TRT HV System Simulations

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A preliminary model of a TRT HV system has been assembled in order to understand the limits of sensitivity for Distributor Electronics in USA15 to sparks or discharges in the TRT detector. The model is described in some detail and sample simulations are presented.

1.0 Introduction

The ATLAS TRT detector is a very large array (424,576) of proportional drift tubes operated with a negative (~1.5kV) potential on the cathode (straw) relative to the anode wire which is DC connected to system "ground" through the ASDBLR chip input. By keeping the anode at "ground" it is possible to greatly reduce the number of HV capacitors required - from the classical one per anode to one per eight cathodes. This arrangement of eight straws sharing an AC return path is echoed in the construction of the DC feed where, in general, eight cathodes (straws) are fed from one HV fuse (a custom low current fuse developed in Moscow[1]) and a number of fuses (typically eight, but ranging from six to ten) are fed from a single HV cable. For the entire TRT detector there are somewhat more than 6,000 such cables.

The TRT requires a HV supply to feed these 6,000 cables. Because of high radiation and high magnetic fields in the area immediately around ATLAS, it seems infeasible to have a HV supply close to the detector and so space has been reserved in the USA15 cavern - about a 150 meter cable run. For a much smaller system one might imagine a commercial supply[2], but the cost of such systems with many thousands of lines is prohibitive. For that reason the TRT group has developed the concept of a commercial bulk supply (to avoid the design and reliability problems inherent in HV and power supply design in general) feeding many cables but with custom trip circuitry monitoring each cable. This system is outlined in a Technical Note by Zbyszek Hajduk[3].

1. Need a reference for fuses
2. e.g. CAEN or Lecroy
3. TRT detector HV power supplies - specifications - version 2.0 - March 2001.

The trip circuitry is necessary to guard against sparks or other discharges that could damage the detector or leakage currents that could indicate incipient damage. Thus the trip circuitry must be capable of sensing such discharges, record and report them, and quickly turn off (or down) the HV to the affected area. In addition, it is useful to monitor the current in the detector (without beam) to watch for any increase in leakage. Since the event rate in ATLAS is very high, the current draw per straw at high luminosity is many microAmperes and so the nano or pico amp leakage currents can only be measured when the beam is off.

Because we need to monitor the detector over a very broad range of currents and the detector and power supply must be separated by a long cable run, it seems prudent to simulate the system behavior prior to constructing prototypes. This note describes the model(s) used for the simulation and some of the early simulation results.

2.0 Methodology

Since the goal is to eventually build a prototype system, the TRT HV System model is built using the Cadence Analog Workbench tools. This should allow direct circuit board implementation of the trip (and control) circuitry that has been modeled. Analog Workbench uses Concept schematics and Cadence Spice and will port directly to Allegro for layout.

While what we need to prototype is only the trip and control circuitry, the model must include the entire system. For this initial version, we take the system to be:

- A Bulk Power Supply[1] requiring 220V AC input plus on/off, interlock, and HV setpoint controls and providing I and V monitor voltages plus up to 40 mA at -2kV.
- A Distributor Board that provides controls for and reads monitors from the Bulk Supply and contains all the trip sensors and logic and has some logical connection to the ATLAS DCS computers.
- A Cable that carries the HV supply current from the Distributor to the TRT.
- A Filter, located at the detector, that removes possible high frequency noise from the long cable.
- The load - 64 Straws, each drawing a preset DC current with appropriate capacitances and other impedances.

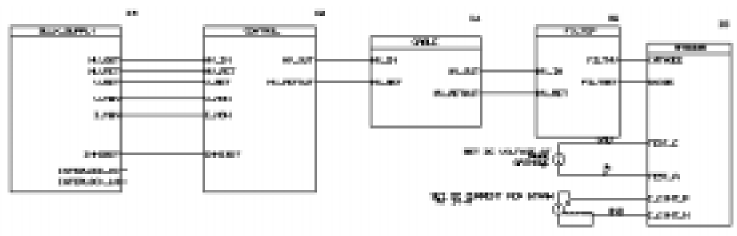
As this is an initial attempt, it is expected that the model will be added to, tuned, and adjusted to become as realistic as necessary before any prototype devices are fabricated. In particular, the model itself should help to finalize or validate our choices in cable and in filter components - the granularity of the detector and the impedance of the fuses, for instance, is already fixed.

