Internal Report:

Adaptation of the ISIS Induction-Cell Driver to a Low-Impedance X-Pinch Driver

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Abstract. In this report we summarize the work done to design a system to non-destructively convert the Idaho State Induction System (ISIS) induction cell driver (ICD) to a low impedance pulse power driver for x-pinch applications. The simulation results show that such a driver can supply of about 300-kA peak current with about 70-ns rise time (10-90%). However, simulations also show, that the negative reflective wave is formed, which can cause the destruction of the ISIS ICD' pulse forming line (PFL). The particular attention was taken to simulate the effect of misfire of one of the PFL. To reduce the amplitude of this destructive wave, high power damped resistors should be placed after the output of each PFL. As a result, the maximum current achievable by this driver will be limited to about 200-kA peak value. Taking into account this result and some other considerations, the decision was made to design a new, stand-alone, compact and portable pulse power x-pinch generator.

Keywords: pulsed power accelerator, pulsed power generator, x-ray source, z pinch, x pinch.

OVERVIEW

Idaho State Induction System (ISIS) is a high intensity pulsed power electron accelerator capable to supply of about 80 GW of power in a 35 nanosecond pulse [1-2]. It was donated to the Idaho State University by Titan Pulse Sciences, Inc. in 2002 and its primary purpose is to serve as a radiation source for radiation effect testing in biological and electrical system [3]. The power supply of ISIS [4] is composed from Marx generator and five separate pulse forming lines (PFLs). Forty oil-filled 77-ns long cables connect the power supply to each acceleration unit (AU) of ISIS. The power supply circuit of one PFL is shown in the Figure 1. Each PFL produces a perfect 84-ns long, flat 300-kV pulse which is directly used to accelerate electrons inside each AU.

