

# Wells-Gardner K6100 Deflection Board Circuit Description (and Input Protection Modifications)

© Mark Spaeth, 2002/03/12

Questions? Comments? Email [mspaeth@geeks.org](mailto:mspaeth@geeks.org)

## 1 Introduction

The purpose of this document is to describe the operation of the deflection circuits used in the Wells Gardner K6100 color vector monitor. Several publicly available documents discuss trouble-shooting the 6100, common failures in its circuitry, and modifications meant to improve its reliability. Unfortunately, these include no analysis of the circuits or discussions of what the modifications really do. I'll try to fill that void.

I'll start by giving a somewhat technical, but hopefully intuitive description of how the WG K6100 deflection circuit works. There is a very cursory description of the deflection circuit in the 6100 / QuadraScan manual, but I found it quite unsatisfying. I've redrawn a handful of the original schematics to ease discussion, but you'll probably want to have a copy of the manual handy for the schematics I was too lazy to redraw. I'll continue by discussing the three popular input protection circuits used on the 6100, and finally give a few words about some of the other hacks I've seen mentioned in various places.

## 2 Low Voltage Power Supply

The low voltage power supply was one of the primary problems with the WG6100. The schematic for the positive voltage regulator circuit is shown in Figure 1. I won't bother discussing the negative regulator, as it's essentially the same.

### 2.1 LVPS Circuit Description

The operation of this circuit is relatively simple. Diodes D100 and D101 form half of a diode bridge, rectifying the two center-tapped 25VAC power inputs. This output is smoothed by the

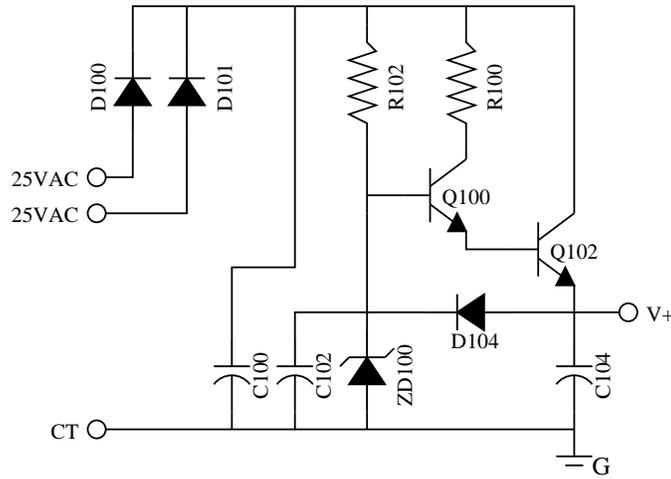


Figure 1: WG K6100 low voltage power supply

large electrolytic capacitor C100, to give a ripply but mostly DC voltage of approximately 34V to power the rest of the circuit.

R102, C102, and ZD100 form a biasing circuit for the Darlington pair formed by Q100 and Q102. ZD100 has a reverse breakdown of about 28V, at which point it conducts current exponentially. R102 stabilizes the current-voltage relationship so that about 29.1V is across ZD100. C102 filters this regulated voltage (since the main 34V supply is still a bit ripply). Q100 and Q102 form a high current gain Darlington pair. Each transistor drops about  $.7V V_{BE}$ , so the output voltage at the emitter of Q102 is about 1.4V below the base of Q100, yielding 27.8V. This high current output gets a little bit of filtering from Q104, then feeds the rest of the deflection circuitry.

## 2.2 LVPS Failure Modes

D104 is probably the cause of the catastrophic LVPS failure. When the transistors are operating properly, if the output voltage goes more than  $.7V$  above the base of Q100, D104 will turn on and bring this voltage down, stabilizing the circuit. If Q102 (the chassis transistor) fails and shorts as it often does, the output is shorted to the high current 34V input the to circuit and D104 turns on, and pulls the voltage across the ZD100 up, causing it to sink more current, and eventually frying ZD100 and D104 (and possibly other components). According to some of the 6100 documentation on the net Q101 (in the negative regulator) was a common failure also, but I haven't played with enough dead 6100's to discern whether that was the cause or effect of other failures.