1. At this point we are using Glassman MK series as the gedanken model - see www.glassmanhv.com

3.0 The Model (A work in progress...)

The overall model is arranged in hierarchical form. The top level schematic is shown in Figure 1.

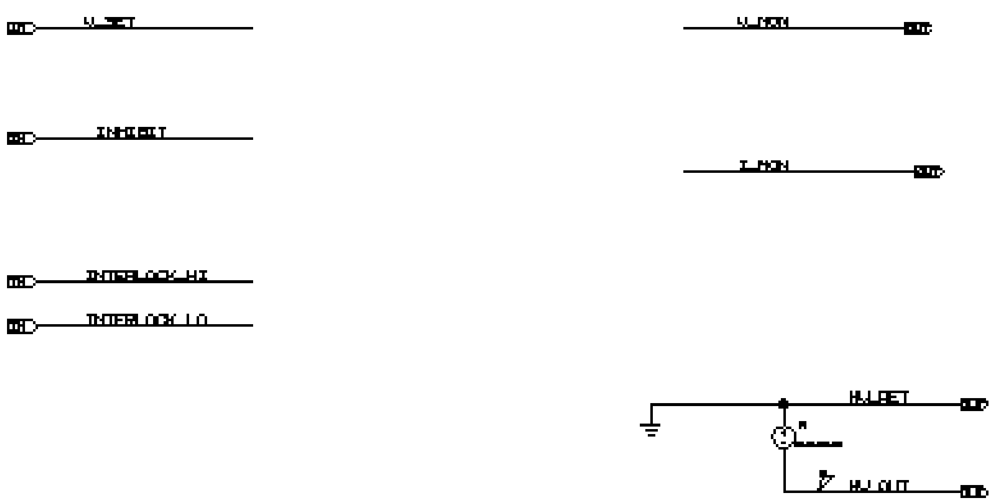
FIGURE 1. Top Level Model of TRT HV System



3.1 The Bulk Supply

At the moment, the model of the bulk supply is exceptionally simple minded - a set of dummy control lines (Voltage Set, Voltage Monitor, Current Monitor, Inhibit, and Interlock) and a Spice voltage source set to -1400V. A perfect supply, no control, no variation, no worries. Eventually we will want to model an actual bulk supply, but this is not yet important for understanding the AC behavior of the system.

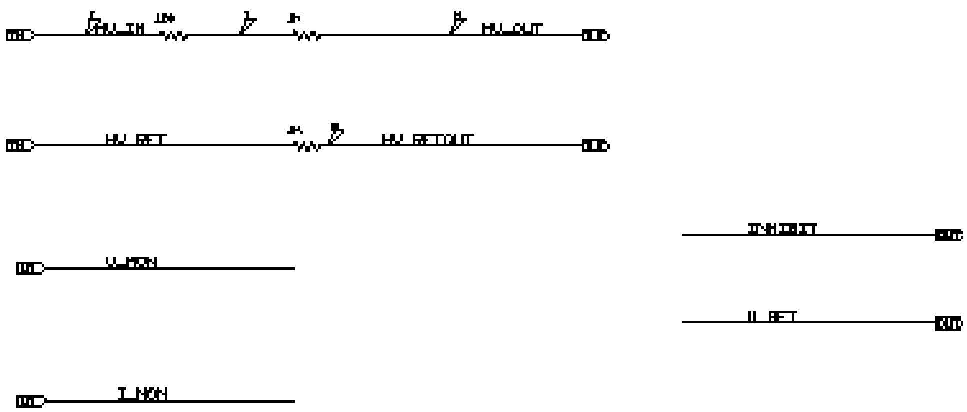
FIGURE 2. Bulk Supply Schematic



3.2 The Distributor

The Distributor model is also very simple, but does have current sense resistors in the HV supply and return lines as shown in Figure 3.

