

# Analog Technologies, Inc.

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ANHVPS-8 · Rev. A.1

## High-Voltage Power-Supply Spark Protection

### AN APPLICATION NOTE FOR ATI HIGH-VOLTAGE POWER SUPPLIES

Three topologies — protect the supply, energize a spark on purpose, and keep stored energy under control — with named currents, the real self-firing waveform, and a quantified bleeder discharge.

**One-sentence rule.** The series resistor protects the supply; the load capacitor energizes the spark; the bleeder, enclosure, interlock, and measurement record protect the human. Assign each part one job — a circuit that sparks without knowing which part is in charge is a hazard, not a design.

#### **⚠ SAFETY WARNING — ALWAYS DISCHARGE BEFORE YOU TOUCH**

At no point should you touch the high-voltage output, the load capacitor, the cable, or the spark electrodes until they have been discharged. After turning off the supply, always use a ground wand (also called a “chicken stick”) to bleed the output to ground before touching it — every time, without exception. Do not assume the supply’s internal bleed or an external bleeder has done the job: the internal bleed is slow (about a minute) and an external bleeder can fail open silently. Shut down, allow the bleed-down time, hook the grounded wand onto the output to drain any remaining charge, then measure the terminal below 50 V before contact. Treat every high-voltage terminal as live until you have personally bled and grounded it with the chicken stick. Make this a habit, not an exception.

**Scope.** Engineering design guidance for electronic engineers and technicians applying ATI 5 kV high-voltage power supplies with external spark loads, intentional pulse-energy delivery, or credible fault sparks. The worked examples use a single 5 kV working voltage throughout and three named 5 kV ATI models (§1). This is a design method, not a certification standard; higher-voltage parts of the ATI portfolio scale strongly with voltage and require their own per-model limits and testing.

**Prepared for:** Analog Technologies, Inc. · **Revision:** A.1 · **Date:** June 2, 2026 · **Audience:** electronic engineers & technicians

#### **PRELIMINARY CUSTOMER-FACING DESIGN GUIDANCE — WITH STATED ASSUMPTIONS**

Worked values are first-order design aids. Some supply parameters are stated assumptions and the breakdown/arc figures are engineering estimates (see Notation & assumptions, §1). Values marked assumption are placeholders for first-pass calculation only and must be replaced with model-specific or measured data before a result is used in a design file. Application-specific component qualification, safe-access confirmation, and on-fixture measurement remain the integrator’s responsibility (§9, §12). Release-approval status. This note shall not be treated as a released controlled application note until the document owner, technical reviewer, system-safety reviewer, and source-control reviewer have approved the released revision and all controlled-source identifiers have been recorded (see Release approval, §14).

## Abstract

A high-voltage spark is four problems arriving at one terminal at high speed: the supply must survive the transient, the external circuit must control spark-loop current and stored energy, the layout must avoid unintended discharge paths, and the user must be protected from the energy that remains afterward. This note treats spark protection as a topology choice. Mode 0 (direct connection) should be avoided unless the system is rated for that abuse. Mode A adds a high-voltage series resistor so the spark cannot pull unlimited current from the supply. Mode B keeps that resistor and adds a capacitor in parallel with the load when local pulse energy is the goal.

One physical fact governs Mode B and is the most common modelling error in spark work: with a passive gap, the capacitor does not rest at the supply voltage waiting to be fired. It charges, self-fires at the gap’s breakdown voltage  $V_{bd}$ , and partially collapses — a relaxation oscillator. Air breaks down at roughly 3 kV per mm, so a 1 mm gap fires near 3 kV; after firing, the arc holds at a low retaining (extinction) voltage of about 100 V and needs roughly 100 mA to stay lit. The gap voltage is therefore a sawtooth between ~100 V and 3 kV, and the spark

delivers the energy stored between those two levels — not the energy that would be stored at the full 5 kV supply voltage.

The series resistor does double duty here. Sized large enough, it not only protects the supply but also starves the arc so it cannot sustain itself: once the local capacitor has dumped, the resistor cannot pass the ~100 mA the arc needs, the arc extinguishes, and the cycle repeats. This is precisely what makes the sparking repetitive rather than a single sustained discharge (§5).

The distinction matters for ATI products. The portfolio spans roughly 100 V–50 kV with power classes to ~10 kW, and several families — including rack-mount A1U/A2U AC-DC units — advertise built-in arc and short-circuit protection. Representative AHVAC AC-DC datasheets list overcurrent and short-circuit protection (output shutdown) with a short-circuit alarm, yet still instruct users to avoid output short circuits and to insulate the output lead. Internal protection guards the supply within its design envelope; the external circuit still decides spark-loop current, stored energy, EMI, layout stress, discharge time, and human-access risk.

## 1. Covered 5 kV models

This note is written around three ATI 5 kV output models — one for each common input type. The method and worked numbers below apply to all three; the differences that matter for spark design are the input type, the maximum output current, and the package. Confirm the exact ratings, output capacitance, alarm, and shutdown behavior against each model's controlled datasheet before relying on them.

| Model          | Input       | Output | Max current | Type / package                | Notes  |
|----------------|-------------|--------|-------------|-------------------------------|--|
| AHVR12V5KV2MAP | 12 V DC     | 0–5 kV | 2 mA        | I/O-proportional DC-DC module | Output proportional to a 0–5 V control input; short-circuit and overcurrent protection. Confirm the exact ordered part number and input range (12 V vs 15 V variant) before relying on the 2 mA rating (see Ref. 5). |
| AHV24V5KV1MAW  | 24 V DC     | 0–5 kV | 1 mA        | DC-DC module                  | 0–5 V or potentiometer control; electronic shutdown; metal enclosure.  |
| AHVAC5KV5MABT  | 90–230 V AC | 0–5 kV | 5 mA        | AC-DC benchtop unit           | Mains-powered bench supply; overcurrent and short-circuit protection.  |

**Source-control note.** The ATI datasheet served for the proportional 5 kV / 2 mA part is the 15 V-input variant (AHVR15V5KV2MAP, VIN 0–15 V); confirm whether the ordered unit is the 12 V- or 15 V-input version before relying on the input rating. No ATI datasheet for these three models publishes an internal output capacitance or self-bleed time; both remain stated assumptions to confirm from ATI internal data.

### WHY THE INPUT TYPE MATTERS LESS THAN YOU WOULD THINK

For spark protection the supply's rated DC output current (1–5 mA here) is the smallest of the four currents that matter (§2, Fig. 2) and is not what limits the spark. A spark pulls its peak current from local capacitance, not from the supply, so the same external network (series resistor, parallel capacitor, bleeder) applies to all three models. The proportional/control and packaging differences affect how you set and interlock the output, not the spark-loop physics.

## Notation and assumptions

Symbols and the status of every key value used in this note. Confirmed = from ATI product data; estimate = engineering value for an air gap, confirm for the actual geometry; assumption = stated placeholder to confirm per model; selected = example value for the procedure, confirm under the governing safety procedure.

| Symbol | Meaning                              | Value used   | Status                   |
|--------|--------------------------------------|--------------|--------------------------|
| V_HV   | Supply output (working) voltage      | 5 kV         | Confirmed (model rating) |
| V_bd   | Gap breakdown voltage (~3 kV/mm air) | 3 kV at 1 mm | Engineering estimate     |

| Symbol           | Meaning   | Value used     | Status                                  |
|------------------|---|----------------|---|
| V_min            | Arc retaining / extinction voltage                            | 100 V          | Engineering estimate                    |
| I_hold           | Arc retaining current   | 100 mA         | Engineering estimate                    |
| R_series         | External series (current-limit) resistor                      | 5–10 MΩ        | Design choice                           |
| R_bleeder        | External bleeder across the load capacitor                    | ≥10 MΩ rec.    | Design choice                           |
| C_int            | Supply internal output capacitance                            | ≈20 nF         | Stated assumption (per model)           |
| internal bleed   | Supply self-bleed to 50 V after shutdown                      | ≈1 minute      | Stated assumption (per model)           |
| C_load / C_total | External / total load-node capacitance (incl. cable, fixture) | 40–60 nF (ex.) | Application-specific                    |
| V_safe           | Safe-access threshold at the accessible terminal              | 50 V           | Selected (confirm via safety procedure) |

### USE OF ASSUMED VALUES

Values marked assumption are placeholders for first-pass calculation only. If a result depends on an assumed value — most importantly the supply's internal output capacitance ( $C_{int} \approx 20$  nF) and internal self-bleed ( $\approx 1$  minute) — replace that value with model-specific or measured data before using the result for component selection, safe-access timing, service labeling, or design-file approval. The worked tables in §6 and §7 inherit these assumptions; each is flagged again at the point of use.

