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RF Note #40

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Crowbar, fast trip, and other protection circuits

With any high power rf system employing vacuum tubes, one needs circuits to protect the tubes which fire crowbars when a tube sparks, shuts off power supplies when over-currents occur, and, or, reduces the drive so that over-currents are within tolerable limits. With the extra complications of the superconducting cyclotron rf system resulting from weak coupling and a long transmission line between the tube and the dee resonator, and the 3ϕ operation of 3 coupled dees, considerably more complication and sophistication in these circuits is required. This rf note will delineate the specifications for the necessary black boxes.

Crowbars

A "crowbar" is a device that shorts out a power supply within 3 μs of a sudden, fast overcurrent, presumably resulting from a tube spark. The primary logic event that triggers it is a dI/dT monitor, as in Figure 1 below.

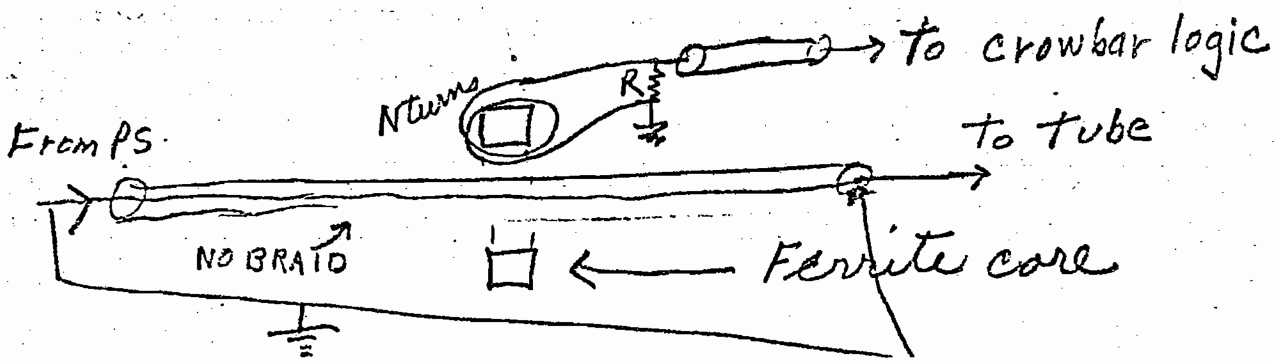


FIGURE 1

The arithmatic follows: Assume the core has a cross section area of 1/4 x 1/4 = 1/16 sq. in., a mean diameter of 2 inch, a permeability of 2,000, and a saturation flux density of .2 Teslas. For a nominal current of 10 amps, the flux density in the ferrite will be

$$B = \mu\mu_o H = \mu\mu_o I/\pi d \simeq .14 \text{ Teslas}$$

which does not saturate the core, in fact, there are

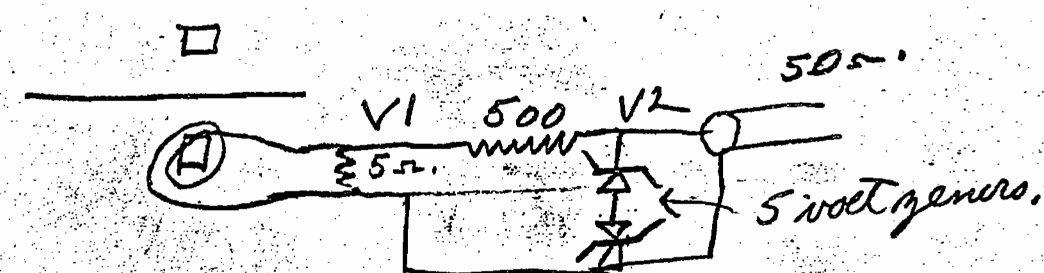
$$W = \frac{.6 \text{ Webers}}{m^2} \times \frac{1 \text{ in}^2}{16} \times \frac{6.25 \text{ cm}^2}{\text{in}^2} \times \frac{10^{-4} \text{ m}^2}{\text{cm}^2} = 2.3 \times 10^{-5}$$

Webers or volt seconds/turn left in the core before it saturates.