FIGURE 3. Distributor Model

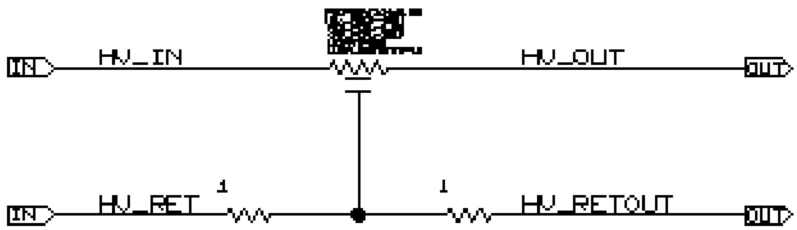


3.3 The Cable

At the moment the cable is modeled as a single 200 m long object. In real life we will have a long relatively large cable followed by a much shorter subminiature cable and some connectors as well. For the present purposes the model shown in Figure 4 is probably adequate. Note that the cable is a standard Spice 10 node lumped impedance model (which we know is not terribly good for detailed signal shape) with parameters modeled after RG59 which may be slightly optimistic, but with a full length of 200 m which is certainly pessimistic - so some balance, but we need to make this model more realistic fairly soon.

The small resistors in the return lines are to break the identity of the left and right sides of the return line in the Spice netlist. The values are simply set small with respect to other impedances in the line.

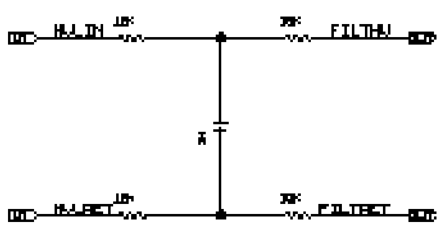
FIGURE 4. The Cable



3.4 The Filter

At the end of the long cable, just before entering the detector region, there is planned to be a filter. The model in Figure 5 is a fully symmetric differential filter. This may be overly conservative. The RC values shown give a 10 microsecond time constant which would give a rejection of about a factor of 1000 for incoming noise to the ASDBLR (based on a shaping time of 7ns). Again, this may be conservative and, since the filter seems to dominate the pulse response of the system, it is an area where we should carefully optimize the system.

