Recom mend ed Test Procedure for
High-Voltage Membrane Integrity Testing

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ABSTRACT

Designers, building owners, contractors, and manufacturers alike are constantly on the lookout for new techniques to confirm the quality of initial installation or continued viability of the roofing and waterproofing membranes protecting their structures. High-voltage membrane integrity testing (HVIT) provides instant, accurate, and reliable feedback on the watertightness of many roofing systems. With HVIT being a relatively new technology in the U.S., clear guidelines have yet to be established to standardize the technique. Learn the fundamental principles of HVIT, and discover how it could be used to quickly identify even the smallest breach on most roofing membrane types.

SPEAKER

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CAROLE CEJA has gained roofing and waterproofing experience since joining Wiss, Janney, Elstner Associates, Inc. in 2006. As a registered architect in Illinois, Ceja has participated in the investigation, inspection, repair, design, and construction observation of more than 100 roofing projects. She has personally participated in high-voltage testing on PVC, modified-bitumen, and liquid-applied membranes. Her participation in the ASTM D08.22 subcommittee is advancing the practice of electric-based nondestructive investigation techniques for roofing and waterproofing. Ceja has previously authored and presented articles for the 2010 RCI Building Envelope Symposium and the NRCA 2011 International Roofing Symposium.
High-voltage integrity testing (HVIT) is gaining popularity in the U.S. market. The technology allows a roofing technician (or consultant) to quickly and accurately identify breaches in electrically insulating membranes. As most roofing and waterproofing membranes are electrically insulating, the technology is appropriate to verify the installation of a watertight system or to locate a known defect. If no breaches exist to allow the passage of electric current, then no breaches exist to allow the penetration of water in a liquid state. While similar technology has been adapted for liquid-applied coating evaluations and geomembrane seams (ASTM D4787, ASTM D5162, ASTM G62, and ASTM D6365), a method for full-scale roofing or waterproofing scans has not yet been adopted. A draft document is in development currently within ASTM to describe various electric conductance methods of leak detection, but as of this writing, the document has not been finalized.

Herein is a recommended procedure for high-voltage electric integrity testing as well as initial ideas for further laboratory research needed to refine the test method. To limit scope, roofing membranes will be the focus of this article. The principles contained within are equally applicable to waterproofing membranes, provided similar electric properties of the membrane and substrate can be established.

The concept of HVIT is straightforward. A technician applies electric energy to a roofing system with an electrode. The electric energy is typically prevented from flowing by a continuous insulating membrane. At discontinuities or breaches in the membrane, energy can flow in the form of current from the electrode into the electrically conductive substrate located below the membrane. This substrate must be grounded, which allows the energy to dissipate into the mass of the earth. Electricity will only flow if a complete circuit exists. The flow of electricity alerts the technician to the precise location of the leak.

**THE EQUIPMENT**

HVIT equipment consists of three main portable components: the power pack, the electrode, and the grounding wire (see Figure 1). The fourth and fifth necessary components—ground and a conductive substrates—must be present at the testing site. The power pack contains the batteries and controls to adjust the levels of voltage. The power pack also contains circuitry to alert the technician when current begins to flow through the system. Some manufacturers produce power packs that are equipped to allow the technician to adjust the sensitivity of this alert for differing rooftop conditions.

The electrode is a flexible conductive array attached to a handle to be manipulated by the technician. These can come in a variety of sizes and materials to suit different technicians and roofing configurations. Several common examples include point, fan, and broom styles (see Figure 2). Point electrodes are very precise and apply energy to a single point. This may be the most useful for seam checking or for greater accuracy in locating the smallest defects when no visible arc is created. Fan electrodes apply energy to an area of membrane approximately the size of the technician’s hand. They are very flexible and are often

![Power Pack](image1.png)

![Electrodes](image2.png)

![Grounding Wire](image3.png)

Figure 1 – Portable components of HVIT equipment.