### TOTAL LOAD-NODE CAPACITANCE (C\_TOTAL)

For energy, firing-rate, and discharge-time calculations,  $C_{total}$  means the sum of all capacitance connected to the high-voltage load node, including the power-supply internal output capacitance, any intentionally added external capacitor, cable capacitance, fixture capacitance, DUT capacitance, and measurement-probe capacitance when present. Underestimating any contributor underestimates both stored energy ( $E = \frac{1}{2} C_{total} \cdot \Delta V^2$ ) and safe-access discharge time ( $t \propto R_{bleeder} \cdot C_{total}$ ), so account for every element on the node, not only the deliberate capacitor.

## 2. A spark is a topology problem, not a parts-list argument

“Add a resistor, or add a capacitor?” is the wrong first question, because the two parts have different jobs. A series resistor adds deliberate impedance between the supply and the discharge. A parallel capacitor stores local energy at the load so the spark draws its peak current locally rather than through the supply. Both are useful — once the topology decides what each is allowed to do.

A water picture makes the roles intuitive: voltage is height, current is flow, resistance is a narrow pipe, capacitance is a tank. Connect a spark straight to the supply reservoir and the supply is dragged into the event; put a long thin pipe in series and the supply sees only a controlled refill; add a local tank after that pipe and it can dump energy into the spark on purpose — but it is now a stored-energy hazard after the event. Note the time axis: current regulation is a long-term function, whereas arcs occur in microseconds and behave like capacitive discharges, so a supply rated for milliamperes can pass amps during an arc. The right question is: what impedance and stored energy does the spark see at the instant it forms?

Figure 1 · The three spark-protection modes

**Figure 1 · The three spark-protection modes**

**Mode 0 — Direct Connection**

[ AVOID ]



No deliberate impedance: the spark draws on the supply and all stray capacitance.

**Mode A — Series Resistor**

[ PROTECT ]



$R_{series}$  caps the current the spark can pull from the HVPS during breakdown.

**Mode B — Series Resistor + Parallel Load Capacitor**

[ ENERGIZE ]



$C_{load}$  sits in parallel (node-to-ground), supplying the fast local spark energy.

Mode 0 is direct and generally unacceptable for repetitive sparks. Mode A adds a series resistor to cap supply current. Mode B keeps the resistor and connects the capacitor in parallel with the load (one lead to the node on the load side of  $R_{series}$ , the other to ground): the local node — not the supply output — provides the fast spark energy. Conceptual schematic; not validation evidence.

Most spark-protection mistakes come from treating four different currents as one. The supply’s rated DC current is the smallest and the only one on the datasheet. The refill current is what the series resistor governs after a discharge. The local spark current is the fast pulse the capacitor and stray capacitance dump into the arc — it can be amps even when the supply is rated for milliamperes, and the series resistor does not limit it. The measured current is the only one that counts as evidence, and only when the probed loop and bandwidth are stated.

**Figure 2 · Four currents that are easy to confuse**

| 1 · Rated DC ( $I_{DC}$ )                                     | 2 · Refill ( $V_{HV}/R$ )   | 3 · Local spark ( $C$ , loop $Z$ )   | 4 · Measured $i(t)$   |
|---|---|--|---|
| Continuous rated current. Steady state. Smallest of the four. | Supply-side current after a discharge. $\tau = RC$ . This is what $R$ limits. | Fast pulse from $C$ (and stray $C$ ) into the arc. ns– $\mu$ s. Amps. $R$ does NOT limit it. | What an instrumented loop records. Valid only if loop & BW stated. The only evidence. |

A series resistor sizes the refill current (2) and protects the supply, but does not set the local capacitive spark current (3), governed by  $C$  and loop impedance. The measured waveform (4) is the only release evidence.

### 3. ATI context: protected supplies still need protected systems

ATI supplies may include internal protection, monitoring, alarms, galvanic isolation, and arc-related features depending on family and model — yet the external circuit determines the severity and repeatability of the spark. The series resistor exists to define external fault current and stored energy, not because the supply is weak.

**CLAIM BOUNDARY**

Internal protection features are model- and configuration-specific. Do not generalize a family-level feature to every SKU; confirm exact behavior, thresholds, and limits from the specific model datasheet and ordered configuration before relying on them.

| ATI source fact   | Evidence     | Design implication   |
|---|--------------|--|
| Portfolio: DC-DC (~100 V–20 kV), AC-DC (~500 V–50 kV), rack-mount A1U/A2U, I/O-proportional, CC/CV capacitor- | Family-level | Treat this note as a system-level method; apply the specific model’s datasheet limits. |

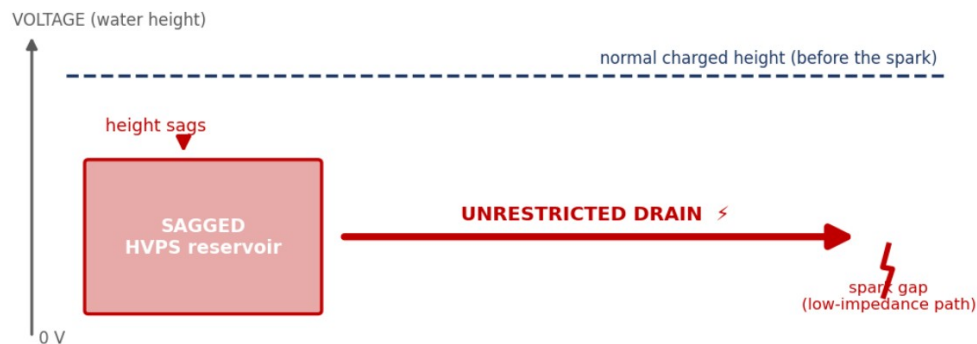
|  |              |  |
|--|--------------|--|
| charging; overall ~100 V–50 kV, to ~10 kW.   |              |  |
| Several families advertise overvoltage, overcurrent, short-circuit, isolation, and arc protection.   | Family-level | Credit internal protection, but it complements — does not replace — external spark-loop design.  |
| AHVAC AC-DC units list overcurrent/short-circuit protection with output shutdown and alarm, while warning against output shorts and calling for lead insulation. | Model-level  | A protected supply does not authorize operation with an uncontrolled arc path; the resistor, layout, and bleeder are the controlled interface. |
| ATI capacitor-charging supplies are CC/CV products for HV energy storage and pulse use.  | Family-level | Mode B is a supported architecture — but the added capacitor is a stored-energy hazard requiring a bleeder and access controls.                |

### 4. Mode 0 and Mode A: keep the supply out of the event

Mode 0 is the accidental topology — the HVPS output reaches a spark-prone load through only stray resistance and parasitics. When the gap fires, the load node collapses, the supply is pulled down, and the transient is decided by stored capacitance and loop impedance, not by a steady-state rating. Many ATI products survive occasional arcs, but repetitive direct arcing can overheat limiting assemblies, inject EMI, stress insulation, and carbonize surfaces. If sparks are expected, put a known impedance between supply and spark before the first breakdown; Mode 0 should trigger redesign, not release.

