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# Notes on the RHIC Injection Magnet Pulser Ground System

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**Brookhaven National Laboratory**

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**RHIC PROJECT**

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## Introduction

The ground system design has an impact on safety, electromagnetic interference and beam impedance problems. Two grounding methods have been investigated using computer circuit simulation. The first method provides a dedicated ground at the pulser, which is located outside the ring in the 5 o'clock house. The second method permits the injection kicker magnet to be grounded to the vacuum chamber in the ring.

## Circuit Simulation

Simplified versions of the two systems studied are shown in Figs. 1 and 2.

Two grounds are shown in Fig. 1; the dedicated pulser ground and the ring ground. These share a common mutual resistance*. The impedance $L_2$, R represents stray inductance of the coaxial cable outer conductor and the resistance of the outer conductor. If the cable acted as an ideal coaxial conductor and all shielding conductors were thicker than several skin depths then $L_2$ should be identically zero. The outer conductor of the coaxial cable (RG-220) is copper braid. In the simulation $L_2$ represents the departure from ideal. This impedance causes a voltage drop on the outer conductor between the pulser and the magnet. The function of $S_1$ is to simulate a short circuit caused by a flashover from the live conductor to the grounded conductor of the magnet. The program permits this switch to be activated at any time during the pulse. Figure 1 has a low impedance representing

*A discussion of the representation of ground circuits is given in: "Calculation of the Earth Transients and Design of Ground Fault Protection at the Fifth Avenue Test Site", M. Meth, PTP Tech Note 75, 1977.

the dedicated ground at the pulser and a higher impedance simulating the machine ground in the ring. Figure 2 has a 'weak' ground at the pulser; this ground is used to connect the stray capacitance of the coaxial cables and support equipment transformers to ground. In Fig. 1, the capacitance of the magnet and support assembly to the machine ground is represented by $C_1$. In Fig. 2 the capacitance of the pulser to the equipment ground is represented by $C_2$.

Simulation Results

FIG. 1 (hard ground at pulser)

| Conditions (all results are for 50 kV on load resistor) | Pk Voltage on Coax. Outer Conductor* | Pk Voltage at Ring Ground |
|---|---|---|
| 1. Normal Operation | 900 | 1200 |
| a) $L_2$ = 20 nH, $C_1$ = 200 pF | | |
| b) $L_2$ = 20 nH, $C_1$ = 500 pF | 900 | 1000 |
| c) $L_2$ = 10 nH, $C_1$ = 500 pF | 400 | 800 |
| 2. Magnet Flashover at 100 ns | | |
| a) $L_2$ = 20 nH, $C_1$ = 200 pF | 1400 | 2500 |
| b) $L_2$ = 20 nH, $C_1$ = 500 pF | 1500 | 2800 |
| c) $L_2$ = 10 nH, $C_1$ = 500 pF | 800 | 1400 |

*Voltage are referenced to infinite ground bus.

FIG. 2 (hard ground at magnet)

| Conditions (all results are for 50 kV on Load Res.) | Pk Voltage on Coax. Cable* Outer Conductor | Pk Voltage at Ring Ground |
|---|---|---|
| 1) Normal operation | | |
| a) $C_2$ = 1000 pF | 1000 | 600 |
| $L_3$ = 20 $\mu$H | | |
| b) $C_2$ = 2000 pF | 1000 | 600 |
| $L_3$ = 20 $\mu$H | | |
| c) $C_2$ = 5000 pF | 1300 | 400 |
| $L_3$ = 50 $\mu$H | | |
| 2) Magnet Flashover at 100 ns | | |
| a) $C_2$ = 1000 pF | 2000 | 1000 |
| $L_3$ = 20 $\mu$H | | |
| b) $C_2$ = 2000 pF | 2100 | 1200 |
| $L_3$ = 20 $\mu$H | | |
| c) $C_2$= 5000 pF | 3000 | 700 |
| $L_3$ = 50 $\mu$H | | |

Comments on Simulation

Numerous combinations of component values and timing of $S_1$ were simulated. The results tabulated for Fig. 1 show the result of changing $L_2$ and the effect of a flashover. Those for Fig. 2 show the effect of changing the relative impedances of the grounding system.