![Figure 2 – Several types of electrodes.](image4.png)
used around flashings and other vertical surfaces where high levels of control are needed to safely apply energy and to ensure every inch of membrane is tested. Broom electrodes are the workhorses of HVIT. They can be produced in a variety of widths and can be used with extension arms to easily cover larger areas of membrane more quickly. They consist of a group of tightly spaced wires, like broom bristles, that can be pushed or pulled over the surface of the membrane.

The grounding wire connects the HVIT equipment back to ground, which permits a complete circuit to form. It is important that the grounding wire remain in contact with ground during the testing, so a clamp or other device should be included at the end of the grounding wire to ensure positive connection.

THE PRINCIPLES IN ACTION

With the equipment assembled, the basic principle of HVIT is as follows:

A specific voltage is applied to the surface of the membrane through direct contact with the electrode. As this energy is pushed into the surface of the membrane by the power pack, it is resisted by the membrane itself, and no energy flows; therefore, no current is detected. At a discontinuity or breach in the membrane, energy bypasses the membrane and can flow through conductive surfaces below the membrane to ground. As the power pack is also connected to ground through the grounding wire, a complete circuit is formed and energy begins to flow in the form of current (see Figure 3). The power pack senses this flow of energy and sounds an alarm to alert the technician that a breach has been encountered.

If a breach exists that allows current to pass, then water can pass as well.

Having not given electricity much serious consideration since high school physics class, this author finds the common analogy for electric circuits as plumbing more enlightening. See Figure 4 for a diagrammatic representation of this water-to-electricity analogy. The power pack represents a pump that performs work. Voltage is analogous to water pressure caused by the pump; current is water flow rate. Electric energy moves through conductive substances like water through hoses and funnels, and is stopped by insulating substances such as a cap at the end of the hose. In HVIT, the electrode is like the open end of a hose held tight against the membrane. Insulating membranes are like covers that keep the water in the hose and, therefore, not moving. However, no roofing membrane is perfect at keeping all the water (current) in the hose. Some roofing membranes are the electrical equivalent of cheesecloth and readily allow current to pass while most other roofing membranes are more like a heavy felt where, if enough pressure (voltage) is in the hose, one can force water (current) to pass through with some effort. The amount of current passing through the membrane is also dependent on the thickness of the membrane in the same way 50 layers of cheesecloth would hold back more water than a single layer. For the electric energy to begin flowing, there must be a complete circuit or path back to the source of the work (pump). In high-voltage testing, this complete path is created through the most readily available conductive object: ground. The battery supplying the voltage must be connected back to the ground and a conductive substrate (i.e., a really big funnel) must also be in contact with the ground. The ground becomes a reservoir for water (energy) in the circuit and closes the cycle.

WHICH SYSTEMS CAN BE TESTED?

Given the electric principles above, what types of roofing systems can be tested? Generally, any electrically insulating membrane installed over a conductive substrate that has some connection to ground. Only surfaces in direct contact with the electrode are tested. It is therefore the responsibility of the technician to ensure every square inch of membrane requiring testing comes in contact with the electrode. The surface of the membrane to be tested must also be clear of conductive conditions such as water, ballast, etc.

Most roofing membranes meet the insulating requirement with the notable exception of black EPDM, which contains high levels of carbon black, which conducts electricity. White EPDM is potentially testable, provided the equipment is carefully calibrated to avoid false alarms at the seams where the edge of the black reverse face is exposed.

The conductive surface below the membrane can be typical construction elements such as metal or concrete decking. Other roofing layers that can hold even low levels of moisture such as gypsum board or plywood can also serve as conductive layers, provided their moisture levels are high enough to carry current. Roofing systems can also be specifically designed to incorporate additional layers of material for the sole use as conductive layers such as foil-faced insulation panels or wire meshes.

If any additional insulating material in the roofing system forms a complete separation between the membrane and the conductive surface, HVIT will not be effective. Vapor retarders and temporary roofing against the deck are the most common hindrance to effective HVIT. In addition, most insulation products used for roofing are electrically insulating, with the potential to interfere with testing. Thankfully, most roofing insulation is not continuous, and
joints between the boards and paper facers can become saturated with water (very conductive), providing a path for energy to flow. Mechanically fastened insulation potentially provides additional conductive pathways (metal screws) through insulation into a conductive substrate.