I wouldn't recommend removing D104 (or D105) from the circuit, since they're necessary to

ensure the regulators start up properly at power up, but putting in a beefier diode (such as a fast-acting rectifier diode instead of the 1N914 signal diode currently used) couldn't hurt. Inevitably, this circuit should be replaced with modern parts as described next.

### 2.3 LVPS Solutions

The real purpose of the low-voltage regulator circuit is most likely to isolate the amplifiers from changes in the line voltage (which will directly affect the rectifier output), and from ripple in the rectifier output (which will be more apparent as the large electrolytic filter caps dry out). It's worthwhile to note that the Amplifone (which is generally regarded to be more reliable after the obvious red high voltage transformer is replaced), doesn't mess around with any of this regulation foolishness, and instead just sends the unregulated  $\pm 34V$  from the bridge rectifier and capacitors to the deflection circuits.

Near the end of Woodcock's 6100 guide, he mentions seeing one board that was modified this way. Offhand, I don't see any real difference between the 6100 and Amplifone deflection circuits to justify the need for the low voltage regulator. If you wish to bypass the low-voltage regulators in this way, I would recommend putting in new filter caps on the rectifier outputs. These caps are included in the standard Amplifone cap kit, but are omitted in the 6100 kit, but I'm sure Bob Roberts will include them if you ask nicely. Additionally, to account for the additional voltage that needs to be dropped in the differential pair transistor/resistor stack, it wouldn't hurt to bump up the value of R604/R704 a bit to absorb some of the extra swing, and keep the diff pair closer to its original bias point.

Woodcock also mentions seeing another deflection board with large 10W,  $25\Omega$  resistors added between the rectifier outputs and the  $V\pm$  outputs. This hack was probably done by someone who incorrectly assumed that the amplifiers needed the lower voltage rails to operate correctly, and added the power resistors to drop the voltage a bit. The amount of heat generated by this mod far outweighs any adverse affects of running the deflection amps off  $\pm 34V$  (unregulated), so I would definitely avoid it.

If you are adamant about voltage regulation, the real solution is to replace the low-voltage power supply with with modern integrated circuit regulators, as shown in Figure 2 Anders Knudsen and Jeff Hendrix cleverly copied the reference circuits from the LM317 and LM337 adjustable voltage

regulator data sheets, and have been selling the resulting PCB as the *LV2000* for years. From the original circuit, the bridge rectifier diodes, filter caps, and chassis transistors remain intact, with the remainder being replaced by the integrated regulators.

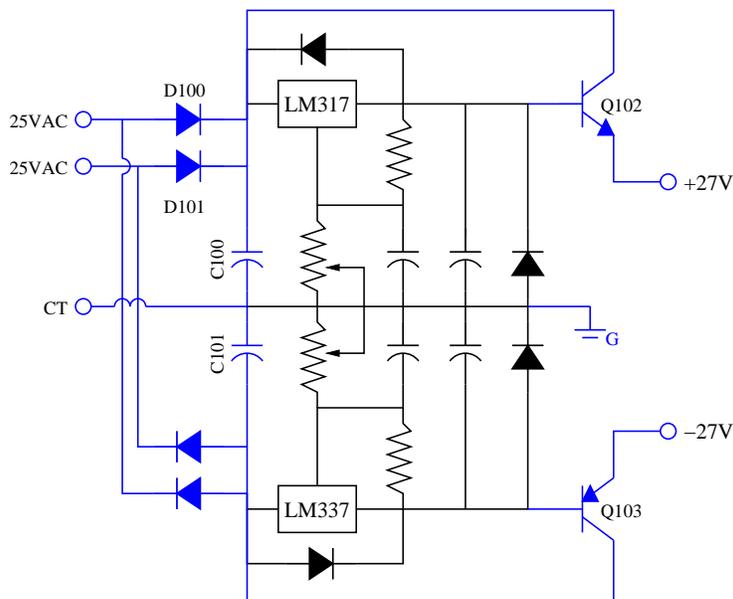


Figure 2: WG K6100 replacement low-voltage regulator

A more compact solution might be to use fixed voltage regulators, but as of 2002, the 7827 and 7927  $\pm 27V$  fixed voltage regulators are no longer available, and the 7824 and 7924  $\pm 24V$  fixed voltage regulators are getting harder to find (and may not provide sufficient voltage to achieve the desired slew rates), so we're probably stuck with using the LM317 and LM337. Since the amplifiers aren't sensitive to their rails, the variable resistors can be replaced with fixed resistors. The diodes (other than the rectifiers, of course) strewn around the schematic aren't really necessary, and serve no function during normal operation. If fixed regulators are used (ie, 7824/7924), the resistors and the caps across the pots can be eliminated.