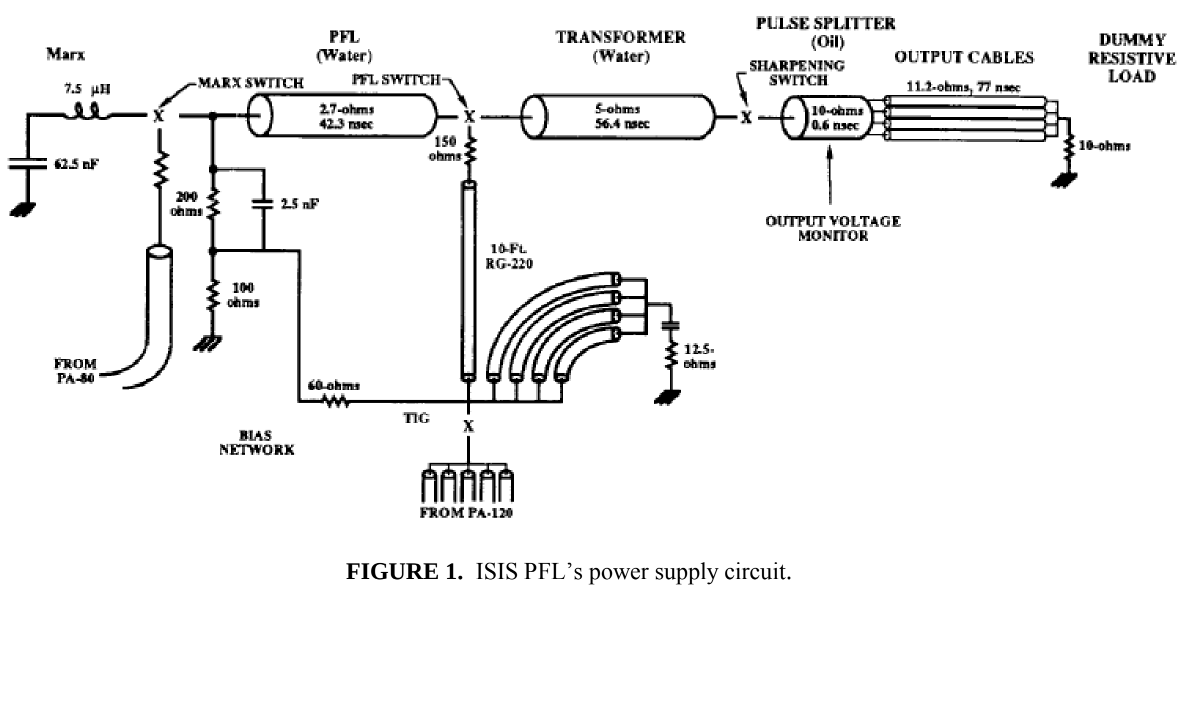


FIGURE 1. ISIS PFL's power supply circuit.

In order to convert the ISIS power supply to a low-impedance x-pinch driver, the impedance transformer was designed [5]. The impedance transformer is the most important part of the x-pinch driver and serves to combine the five 300 kV outputs of the ISIS' induction cell driver (5 Ω each) into one low impedance (<1 Ω), 40-80 kV output to be fed to the x-pinch chamber. Analysis of the ISIS' induction cell driver showed that the most suitable spot for tapping its output pulse is at the end of the water-filled PFLs before the oil-filled connectors to the high-voltage cables [5].

In this report, we present electrical circuit simulation results of proposed ISIS' based x-pinch driver. LTspice [6] simulations show, that after directly connecting the output of each PFL to the impedance transformer and feeding the output pulse to x-pinch load, such a x-pinch driver can supply of about 300-kA peak current with about 150-ns rise time (Figure 5 a). However, simulations also show, that the negative reflective wave is formed, which can cause the destruction of the ISIS' PFL. The particular attention was taken to simulate the effect of misfire of one of the PFL (Figure 5 b). To reduce the amplitude of this destructive wave, high power damped resistors should be placed after the output of each PFL. As a result, the maximum current achievable by this driver will be limited to about 200-kA peak value (Figure 7 a).

Taking into account this result and some other considerations (time and effort needed to switch between the x-pinch operation mode and the normal operation mode of ISIS), the decision was made to design a new stand-alone compact and portable pulse power x-pinch generator [7].

LTSPICE SIMULATIONS: UNMODIFIED ISIS' POWER SUPPLY

LTspice [19] Linear Technology circuit simulation program was used to simulate the behavior of the proposed ISIS' based x-pinch driver. To verify that LTSpice program can be correctly used, we first simulated the unmodified ISIS' power supply circuit. The electrical circuit diagram used for simulation are shown in the Figure 2. There are total of five PFLs followed by the 77-ns long cables which connect the ISIS power supply to each AU. Each PFL consists from two 42.3-ns and 56.4-ns long transmission lines with the PFL switch placed in the middle.