Air is generally electrically insulating as well and can interfere with HVIT. To a certain extent, energy can jump through air gaps without a substrate present, as the energy can follow water vapor held in the air. Air gaps below a membrane such as tented fasteners or wide insulation board gaps may or may not permit energy to flow from the electrode to the conductive substrate below when a breach is present in the membrane. However, if the distances of these air jumps are small and the humidity of the air in the gap is high enough, positive results at membrane breaches can be found.

A SIDEBAR ON SAFETY

High-voltage testing gets its name by definition of test voltages higher than 1,000 volts, or 1 kV. With test equipment strength for roof integrity testing ranging from 1 to 30 kV, there is a potential for damage to the membrane being tested. All materials have a limit where electric potential begins to break down the material on a molecular level. Applying levels of electric energy that are too great will create breaches in the membrane rather than assist in their detection. To return to the water for electricity analogy, enough water pressure applied to even that heavy felt can damage it over time. As electric energy arcs through air, the visible streak of light is accompanied by very intense levels of heat, albeit in a very small area, that may also burn the membrane. Similarly to the roofing membrane, human skin can suffer the same negative consequences if exposed to high voltages. Applied electric charge can also potentially affect muscle and nerve behavior deeper in the human body, and the special procedures required for technician safety bears some discussion.

Most individuals have experienced some form of electric shock in the presence of static electricity on a doorknob or through an inadvertent brush against an electrified fence. The effects of contact with sources of electric charge on the human body are dependent upon both current and voltage (the volume of energy and how hard it is pushed). Direct contact with the source of the electric energy is not necessary to inflict damage. In average conditions, an electric arc can form within an air gap of 1 millimeter when supplied with 2 kV of pressure. That is the voltage level of a typical dairy cow fence and is near the lower end of testing voltages used during HVIT for roofing membranes. Depending on a person’s sensitivity, a 2-kV shock may barely be perceived. An intense static electric shock (of the doorknob persuasion) under optimal conditions could register as much as 30 kV. This is the upper boundary of most high-voltage testing equipment.

The real effect of this range of voltage on the technician’s body is more closely tied to the current (amperage). The 1-10-100 amperage rule of thumb describes the effect of specific amperage on people. 1 mA (0.001 amp) can be felt, 10 mA can cause gripping muscle spasms, and 100 mA can stop the human heart. Give or take, dry human skin induces a resistance between 500,000 Ohms and 2,000,000 Ohms.1

Actual resistance of each person depends on a series of variables too large to define here. Looking back to high school physics and the basic equation Voltage = Current x Resistance, a two-handed grab of the electrode set at 30 kV could subject a technician to something between a 15-mA and 60-mA shock, depending on his or her personal level of resistance. That is somewhere between uncontrollable muscle spasm and approaching death. With this in mind, proper precautions should be taken with equipment and personal protective equipment. Dry gloves and long sleeves and pants (preferably made from cotton materials) will increase the resistance of the skin against accidental contact. More resistance equals less current and less injury to the technician, given accidental contact.

Each technician should also be aware of the power of the equipment he or she is using. Curiosity about the strength of the shock should be discouraged. Also, people with known heart conditions or embedded electric health equipment (i.e., pacemakers, etc.) should talk with their doctors before performing testing.

WHY USE THIS TOOL?

Given the potential to harm the membrane or the technician if not properly performed, why should HVIT be performed at all? Properly performed, HVIT can definitively show where even pinhole-size breaches exist in the field, at flashings, and at seams of the most common roofing membranes. It can even detect some defects in the membrane that have not yet developed into full-depth breaches. It provides instant, visible, decisive evidence of locations where water can penetrate. The test procedure is relatively quick, straightforward, and repeatable as necessary. In short, HVIT should be used because it is effective, and the safety and material risks can be nearly removed with proper technique.

SO WHAT IS PROPER TECHNIQUE?