**Figure 3 · Mode 0 water analogy — the spark drags the supply down**

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*The normal charged height sits at the top; the spark opens a large, unrestricted drain and pulls the HVPS reservoir well below it. This is not a claim that every spark destroys every supply — it is a warning that the external circuit has let the spark*

*The normal charged height sits at the top; the spark opens a large, unrestricted drain and pulls the HVPS reservoir well below it. This is a warning that the external circuit has let the spark choose the current before the supply can manage the event. Conceptual teaching figure; not validation evidence.*

Mode A is the default for incidental or diagnostic sparks. A high-voltage series resistor does not prevent breakdown or hold up the load voltage; it limits the current the HVPS delivers into the channel. Size it from the maximum supply-side fault current, then qualify it as a high-voltage, pulse-energy, spacing, and thermal component — not merely an ohmic value:

$$R_{series} \geq (V_{HV} - V_{arc}) / I_{supply\_fault,max} \quad (\approx V_{HV} / I_{fault} \text{ when } V_{arc} \ll V_{HV})$$

$$P_{R,cont} \approx I_{DC}^2 R_{series} \quad P_{R,fault} \approx V_{HV}^2 / R_{series}$$

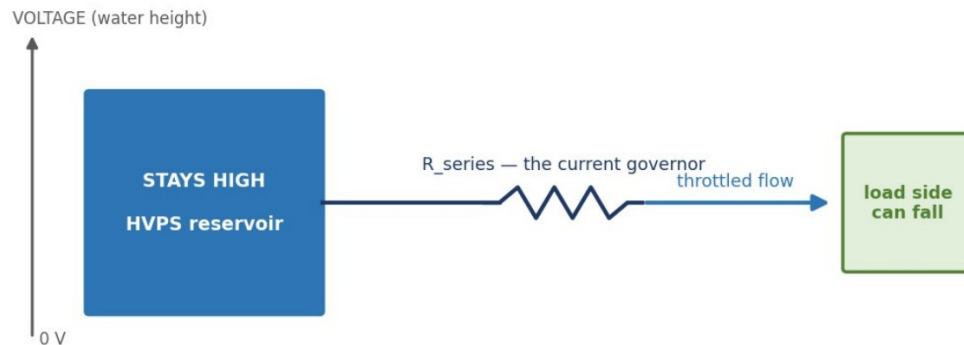
*Applies to first-order current limiting from a 5 kV source through the selected resistor; does not replace pulse-energy, voltage-rating, spacing, or thermal verification. At 5 kV the worst-case fault dissipation  $V_{HV}^2/R$  is 0.5 W at 50 MΩ and 5 W at 5 MΩ — recompute it for the resistor actually used and derate for enclosure temperature. A long series string is often more robust than a single high-stress component, because voltage, heat, and creepage are shared.*

**CONTINUOUS-FAULT POWER IS ONLY ONE STRESS CASE**  
 $V_{HV}^2/R$  is the steady-state dissipation, not the whole story. A self-firing or repetitive spark drives pulse energy and localized heating into the resistor that a DC power figure does not capture, and a long string can redistribute voltage unevenly under fast edges. Qualify the resistor for single-pulse and cumulative pulse

energy, voltage coefficient, and grading — not average power alone. A value of R that is comfortable on paper can still drift or fail under repeated transients.

#### Figure 4 · Mode A water analogy — the series resistor is a long, thin pipe

Figure 4 · Mode A water analogy — the series resistor is a long, thin pipe



*The resistor is the long, thin pipe. The load-side level can fall during breakdown, but the flow from the supply is throttled — which is why the resistor must be chosen as a high-voltage, pulse-energy, spacing, and thermal component, not merely as an ohmic value. Conceptual teaching figure; not validation evidence.*

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#### MODE A STILL PRODUCES A LOCAL PULSE

The resistor governs only the supply-side contribution. Whatever capacitance sits on the load side of the resistor (cable, fixture, stray, and any deliberate capacitor) still discharges through the gap as a fast local pulse. That pulse is a Mode B phenomenon whether or not a capacitor was added on purpose — which is why §5 treats the self-firing waveform as the general case.

## 5. Mode B: resistor plus parallel load capacitor

Mode B is not “more protection”; it is a different machine. The series resistor still limits refill current from the supply, while a capacitor in parallel with the load (Figure 1) provides local pulse energy. It is the right architecture for deliberate pulse-energy work, capacitor-charging systems, plasma experiments, and trigger gaps — and it creates the most obvious stored-energy hazard.

#### HOW A PASSIVE GAP ACTUALLY BEHAVES

A passive spark gap in Mode B is a relaxation oscillator. The capacitor charges through  $R_{series}$  toward  $V_{HV}$ , but the gap fires the instant its voltage reaches the breakdown voltage  $V_{bd}$ . Air breaks down at about 3 kV per mm, so a 0.5–1 mm gap fires at roughly 1.5–3 kV — well below the 5 kV supply. It then dumps through the arc in microseconds and the voltage collapses toward the arc’s retaining (extinction) voltage  $V_{min}$  — about 100 V, not zero. The arc extinguishes, the resistor recharges the capacitor, and the gap voltage traces a sawtooth between  $\sim 100$  V and  $V_{bd}$ , repeating on its own. A capacitor resting at full supply voltage before a commanded discharge describes a triggered gap, not the self-firing gap most bench setups build.

#### WHY IT REPEATS INSTEAD OF STAYING LIT — THE ARC-STARVING RULE

A glow/arc needs a minimum retaining current to stay conducting — on the order of 100 mA at the  $\sim 100$  V retaining voltage for a small air gap. After the capacitor has dumped, the only thing that can feed the arc is the supply through  $R_{series}$ , which can deliver at most  $(V_{HV} - V_{min})/R$ . The arc therefore self-extinguishes — and the sparking is repetitive — only when  $R_{series} > (V_{HV} - V_{min})/I_{hold} \approx (5000 - 100)/0.1 \approx 49$  k $\Omega$ . Any  $R_{series}$  above  $\sim 49$  k $\Omega$  starves the arc and gives clean repetitive sparks; the 5 M $\Omega$  used below is  $\sim 100\times$  past that margin. A resistor smaller than  $\sim 49$  k $\Omega$  would let the supply hold the arc on continuously — a sustained discharge, not a spark train.

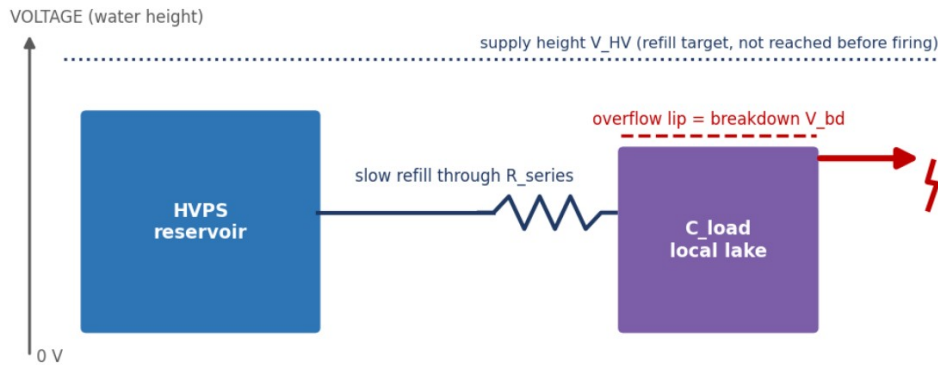
#### NEEDLE-TO-NEEDLE VS NEEDLE-TO-PLANE

Whether the load is two needles or one needle against a ground plane, the breakdown still follows the  $\sim 3$  kV/mm field rule for the same gap spacing, so  $V_{bd}$  stays about the same and the repetitive-spark behavior is

unchanged. Geometry mainly shifts the field concentration and the exact  $V_{bd}$  (sharper points lower it slightly); it does not turn a self-firing gap into a non-firing one as long as the capacitor and series resistor are present.

**Figure 5 · Mode B water analogy — a local energy lake that overflows at breakdown**

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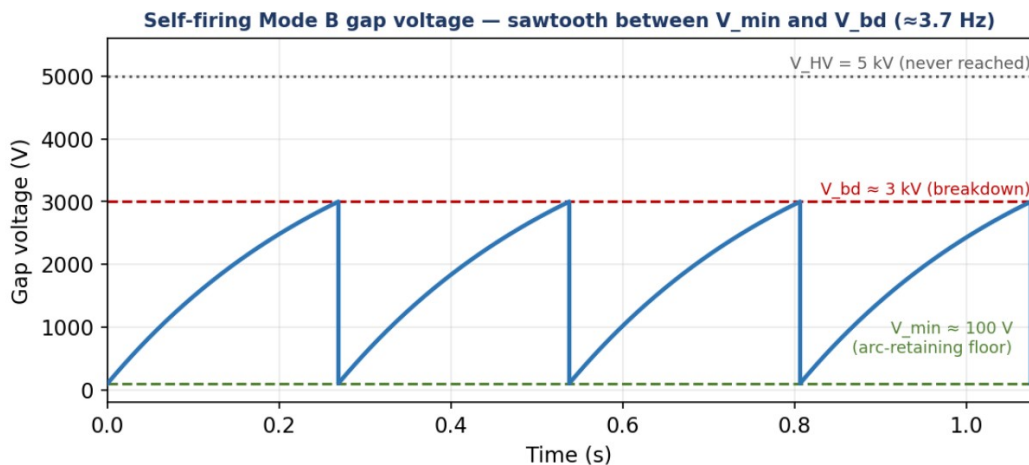


The local lake fills through the thin pipe ( $R_{series}$ ) but spills the moment it reaches the overflow lip at  $V_{bd}$  — it never rises all the way to the supply height before firing. Each overflow is one spark; the lake then refills and spills again. It does not drain fully — a small residual ( $V_{min} \approx 100\text{ V}$ ) remains each cycle. Bigger lake → bigger lightning per spark and slower refill; a lower lip (sharper electrodes, closer gap) → more frequent, smaller sparks. Conceptual teaching figure; not validation

The local lake fills through the thin pipe ( $R_{series}$ ) but spills the moment it reaches the overflow lip at  $V_{bd}$  — it never rises all the way to supply height before firing. Each overflow is one spark; the lake refills and spills again, never draining fully ( $V_{min} \approx 100\text{ V}$  remains). Bigger lake → bigger spark, slower refill; lower lip → more frequent, smaller sparks. Conceptual teaching figure; not validation evidence.