### 3 X and Y Amplifiers

Since the X and Y amplifier circuits are essentially the same I'll only talk about the X circuit. Since the circuits aren't really drawn very clearly in the manual, I took the liberty of redrawing the X section in Figure 3.

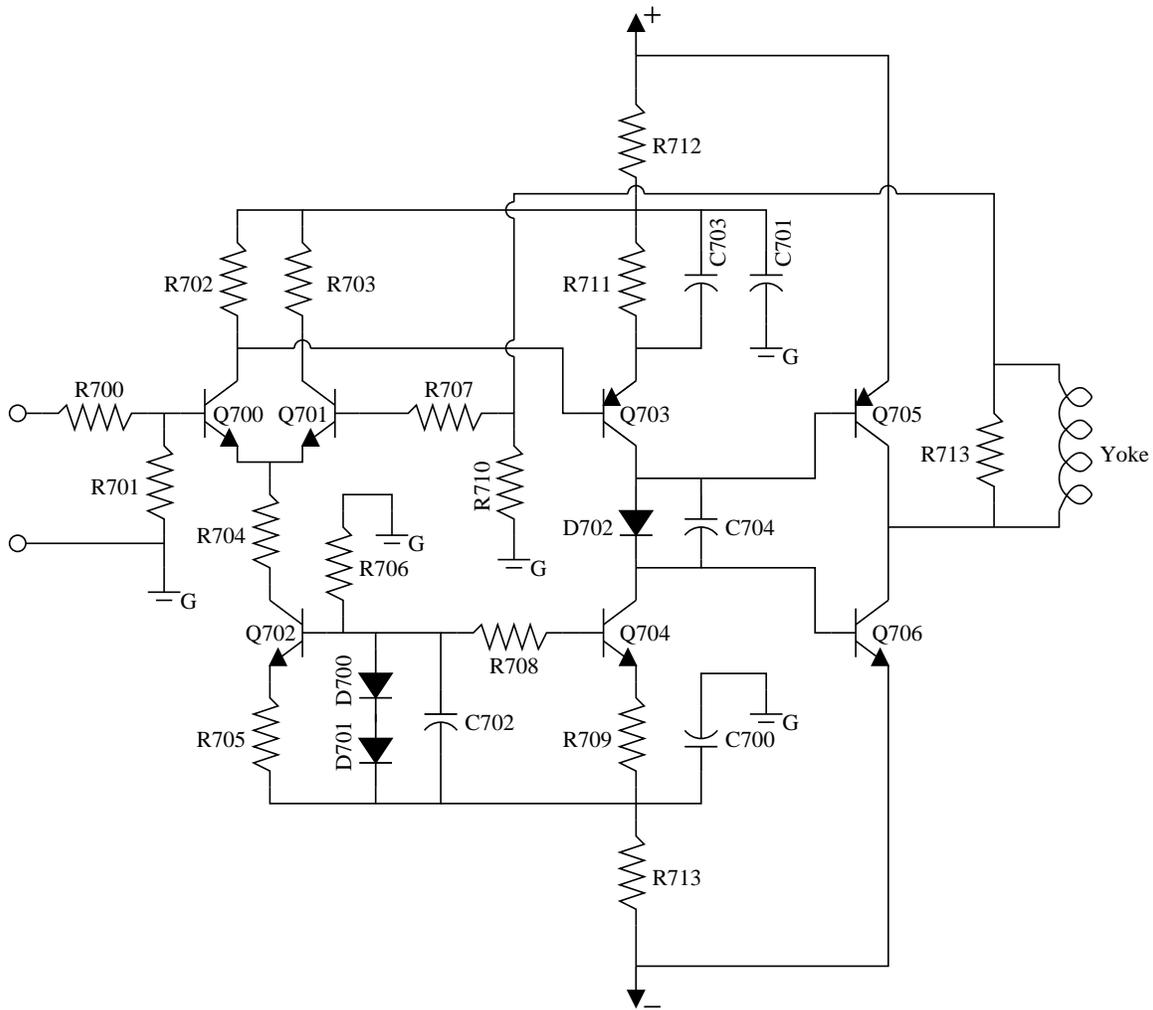


Figure 3: WG K6100 X deflection circuit

The + and - arrows are the +27 and -27 rails respectively, and the ground symbol is (of course) signal ground. It will be handy to have the original schematics handy as you read this, since they include the static DC voltages with no signal input applied (or equivalently, with both inputs grounded).

