Application Note No. 4

Avtech Electrosystems Ltd.

Choosing & Using Pulsed Constant-Current Sources

Introduction

The usual garden-variety pulse generator is designed to supply pulses of a certain voltage to a resistive load. However, there are many applications where the engineer requires a pulse of a certain *current* which must remain constant, independent of the load voltage or resistance. This is a common requirement in applications as diverse as the testing of superconductors, airbag squibs and inflators, fuses, explosives, laser diodes and a wide variety of semiconductor devices. These applications often require fairly large currents of a few amps or more. Avtech has several models ideally suited to these pulsed constant-current applications - see Table 1 for a selection guide. (Avtech also manufacturers a very broad line of pulsed voltage sources, some of which have current ratings as high as 500 Amps!)

Table 1 - Pulsed Constant-Current Generator Selection Guide

Model	I_{out}, max (A)	Compliance Voltage	Maximum Current Variation	Pulse Width	Rise Time	Fall Time	Max. Duty Cycle (%)	PRF (kHz)	Catalog Page
AV-155A-C	0.4	0 to 4V	< 1%	20ns-2us	10ns	10ns	100	0-10 MHz	60
AV-155B-C	1	0 to 4V	< 1%	100ns-10us	50ns	50ns	100	0-1 MHz	60
AV-155C-C	2.5	0 to 4V	< 1%	100ns-10us	50ns	50ns	100	0-1 MHz	60
AV-156A-C	5	0 to 15V	< 1%	10us-10ms	3us	3us	100	0-10	New!
AV-156B-C	1	0 to 40V	< 1%	10us-10ms	5us	5us	100	0-10	New!
AV-151F-C	±2.5	0 to ±5V	< 1%	func. gen.	10us	10us	100	0-20	102
AV-107A-C	0.5	0 to 60V	< 5%	20-200 ns	10ns	10ns	1	0-50	77
AV-107B-C	2	0 to 60V	< 5%	20-200 ns	10ns	10ns	0.4	0-20	77
AV-107C-C	10	0 to 60V	< 5%	50ns-1us	20ns	20ns	0.5	0-5	77
AV-107D-C	20	0 to 60V	< 5%	0.1-5.0us	30ns	30ns	0.25	0-0.5	77
AV-107E-C	2.5	0 to 60V	< 5%	0.2-200us	30ns	30ns	20	0-1	New!
AV-107E1-C	50	0 to 10V	< 4%	8.3ms	NA	NA	NA	1 Hz	27
AVO-7C-C	30	0 to 30V	< 10%	0.5-50us	50ns	50ns	0.25	0-1	68
AVO-7D-C	100	0 to 100V	< 10%	2-200us	1.0us	1.0us	0.1	0-0.1	68
AVO-7E-C	15	0 to 20V	< 10%	1us-1ms	50ns	50ns	1	0-1	68
AVO-7F-C	5	0 to 5V	< 10%	1us-1ms	0.5us	0.5us	50	0-1	68
AV-108A-1-C	50	0 to 20V	< 5%	4us-1ms	2us	2us	4	0-1	78
AV-108B-1-C	50	0 to 20V	< 5%	4us-10ms	2us	2us	40	0-1	78
AV-108A-2-C	100	0 to 50V	< 5%	4us-1ms	2us	2us	0.8	0-1	78
AV-108B-2-C	100	0 to 50V	< 5%	4us-1ms	2us	2us	8	0-1	78
AV-108A-3-C	200	0 to 20V	< 5%	4us-1ms	2us	2us	1	0-1	78
AV-108B-3-C	200	0 to 20V	< 5%	4us-1ms	2us	2us	10	0-1	78

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Compliance Voltage and Maximum Amplitude Variation

Aside from the obvious current pulser specifications such as maximum current amplitude, the rise time, and the pulse width range, there are two other key parameters: compliance voltage and the maximum amplitude variation. The compliance voltage, V_C, is simply the ranges of load voltages that the pulsed constant-current source will work properly with. For instance, the Avtech AV-108A-1-C pulsed constant-current generator is specified as having a maximum amplitude of 50 Amps, and a compliance voltage of 20 V. The AV-108A-1-C will function properly only if the load voltage remains below 20 V. As an example, if the amplitude of the AV-108A-1-C was set at 40 A, the largest resistive load that could be used would be 0.5 Ohms, since 40A x 0.5 Ohms = 20 V. (The smallest usable resistive load is 0 Ohms - a current source is not harmed by a short circuit, unlike some voltage pulsers.)