Before performing any scan, the following research should be performed to gain an understanding of the roofing system to be tested:

1. Determine the design of the roofing system. Construction documents such as drawings and specifications may be helpful for new construction projects. As roofing components often change after initial bidding, approved submittals, actual construction reports, or photographs may be more accurate to identify the materials included. In some cases, roof cores may be necessary before testing to ensure reliable results. Also, roofing warranty paperwork often contains a description of the materials installed and can be another resource for initial research. Ensure the roofing membrane to be tested is an insulating material and that there is a conductive substrate material that is connected to a grounded surface.

2. Contact the manufacturer of the roof system. This step is helpful even if the roof warranty has expired. Manufacturers can often supply information about specialty products and their electric properties. Some manufacturers may object to high-voltage testing, based on an incomplete or inaccurate knowledge of the testing procedure. High-voltage testing by name alone can seem intimidating, dangerous, and destructive.

3. Obtain a sample of the membrane in place for calibration of the equipment. As no extensive research has been undertaken to determine proper voltage, settings for specific membrane types, and manufacturers, some trial and error as further
explained below will be necessary to determine appropriate testing voltages. Performing these trials on a piece of membrane away from the roof in question will limit the potential to harm the in-place roofing.

Optional: Obtain a sample of the workmanship at seams for single-ply membranes. For further thoroughness, request that a sample seam be provided that meets the installer’s standard of care, as well as one where a defect is purposely included.

4. Arrange for clear access to all roof surfaces to be tested. Only roofing that can be physically contacted by the electrode can be tested. If other construction material or ballast exists on the membrane, testing will not be complete. The roofing membrane must be free of all overburden.

5. Arrange for safe access to all roof surfaces to be tested. Tie-off locations should be identified if the roof is not surrounded by an appropriately tall parapet. Ropes and harnesses for the technicians should be present at the site as necessary. Other potential hazards on the roof should be identified, as well, such as antennas, chemical exhausts, or microwave transmitters. Additional pretesting procedures include but are not limited to checking HVIT equipment for damaged wires and connections, charging battery packs, and inspecting electrodes for damage.

6A. Calculate recommended test voltage based on equipment manufacturer specifications. An acceptable place to start is calculating the thickness of the membrane in microns (1 micron is 1/1000 of a millimeter). Take the square root of that thickness and multiply by 250. For example, a 5-mm (200-mil) membrane would need 17,677 volts or 17.6 kV. (√5000 x 250 = 17677.) In lieu of test voltages based on thickness provided by the manufacturer, a list of test voltages for specific membrane types can be compiled using the methods directly below.

6B. Test the sample of the membrane in direct contact to a good conducting surface such as a sheet of metal or against bare concrete to establish boundary voltage and sensitivity levels. Complete the circuit of the test equipment by grounding the battery pack to the sheet metal. (Safety warning: The sheet metal could become electrified during these trials. Appropriate precautions should be taken.) Testing the membrane directly against a conductive surface allows for evaluation of the membrane alone. In the field, other layers of the system may interfere and require additional adjustments. This initial calibration will supply the maximum limit of voltage that should be applied on the actual roofing system to be tested to avoid damage.

Begin with the smallest electrode available for the HVIT test equipment. To a certain extent, the cross-sectional area of the electrode can create a concentrating or diluting effect of the electric energy as it is applied to the membrane. Setting limits based on the smallest cross section will help to prevent damage to the actual roofing by providing conservative limits. Ensure a complete circuit is established by directly touching the electrode to the sheet metal (or other conductive substrate). If the equipment does not sound the alarm, recheck the grounding wire’s attachment to the sheet metal. Once a potential circuit is established, beginning at the calculated test voltage recommended by the equipment manufacturer, apply energy to the membrane by touching the electrode to the membrane resting on the sheet metal base. Observe the results. Undamaged membranes should resist the flow of electric energy. Often, an audible static hissing/popping is observed. If the power pack is equipped with feedback on current, some amount of electric bleedout may be observed. If the electrode produces an arc over the membrane, the voltage is too high and has damaged the membrane in the local area of the arc. Reduce voltage and try again. The highest voltage that does not alarm or arc through an undamaged section of membrane is the maximum testing voltage. Testing above this voltage has the potential to damage the membrane and adds unnecessary risk to the technician.