**Figure 6 · The Mode B gap-voltage waveform is a sawtooth that floors at  $V_{min}$**

**Figure 6 · The Mode B gap-voltage waveform is a sawtooth that floors at  $V_{min}$**



Gap voltage in a self-firing Mode B loop (illustrative: 5 kV supply,  $R_{series} = 5\text{ M}\Omega$ , total  $C = 60\text{ nF}$ ,  $V_{bd} = 3\text{ kV}$ ,  $V_{min} = 100\text{ V} \rightarrow \approx 3.7\text{ Hz}$ ). The capacitor charges toward  $V_{HV}$  (dotted, never reached), fires at the 3 kV breakdown line, and collapses to the  $\sim 100\text{ V}$  arc-retaining floor — not to zero — before recharging. Figure 6 is an idealized model used for sizing and explanation; waveform evidence on the assembled fixture is required when energy, timing, EMI, or safety margins are design-critical (§9)

Gap voltage in a self-firing Mode B loop (illustrative: 5 kV supply,  $R_{series} = 5\text{ M}\Omega$ , total  $C = 60\text{ nF}$ ,  $V_{bd} = 3\text{ kV}$ ,  $V_{min} = 100\text{ V} \rightarrow \approx 3.7\text{ Hz}$ ). The capacitor charges toward  $V_{HV}$  (dotted, never reached), fires at the 3 kV breakdown line, and collapses to the  $\sim 100\text{ V}$  arc-retaining floor — not to zero — before recharging. Idealized model; waveform evidence on the assembled fixture is required when energy, timing, EMI, or safety margins are design-critical (§9).

### Energy and rate (corrected for a nonzero retaining voltage)

The energy, charge, and time-constant relations are standard; what matters is which voltages go into them. Because the capacitor swings between the retaining voltage  $V_{min}$  and the breakdown voltage  $V_{bd}$  rather than between 0 and  $V_{HV}$ :

$$E_{\text{spark}} = \frac{1}{2} C (V_{\text{bd}}^2 - V_{\text{min}}^2) \quad \tau = R_{\text{series}} C$$

$$t_{\text{charge}} = R_{\text{series}} C \cdot \ln[ (V_{\text{HV}} - V_{\text{min}}) / (V_{\text{HV}} - V_{\text{bd}}) ] \quad f \approx 1 / t_{\text{charge}}$$

Capacitor-energy and firing-rate formulas apply to the measured or controlled total load-node capacitance and the measured swing from  $V_{\text{bd}}$  to  $V_{\text{min}}$ ; the rate formula applies only when the circuit behaves as an RC charge to breakdown followed by rapid collapse — verify by waveform capture. Self-firing relaxation gap;  $V_{\text{min}} \approx 100 \text{ V}$ ,  $V_{\text{bd}} \approx 3 \text{ kV}$  (1 mm air gap at  $\sim 3 \text{ kV/mm}$ ), with  $V_{\text{HV}} > V_{\text{bd}} > V_{\text{min}}$ .

**USE  $V_{\text{BD}}$  AND  $V_{\text{MIN}}$ , NOT  $V_{\text{HV}}$**   
 Per-spark energy is  $\frac{1}{2}C(V_{\text{bd}}^2 - V_{\text{min}}^2)$ , not  $\frac{1}{2}C V_{\text{HV}}^2$ . At 5 kV with a 3 kV gap and 40 nF, that is  $\approx 180 \text{ mJ}$  delivered, versus the  $\approx 500 \text{ mJ}$  a flat-charge (0  $\rightarrow$  5 kV) assumption would predict — roughly a 3 $\times$  overstatement. The 100 V retaining floor changes the energy only slightly, but it is real stored charge on every cycle, so the capacitor is never fully safe between sparks. Only a triggered gap, fired near full charge, approaches  $\frac{1}{2}C V_{\text{HV}}^2$ .

Worked at 5 kV with  $V_{\text{bd}} = 3 \text{ kV}$  and  $V_{\text{min}} = 100 \text{ V}$  (total C includes the supply’s assumed  $\sim 20 \text{ nF}$  internal output capacitance plus any external capacitor):

| Loop (5 kV)                            | $\tau = RC$ | $E_{\text{spark}}$       | Self-firing rate $f$  |
|--|-------------|--------------------------|---|
| 5 M $\Omega$ , 20 nF (internal only)   | 100 ms      | $\approx 90 \text{ mJ}$  | $\approx 11 \text{ Hz}$ — internal output capacitance alone, no external capacitor.           |
| 5 M $\Omega$ , 60 nF (20 int + 40 ext) | 300 ms      | $\approx 270 \text{ mJ}$ | $\approx 3.7 \text{ Hz}$ — deliberate 40 nF dominates; bigger, slower, more energetic sparks. |
| 10 M $\Omega$ , 40 nF                  | 400 ms      | $\approx 180 \text{ mJ}$ | $\approx 2.8 \text{ Hz}$ — larger resistor lowers both refill current and rate.               |

**REPLACE ASSUMED  $C_{\text{INT}}$  BEFORE USING THESE NUMBERS**  
 The “internal only” rows depend on the assumed  $C_{\text{int}} \approx 20 \text{ nF}$  and the total-C entries inherit it. If these model-specific values are not confirmed, replace them before applying the numerical examples — the energy scales with C and the rate with RC, so an incorrect  $C_{\text{int}}$  shifts every result here.

| Gap type                             | Firing & waveform   | Rate / energy model   |
|--------------------------------------|---|---|
| Self-firing (passive gap)            | Fires at $V_{\text{bd}} \approx 3 \text{ kV} < V_{\text{HV}}$ ; sawtooth; jitters with air, humidity, electrode wear. | $f = 1/[RC \cdot \ln((V_{\text{HV}} - V_{\text{min}})/(V_{\text{HV}} - V_{\text{bd}}))]$ ; $E = \frac{1}{2}C(V_{\text{bd}}^2 - V_{\text{min}}^2)$ . |
| Triggered (third electrode / driver) | Held off, then commanded to fire near full charge; rate set by the trigger.   | Rate = trigger rate ( $\leq RC$ recovery ceiling, $3\tau \approx 95\%$ , $5\tau \approx 99\%$ ); E up to $\frac{1}{2}C V_{\text{HV}}^2$ .           |

**THESE ARE NOT INTERCHANGEABLE**  
 A capacitor chosen for a triggered 0.5 J pulse at 5 kV delivers a smaller self-firing pulse because the gap fires at  $\sim 3 \text{ kV}$ , not 5 kV. Conversely, a small capacitor chosen for fast self-firing can produce a high repetition rate that stresses the resistor, electrodes, enclosure, insulation, and supply recovery. State which mode the design uses before sizing parts.

**$V_{\text{BD}}$  AND  $V_{\text{MIN}}$  ARE DISTRIBUTIONS, NOT SINGLE NUMBERS**  
 Breakdown is stochastic.  $V_{\text{bd}}$  and  $V_{\text{min}}$  move shot-to-shot with electrode shape, spacing, wear, humidity, pressure, contamination, polarity, and discharge history, so the 3 kV and 100 V values are representative, not exact. For a real design, measure them as a distribution (min/typical/max) on the intended fixture and propagate that spread into the energy and rate estimates rather than quoting one figure.