The second key parameter is the maximum variation of the current amplitude with a change in the load voltage. An ideal current pulser has *no* current amplitude variation when the load voltage changes. However, most current pulsers will in reality display a slight change in the current. This change is usually specified as a percent change in the current when the load voltage is changed from the zero Volts to the compliance voltage V_C. This is the worst case variation. As an example, if the AV-108A-1-C were set at 40 Amps, into a short circuit (zero Ohms), and the load resistance then rises to 0.5 Ohms (perhaps due to thermal effects, or the opening of a switch) where the load voltage is equal to V_C, then the current is specified to changed by no more the 5% - it will lie in the range of 38 to 40 A.

Capacitive Loads

In the preceding discussion, we've assumed that the load is a purely resistive one, and indeed this is the situation that most pulsed constant-current generator data sheets assume. However, there are many situations where an engineer may wish to drive a reactive load. If this load is capacitive, the time to charge up the capacitor voltage will often be limited by the laws of physics rather than the pulse generator rise time. The defining equation for a capacitor is I = C dV/dt. For instance, consider the Avtech Electrosystems AV-107E-C pulse generator, which will supply pulses of up to 2.5 A with a specified rise time of less than 30 ns (see upper waveform, Figure 1). However, if this pulsed constant-current generator is set at a low amplitude of 20 mA and is used to drive a 1 kilohm load, a voltage risetime of about 1 us is observed (see bottom waveform, Figure 1). The voltage rise time is limited by the parasitic output (and load) capacitance (which can exceed several hundred picofarads) through the relationship I = C dV/dt. If the load were a laser diode, this parasitic capacitance would delay the time for the diode voltage to reach the lasing threshold voltage.

The fall time of a current pulser may or may not be affected by the presence of capacitance, depending on the particular model that is used. For the example discussed above (see bottom waveform, Figure 1) the fall time is still very short, because the pulser output is shorted to ground when the output isn't supplying a current pulse. This discharges any capacitance very quickly. Other models, such as the AV-155-C, do not short the output to ground, so the fall time is controlled by the I = C dV/dt relationship, just like the rise time.

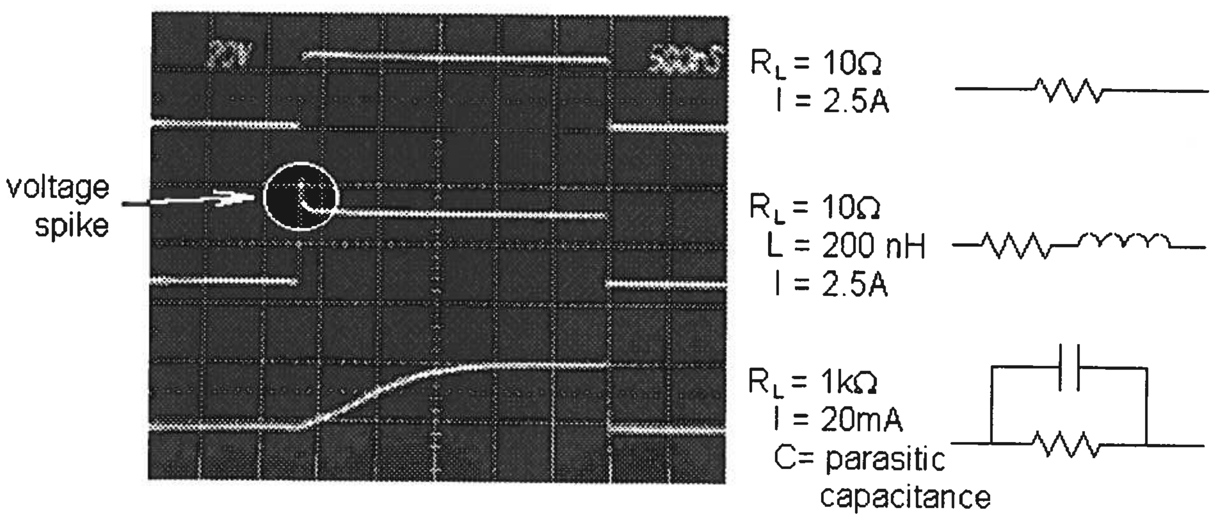


Figure 1

Inductive Loads

While capacitive loads may degrade low current pulses, the true mortal enemy of current pulsers is inductance. Extreme care has to be used when using current pulsers, and especially higher-current, higher-speed ones, with any sort of inductive load or cabling. Even a small inductance can generate a significant "inductive kick", which is a voltage spike predicted by Lenz's Law: $V = L\, dI/dt$. As an example, consider the situation where an Avtech AV-107E-C is used to drive a resistive load of 10 ohms, and the load is connected 4" away from the generator, using 20 AWG wire on the signal line and the ground return, for a total of 8" of wire. The AV-107E-C will provide 2.5 Amps of current with a rise time of 30 ns, and the wire will have an inductance of approximately 200 nH. Lenz's Law then predicts an inductive voltage spike of 15V! (See middle waveform, Figure 1). Even if the total lead length is reduced to 1 inch, the inductive spike will still be over 1 V. As you can see in this example, even the parasitic inductance of a short length of regular wire can create serious problems, particularly for fragile and easily-damaged loads such as laser diodes.