A maximum test voltage determined directly against a conductive surface will simulate the most conservative values to protect the membrane in the field from damage. This way, if an unanticipated conductive layer is located directly below the membrane (such as water), the limit of damage is known.

Once voltage limits that the undamaged membrane can resist are established, damaged membrane must be evaluated to ensure sufficient energy is in use. For example, very dry systems with sufficient depth may require more voltage to push energy through a tight breach.

Puncture the test membrane with a small-diameter tool (literal pin-hole). Begin at the calculated voltage from step 6A above. Apply an electrode over the hole. Watch for an arc or alarm. If there is none, increase the voltage until the alarm sounds. If the alarm sounds or an arc is observed, decrease voltage until no arc or alarm occurs. The lowest voltage that registers an alarm or arc is the minimum testing voltage. Testing below this voltage will not produce reliable results.

Depending on the membrane type and thickness, maximum testing voltage limits may not be reached given equipment limitations.

Switch to a fan-style electrode and repeat the process, beginning at the maximum and minimum voltages established by the point electrode. In general, maximum and minimum test voltages for fan-style electrodes will be greater than point-style. Broom-style will be greater still. It is generally not necessary to calibrate the broom-style electrodes prior to their use in the field. Voltage limits established by the fan-style electrodes will serve as the starting point. Find the mathematical average of the maximum and minimum voltages of the fan style (use the equipment maximum voltage if true material maximum was never reached). This will be the starting voltage for testing.

7. Depending on the type of documentation required, prepare survey sheets of the roofing. When reason-
able, include penetrations and membrane seams or other area dividers to improve the accuracy of field documentation.

ON-SITE TESTING

8. Upon arrival at the testing site, the roof surface should be visually examined for safety hazards. These include those hazards typical to any kind of roofing inspection, such as tripping hazards, overhead projections, radio antennas, etc. Falling hazards at roof edges and major penetrations such as skylights should also be noted.

9. Additional safety considerations specific to HVIT should be identified such as access to ground, chemical exhaust (potentially combustible in the presence of arcs), and electrically sensitive equipment below or adjacent to roof levels such as medical equipment or major computer hubs. HVIT will create electric fields that may interfere with this type of equipment. A general rule of thumb is to consider that if arc welding would be permitted, HVIT would be permitted.

10. Determine the last time the roof was wet. Water is often the greatest conductive surface. If the membrane has never been wet, it may test differently.

11. (If possible:) To further confirm the calibration of the equipment, set the voltage and alarm levels as determined previously for the specific roof configuration (average of maximum and minimum at fan-style electrode). If possible, create a small puncture through the installed membrane to be tested. This additional calibration test should only be performed if a qualified roofing contractor is available to make repairs the same day. Pass the broom-type electrode over the known breach to check that the alarm sounds. If it does not, raise the voltage (without exceeding the upper boundary established during initial calibration testing) in small increments and retest the known breach until suitable alarms are encountered. Make note of the voltage levels required to identify the breach.

(Otherwise): If no roofing contractor is available to perform repairs and the equipment displays current feedback, pass the broom electrode over a typical area of roofing and observe the levels of current "leaking" through the system. No roofing material is 100% effective at resisting all electric energy. To provide some reassurance that sufficient voltage is in use to detect a breach in the roofing assembly, increase voltage by small increments until the typical current feedback is 20 microamps. Do not exceed the maximum voltage established for the membrane type, however. Make note of the voltage levels required to provide some current feedback. The lowest voltage that produces positive results should be utilized during testing for the safety of the technician and the membrane.

12. Once all safety and calibration checks are completed, the full-scale roof scanning can commence. It is important to proceed in a logical pattern to ensure all the roofing is tested. HVIT only tests the portion of the membrane in direct contact with the electrode. Beginning with the largest appropriate electrode—most often the broom style—brush the field of the roof (see Figure 5). Following sheet seams is a good technique to ensure complete coverage for the test. Monolithic membranes or very large sheets may require some additional method of surface marking to ensure the test is complete.