## 6. One voltage, three design intents (5 kV)

The rows below are examples, not product ratings. They depend on the stated internal-capacitance, air-gap, and residual-voltage assumptions; replace those values before using the table as a design record. Fixing a single working voltage and varying only the design intent makes the trade-offs clear.

| Design intent (5 kV)      | $R_{\text{series}}$ | Refill I            | Fault P | Total C                    | $E_{\text{spark}}$      | Practical meaning   |
|---------------------------|---------------------|---------------------|---------|----------------------------|-------------------------|---|
| A · Incidental protection | 5 M $\Omega$        | $\sim 1 \text{ mA}$ | 5 W     | $\sim 20 \text{ nF}$ (int) | $\approx 90 \text{ mJ}$ | No external capacitor; the $\sim 20 \text{ nF}$ still self-fires at $\approx 11 \text{ Hz}$ |

| Design intent (5 kV) | R_series | Refill I | Fault P | Total C       | E_spark | Practical meaning   |
|----------------------|----------|----------|---------|---------------|---------|---|
|                      |          |          |         |               |         | through a 3 kV gap. R starves the arc.  |
| B · Energy-led       | 5 MΩ     | ~1 mA    | 5 W     | 60 nF (20+40) | ≈270 mJ | A deliberate 40 nF raises per-spark energy ~3×; rate drops to ≈3.7 Hz. Bigger, slower, more hazard. |
| B · Lower-rate       | 10 MΩ    | ~0.5 mA  | 2.5 W   | 40 nF         | ≈180 mJ | Larger resistor halves refill current and power and lowers the rate to ≈2.8 Hz.                     |

**ILLUSTRATIVE ONLY**

First-pass calculations, not ATI product ratings, certifications, or measured data. Binding numbers come from the specific model datasheet, the governing safety standard, and the measured fixture. Fault power is the worst-case steady dissipation  $V_{HV}^2/R$  if the output is held shorted; refill current is  $(V_{HV}-V_{min})/R$  at the start of recharge. Both are well within the arc-starving condition of §5, so all three rows give clean repetitive sparks. The Total-C column depends on the assumed ~20 nF internal capacitance; confirm per model before use.

## 7. Bleeder discharge: residual decay and the mandatory measurement

Saying a charged capacitor is dangerous is not enough; the design must say how long it stays dangerous. With a bleeder  $R_{bleeder}$  across  $C$ , the residual decays exponentially and the time to a chosen safe-access threshold  $V_{safe}$  is a logarithm:

$$V(t) = V_0 \cdot e^{(-t / (R_{bleeder} C))}$$

$$t_{safe} = R_{bleeder} C \cdot \ln( V_0 / V_{safe} )$$

*Bleeder-decay applies only to the node actually connected to the bleeder — verify at the accessible terminal.*  $V_0$  = voltage at shutdown (assume up to  $V_{HV}$  for a conservative service procedure);  $V_{safe}$  = the selected 50 V safe-access threshold (§11; confirm under the governing safety procedure). The bleeder must be rated for the full working voltage and for its standing dissipation  $V_{HV}^2/R_{bleeder}$ .

**INTERNAL VS EXTERNAL CAPACITANCE AND BLEED**

Stated assumption (confirm per model; replace before use): the supply has an internal output capacitance of ≈20 nF and an internal self-bleed path that pulls its own output down to ~50 V in roughly 1 minute after shutdown — a very gentle internal bleeder (~650 MΩ, ~40 mW), so the supply's own terminal stays hazardous for about a minute, not seconds. That internal bleed does not drain a capacitor you add on the load side of  $R_{series}$ : the series resistor isolates your external capacitor from the supply's internal bleeder. Any external load capacitor therefore needs its own bleeder across it, sized for the total load-node capacitance. A ~5 MΩ external bleeder (~1 s) is ~100× stiffer than the internal path and dominates the load-node decay. Confirm the actual discharge curve at the accessible terminal before relying on any wait time.

The standing bleeder current is the binding constraint, not just the decay time: it draws  $V_{HV}/R_{bleeder}$  from the supply whenever the output is energized, and that counts against the model's rated output current (1/2/5 mA). For the 1 mA unit,  $R_{bleeder} \geq \sim 10$  MΩ (0.5 mA, leaving headroom):

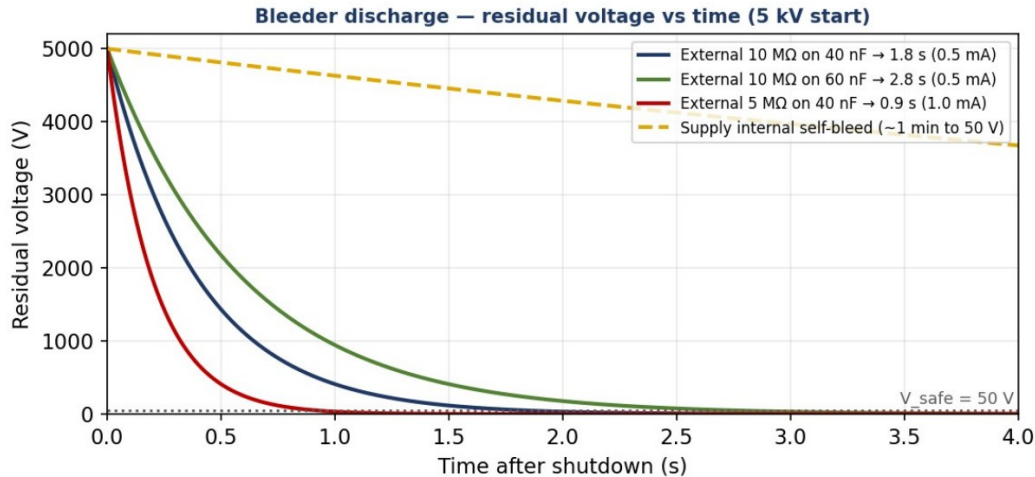
| External cap        | R_bleeder | $\tau = RC$ | t to 50 V | Standing I | Standing P | Note   |
|---------------------|-----------|-------------|-----------|------------|------------|--|
| 40 nF               | 10 MΩ     | 0.40 s      | ≈1.8 s    | 0.50 mA    | 2.5 W      | Recommended starting point — safe standing current on all three example models.              |
| 60 nF (incl. cable) | 10 MΩ     | 0.60 s      | ≈2.8 s    | 0.50 mA    | 2.5 W      | Larger load; same bleeder, slightly longer wait.   |
| 40 nF               | 5 MΩ      | 0.20 s      | ≈0.9 s    | 1.00 mA    | 5.0 W      | Faster, but 1 mA standing current is at the limit of the 1 mA unit — only the 2/5 mA models. |

For the example cases, a 10 MΩ bleeder (0.5 mA, 2.5 W) is the recommended starting point, subject to verification of model rating, total load-node capacitance, duty cycle, thermal design, component rating, and service procedure; it gives a ~1.8 s decay for 40 nF, well inside a practical service wait. Like the series resistor,

the bleeder must be a 5 kV, multi-watt high-voltage part (§10). Decay time is set by the total load-node capacitance, so include cable and fixture capacitance; the safe-access threshold is the selected 50 V value and the full procedure is in §11.

**Figure 7 · Bleeder discharge — residual voltage vs time (5 kV start)**

**Figure 7 · Bleeder discharge — residual voltage vs time (5 kV start)**



*External-bleeder discharge from a 5 kV start to the 50 V safe-access threshold (early-time zoom: the 4 s window shown captures the external-bleeder decay; the internal self-bleed does not reach 50 V within this window). A 10 MΩ bleeder (0.5*

*External-bleeder discharge from a 5 kV start to the 50 V safe-access threshold. A 10 MΩ bleeder (0.5 mA standing current — the recommended starting point) reaches 50 V in ~1.8 s for 40 nF; a 5 MΩ part is faster (~0.9 s) but its 1 mA standing current is only acceptable on the 2/5 mA units. The supply's internal self-bleed (dashed) is ~100× weaker and takes about a minute, so it cannot make an external capacitor safe. Measure at the accessible terminal, never assume.*

## 8. Layout, grounding, and the parts not on the schematic

At high voltage and fast edges, the schematic is the polite version of the circuit. The real circuit includes cable capacitance, stray inductance, ground-return impedance, fixture geometry, dirt, and humidity. Keep the high-current loop short and local — especially in Mode B — and make the supply see the event through the series resistor, not through an accidental low-impedance shield, chassis, or measurement path. An external series limiting resistor also reduces the short-circuit discharge current and the stress on the supply's internal limiter.