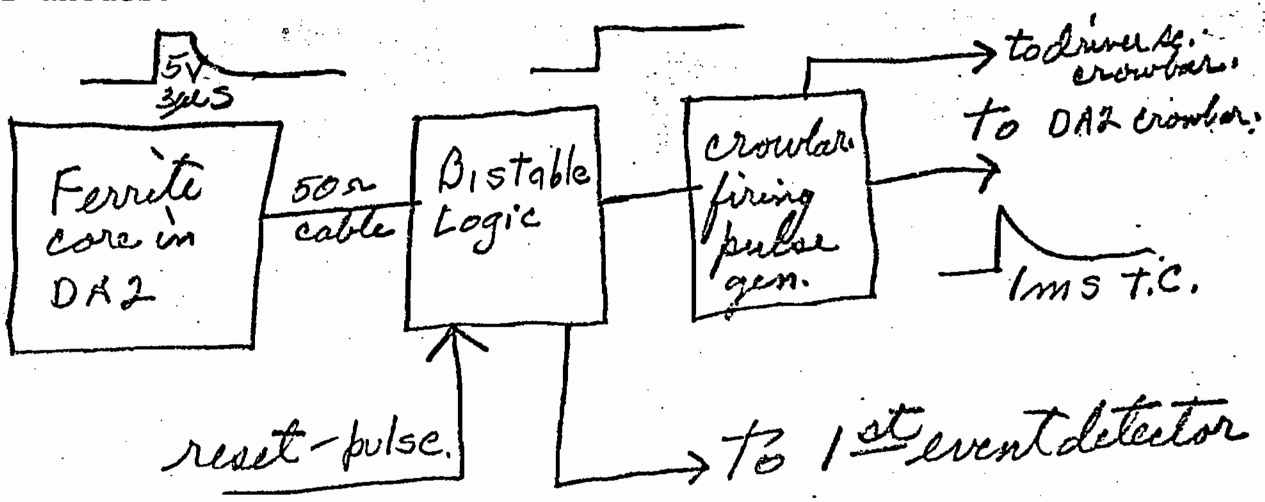
Now when a tube spark occurs, the current will be initially limited by the impedance of the cable, and then by the series resistor between it and the filter capacitor. For $V\phi = 20$kV and a 50Ω cable, the initial overcurrent will be $2 \times 10^4/50 = 400$ amps, and after a few tenths of microseconds would rise to perhaps 2000 amps, and the secondary voltage will be Vs = I x R/N.

Crowbar and fast trip monitors for DA2 supplying anode power to the driver.

The driver anode current is nominally 1 amp. In series with each pair of tubes is a 20 ohm 50 watt resistor to limit the peak tube current in the event of a spark to 3000/20 = 150 amps. So we use the following circuit:

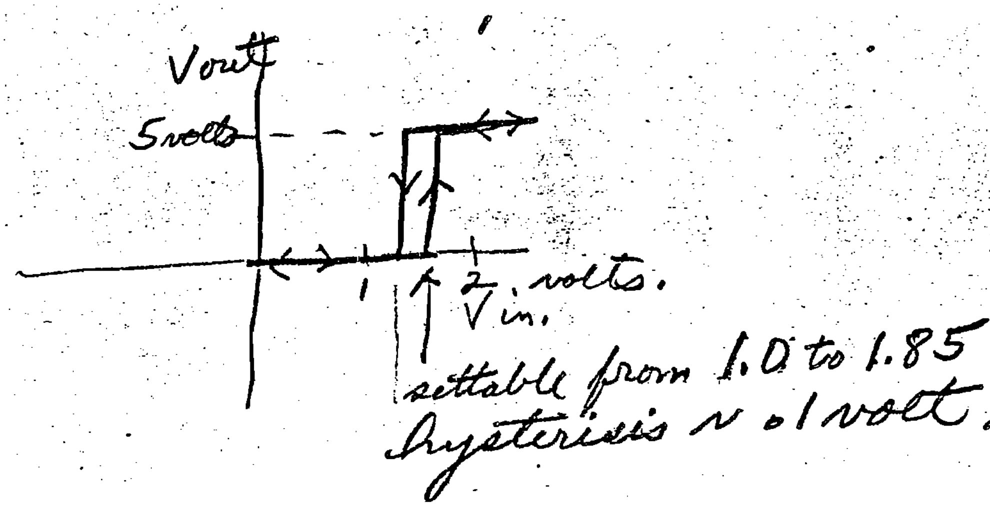


V1 will jump up to 75 volts for N = 10 and the zeners will limit V2 to 5 volts and must transiently carry 150 ma. The 5 volts will last for $T = \frac{2.3 \times 10^{-5}}{7.5} = 3\mu s$ before the core saturates, so resettable a flip flop fed by V 2 must fire in 1 µs. So we identify the following BBs for each of the 3 driver anodes.



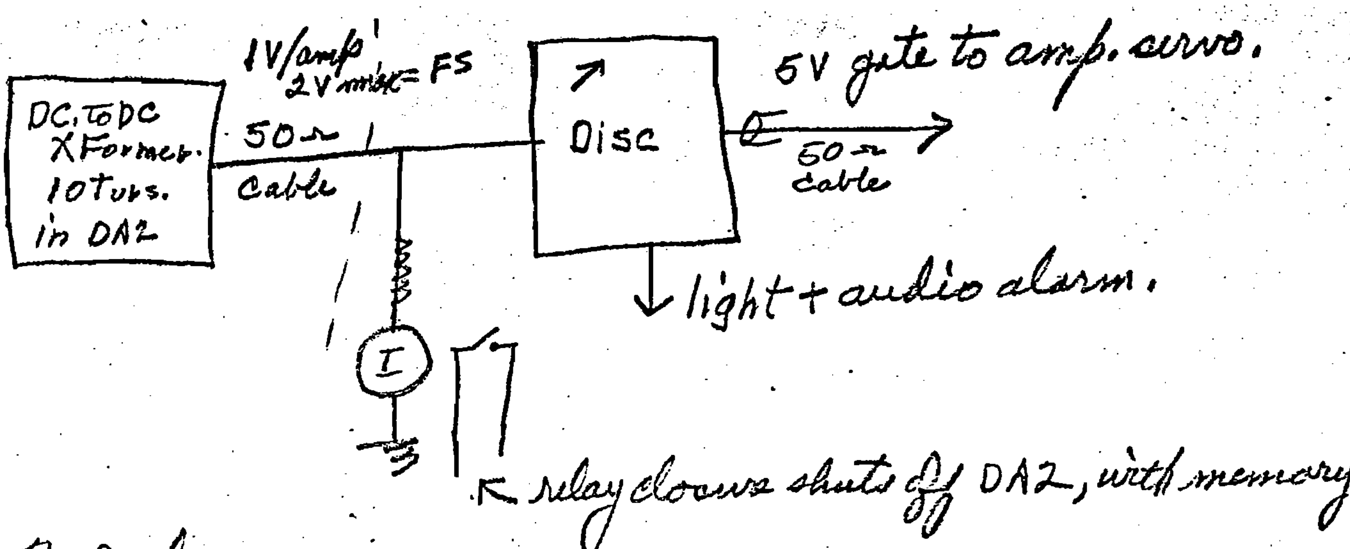
In the DA2 are mounted the dc to dc 4 core current transformers in each of the six outputs (3 for driver anode, 3 for final screen). These have a sensitivity of .1 volt per ampere turn when feeding a 50 ohm terminated cable. For the driver anodes, we will wrap 10 turns of the guts of RF58U thru them to feed the anodes. Thus the sensitivity will be 1 volt per amp, saturation occuring at 3 amps. The 50 ohm output cable goes to the fast trip unit where a piece is sent to the station panel current meter (FS = 2 amps). This meter has a settable overcurrent switch which will shut off DA2 if the current exceeds 1.9 amps.

The main signal goes to a screw driver settable discriminator with very small settable hysterisis. Its output is as below:



This signal will go to the amplitude regulator to cut back the drive, light a light, and give an audio alarm to tell the operator that the dee voltage is no longer regulated. This avoids having to shut anything off and permits someone to fix whatever caused the overcurrent.