### 3.1 Deflection Theory

The first thing to note is that current, not voltage, causes the yoke to generate a magnetic field to deflect the electron beam, so the deflection board translates the input voltage into a high gain current output. (Technically, of course, the output of the amplifier itself is a voltage which drives current through the yoke by  $V = L \cdot \frac{\delta I}{\delta t}$  or  $I = \int_0^t V$ , and this current is sensed and fed back to

the amplifier, but I'll get into that later). The 6100 deflection amp is essentially a 3 stage amp, starting with an input differential pair, followed by a common source gain stage, which drives a high current push-pull gain stage, which finally drives the yoke. I'll talk about each of these stages in turn.

### 3.2 Deflection Amp Supply Filters

Let me first talk about R712 and R713. The original power supply on 6100 generates approximately  $\pm 28V$  using Zener diodes as references to drive power transistors Q102 and Q103 which provide the current to supply the rest of the circuit. Since the  $\pm 27V$  supplies are connected directly to the output transistors, when the vectors are moving wildly, the current drawn from the supply varies widely. Since the power supply isn't very "stiff," the supply voltages vary slightly as the current load varies. R712 and R713 were insert to isolate the first two amplifier stages a bit from the supply transients during normal operation. C700 and C701 shunt the other ends of R712 and R712 to ground, forming a low-pass filter which will help to filter small transients. If you've replaced the failure-prone original supply, these resistors aren't really necessary. In any case, they really don't affect the operation of the amplifier much at all. We will assume that the the first two stages operate with the supply voltages as printed on the original schematics.

### 3.3 Deflection Amp Bias Circuitry

The first two gain stages are an emitter degenerated differential pair, and an emitter follower. The active portions of these circuits consist of a handful of resistors and transistors, but constant current biases are required for them to function. The bias circuits are shown in Figure 4.

The bias currents for the first two amplifier stages are supplied by Q702 and Q704 respectively. Q702/704 are NPN transistors, which means that they conduct current when the base terminal voltage exceeds the emitter voltage by a specified amount (usually about .7V). [The current-voltage relationship is exponential, so whenever  $V_{BE} > 0$ , the transistor is in fact conducting, but it isn't considered on until the current reaches an appreciable level.] To generate base biases, for Q702/704, R706 provides current to forward bias diodes D700/701. Diodes also conduct current with an exponential relationship, and also "turn on" at about .7V, so with two diodes in series between R706 and the negative rail, the voltage at the base of Q702 at 1.4V above the negative rail (-27.1V),

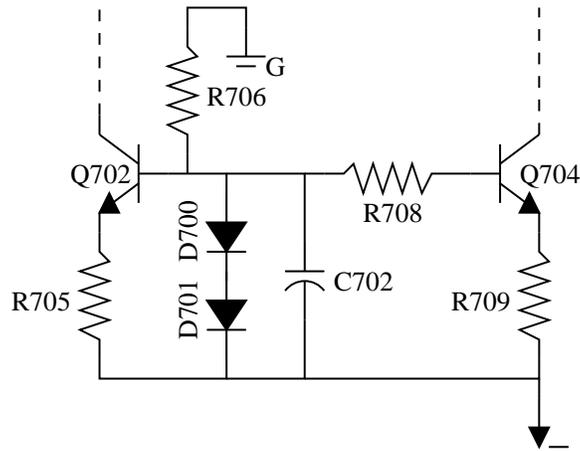


Figure 4: WG K6100 X deflection amp bias circuit

or approximately  $-25.7V$ . C702 filters this voltage to deal with any fluctuation in the rail.