### ARC-DETECTION BLIND SPOT

The same external resistor that protects the supply can drop the short-circuit discharge current below the threshold of the supply's own arc-detection circuit, so the supply may never register an arc that is still energetic at the load. The absence of an internal trip or alarm is not evidence that the load-side event was safe. Where this matters, do not rely on the supply's status indicators; use a measured spark-loop waveform, and add external detection, interlocks, or conservative fixture design as appropriate.

**Figure 8 · The hidden schematic: parasitics and accidental return paths**

**Rule: if a return path was not intentionally designed, assume the spark will find one anyway.**

| Cable capacitance  | Shield / chassis current  | Loop inductance   | Contamination & corona  |
|--|---|---|---|
| HV cable stores charge and can join the spark even with no deliberate capacitor. | A convenient shield can become an unintended low-impedance return path. | Fast edges produce voltage where the schematic shows only a wire. | Dust, humidity, sharp metal, and carbon tracks are unofficial circuit elements. |

*Cable capacitance, shield/chassis return current, loop inductance, and contamination/corona are real circuit elements even though they appear on no schematic.*

## 9. Verification: what to measure when the fixture is built

A series resistor — and, in Mode B, a parallel capacitor — does not make a design automatically safe. The behavior becomes trustworthy only when the assembled fixture is measured. This section defines the

measurement set the integrator should capture and record in the project file, now with explicit pass/fail acceptance criteria so the table can be used directly as a design-review checklist.

| Item                            | Measure / inspect   | Pass / fail acceptance criterion  | Owner              |
|---------------------------------|---|---|--------------------|
| Peak spark current              | Current in the intended loop with a rated probe/shunt; state bandwidth and placement.             | PASS if measured peak stays within the design limit and the raw trace is retained; FAIL if loop/BW unstated.  | Test Engineering   |
| Gap firing & rate               | Gap voltage at firing ( $V_{bd}$ ), residual ( $V_{min}$ ), and repetition rate over many cycles. | PASS if the sawtooth matches predicted relaxation behavior and energy = $\frac{1}{2}C(V_{bd}^2 - V_{min}^2)$ within margin.                         | Test Engineering   |
| Supply droop & recovery         | Supply output during repetitive sparks.   | PASS if recovery is stable and within the operating envelope.   | Design + Test Eng. |
| Resistor stress                 | Thermal rise and value drift after a representative pulse sequence.                               | PASS if temperature margin and drift are within derated limits.   | Component Eng.     |
| Capacitor / load-node discharge | Voltage at the accessible terminal after shutdown and after the bleeder time.                     | PASS if accessible voltage is below the approved threshold within the specified wait, with margin; FAIL if it depends on unverified internal bleed. | Safety + Test Eng. |
| Total load-node capacitance     | Measure $C_{total}$ incl. cable, fixture, DUT, probe.   | PASS if measured/controlled $C_{total}$ is used in all energy, rate, and decay calculations; FAIL if assumed $C_{int}$ is used unconfirmed.         | Test Engineering   |
| Interlock & insulation          | Door/cover/E-stop, ground bond, creepage, clearance, contamination.                               | PASS if opening the enclosure removes energy and no corona or tracking is present.  | Safety Engineering |

#### VERIFICATION CRITERION

A calculation may support design selection, but it does not close a verification item until the project file contains the measured value, the pass/fail criterion, the instrument method, the owner, the date, and reviewer approval.

## 10. Component selection

Ohmic value and capacitance are the easy part; high-voltage parts fail by voltage stress, pulse energy, spacing, contamination, and failure mode. Voltage rating alone is insufficient. Specific limits are application-dependent and verified on the fixture (§9).

| Part                    | Specify and verify  |
|-------------------------|---|
| Series resistor         | HV-rated technology for repetitive pulses (not DC-average only); per-element voltage rating with a graded string where needed; single-pulse and cumulative pulse-energy margin; continuous power $I_{DC}^2R$ derated for enclosure temperature; voltage coefficient; creepage/clearance for pollution degree; defined fail-open/fail-short behavior.    |
| Load capacitor (Mode B) | DC working-voltage rating with margin above $V_{HV}$ and adequate voltage reversal for ringing; peak/RMS discharge current, ESR, and ESL rated for the intended $dV/dt$ and rate; dielectric suited to fast discharge (dielectric absorption understood); defined low-inductance discharge path and safe failure mode. Sourcing examples in Appendix B. |
| Bleeder & return path   | Voltage rating and standing dissipation $V_{HV}^2/R_{bleeder}$ ; consider redundancy so a single open bleeder is not silent; residual verified at the accessible terminal, not an internal node; documented return-current map and shield/chassis bond; defined current-loop measurement insertion point.   |

### Recommended series resistor (~5 M $\Omega$ , $\geq$ 5 W, 5 kV)

A single resistor rated for the full 5 kV stand-off and 5 W is possible, but a series string of smaller high-voltage resistors is usually more robust: each element sees a fraction of the voltage, and heat and surface creepage are shared. The simplest approach uses five 1 M $\Omega$ , 1 W high-voltage resistors in series — total 5 M $\Omega$ , 5 W, with each element holding only ~1 kV. Use HV-rated thick-film parts (Ohmite MOX / Caddock MX series), not ordinary axial resistors, which flash over and drift under high field. Detailed part numbers and indicative pricing are in Appendix A.

## Recommended external bleeder (~10 MΩ, ≥3 W, 5 kV)

The bleeder's standing current  $V_{HV}/R$  is drawn from the supply whenever the output is on, so it must stay well under the model's rated output current (§7). For the 1 mA unit that requires  $R_{bleeder} \geq \sim 10 \text{ M}\Omega$ . For the three example models, 10 MΩ (0.5 mA, 2.5 W) is the recommended starting point, subject to verification of model rating, total load-node capacitance, duty cycle, thermal design, component rating, and service procedure; it gives a ~1.8 s decay for 40 nF. Build it as a 5 kV, multi-watt high-voltage string, and keep it connected across the load capacitor whenever the capacitor can be charged.

### CONFIRM PER APPLICATION

The parts above are recommended starting points for the 5 kV, ~5 MΩ / ~5 W case; exact part numbers, tolerances, derating margins, and the gap/electrode/enclosure selections are confirmed by the integrator for the specific configuration. The checklist is the method; the chosen parts and their margins belong in the project design file.

## 11. Design-review checklist and safe access

| Question                        | Mode A   | Mode B  |
|---------------------------------|--|---|
| Spark's intended job?           | Incidental, tolerated, or diagnostic.                              | Intentional pulse-energy event.   |
| Self-firing or triggered?       | Usually self-firing on stray C; fires at $V_{bd}$ .                | State which; it sets the energy/rate model (§5).                              |
| What limits supply current?     | $R_{series}$ , sized for current, voltage, pulse, thermal, layout. | $R_{series}$ limits recharge; $C_{load}$ supplies the pulse.                  |
| Where is the stored energy?     | Parasitic, supply, cable capacitance.                              | In $C_{load}$ plus cable/fixture capacitance.                                 |
| How is residual energy removed? | Bleeder may be needed for cable/load capacitance.                  | Bleeder, interlock, warning label, and measured discharge time are mandatory. |

### SAFE-ACCESS SEQUENCE — 50 V SELECTED THRESHOLD, TO BE CONFIRMED BY THE SYSTEM SAFETY AUTHORITY

This note uses 50 V at the accessible terminal as the safe-access threshold for the example procedure. The 50 V value and this sequence are an example requiring approval by the Responsible System Safety Authority under the governing ATI high-voltage service-access procedure (Ref. 4); they do not by themselves constitute an approved safety standard. Follow this sequence every time before contact:

(1) Shut down the supply and remove input power. (2) Wait for the bleeder discharge interval ( $\geq t_{safe}$  for the total load-node capacitance — at least ~1 s for a correctly bleedered external capacitor, and allow ~1 minute for the supply's own slow internal bleed if no external bleeder is fitted). (3) Measure the residual voltage at the exposed terminal with a rated HV probe and confirm it is below the approved threshold. (4) Apply lockout/tagout. (5) Bleed the output to ground with a ground wand ("chicken stick") and leave a grounding strap on the node while working.

A timer alone never proves safety — the measurement in step 3 is mandatory because a failed-open bleeder, a disconnected load, or dielectric absorption can leave a terminal charged after the expected wait, and the manual ground in step 5 is the final required protective step that shall remain in place while work is performed. It is the final independent protective control, not a substitute for steps 1–4. Label the enclosure with the stored-energy hazard and the measure-before-touch requirement.