*Voltage are referenced to infinite ground bus.

As may be expected, the voltage excursions are kept to a minimum at the nodes with a hard ground. Moving the hard ground from the pulser (Fig. 1) to the magnet (Fig. 2) reduces the peak voltage on the vacuum chamber ground from 2800 v to 1200 v (assuming a magnet flashover). Voltages during normal operation are approximately one-half of those present when a flashover is simulated.

For both grounding situations the magnitude of the ground voltage depends critically on the value chosen for the stray inductance between the magnet and the pulser; "$L_2$" in Figs. 1 and 2. The values used in the simulation of 10 and 20 nH are considered reasonable but the actual value will be hard to measure in practice. The self inductance of the two cables in parallel (~ 250 ft run) is 10 $\mu$H. Thus 20 nH represents ≈ 0.2% The simulation clearly indicates $L_2$ should be as low as possible. From Fig. 1 we see the value of the stray capacitance from the magnet to vacuum chamber ground is not critical, likewise the stray capacitance $C_2$ in Fig. 2 is not critical. However the simulation indicates that the absolute value of the ground impedances, (for example $L_3$ and 20 ohm in Fig. 2) is not as important as the ratio of the impedances at the two ground nodes. Compare the voltage at node 13 for the cases of Fig. 2 results, 2b and 2c. Basically the impedances to ground act as a potential divider across the voltage generated across $L_2$ and R.

The addition of other parasitic components, for example a capacitor in parallel with $L_2$, can cause resonances which greatly increase the peak voltages observed in the simulation. Such a component can represent the effective capacitance of the cable outer conductor to ground, in practice the capacitance will be distributed along the length of the cable. Detailed simulation of this effect is difficult as precise values of the components to be simulated are not known. The computer simulation circuit for Fig. 2 is given in Fig. 3, Fig. 4 shows the voltage waveforms at the ground nodes. Note the propagation times of the cable and magnet in Fig. 3 are smaller than those in the actual system.

Recommendations for the Grounding System

The pressing need to minimize the impedance presented by the beam tube argues for Fig.2. This scheme permits the vacuum chamber to have a continuous electrical connection with the outer conductor of the kicker magnet. The practical realization is shown in Fig. 5. The Blumlein pulsers are insulated from the building ground using G-10 supports or similar. A rating for the insulation withstand at the pulser location to ground must be decided. Based on the computer simulation, an insulation level test of 10 kV rms, 60 Hz for 2 minutes is suggested. This rating applies to the following:

1) Secondary to core and shield for all filament and reservoir transformers.
2) Primary to core and shield for all filament and reservoir transformers.
3) Primary to core and shield for all auxiliary equipment such as trigger generators, charging supply*, etc.
4) Pulser outer conductor to building ground.
5) Coaxial cable outer conductor to building ground.**
6) Charging supply negative dc terminal.
7) DC bias supply for thyratron grids.

* The use of switching supplies for charging which do not possess a 60 Hz input power transformer will require special consideration.

** The cable jacket failed at 40 kV dc between outer conductor and a simulated ground and thus seems more than adequate for the suggested withstand level.

8) Trigger transformer secondary to primary and core.

9) Current monitor Pearson transformer.

All 60 Hz power transformers must be insulated on both primary and secondary for the suggested level of withstand voltage. In addition the transformers should be equipped with an internal Faraday shield. Filters may also be needed on the ac side to minimize EMI. Power supplies such as grid bias, trigger generator and charging shall be designed so that the chassis, panel and controls are referenced to building ground. The simulation suggests it may be desirable to enclose the equipment in a protective cage connected to a third ground. In Fig. 3 the node 22 voltage is essentially zero, this node represents the voltage present at a third ground connection. All controls and monitoring signals should be optically isolated. The building ground in the 5 o'clock house shall be as good as possible, a well-pipe into the water table is recommended.