There are two complementary approaches to combat this problem. This first approach is to place the load extremely close to the pulse generators, and avoiding the use of cabling or connectors. For the ultimate in performance and convenience, socket-mounting of the load is available on many models. (The specially-designed low inductance socket allows a diode load to be mounted directly on the pulse generator output module.) The second approach, discussed below, is to use a low impedance transmission line.

Low Impedance Transmission Lines

Transmission lines are characterized by a parameter Z_0, the "characteristic impedance" of the transmission line. When a transmission line is connected to a load that is equal to its characteristic impedance ($R_L = Z_0$), then the transmission line acts as a perfect cable: the pulse generator does not "see" the parasitic capacitance or inductance in the line. This technique can be used for lengths of up to a few feet. The primary difficulty lies in obtaining a transmission line of the correct impedance - virtually all commercially available cables have impedances of 50 Ohms or higher. Laser diodes and other high-current loads are more likely to have resistances of only a few Ohms. Fortunately, Avtech Electrosystems produces a line of low-Z_0 transmission lines (the AV-LZ series). These are available with Z_0 values of 1, 2, 3, 6, and 12 Ohms. The AV-LZ lines are available with a diode socket option, to allow convenient mounting of a diode load at the end of the transmission line.

Current Pulsers Are Lossy

Current pulsers are inherently lossy - that is, they dissipate much more waste heat than voltage pulsers. For this reason, current pulsers are often limited to low duty cycle operation. (Duty cycle is the fraction of the time that the pulser output is high - i.e. 100% x pulse width / period). In voltage pulsers, the output transistors switch between saturation (low voltage drop, high current) and cutoff (high voltage drop, no current) which are both efficient modes of operation because high currents and high voltage drops never occur simultaneously. However the output transistors in a current pulser switch between the active and cutoff modes, and high currents and voltage drops exist simultaneously in the active mode of a transistor. The worst-case instantaneous power dissipation in the pulser occurs when the load is a short-circuit, and is approximately equally to the compliance voltage times the current amplitude. For instance, the Avtech AV-108B-3-C will supply 200A pulses with a compliance voltage of 20V, leading to a worst-case instantaneous power dissipation of 4 kW! (The maximum allowed average power dissipation in the AV-108B-3-C is 400W, which results in duty cycle limitations.) The photo in Figure 2 shows the AV-108B-3-C. The timing circuitry is contained in the instrument on the left, and the output stage is encased in the heatsink structure on the right. The output module is both fan-cooled and water-cooled. This ultra-high-power unit also requires a user-supplied 25V DC power supply rated at the average output current. (Note that lower average-power models do not require external DC power supplies.)

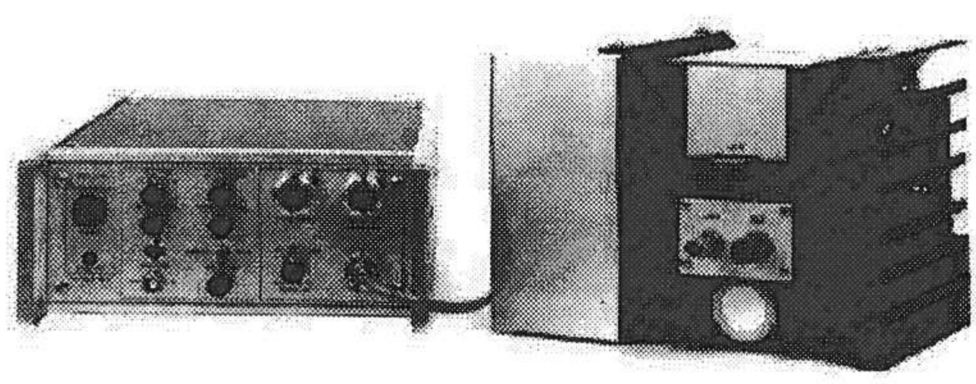
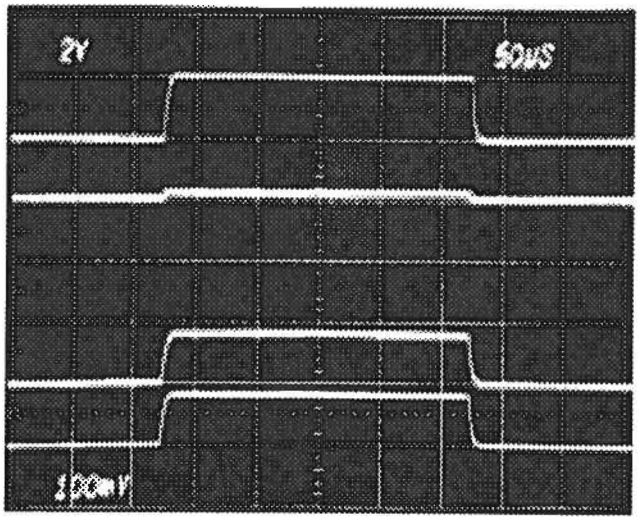


