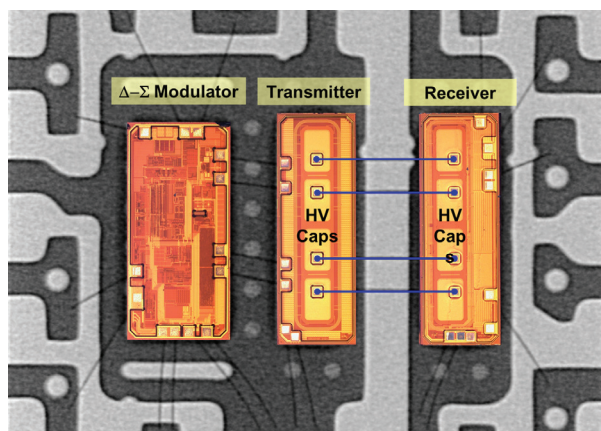


Figure 2: AMC1305 High-voltage isolation multi-chip module with HV capacitors on transmitter and receiver connected in series.

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

- $V_{IOTM} = 5.0 \text{ kVrms transient overvoltage}$
- $V_{IORM} = 1.0 \text{ kVrms 20 yrs reinforced iso working voltage}$
- 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 $\geq 1.875 \times V_{IORM}$ 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

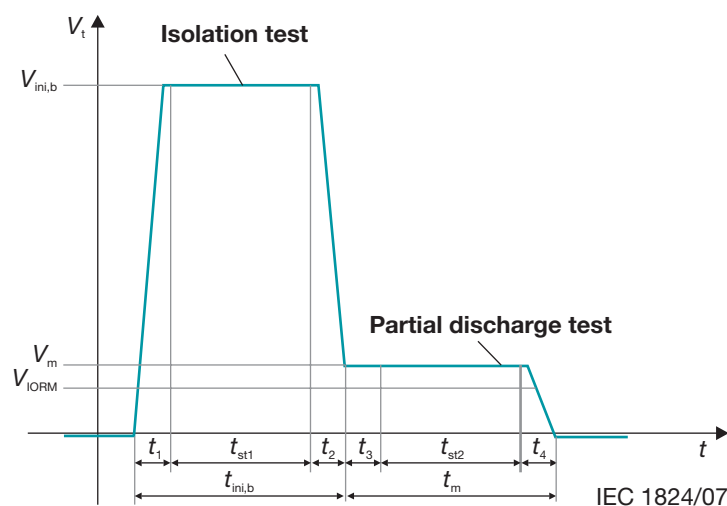


Figure 3: Method-B1 routine production test performed on all parts

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

Histogram – RTB_kVrms

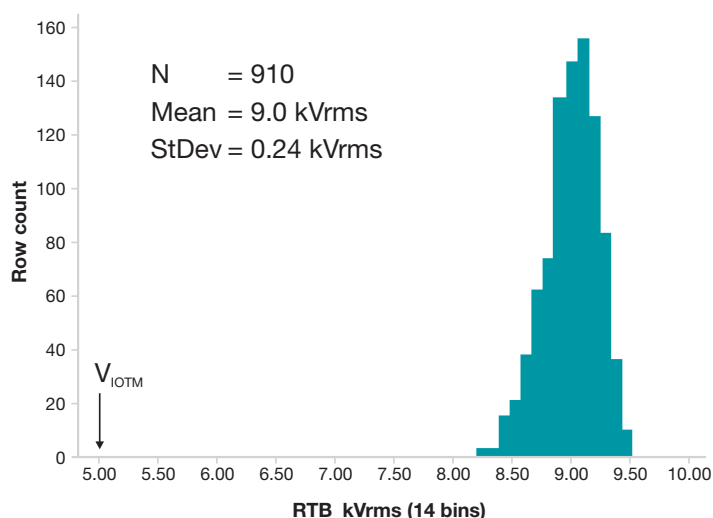


Figure 4: RTB voltage distribution, with 1kVrms/sec ramp rate

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.

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.

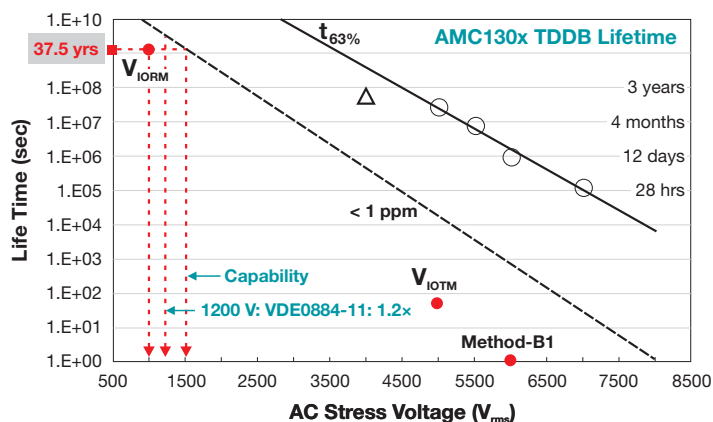


Figure 5: Time Dependent Dielectric Breakdown (TDDB). Circles are the time for 63% of units to break down. The triangle is on-going TDDB testing at 4 kVrms with no units failed as of 17,000 hours

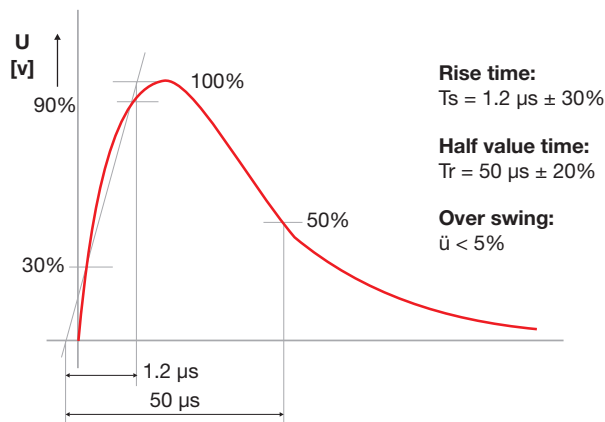


Figure 6: Surge test waveform

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.

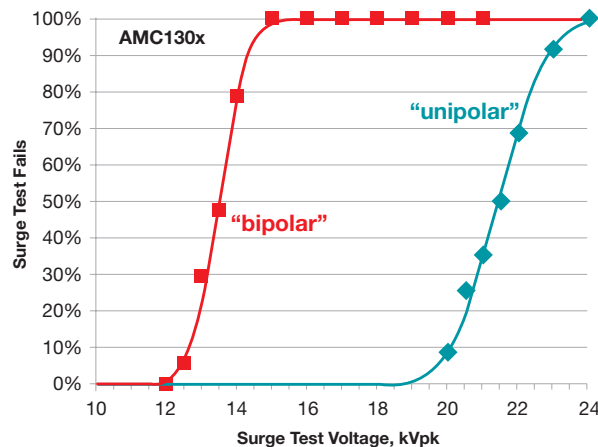


Figure 7: Surge breakpoint statistical assessment, by both “unipolar” and “bipolar” surge test methods

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 TDDDB, 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.
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