## 12. Integrator checklist and stated assumptions

This note is released as design guidance. The values below are either confirmed against ATI product data and standard high-voltage practice, or are stated assumptions/estimates the integrator should confirm before committing a design. Application-specific confirmations are the integrator's responsibility; this note does not constitute ATI validation of the final fixture, enclosure, interlock, or service procedure.

| # | Item                                      | Status in this note   | Integrator action   | Owner                    |
|---|---|---|---|--------------------------|
| 1 | Model ratings (V, I)                      | From ATI product pages for the three named 5 kV models (§1, Refs 5–7).                | Verify against the controlled datasheet for the ordered configuration.  | System Integrator        |
| 2 | Internal output capacitance ( $C_{int}$ ) | Stated assumption $\approx 20 \text{ nF}$ ; affects energy, charge time, firing rate, | Use a model-specific controlled or measured value for the ordered unit. | Integrator + ATI Product |

| # | Item                            | Status in this note  | Integrator action  | Owner                         |
|---|---------------------------------|--|--|-------------------------------|
|   |                                 | bleeder sizing, total C.   | Do not use the example value for design-file approval.   | Eng.                          |
| 3 | Internal self-bleed             | Stated assumption ~1 min to 50 V; affects supply-side discharge timing only.                 | Use a measured discharge curve at the accessible terminal. Do not assume it drains a load-side capacitor isolated by R_series. | Integrator + ATI Product Eng. |
| 4 | V_bd, V_min, I_hold             | Engineering estimates (3 kV/mm, 100 V, 100 mA) for an air gap.                               | Confirm for the actual electrode geometry and environment; measure if energy/rate is critical.                                 | System Integrator             |
| 5 | Series resistor / bleeder parts | Recommended starting points (Ohmite MOX, Caddock MX); pricing in Appendix A.                 | Qualify for voltage, pulse energy, derating, creepage, and failure mode.   | System Integrator             |
| 6 | Safe-access threshold           | Selected 50 V with measure-before-touch (§11), to be confirmed by the safety authority.      | Confirm threshold under the governing safety procedure; add site LOTO and labeling.  | Integrator + Safety           |
| 7 | Arc-detection blind spot        | Warned (§8): the series resistor can hide a load-side event from the supply's arc detection. | Do not rely on supply status for load-side safety; use the measured waveform and interlocks.                                   | System Integrator             |

### 13. Conclusion

A spark turns a high-impedance node into a fast, low-impedance discharge path. In Mode 0 it drags on the supply; in Mode A a series resistor makes the supply see the fault through a defined impedance; in Mode B a parallel load capacitor becomes a deliberate local energy reservoir — stronger sparks, but a stored-energy hazard. In any passive Mode B loop the gap is a relaxation oscillator: it self-fires at V\_bd, collapses to a small residual, and repeats, so the waveform is a sawtooth and the per-spark energy is set by V\_bd and V\_min, not by V\_HV. The rule is short: protect the supply with impedance, energize intentional sparks locally, model the gap as the relaxation oscillator it is, and confirm the design by measurement before relying on it.

Treat the equations here as screening tools, not proof of safety. The final system shall be released only after the project file contains confirmed model data, measured load-node capacitance, measured spark-waveform behavior, verified component stress, verified residual-voltage decay, and an approved service-access procedure. Supply protection, load behavior, and operator protection shall each be closed independently — supply survival is not operator safety.

#### TO BE VERIFIED PER DESIGN

The worked values here are first-order design aids for the 5 kV models named in §1; the assumed C\_int ≈ 20 nF and ~1-minute internal self-bleed must be replaced with confirmed model data before use; and the 50 V safe-access threshold and its procedure (§11) are selected example values, to be confirmed by the system safety authority. Because spark breakdown is stochastic and fixture-dependent, confirm the actual V\_bd, V\_min, peak current, rate, resistor temperature, and discharge time on the assembled hardware (§9) and qualify the specific resistor, capacitor, and bleeder parts.

### 14. Release approval and document control

This note is preliminary customer-facing design guidance. It becomes a released controlled application note only when the approval block below is complete and all controlled-source identifiers (References) have been recorded.

| Control field      | Value   |
|--------------------|---|
| Document number    | ANHVPS-8 (assign internal control number on issue).   |
| Release status     | Preliminary customer-facing design guidance with stated assumptions — controlled ATI source identifiers pending release-control completion. |
| Document owner     | ATI Document Owner / Applications Engineering — name and department recorded at issue.  |
| Technical reviewer | Engineering reviewer responsible for equations, topology, and component guidance — recorded at issue.                                       |

| Control field           | Value   |
|-------------------------|---|
| Safety reviewer         | Responsible System Safety Authority for the safe-access threshold, grounding sequence, and service wording — recorded at issue.                     |
| Source-control reviewer | Document Control function confirming datasheet identifiers, revisions, release dates, and archived URLs — recorded at issue.                        |
| Effective date          | Date after approval (not the draft preparation date).   |
| Revision trigger        | Any change to a model datasheet, internal capacitance or self-bleed value, sourcing list, or governing safety procedure requires document revision. |

### RELEASE-APPROVAL STATEMENT

This technical note shall not be treated as a released controlled application note until the document owner, technical reviewer, system-safety reviewer, and source-control reviewer have approved the released revision and all controlled-source identifiers have been recorded. This wording allows the document to be useful during engineering review while preventing it from being mistaken for a completed, safety-approved publication.

### Stated assumptions

Internal output capacitance  $\approx 20$  nF and  $\sim 1$ -minute internal self-bleed (per model, replace before use);  $V_{bd} = 3$  kV/mm,  $V_{min} = 100$  V,  $I_{hold} = 100$  mA as engineering estimates; 50 V safe-access threshold as a selected example value to be confirmed by the safety authority.

### References and source control

Model-specific parameters are controlled only by the applicable ATI released datasheet or product-control record. The controlled-source column gives the record to be cited in the released design file; until each controlled identifier is recorded, the corresponding model-specific value remains preliminary. Public-page evidence is retained in the internal release dossier and is summarized, not reproduced, here.

| # | Source  | Controlled record / status  |
|---|---|---|
| 1 | ATI High Voltage Power Supplies family overview (DC-DC, AC-DC, rack-mount A1U/A2U, I/O-proportional, capacitor-charging; $\sim 100$ V– $50$ kV, to $\sim 10$ kW). | Controlled family-overview record — identifier and revision recorded in the release dossier at issue.   |
| 2 | AHVAC AC-DC HVPS datasheets — overcurrent/short-circuit protection with output shutdown and alarm; output-short and lead-insulation guidance.                     | Controlled AC-DC datasheet set — document numbers and revisions recorded at issue.  |
| 3 | ATI 12 V / 24 V capacitor-charging HVPS families (CC/CV, to 50 kV) — context for Mode B energy storage.   | Controlled capacitor-charging family record — recorded at issue.  |
| 4 | ATI system-safety procedure for high-voltage service access — residual-voltage threshold, measurement method, grounding method, LOTO sequence.                    | Controlled safety procedure — governs the §11 safe-access threshold; revision recorded at issue.  |
| 5 | AHVR12V5KV2MAP — I/O-proportional DC-DC HVPS, 0–5 kV / 2 mA; short-circuit/overcurrent protection.  | Served datasheet is the 15 V-input variant (AHVR15V5KV2MAP, VIN 0–15 V), “Updated 8/13/2024.” Confirm 12 V vs 15 V input for the ordered part. Internal C / self-bleed not published. |
| 6 | AHV24V5KV1MAW — DC-DC HVPS, 24 V $\pm 1$ V in, 0–5 kV / 1 mA, 0–5 V / pot control, electronic shutdown, metal enclosure.  | 24 V DC-DC HVPS selection-guide series, “Updated 9/14/2024.” Confirm single-model controlled datasheet number at issue. Internal C / self-bleed not published.                        |
| 7 | AHVAC5KV5MABT — AC-DC benchtop HVPS, 90–230 V AC in, 0–5 kV / 5 mA; overcurrent/short-circuit protection.   | Family verified against sibling AHVACN5KV1MABT, “Updated 3/3/2021.” Confirm exact controlled datasheet number and revision at issue. Internal C / self-bleed not published.           |
| 8 | Ohmite MOX / Maxi-Mox / Slim-Mox HV thick-film resistor datasheets; Caddock MX series; distributor stock at DigiKey / Mouser.                                     | External component references — record manufacturer datasheet revision in the design file at part selection.  |

*Citation note. Family-level statements are kept separate from model-level requirements. Each model-specific claim is controlled only once its controlled-record field is completed in the release dossier. No document or revision numbers have been invented.*

## Appendix A · Resistor and bleeder sourcing examples (nonbinding)

### SOURCING MAINTENANCE RULE

Nonbinding sourcing examples, not part of the controlled design recommendation. Prices are indicative single-unit distributor estimates as of mid-2026 and age quickly. Appendix part examples shall be reviewed at least every six months and before every controlled procurement release; the maintenance owner (Component Engineering / Purchasing Engineering) shall record the review date, manufacturer datasheet revision, distributor access date, and disposition of any obsolete items. Final part selection shall be based on current manufacturer datasheets, procurement records, and application-specific qualification (§9, §10).