Figure 2 - The AV-108B-3-C

Current Monitors

Measuring and observing current pulses can be a tricky problem, since oscilloscopes are designed to measure voltages. Several approaches are available. Current transformers are available from a number of sources, such as Tektronix, Pearson or American Laser. The current-carrying conductor must be fed through these donut-shaped transformers, so they can not be used with transmission lines, since the main conductor is shielded by a ground conductor. Or, low-inductance current-sensing resistors (such as those available from Isotek and Caddock) can be added in series with the load, and the voltage across the resistor will be proportional to the current. The resistance must be kept small to avoid excessive voltage drops and power dissipation. In addition, many Avtech current pulsers are available with convenient built-in current monitors. The current monitor output supplies a voltage pulse that is proportional to the main output current pulse (with equal pulse width).

Figure 3 shows four waveforms for an Avtech current pulser. The top waveform shows the voltage across a 5 Ohm load when a constant pulse of 400 mA is applied. The second waveform shows the load voltage when a 0.5 Ohm load is used instead, with the same current amplitude. Naturally, the load voltage is ten times smaller, since the resistance is ten times smaller than before. The third and fourth waveforms show the output of the current monitor for these two cases. These two waveforms are identical, since the current amplitude has not changed, despite the different load resistances and voltages. (In this particular example, the current monitor output provides $V_{monitor} = I_{OUT}/5$. Since I_{OUT} = 400 mA in both cases, $V_{monitor}$ = 80 mV, as shown in the photo.)



$R_L = 5\Omega$ } Load Voltage
$R_L = 0.5\Omega$ } for I = 400 mA

$R_L = 5\Omega$ } Monitor Output
$R_L = 0.5\Omega$ } for I = 400 mA

Figure 3

Current-Output Function Generators and Arbitrary Waveform Generators

This article has focused exclusively on constant-current pulse generators, but occasionally current-output function generators or arbitrary waveform generators are needed. Current-output function generators such as the Avtech AV-151F-C are available. This instrument provides sine, square and triangle wave outputs with amplitudes of up to 2.0A at frequencies up to 20 kHz. In addition, some Avtech pulsed constant-current generators also offer a linear voltage-to-current mode that can be used to convert a voltage waveform from any source (such as a voltage-output arbitrary waveform generator) into a current waveform. The AV-155-C, AV-156-C, and AV-108-C series offer this mode as a standard feature.

Using a Voltage Pulser as a Current Pulser

It should be noted that if the user does not require a current of more than an amp or two, and can tolerate some current amplitude variation with load voltage, a regular 50 Ohm voltage pulse generator can be used to approximate a pulsed constant current-source source by adding a series resistance. Figure 4 illustrates this technique. The main problem is that both I_D and $R_{SERIES} + R_D$ must be kept relatively low if the pulse generator voltage, V_0, is to be kept at a reasonable level. Most lab pulse generators will not deliver more than 10V, but the Avtech AV-1010-C and AV-1011-C pulse generators are designed to deliver 100V pulses into a 50 Ohm load. For example, if the 50 Ohm load is replaced with a 49 Ohm resistor (R_{SERIES}) in series with a 1 Ohm laser diode (R_D), the AV-1010-C could be used as a 2 A current source (since 100V / R_{SERIES}+R_D = 2A). This setup has the advantage that a 50 Ohm transmission line can be used, since the transmission line will be terminated in 50 Ohms (i.e., the 49 Ohm series resistor and the laser diode provide a proper 50 Ohm termination for the transmission line).

