Application Note 4

How Do I Connect My HV Pulser to a Load?

All high voltage pulser applications require a proper connection to the load. What's the best way to do it?

Single Wire

We might be inclined to simply run a single insulated wire from the "hot" pin of the pulser's output connector to one side of the load, then then connect the other side of the load to the nearest "ground" – a metal enclosure, support, fixture, or table.

This is a bad idea for several reasons.

- The entire current path can act as an antenna, creating EMI (Electromagnetic Interference) that may disturb nearby equipment.
- A single wire doesn't make a very good transmission line, resulting in degradation of the pulse shape.
- But most importantly, we might inadvertently create an electrical hazard. Current from the load is supposed to return to the ground connection at the pulser's output connector. If that connection is absent, the return current will find another path back to the pulser chassis, perhaps through personnel and/or other equipment – a very dangerous situation.

Two Wires

Adding a second wire for the return current does not address the EMI or transmission line issues. We need a better solution – and it's coaxial cable.

Coaxial Cable

When we use coaxial cable, current returning from the load flows in the outer shield back to the output connector. If the current in the center conductor matches the current in the outer conductor, EMI is reduced. And, as we will see further down, coaxial cable helps maintain pulse fidelity.

Adapting Coaxial Cable to the Load

If the load is not designed to readily accept coaxial cable, we may have to make an adapter. One possibility is to use HV test probe wire to extend the center conductor; a nonconductive sleeve or tubing can be used over the wire if more insulation is needed. Then, shield the extension as much as possible with conductive tubing or braid connected to the braid of the supplied coaxial cable.

Accessory Kit

The accessory kit included with a PVX-41xx series pulser contains three similar coaxial cable assemblies: two are used to connect the pulser to external HV power supplies and one is used to connect the pulser to the load. (Additional kits are available for purchase if needed.) Each cable has been fitted with the correct connector (MHV, SHV, LEMO, etc.) for the pulser model.

The type of coax was chosen to best meet the conflicting requirements of flexibility, capacitance, and voltage rating.

Cable Flexibility

The coaxial cables supplied with HV pulsers can be somewhat stiff because very flexible cables don't handle high voltage well. *Resist the urge to use highly flexible coax unless you are certain it will handle the voltage!* For example, the RG-11 supplied with the PVX-4110 is stiff, but it handles 10 kV.

Cable Length

The cables in the accessory kit are made relatively short. What's the reason?

Coaxial cable has a characteristic capacitance measured in picofarads (pF) per foot of length. Typically, RG-62 is 13.5 pF/foot, RG-59 and RG-11 is 21.5 pF/foot, and RG-58 is 29 pF/foot. As far as the pulser is concerned, cable capacitance simply adds to the load capacitance. A 25-foot length of RG-58, for example, adds 725 pF to the load. If the total capacitance causes the pulser's maximum internal power dissipation specification to be exceeded, the pulser may be damaged. (The power dissipation calculation can be found in the App Note **How do I Choose an External Power Supply for my Voltage Pulser?**)

Even if no damage occurs, the added capacitance from long cable lengths extend pulse rise and fall times. (The calculation can be found in the App Note **How Do I Slow the Pulse Rise Time of my PVX?**)

For the above reasons, it's always best to use the shortest possible cable.

Connectors

Different pulser models have different output connectors based on engineering requirements. Pulsers in the low- to middle-HV range use bayonet-style connectors such as MHV and SHV. Very high voltage pulsers use special connectors such as those made by LEMO and Kings. Be aware that if you want to build your own cables, you'll need the correct (and usually expensive) crimp tool to mate the HV connector to coaxial cable.

◄ The BNC (Bayonet Neill–Concelman) connector is very popular for video, RF, instrumentation, and test equipment. But it has a maximum voltage rating of 500 V and is not used as a high voltage connector (for our purposes, high voltage is defined as 1000 V or greater).

► The MHV (Miniature High Voltage) connector (right) looks like a BNC with slightly protruding insulation on the plug and slightly different insulation length in the jack. It is possible to get a shock from accidental contact between the center pin and a finger. It is also difficult, but not impossible, to force a BNC cable onto a MHV connector. Never use low-voltage connectors and cables with high voltages!