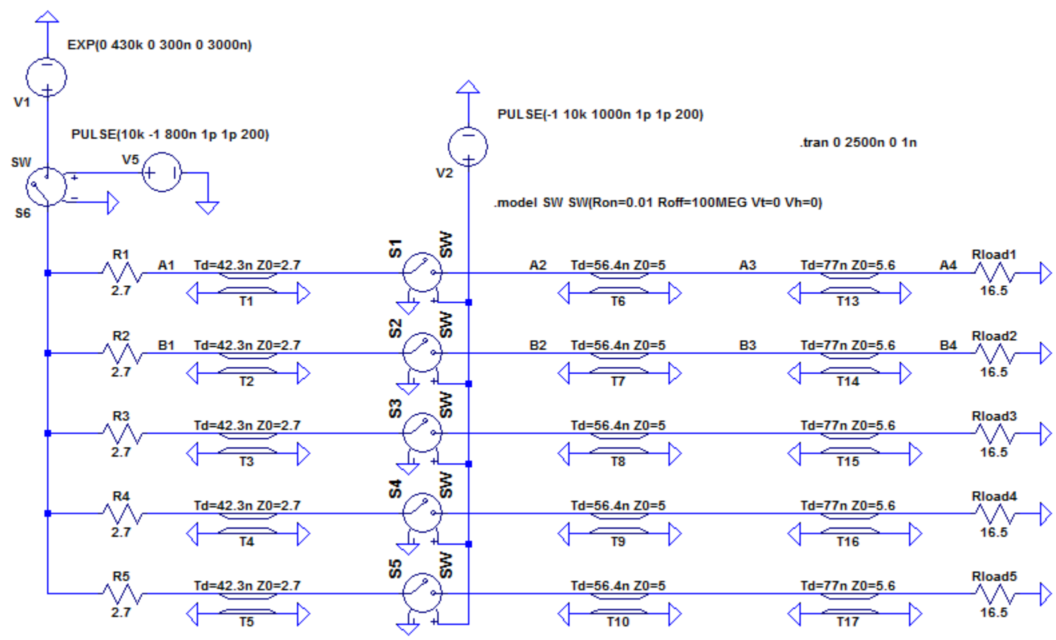
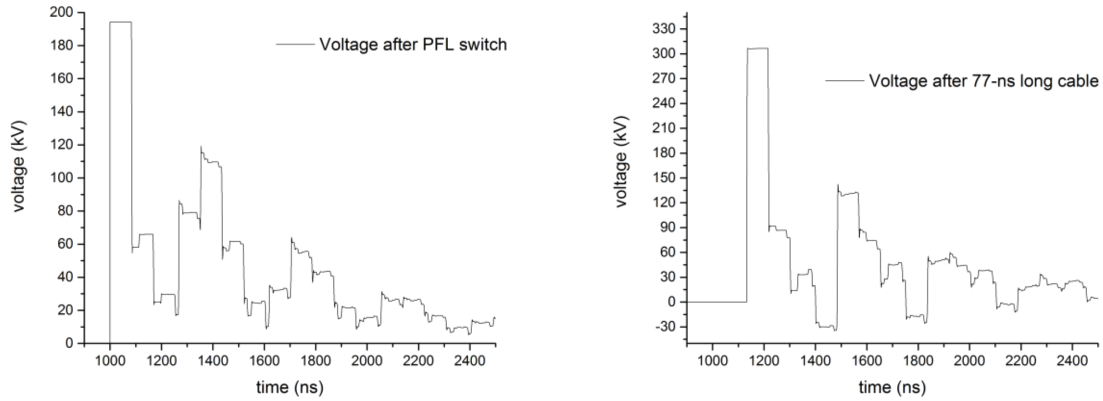


FIGURE 2. LTSpice electrical circuit of ISIS' power supply.

Some simulation results of high-voltage pulse, as it propagate through the PFL, are shown in the Figure 3 (a, b). The voltage behavior at the exit of the PFL switch is shown in the Figure 3 (a). As can be seen, after switch is fired, the perfect-flat 84-ns long high-voltage pulse is formed. It is important to note, that there are no reflective negative waves passing through PFL switch at the later time. From private communication [8] it is known, that the high-voltage negative-reflective wave will probably destroy the PFL switch, because it is designed to hold only the high-voltage positive pulse. The Figure 3 (b) shows the voltage behavior at the end of 77-ns long high voltage cable. As expected, there are perfect 84-ns long, 300-kV voltage pulse is formed, which is directly used to accelerate electrons to 0.3 MeV energy inside each AU.



(a) **(b)**

FIGURE 3. LTspice simulations of a high-voltage pulse as it propagate through the PFL of the ISIS' power supply circuit: (a) voltage measured after PFL switch (b) voltage measured after 77-ns long high-voltage cable.

LTSPICE SIMULATIONS: 300-KA X-PINCH DRIVER

Figure 4 shows the electrical circuit of the ISIS' based x-pinch driver. The impedance transformer (represented by the transmission line element T11) is directly attached to the output of each PFL and the output of the impedance transformer is fed to the x-pinch load located in the middle of the vacuum chamber. The total inductance of the x pinch and all connection lines between the impedance transformer and the x-pinch load (header, lower feed, upper feed, etc.) can be roughly approximated to be equal to about 26 nH [7].