FIGURE 5. The Filter



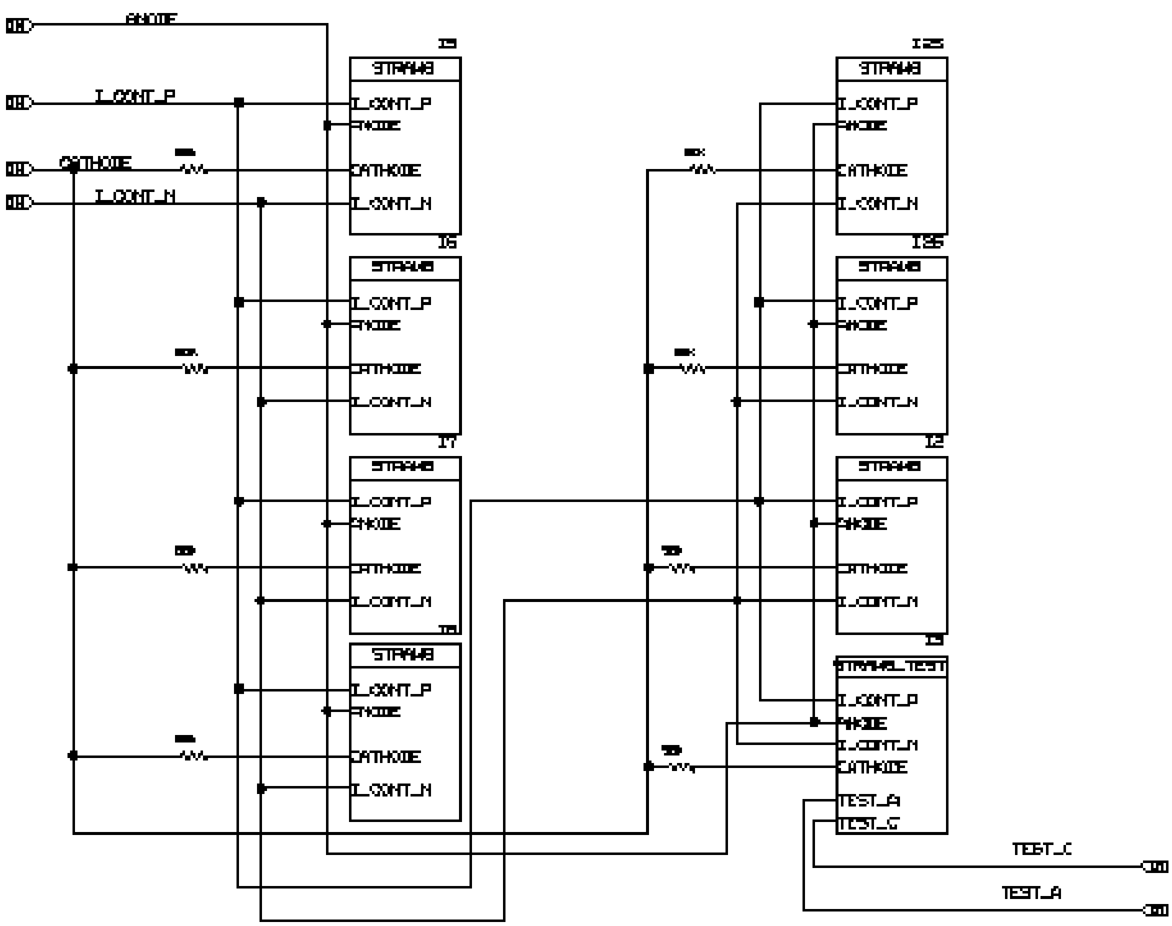
3.5 The Straws

The straw load is modeled as 63 identical objects plus one “test” straw where the “breakdown” or “discharge” or “spark” is modeled. Each straw is modeled as 15 pF of capacitance and the ASDBLR is modeled as 100 Ohms attached between the Anode (wire) and the detector “ground”. There is also a 1000 pF capacitor between the Cathodes and the detector “ground” for every eight straws.

There is also a Spice voltage controlled current source at each straw to model the standing detector current.

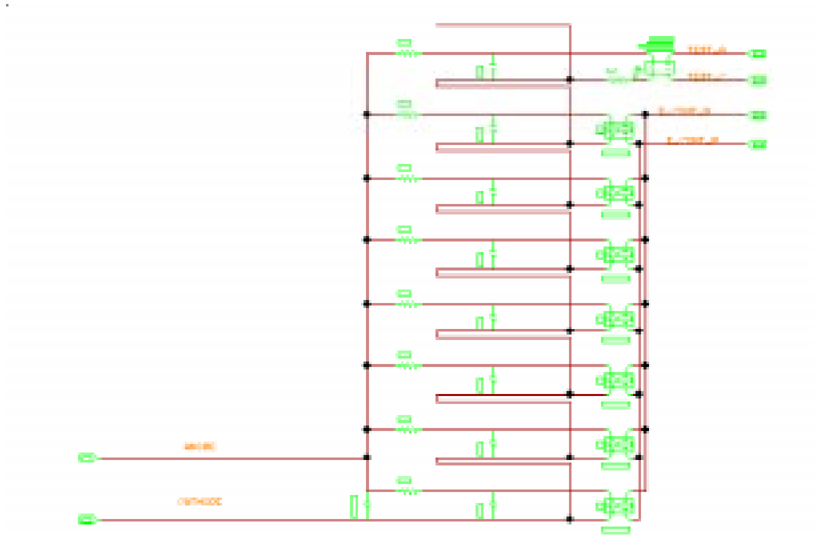
The schematic is done as a two level hierarchy as shown in Figures 6 and 7.

FIGURE 6. The Straw Array - Eight Groups of Eight Straws



The 50 kOhm resistor between the Cathode input and each group of eight straws is meant to model the Fuse. The last group of eight straws on the lower right of Figure 6 has the test straw included.

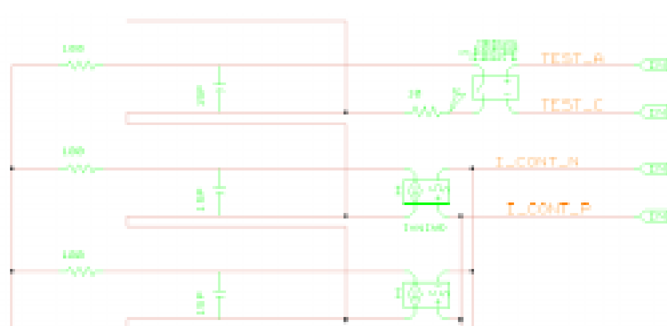
FIGURE 7. Eight Straws (Including the "Test" Straw)



At this lowest level of hierarchy, one can see the individual straws modeled as 15 pF objects plus the Spice voltage controlled current sources on the right and the 100 Ohm model ASDBLRs on the left (with the 1000 pF group decoupling capacitor). The Test Straw (top straw in the schematic) has a Spice Voltage Controlled Switch across its Anode/Cathode but with a 10 Ohm resistor in series with the switch - this arbitrary value is intended to model a discharge some modest distance away from the electrical connections. This is, obviously, a parameter that should be varied in a complete study.