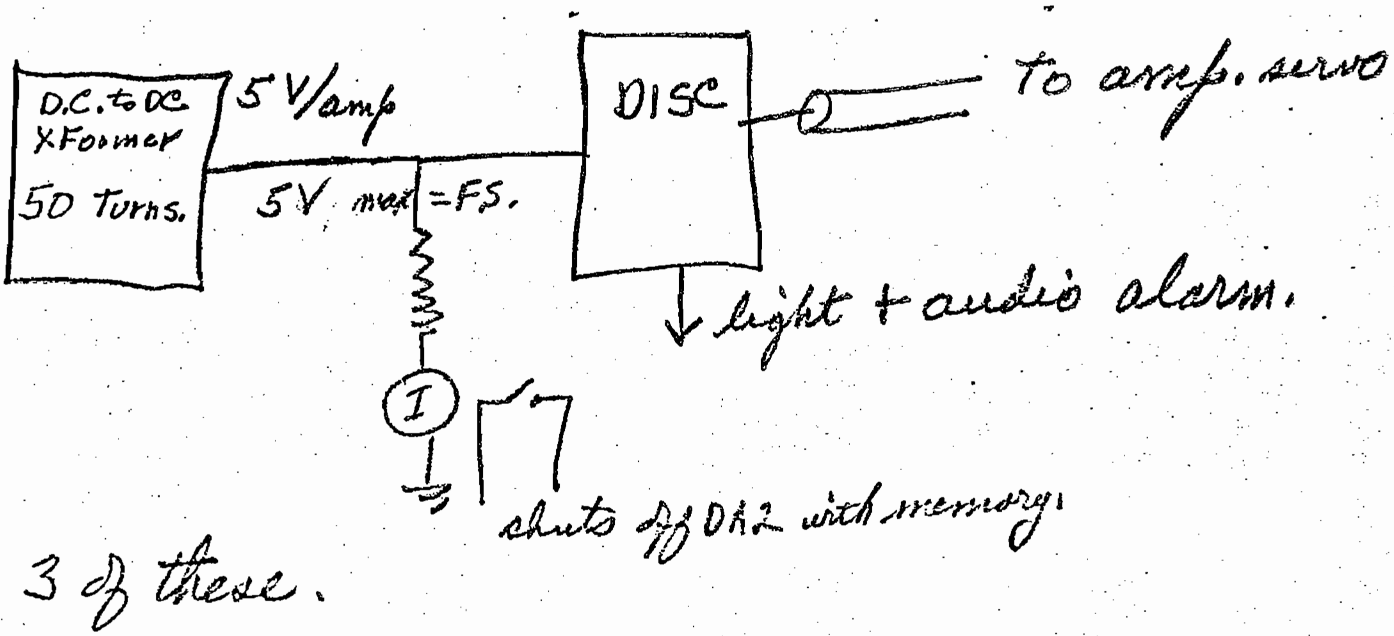
So the BBs for driver anode overcurrent protection is:



3 of these

Final screen fast trip ckts

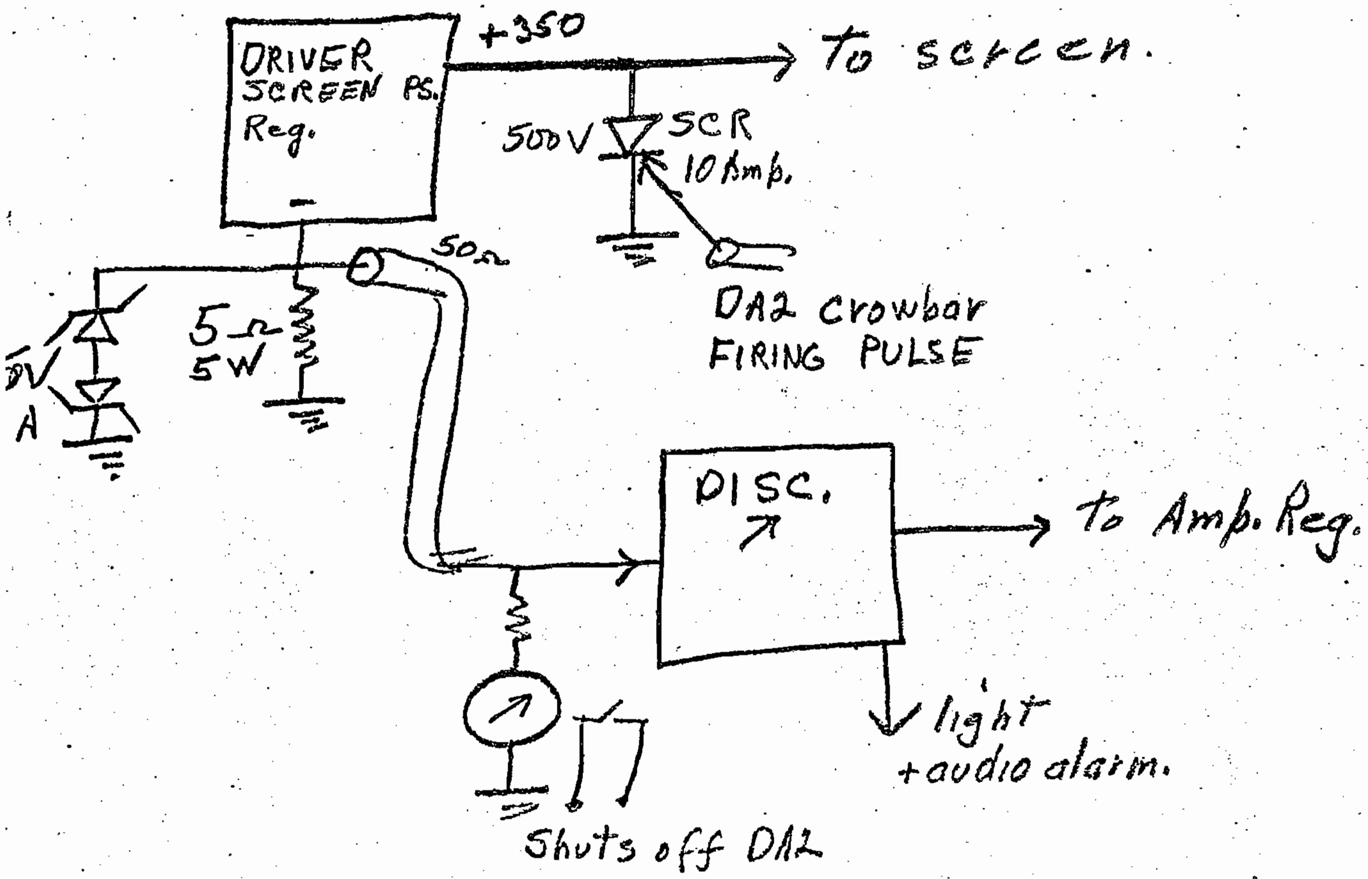
Assuming that we use DA2 for the final screen we have the following ckt. DA2 will be crowbarred if the Final B+ crowbars.



An important feature of this type of protection is that it warns us that there is insufficient final anode B^+ without shutting us down.