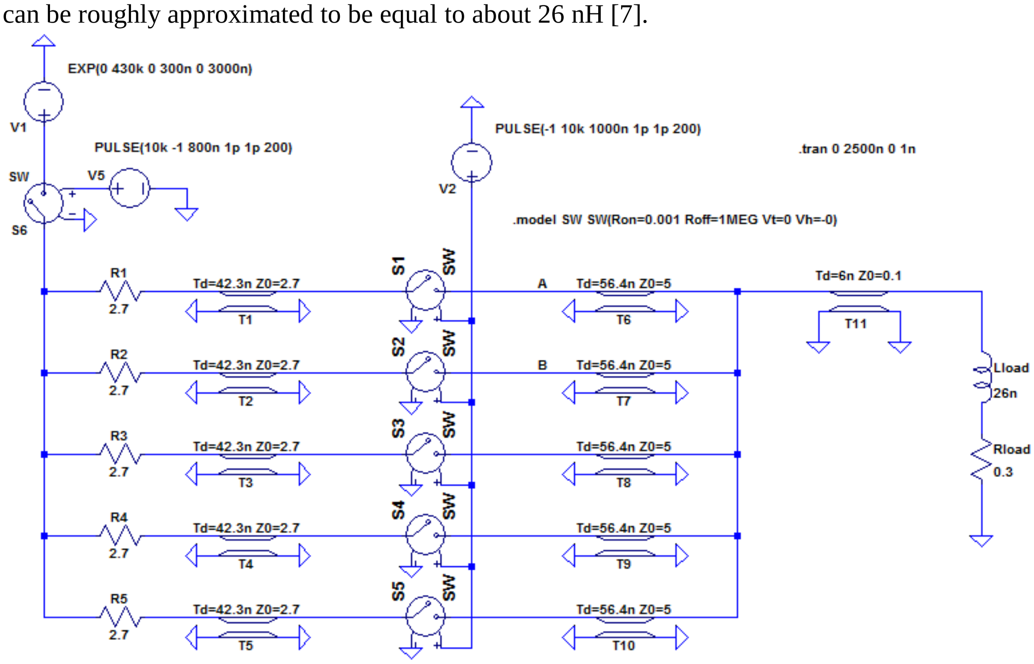
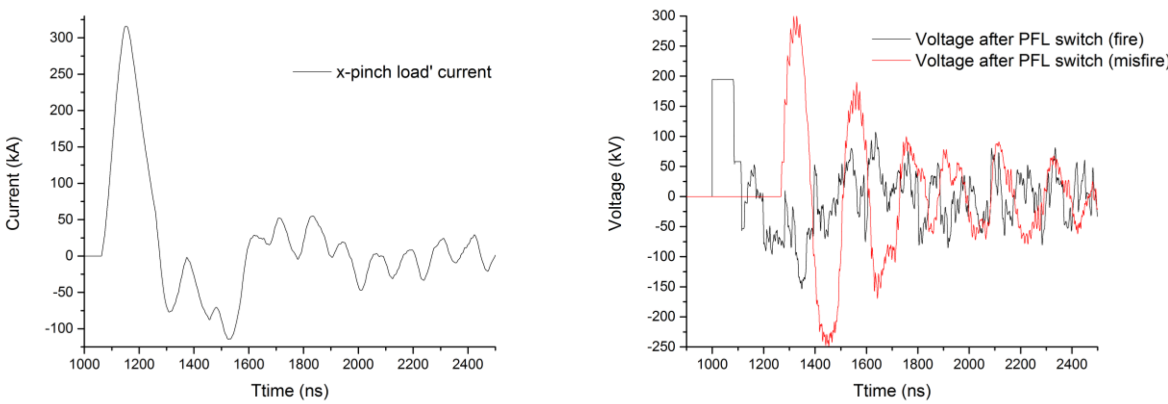


FIGURE 4. Electrical circuit of ISIS' based x-pinch driver.