In the ring the magnets shall be insulated from the support structures so that a single, low impedance, ground connection can be made without introducing loops. The computer simulation indicates the ring ground, located at the kicker magnets, shall be as good as possible. Simply connecting the magnets to the 250 mcm ground wire may not be sufficient. Providing a suitable ground may be difficult and may require a hole in the tunnel floor through which a pipe can be driven into ground water. The enclosure around the magnets and the ducting can be connected to the 250 mcm ground wire, see Fig. 5.

Although a major objective of the system is to provide a continuous electrical connection for the vacuum chamber and magnet other considerations may outweigh having the lowest Z/n possible. It may be prudent to place a ceramic break in the vacuum chamber upstream and downstream of the four magnet kicker assembly. These could be relatively short, perhaps 5 to 10 mm in axial length. These breaks provide the option of isolating kicker induced transients from the vacuum chamber and related equipment such as pumps. Consideration of the impedance coupled into to the kicker magnet by a high conductivity coating may also require a longitudinal break at the vacuum chamber flanges. Studies of these effects are not complete and the question of a conducting coating on the inside of the ceramic vacuum pipes traversing the kicker is still open. If it turns out that beam instabilities develop due to the impedance of the breaks they could be easily shorted out or bypassed by capacitors. At least in this way a compromise could be found between the various competing effects.

## Conclusion

The results of a computer circuit simulation of the RHIC injection magnet grounding system have been presented. In many ways the model analyzed is unsatisfactory. The need to invoke $L_2$ in order to generate a voltage to drive the ground system is speculative. It is possible the transient ground voltages experienced with existing kickers is due in whole or part to other causes, for example capacitive coupling to auxiliary equipment such as the trigger generators connected to the high power circuit. Capacitive coupling from the magnet itself is also a possible source of ground transients as arcing has been observed on the ground side of kicker magnets in the AGS which have the pulser directly connected to the magnet.

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BY CBF DATE 12/5 SUBJECT RHIC INJ. MAGNET SHEET No. ___ OF ___
CHKD. BY ___ DATE ___ GND SYSTEM JOB No. ___
DEPT. OR PROJECT AGS