### Series resistor options (~5 MΩ, ≥5 W, 5 kV)

| Option                    | Part (series)                    | Per-element           | String total         | ≈ unit price    | Note  |
|---------------------------|----------------------------------|-----------------------|----------------------|-----------------|---|
| String of 5 (recommended) | Ohmite MOX (e.g. MOX1, 1 MΩ 1 W) | 1 MΩ · 1 W · ~5 kV    | 5 MΩ · 5 W · 5 kV    | ~\$15–30 string | Share voltage and heat across elements.                                       |
| String of 5 (precision)   | Caddock MX440 (1 MΩ)             | 1 MΩ · 1.5 W · 2.4 kV | 5 MΩ · 7.5 W · 12 kV | ~\$40–60 string | Tighter tolerance and higher voltage margin.                                  |
| Single part               | Ohmite Slim-Mox SM102 (5 MΩ)     | 5 MΩ · 1 W · 5 kV     | 5 MΩ · 1 W · 5 kV    | ~\$30–60        | 1 W ≪ 5 W needed — does not meet fault-power margin; use the Maxi-Mox string. |

Generic “glass-glaze” HV resistors exist at \$5–15 per pack but lack guaranteed pulse and voltage ratings — not recommended for a 5 kV protection resistor. Verify per-element voltage, single-pulse and cumulative pulse-energy rating, voltage coefficient, creepage/clearance, and failure mode (§9).

### External bleeder options (~10 MΩ, ≥3 W, 5 kV)

| Bleeder option             | Value                      | Standing I / P @5 kV | Decay to 50 V  | Suggested part                |
|----------------------------|----------------------------|----------------------|----------------|-------------------------------|
| String of 10 (recommended) | 10 × 1 MΩ 1 W → 10 MΩ 10 W | 0.5 mA / 2.5 W       | ≈1.8 s (40 nF) | Ohmite MOX 1 MΩ 1 W ×10       |
| Higher-power single/string | 10 MΩ, ≥3 W                | 0.5 mA / 2.5 W       | ≈1.8 s         | Ohmite Maxi-Mox 10 MΩ (≥3 W)  |
| Faster (2/5 mA units only) | 5 MΩ, ≥5 W                 | 1.0 mA / 5.0 W       | ≈0.9 s (40 nF) | Ohmite MOX/Maxi-Mox 5 MΩ ≥5 W |

The standing current is the binding limit: do not use a bleeder below ~5 MΩ on the 1 mA model. Consider a redundant bleeder or open-circuit detection so a single failure is not silent.

## Appendix B · Mode B load-capacitor sourcing examples (nonbinding)

Nonbinding sourcing examples, not part of the controlled design recommendation; part numbers verified against catalog listings in mid-2026 and subject to the same six-month maintenance rule as Appendix A. The controlled content is the qualification criteria in §10 (voltage margin above  $V_{HV}$ , peak/RMS discharge current, ESR/ESL for the intended  $dV/dt$ , dielectric, and safe failure mode), not the specific part.

### Why 40 nF and 60 nF are built from standard values

In the high-voltage market (>5 kV), exactly 40 nF and 60 nF are non-standard values; off-the-shelf HV film parts follow the E6/E12 series. The practical approach is to parallel standard capacitors. The recommended base part is the WIMA FKP 1 series — pulse-duty polypropylene film, low ESR, self-healing, rated to 6000 VDC — giving margin above the 5 kV working voltage. Confirm the pulse and  $dV/dt$  rating for the actual waveform (§5, §10) before committing.

| Mfr. part number   | Capacitance | Rated voltage | Tolerance | Est. unit price |
|--------------------|-------------|---------------|-----------|-----------------|
| FKP1Y021006F00KSSD | 10 nF       | 6000 VDC      | ±10% (K)  | ~\$2.50–4 ea    |
| FKP1Y023307G00MSSD | 33 nF       | 6000 VDC      | ±20% (M)  | ~\$7–9 ea       |

### Configuration guide

| Target (load node)   | Build from standard parts         | Resulting C   | Notes   |
|----------------------|-----------------------------------|---------------|---|
| 40 nF, >5 kV         | 4 × FKP1 10 nF / 6 kV in parallel | 40 nF (±10%)  | Preferred for energy/rate-critical work — tighter ±10% tolerance, identical parts.        |
| 60 nF, >5 kV         | 6 × FKP1 10 nF / 6 kV in parallel | 60 nF (±10%)  | Matches the §6 “60 nF (20 int + 40 ext)” example once the ~20 nF internal C is confirmed. |
| ~66 nF, >5 kV (alt.) | 2 × FKP1 33 nF / 6 kV in parallel | ≈66 nF (±20%) | Fewer parts but looser ±20% tolerance; only if tolerance allows a slight overage.         |

### Pulse check: $dV/dt$ and peak current in self-firing service

In self-firing Mode B the capacitor discharges from  $V_{bd}$  (≈3 kV) to  $V_{min}$  (≈100 V) through the arc in microseconds, then recharges slowly through  $R_{series}$ . The discharge edge, not the DC rating, is what limits film-capacitor life. The capacitor must be qualified for the  $dV/dt$  and peak current of that collapse, not only for 5 kV stand-off. The swing is  $\Delta V = V_{bd} - V_{min} \approx 2.9$  kV; with collapse time  $t_c$ ,  $dV/dt = \Delta V/t_c$  and  $i_{pk} = C \cdot dV/dt$ . For a 40 nF node:

| Collapse time $t_c$                  | $dV/dt = \Delta V / t_c$ | Peak current $i_{pk} = C \cdot dV/dt$ (40 nF) |
|--------------------------------------|--------------------------|---|
| ~1 $\mu$ s (slow, inductive loop)    | ≈2.9 kV/ $\mu$ s         | ≈116 A  |
| ~0.5 $\mu$ s (typical small air gap) | ≈5.8 kV/ $\mu$ s         | ≈232 A  |
| ~0.1 $\mu$ s (tight, low-L loop)     | ≈29 kV/ $\mu$ s          | ≈1160 A                                       |

#### HOW TO USE THIS TABLE

Measure the actual voltage collapse time ( $t_c$ ) on your assembled fixture using a fast HV probe or current-viewing resistor; compute  $dV/dt = \Delta V / t_c$  and compare it against the WIMA FKP 1 (or chosen capacitor) datasheet rating for that specific value. If measured  $dV/dt$  exceeds the rating, add a small series inductance, parallel several smaller (10 nF) units to divide the per-part peak current, or move to a foil capacitor explicitly rated for the required edge.  $dV/dt$  capability is specified per capacitance value, so check it for the exact parts chosen.

#### SAFETY — BUILDING A PARALLEL HV CAPACITOR BANK

When paralleling capacitors at >5 kV, ensure trace/terminal spacing, potting, and wire insulation are rated for the full working voltage with margin to prevent breakdown, corona, or arcing between adjacent terminals. Keep the discharge loop short and low-inductance (§8), fit the bleeder directly across the bank, and verify the

| Collapse time $t_c$   | $dV/dt = \Delta V / t_c$ | Peak current $i_{pk} = C \cdot dV/dt$ (40 nF) |
|---|--------------------------|---|
| residual at the accessible terminal — not an internal node — before access (§7, §11). A parallel bank stores the sum of the individual energies; size the bleeder and the safe-access wait for the total. |                          |   |

*This note is preliminary customer-facing design guidance; controlled ATI source identifiers are pending release-control completion. The worked values are first-order design aids; application-specific component qualification and on-fixture measurement are the integrator's responsibility (§9, §12). The measurement setup is itself part of the high-voltage circuit — probe capacitance, grounding, cable routing, and instrument isolation can change stored energy, spark-loop current, and personnel hazard, so record the measurement configuration and include probe capacitance in  $C_{total}$  when relevant.*