%). LTSpice simulation of current pulse as it propagates through x-pinch load are shown in the Figure 5 (a). After optimization of the impedance transformer parameters (6-ns long, 0.1 Ω), it was found that such a driver can supply of about 320-kA peak current with 70-ns rise time (10-90

Because the impedance transformer is necessary to transform down the impedance of PFLs by the factor of about 10, the reflective negative wave is formed traveling back to the PFL switch. This reflective wave will become even worse, if one or more PFL switches is not fired. Figure 5 (b) shows simulations of the voltage behavior at the exit of PFL switch for two cases: the black line represents the scenario when all PFL switches are fired simultaneously (fire), and the red line represents the scenario when one PFL switch is not fired (misfire). As can be seen, the negative reflective wave with the maximum amplitude of about 150 kV is formed at the switch location for the normal regime of operation (fire). In the case of misfire of one of the switches, this reflective negative wave riches the maximum amplitude of about 250 kV.



(a) **(b)**

FIGURE 5. LTspice simulations of the ISIS' based x-pinch driver: (a) current measured on the x-pinch load (b) voltage measured after PFL switch (black line represents simulation results when all PFL switches are fired simultaneously, and red line represents the case when one PFL switch is not fired).

It is known [8], that such a high-voltage negative reflective pulse will probably destroy the PFL switch. So, even the maximum current of about 320-kA peak value is achievable by this design, such a driver will probably not work for a long time due to possible destruction of PFL switches. As a result, a costly repair will be necessary in the future.

LTSPICE SIMULATIONS: 200-KA X-PINCH DRIVER WITH DAMPED RESISTORS

To reduce the amplitude of this destructive negative wave, some high power damped resistors is necessary to be used. Figure 6 shows the electrical circuit of the modified ISIS' based x-pinch driver. As can be seen, resistors with 4.7 Ω resistance values are placed after each PFL before the impedance transformer. This will allow to reduce the amplitude of the reflective negative wave at the PFL switch location to the appropriate value, so the x-pinch driver can be safely operated.

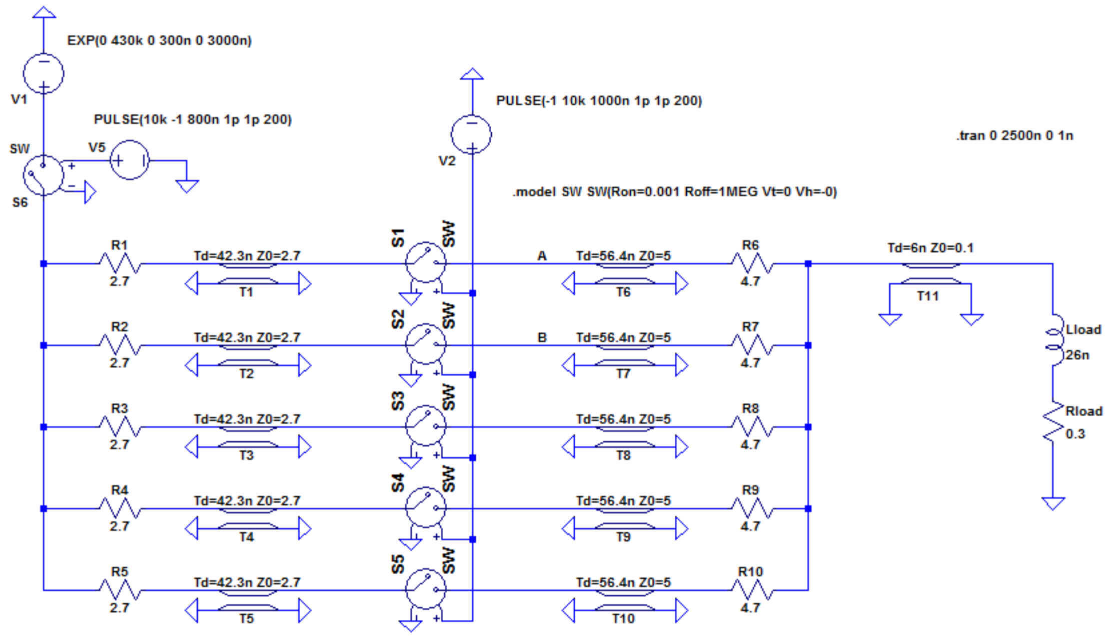
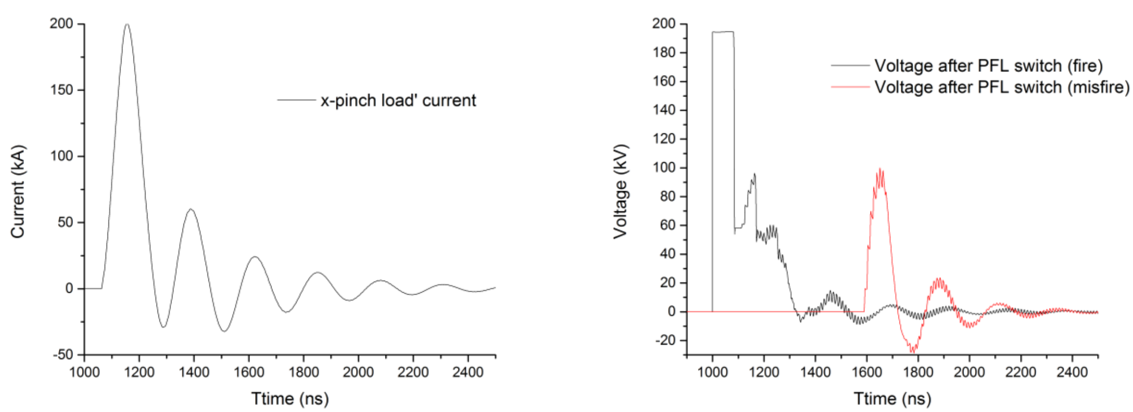