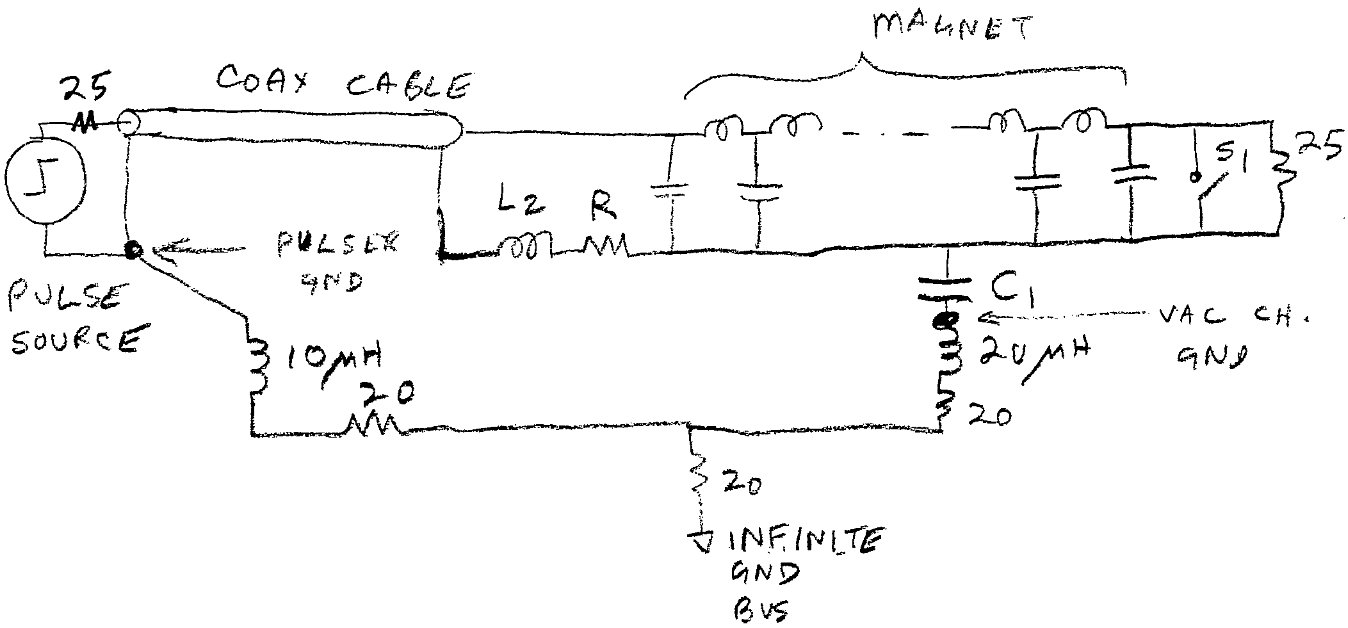


Figure 1. Simplified circuit with good ground at the pulser.

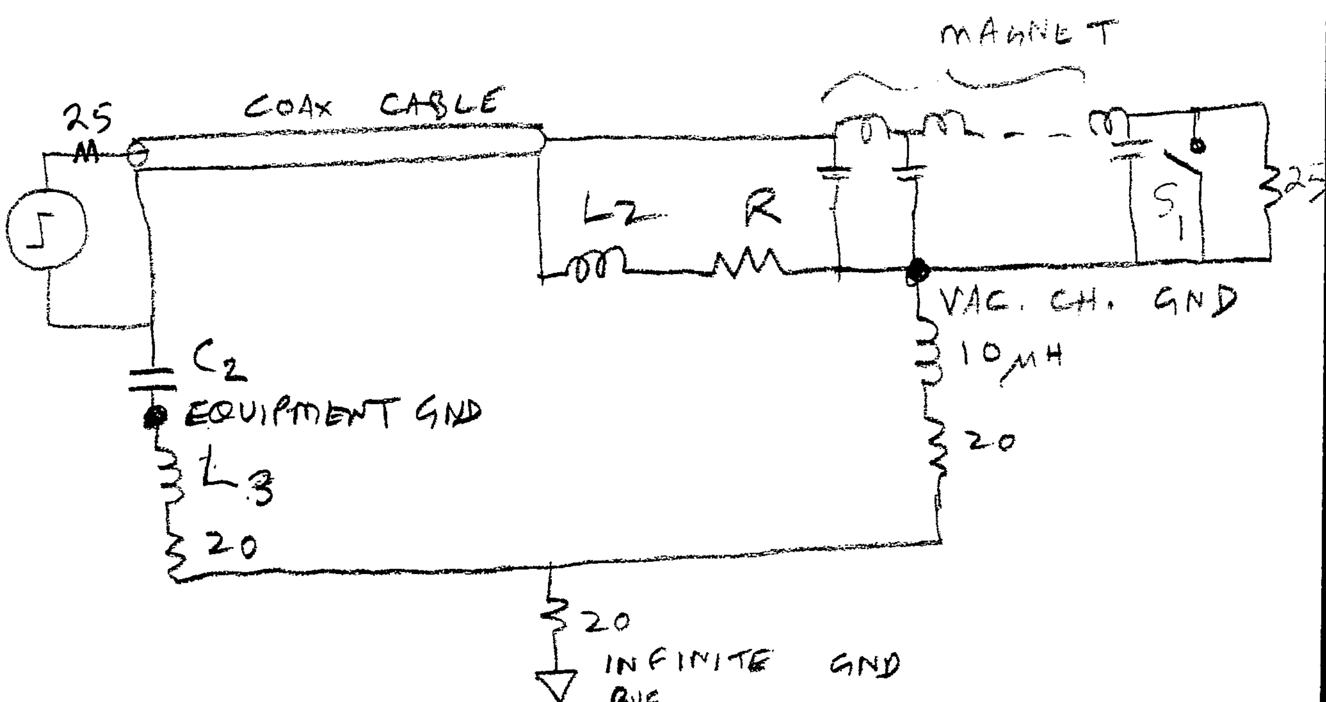


Figure 2. Simplified circuit with good ground at the kicker magnet.