Where possible, the technician should push the broom-style electrode ahead of him or her. Do not walk backwards on a roof. Alternating between pushing and pulling can trigger false alarms as well. A slow walking pace is generally sufficient to catch breaches with properly calibrated equipment.

13. When an alarm is encountered, stop forward progress and rebrush the membrane in the area to look for a visible electric arc. Not all breaches will produce a visible electric arc. Some roof conditions, such as a white membrane in full sun, will make any arc considerably more difficult to see. If an arc is visible, it will occur directly at the breach location. If no arc is visible, brush the membrane at 90 degrees to the original path to help narrow down the area where the alarm occurred. Power down the testing equipment and change to a smaller fan-type electrode for even more precise location of the alarm/breach location. Fan-type electrodes should be pulled across the membrane rather than pushed. Mark on field sheets or directly on the membrane the location of the breach. Photograph the breach (see Figure 6).

Continue across the field of the membrane in this fashion. Do not walk backwards during the testing.

14. Recheck the grounded condition by purposely contacting a grounded metal surface or drain head after each shutdown and restart of the HVIT equipment.

15. After defects in the field have been
identified, flashing can be tested. The size of most flashings makes testing with the broom-style electrode cumbersome. The fan-style electrode is often the most convenient (see Figure 7). Mechanical equipment may be sensitive to voltage and should not be contacted by the electrode.

16A. If a roofing contractor is available to make repairs as the test proceeds, it is possible to repair all noted breaches and retest the repair areas to ensure all paths to the breach have been stopped. This is, of course, provided that the repair material is equally insulating as the base membrane.

16B. If repairs to the membrane are not carried out as breaches are identified, field sheets and photographic documentation should be provided to the client so that repairs can be executed in the future.

It should also be considered good practice to employ two technicians during a survey. Two sets of eyes can better watch to ensure all roofing surfaces are checked. Roof edge and electric safety may be increased as the primary tester can have a tendency to focus on the task at hand rather than his or her surroundings.

**COMMON FALSE POSITIVES**

The telltale spark is the best indication of a breach in the membrane. As “x” marks the spot, the little blast of light points directly to the hole or gap in the seam. However, there are several instances where equipment can provide a false indication of a breach when the alarm level is reached without a visual arc:

1. **Sudden changes in direction or speed of the electrode path can lead to unintended feedback and an alarm.**

2. A change in the membrane thickness, such as several stacked patches, may require higher voltages in localized areas.

3. A change in the substrate material or position of the conductive substrate relative to the membrane—for example, embedded metal such as lead collars at stack vents or drain pan—could create false alarms.

4. Unintentional contact between the electrode and a grounded surface, such as contact with drain clamping rings or broom fly-aways at perimeter flashings, can occur.

5. Unnoticed contact with a conductive layer on the surface of the membrane, such as water at seams close to a drain or moisture clinging to a granule-surfaced cap sheet, is possible.

A legitimate breach over a conductive surface will alarm with less voltage than used for the full roof test as shown during the initial calibration (step 6B before going on site). When in doubt, reduce voltage and retest the area around suspected false alarms.

**WHERE TO GO NEXT?**

Specific laboratory and field research should be conducted to begin to answer the following:

- How often should equipment be calibrated?
- What voltages should be used for specific membrane types and roofing configurations?
- Is there an upper limit on the thickness of insulation that will allow reliable results?
- Does the size of the board stock or the stacking/staggering of joints matter in the detection of breaches?
- Could humidity affect the test procedure?

**CONCLUSION**

Given an electrically suitable roofing system and following the testing procedure described above, a roofing technician can provide confident results that all breaches in an area of tested membrane have been identified. The use of this tool in membrane determination for watertightness or detection of the source of water leakage is unparalleled. HVIT can point out a single installation defect in a vertical seam or a thousand pinholes across a low-slope roof caused by hail damage or foot traffic. This versatile tool should continue to grow in popularity and use as the roofing industry adopts more refined and repeatable methods for its testing applications.

**REFERENCES**