An enlargement of the previous figure is shown below so that the component values are legible.

FIGURE 8. Detail of the Straw Model



4.0 Initial Simulations

There are, obviously, a number of variables that will affect the response of the system to a spark or discharge. For this first look, I have only looked at three:

- The length of the “discharge” - i.e. how long the Spice switch is closed.
- The length of the cable - i.e. is 50m of RG59 much different from 200m
- The RC components in the filter box.

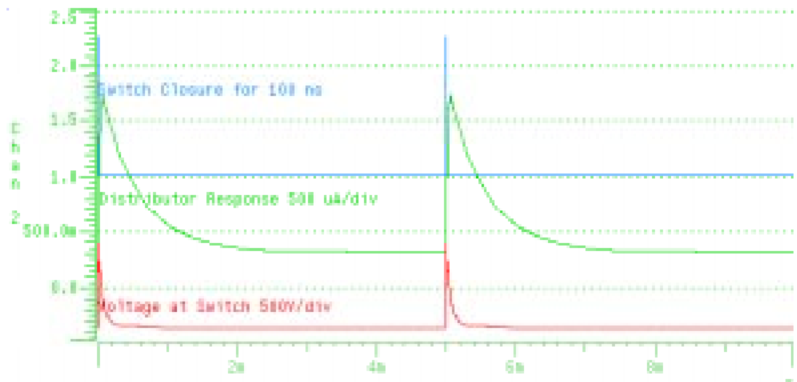
In the following simulations there are three traces - the top (blue) trace is the control for the switch that mimics the discharge, the middle (green) trace is the voltage across the 1kOhm sense resistor (labeled in microAmps), and the bottom (red) trace is the voltage at the switch showing the voltage drop in the affected straw.

Note that the 1kOhm sense resistor (green trace) is on the high voltage side. Through the magic of Spice we can just look at the difference voltage across the resistor. In real life we will need to put two HV caps to feed the AC part of the signal to a difference amplifier kept near ground. Thus very low frequency changes in the load current can not be sensed this way and must, in the bulk/distributor model, be sensed by looking at the amalgam of current out of the bulk supply. This is because running an amplifier at HV and shifting the signal down to ground is very expensive. The time constant that we can achieve is also limited by the size of the HV caps which are also expensive but not prohibitive.

FIGURE 9. 100ns Switch Time, 200m cable, 10k x 10nF filter

The initial switch closure is offset from zero time by 800 nsec to make the waveform clear. This closure is repeated every 5 msec - long enough so that the system has fully recovered - as can be seen in the next figure.

FIGURE 10. Same Simulation Showing 5ms Repeat



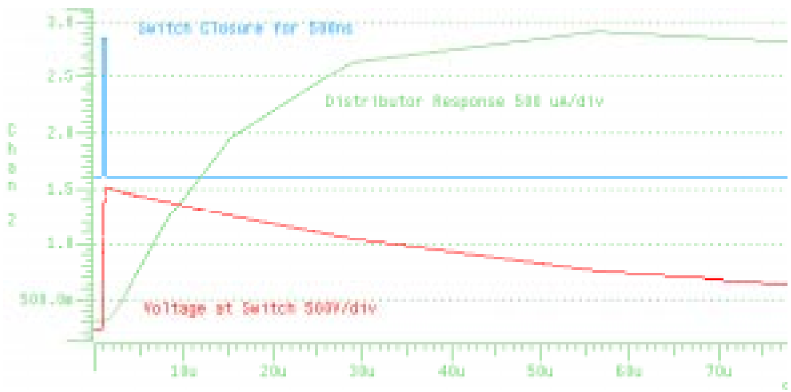
The 100ns switch time was chosen so that the Cathode voltage on the test straw has time to decay to about 50% of its initial value (see the bottom (red) trace above and note that it starts at -1400V and then quickly jumps up to about -700V. I don't really know when a "typical" discharge might stop self sustaining, but I would guess that the voltage would have to go down by at least a factor of two and maybe much more.