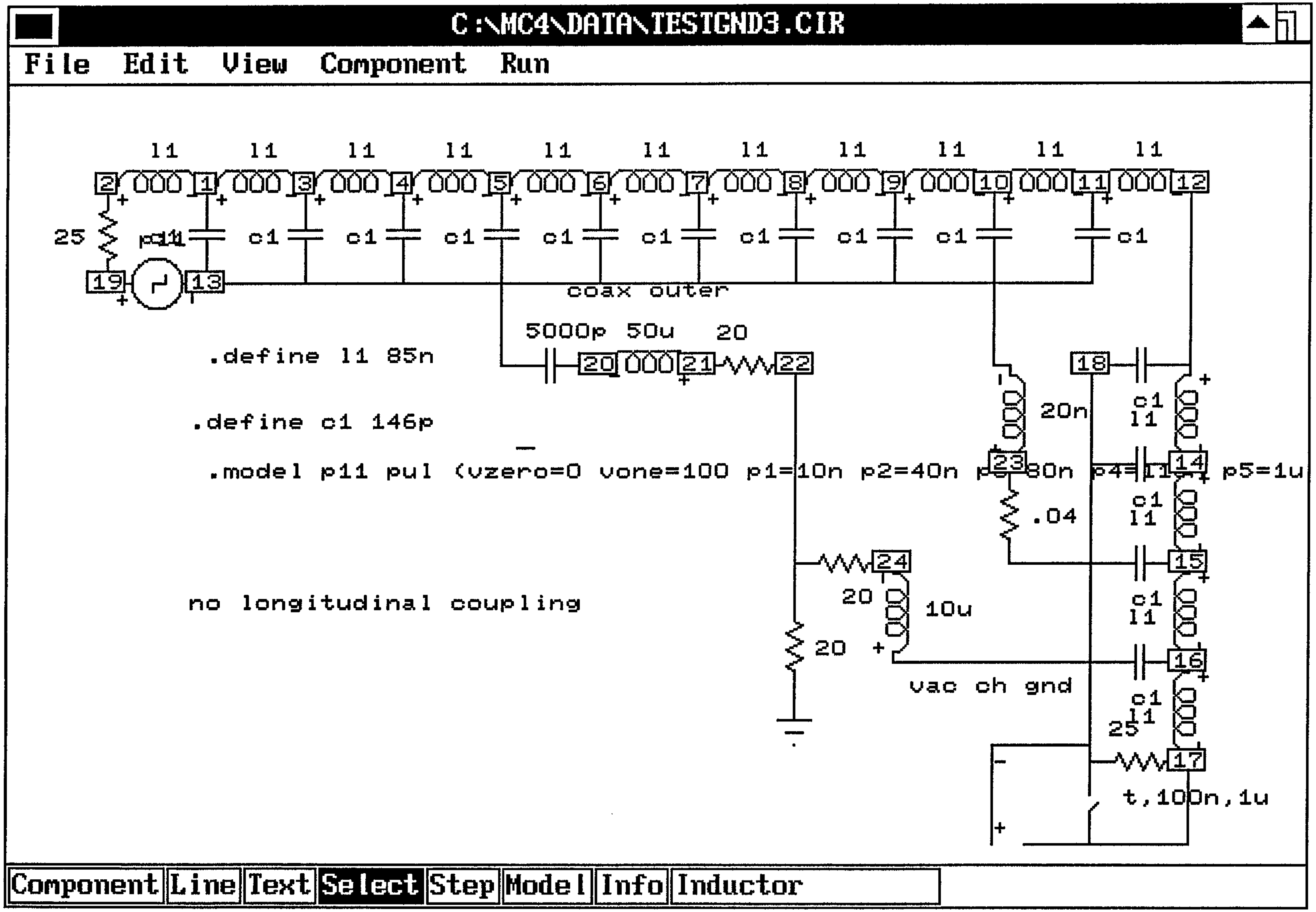


Figure 3. MC4 simulation of Figure 2. Node 18 is the vacuum chamber ground.