FIGURE 6. Electrical circuit of ISIS' based x-pinch driver. To reduce the amplitude of the reflected negative wave, high power damped resistors R6-R10 are placed after the output of each PFL.

As shown in the Figure 7 (a), such a modified x-pinch driver can supply of about 200-kA peak current with 60-ns rise time (10-90%). The simulation results of the voltage behavior at the exit of PFL switch for two cases, fire and misfire, as described above, are shown in the Figure 7 (b). In the normal regime of operation (fire), the amplitude of the negative reflective wave is almost reduced to the zero value. In the case of misfire of one of the switches, there is still some negative reflective wave is formed of maximum amplitude of about 25 kV, but the total duration of this wave is only about of 100 ns. This small negative reflective wave will probably not give any damage to PWL switch.



(a) **(b)**

FIGURE 7. LTspice simulations of the ISIS' based x-pinch driver with five damped resistor added after each PFL: (a) current measured on the x-pinch load (b) voltage measured after PFL switch (black line represents simulation results when all PFL switches are fired simultaneously, and red line represents the case when one PFL switch is not fired).

CONCLUSION

In this report, we presented electrical circuit simulation results of proposed ISIS' based x-pinch driver. LTspice simulations show, that after directly connecting the output of each PFL to the impedance transformer and feeding the output pulse to x-pinch load, such a x-pinch driver can supply of about 300-kA peak current with about 70-ns rise time (10-90%). However, simulations also show, that the negative reflective wave is formed, which can cause the destruction of the ISIS' PFL. The particular attention was taken to simulate the effect of misfire of one of the PFL switches, when the negative reflective wave will become even worse.

To reduce the amplitude of this destructive wave, high power damped resistors is necessary to be placed after the output of each PFL before the impedance transformer. This will allow to reduce the amplitude of the reflective negative wave at the PFL switch location to the appropriate value, so the x-pinch driver can be safely operated. But as a penalty, the maximum current achievable by this driver will be limited to about 200-kA peak value.

Taking into account this result and some other considerations (time and effort needed to switch between the x-pinch operation mode and the normal operation mode of ISIS), the decision was made to design a new stand-alone compact and portable pulse power x-pinch generator.

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