At first glance the magnitude of the signal across the 1 kOhm sense resistor is gratifyingly large - more than 1.25V after about 60 micro seconds. Clearly, any event producing this much charge loss in a single straw would be easy to sense.[1] If one makes the arbitrary assumption that one could sense a 50mV, 50 µsec peaking time signal, then we have about a factor of 25 between the effect of a 100ns long spark and the most sensitive discharge we might be able to detect. In the final system we also have to decide how complex a trip system we want - ranging from a single full trip on any "large" pulse to counting smaller pulses and then tripping on a "high" rate of small pulses or any single "large" pulse - where, of course, "high" and "large" would be programmable at the distributor level, if not, perhaps, at the channel level.

For a sense of scale, increasing the switch closure time to 500ns brings the straw voltage to almost zero as can be seen in:

1. The rule of thumb I am using is that relatively slow pulses like this with amplitudes above a few tens of millivolts are not difficult to detect and the long time constants involved mean that the sensing can be done with inexpensive components.

FIGURE 11. 500ns Switch Closure - 200m cable, 10k x 1nF



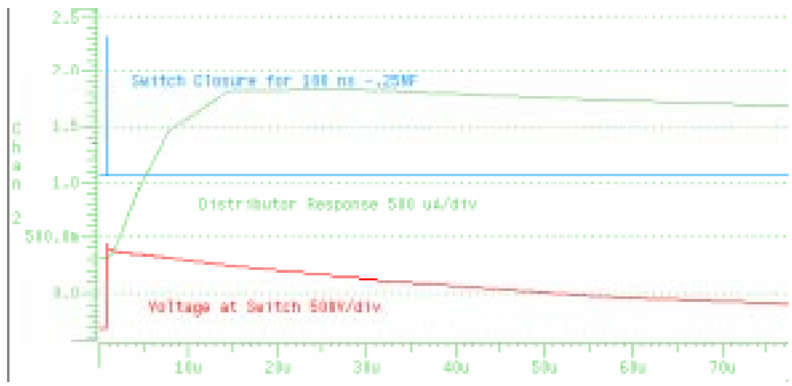
The next question to ask then, is what is the dominant filter term - two hundred meters of coax is a filter as is our explicit filter at the detector. If one reverts to a 100ns switch closure and changes the cable length from 200 m as in the above simulations to 50 m, then one gets the following response:

FIGURE 12. Change Cable from 200m to 50m

The signal response is very nearly the same as in the initial simulation - this is good as it means we can avoid some paranoia about how well we are modeling the real cable and whether subtle things like connectors might have any significant effect.

An obvious next test is to revert to 200m of cable, but change the filter components. In the following simulation, we have gone from 10k x 1nF to 10k x 250pF.

FIGURE 13. 200m Cable with 10k x 250 pF Filter



Now the signal gets up to peak (and a slightly larger peak as one would expect) in about 1/4 the time. From this I deduce that the filter is the dominant term in the response function. The problem, of course, will be to balance the speed of response (and our ability to turn off the HV system expeditiously) with good rejection of possible high frequency noise coming down the HV feed cables from the outside.

On the one hand, the sort of bulk supply that we are considering are high speed switchers with clock times on the order of 20-50 microseconds so that a command might start a voltage turn off process within one or two clocks. Since the ASDBLR peaking time is order 7 ns, a 30 microsecond time constant gives a nominal rejection of about 4,000:1 - probably sufficient. Even if we were to agree on something like a 30 µs time constant, there is still the question of how to choose the R and the C to get that combination. Larger R's mean larger DC voltage drops (the two 10kOhm resistors I have indicated in the model would drop 20V for a full luminosity 1mA group), but larger C's are expensive and bulky - so we need to agree on the best choice here too, but there is clearly a broad range of more or less acceptable values so we should be able to converge fairly quickly.

5.0 Future Work

After some feedback from the collaboration and correction of any errors or omissions, then next step is probably to detail the Distributor with real parts and try to understand how we wish to imlement the fast trip function (or functions). The model can also be expanded from one 64 straw load to a full bulk supply's worth (50 or so loads) to look at HV supply ramp rates and sensitivity to DC changes (although that is directly calculable without the help of Spice).