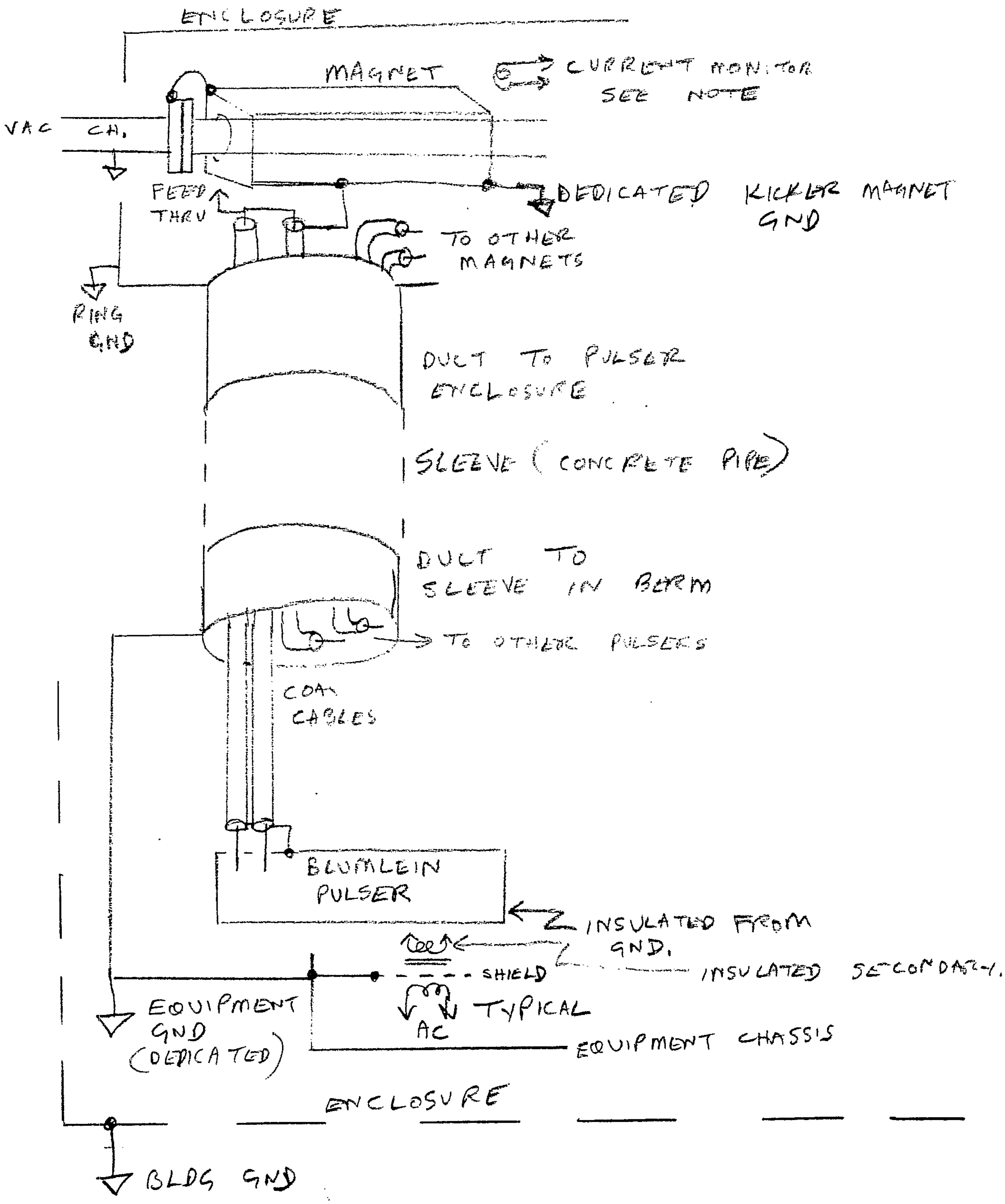


Figure 5. Practical realization of ground system.