Driver screen

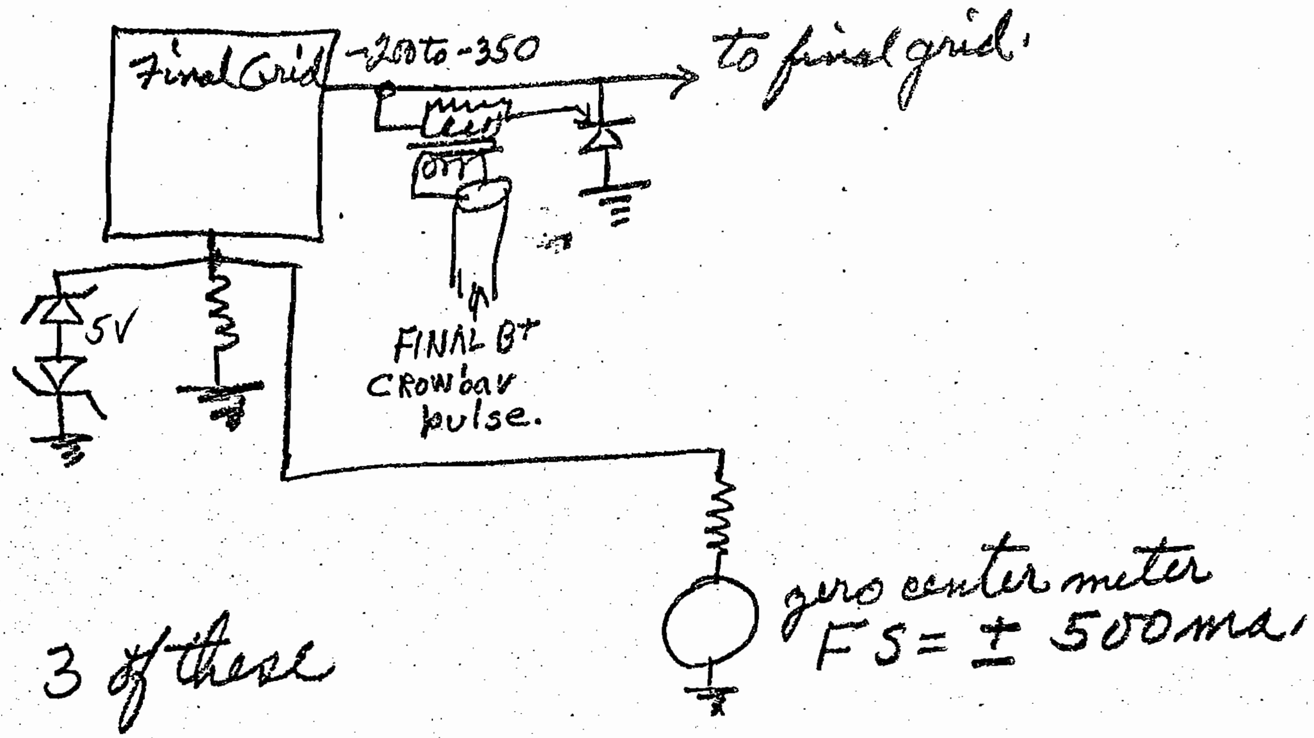
The driver screen supplies will be off the shelf regulated supplies (350 volts, .2 amps) with internal bleeder. We will add a crowbar (SCR), and a shunt for remotely monitoring the current. Whenever the DA2 is crowbarred the driver screen will also be crowbarred. The nominal driver screen current is ± 50 ma. Thus the following ckt. seems appropriate:



3 of these

Final Grid

The final grid supply is, again, an OTS PS variable locally from -200 to -350 volts. Like the driver screens it will be crowbarred when the final B^+ supply crowbars. This means that when the final B^+ supply crowbars, then simultaneously the DA2 supply, the driver screen and the fianl grid supply will also be crowbarred and a first event detector will decide and remember which event occurred first. Below is the circuit.



Since this supply is current limited, and the output current should always be zero, no overcurrent outputs are necessary (I think) other than the interlockery that says the output voltage must be at least -200V for anything else to be on.