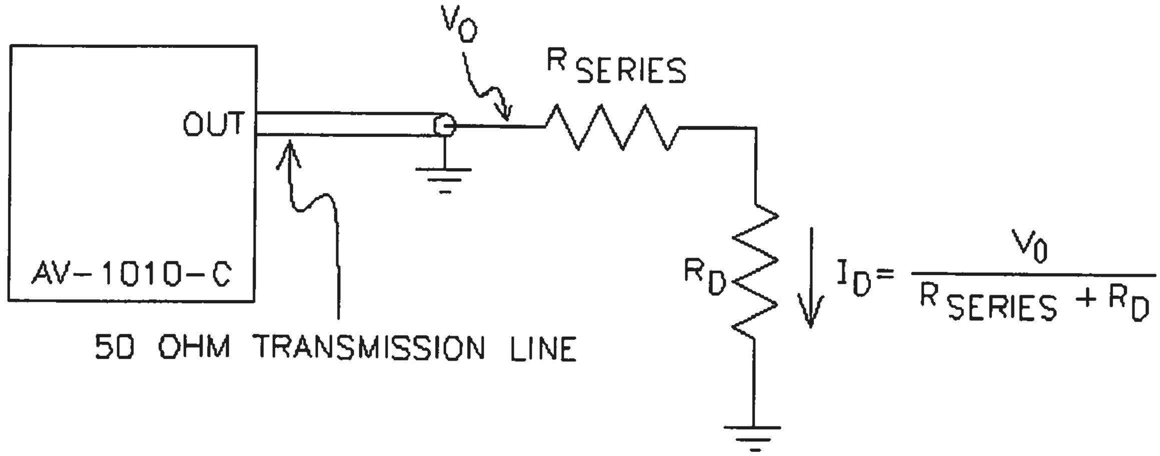
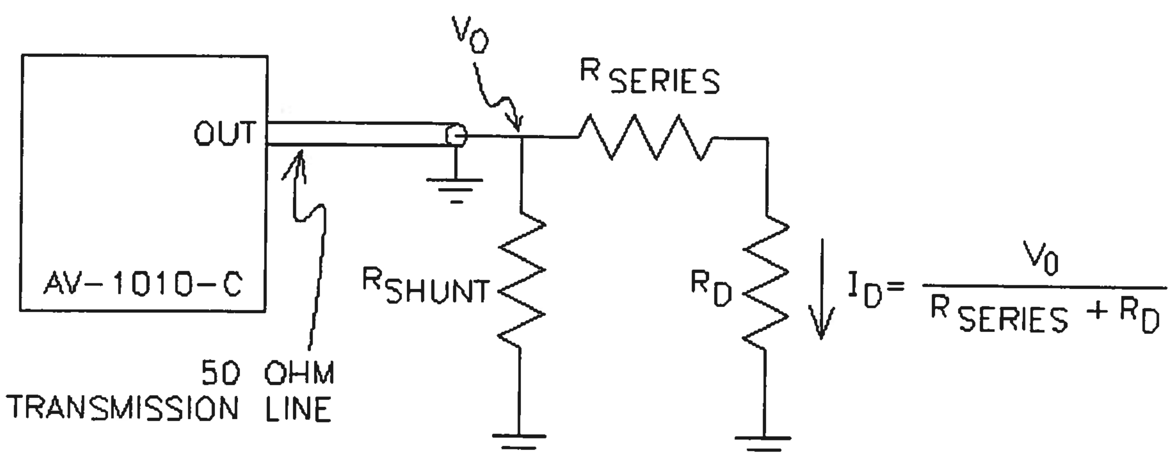


Figure 4

When using the AV-1010-C for much lower load currents (e.g. 10 mA) R_{SERIES} may be increased significantly (e.g. to 10 kilohms), but then a shunt resistor (R_{SHUNT}) must be added to the circuit as shown in Figure 5. This resistor is chosen so that the parallel combination of it and $R_{SERIES}+R_D$ is equal to 50 Ohms, to properly terminate the transmission line. (If the transmission line is not terminated properly, ringing and overshoot will occur on the pulse.) When using the AV-1011-C in such applications, the same effect can be achieved simply by setting the source impedance switch to the 50 Ohm position (i.e. no shunt resistor is necessary).



CHOOSE R_{SERIES} TO SET CURRENT

CHOOSE R_{SHUNT} SO THAT: $\frac{1}{R_{SHUNT}} + \frac{1}{R_{SERIES} + R_D} = \frac{1}{50\text{ohms}}$

Figure 5

Other Questions

If this application note hasn't answered your questions about the Avtech family of pulsed constant-current generators, call us at 1-800-265-6681, or email us at info@avtechpulse.com. More application notes are available at http://www.avtechpulse.com/appnote/.

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