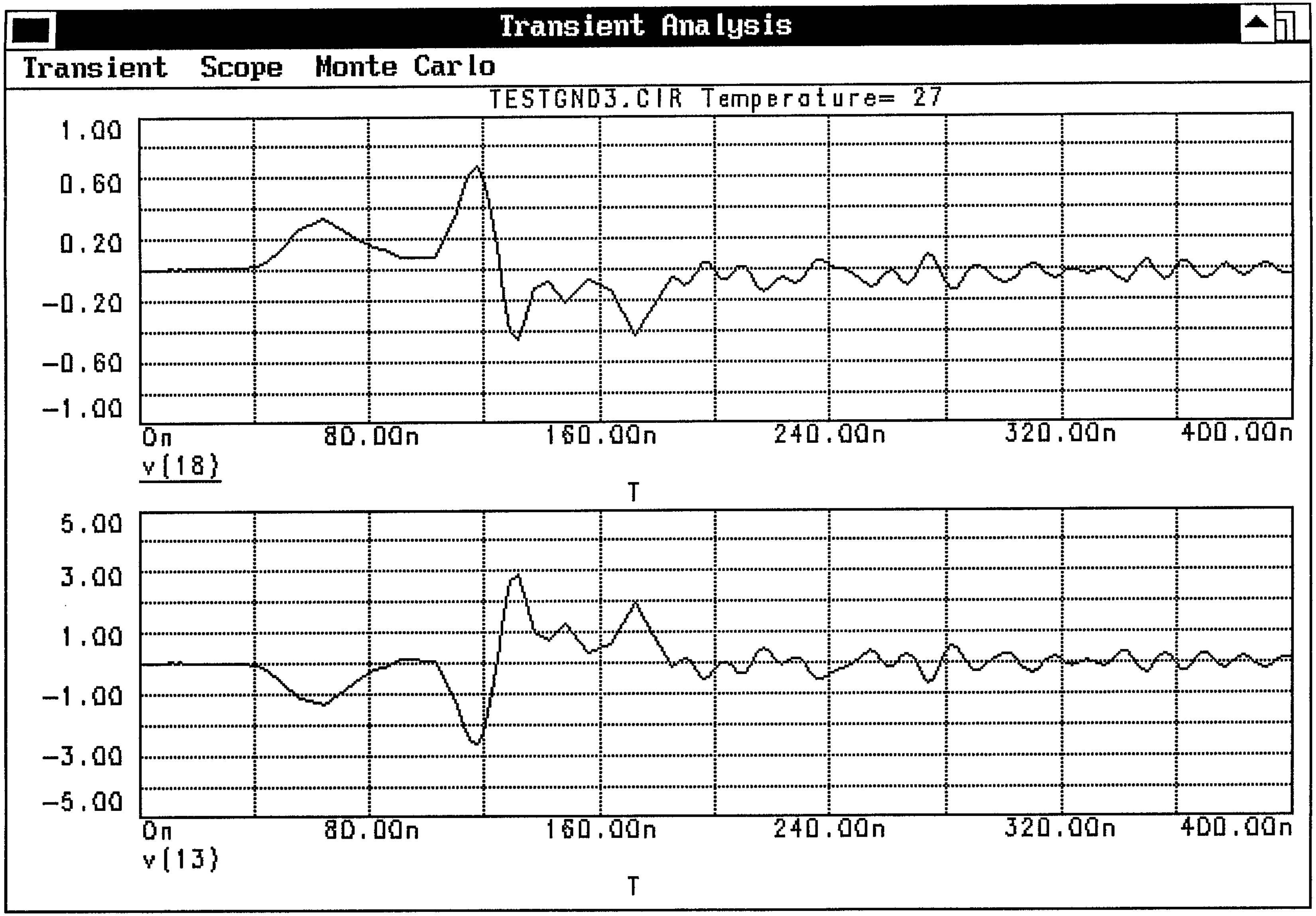


Figure 4. Nodes 18 and 13 voltage waveforms for circuit in Figure 3 assuming $S_1$ (simulated flashover) closes at 100 ns.