◄ The SHV (Safe High Voltage) connector has a thick protruding insulator. It prevents accidental contact between the center pin and finger, and it cannot be accidentally mated to a BNC or MHV connector.

Impedance Matching

The output impedance of a voltage pulser is set by output circuit components such as fixed resistors and power MOSFET "ON" resistance; it's also set by the HVPS source impedance and other items. The coaxial cable has a characteristic impedance as well, and so does the load. If the impedances of the pulser, the cable, and the load are equal and purely resistive, there are no reflections and maximum power is delivered to the load.

On the other hand, if a pulse encounters an impedance mismatch, a reflection is generated that sends energy back to the source. The forward and reflected energies combine to affect the shape of the pulse.

From this, we might expect a PVX-4110 (which has an output impedance of 75 Ω) to perform best when driving a 75 Ω resistive load through a length of 75 Ω coaxial cable.

But there are two complications.

The first one involves the type of load we typically encounter. For example, the PVX-4110 is designed to drive time-of-flight components (extraction grids and deflection plates), power tube grids, Pockels cells, Q-switches, microchannel plates, photomultiplier tubes, image intensifier tubes, quadrupoles, and similar loads. These devices appear as small capacitors to the pulser. Their impedances are very high and thus it would be difficult to match them to a 75 Ω system. And in many cases the impedance of a load is unknown or it may vary dynamically due to the experimental nature of the application.

The second issue is the high current draw from a 75 Ω resistive load at high voltage. At 10 kV, the current is 10000/75 = 133 A, well in excess of the PVX-4110's ratings of 30 A peak and 0.1 A continuous. Those ratings, however, are sufficient to meet the much more common requirement of driving a 50 pF load through four feet of RG-11 with 60 ns rise and fall times.

The limitation on current explains why we do not place a termination resistor across the load. (And for safety reasons, if you do add any auxiliary circuitry to the pulser's output, pay close attention to component spacing and trace requirements for high voltage.)

To sum up, the pulser is matched to the coaxial cable, but the coaxial cable will likely not be matched to the load. Rather than concentrate on the impedance match, it's more important to minimize the capacitance of the load and the coaxial cable to keep the current within bounds and the rise and fall times fast.

One exception to the above discussion are pulsers specifically designed to drive low-impedance loads, such as the PVM-1001 (50 Ω).

Inductance

We've noted that it helps to keep the coaxial cable short to reduce capacitance. There is another, less significant issue involving inductance.

Since there is considerable current flowing during the leading and trailing edges of the pulse, excessive inductance in the output circuit can cause overshoot and possibly ringing to appear on the pulse. To reduce it, minimize all wire interconnections, adaptors, sockets, terminations, etc. If using a pair of wires for a portion of the load connection, twist them together.

Problem Solving

Because many problems are load- or cable-related, troubleshooting starts by disconnecting the coaxial cable at the pulser output and testing the pulser alone. (Note: Pulsers designed to drive low-impedance loads, such as the PVM-1001, must be operated within a given load range and thus should not be operated with an open circuit for a load.)

With a high voltage DC probe connected to the output, verify that the output is the same voltage as the $+V_{IN}$ power supply when the gate input is at a logic high level (+5 V). Verify that the output is the same voltage as the $-V_{IN}$ power supply when the gate input is at a logic low level (0 V).

Generate a pulse train and check it with a high voltage scope probe; a rectangular pulse should appear. If the pulse looks good, the problem lies in the load or coaxial cable.

A clue may be provided by the pulser's overcurrent LED (if present): The LED may blink if an arc or HV breakdown occurs in the coax cable or load. A cable may be suspect if it's old or not supplied by DEI Scientific. Coaxial cable degrades over time, allowing HV leaks such as corona or micro-arcs to appear. Try substituting another load and/or cable to see if the pulse improves. It's important to use good-quality coaxial cable and connectors. Replace them when they get old!

DON'T GET SHOCKED

As a safety precaution, never disconnect the output cable or the load while a pulse generator is operating. Doing so can present a shock hazard to personnel and cause arcing and damage to the load and pulser.

And, remember that benchtop antistatic mats are conductive! If the coax cable's center conductor, the "hot" side of the load, or some other part of the output circuit makes contact with the mat, you can receive a shock.