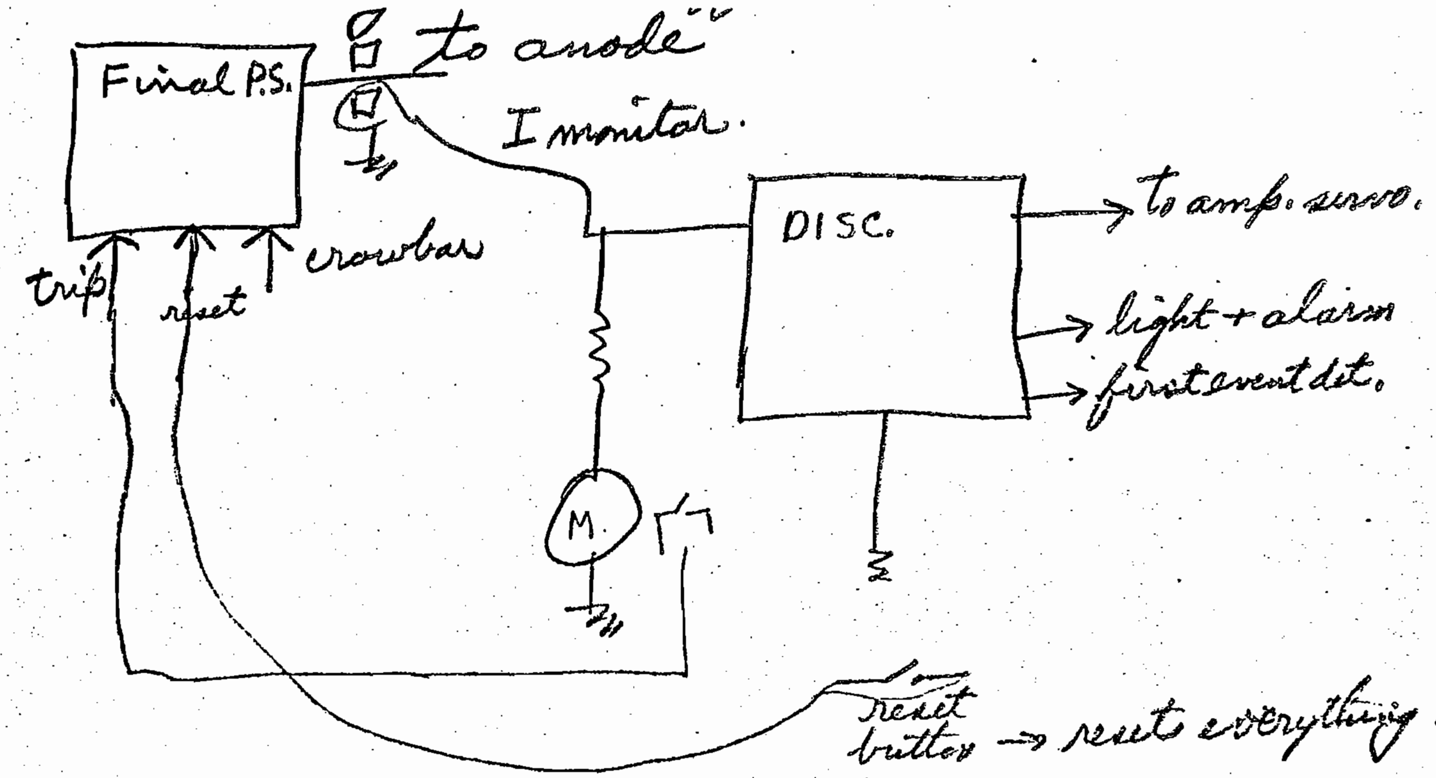
Driver grid

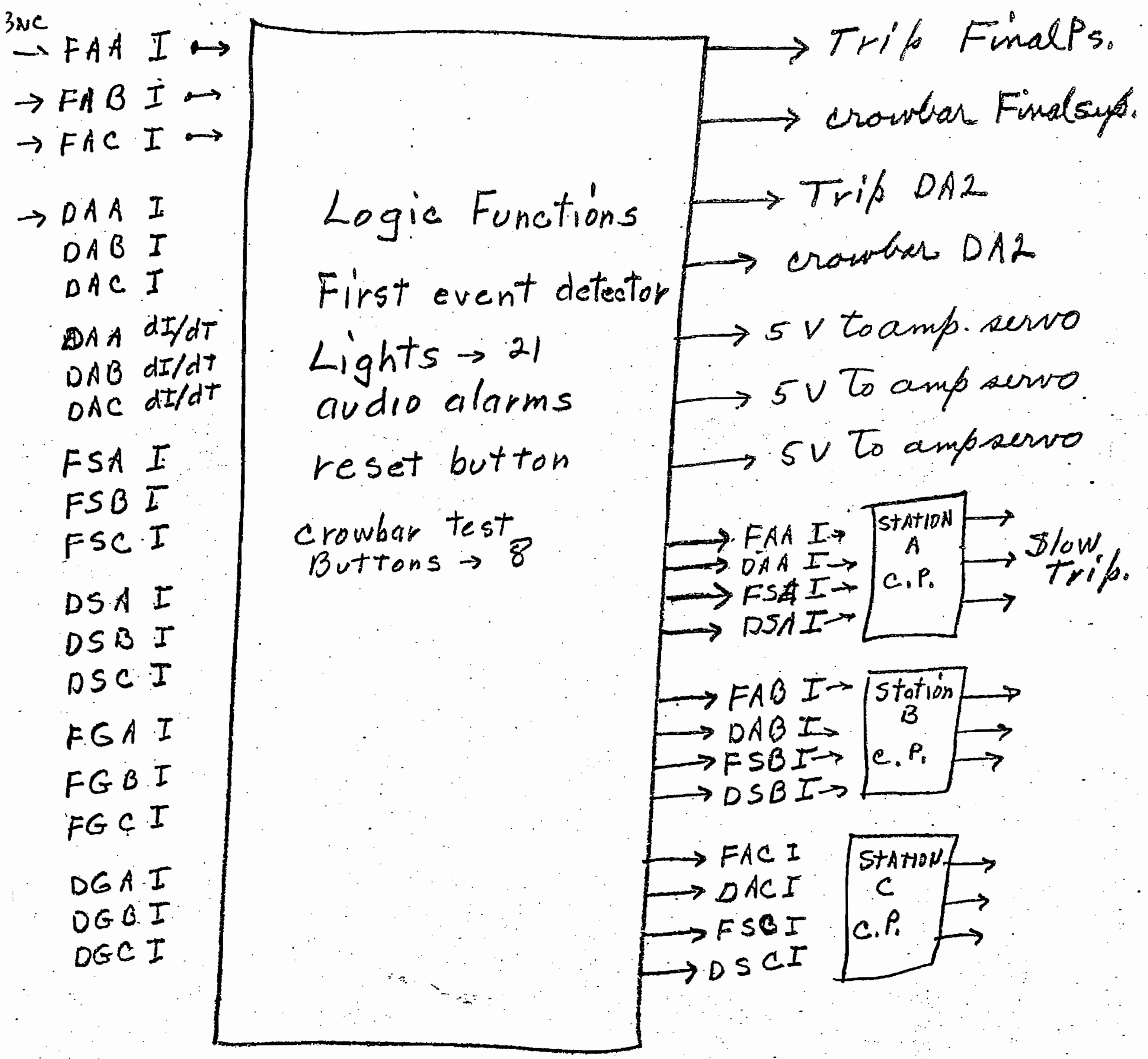
The driver grid is supposed to draw zero current! If it is a current limiting supply (50 ma or less) then no special protection circuits are necessary, and the interlockery should be enough, i.e., if it produces less than -50 volts nothing else can be on!

Note to the Controls Engineer: Of course, whenever any P.S. is crowbarred, the primary power must be shut off so that the crowbar device can recover.

Final Power Supply

The final PS is supposed to be self-crowbarred and to have its own DC to DC current transformers for remote monitoring. However it also has a provision for remote crowbarring and shut off.


Final P.S.
to anode
I monitor.
DISC.
to amp. servo.
light + alarm
first event det.
trip
reset
crowbar
M.
reset button → resets everything.



FAST TRIP BOX

Now, all that is required is that an engineer design, have built, debug, and install this box. I fancy that it will not be a NIM bin, but it could be. Probably it uses vector boards. It has 21 input BNC's,three 8 pin cables to the station monitors and 7 output BNC's. Provision should be made for expansion.

First event detector

There are 24 current signals from the various power supplies--and then we will also have rf spark detectors, perhaps 21, then there may be rf overvoltage monitors, again perhaps 21, making a grand total of 66. Now when something goes wrong within a very short time (maybe .1μs) many other things also go wrong. For example, if a dee sparks down they will probably all spark down if it is a vacuum spark. This will probably happen so fast that we won't be able to tell which dee first sparked. However, if we get an air spark at the stem insulator then it will take a few tenths of μs for the other rf systems to notice this. And if we get a tube spark and fire a crowbar we have a few μs.

So the first event detector is continuously looking at all these 66 signals and remembering which one first exceeded a certain value and locks out the other 55 from displaying on their fault detector lights. A reset button then restores everything.