Since a  $.7V$   $V_{BE}$  turns on Q702, we expect the emitter to be at approximately  $.7V$  below the base, and as the schematic shows, it lies at  $-26.4V$ . (Technically, you have to solve an exponential equation to find the exact  $V_E$  such that  $V_{BE}$  will generate exactly enough emitter current to generate  $V_E$ , but since we're working in round numbers anyway, why bother). Thus, we have  $.7V$  across R705, so  $\frac{.7V}{91\Omega} = 7.7mA$  flows through Q702 to bias the differential pair.

R708 degenerates the base input of Q704 to prevent any oscillation due to negative input resistance (this isn't a normally a problem with 2n3904's, so Q702 doesn't have a series base resistance), so it can be safely ignored, so the base of Q704 is also at  $-25.7V$ . Thus, we also have  $.7V$  across R709, so  $\frac{.7V}{15\Omega} = 46.67mA$  flows through Q704 to bias the emitter follower. Note that this higher current level gives a simple explanation why Q703/704 are bigger than Q700-702 and require heat sinks.

### 3.4 First Stage - Differential Pair

The X and Y outputs from vector boards are meant to drive a nominal  $2.5k\Omega$  load. A quick look at the schematic shows that the input indeed drives into R700 in series with R701, which sum to  $2.5k\Omega$ . R700 and R701 form a voltage divider which roughly halves the input voltage and applies this to the base of transistor Q700. R714 (in parallel with the yoke), and R610 form a voltage divider for the base of Q701. In steady state, the yoke is a low resistance path ( $0.7\Omega$  horizontal,  $1.3\Omega$  vertical), which dominates over the shunt resistor. The shunt resistor is required for stability

when the output of the amplifier is rapidly changing, the impedance of the inductive yoke is high. Since the output of the final stage is the current driving the yoke, R610 is really just sensing the yoke current and turning it back into voltages for the input differential pair.

Q700 and Q701, along with load resistors R702 and R703 and the tail current source transistor Q702 (which we discussed earlier). In the differential amplifier, the emitters of the two transistors are tied together, so the relative values of the base voltages determines how much of the current supplied by the tail current source flows through each transistor. (Due to the exponential nature of the  $V_{BE}$  relationships, this function ends up as an arc-hyperbolic tangent or something wacky like that.) The current flowing through Q700 generates a voltage drop across R702, which goes to the input of the 2nd stage. Note that this is an inverting stage since a higher input voltage causes more current to flow through Q100, causing the collector voltage to drop.

R704 sets a nominal voltage for the emitters of the differential pair. The tail current from Q702 (equal to the sum of the currents through Q700 and Q701) flows through it, fixing the emitter voltages relative to the collector of Q702.

### 3.5 Second Stage - Common Emitter

The second stage is a simple emitter degenerated common emitter transconductance amplifier. As previously discussed the second stage is loaded by a constant current source formed by Q704. The 47 mA of current must flow through Q703 and R711, so the emitter of Q703 is fixed at approximately .47V below the positive supply, or 27V. This voltage is stabilized by filter capacitor C703. For Q702,  $I_C = I_{CS} \cdot e^{\frac{V_{BE}}{V_T}} \cdot \left(1 + \frac{V_{CE}}{V_A}\right)$ . Since  $I_C$  is fixed at 47mA, and  $I_{CS}, V_T$  and  $V_A$  are intrinsic device parameters, this equation can be reduced to show a relationship between the collector (output) and base (input) voltages of Q702. Since the emitter voltage is fixed, a decrease in the base voltage (corresponding to an increased  $V_{BE}$ ) must be compensated by a reduced  $V_{CE}$  to keep the collector current constant at 47mA. This means that the collector voltage must go up and the second stage is an inverting gain stage.

### 3.6 Output Stage - Push-Pull Drivers

The output stage of the deflection circuit is a pair of emitter followers in a push-pull configuration. The output voltage from the second stage is applied to the base of NPN transistor Q705, and a

voltage approximately .7V below (as set by D702), is applied to the base of PNP transistor Q706. Since there is only a .7V difference between the voltage applied to the bases of the two transistors, it is apparent that only one of the two chassis transistors can be 'turned on' at a time.

If the output of the second stage is above ground, the emitter voltage will drop to .7V below the second stage output and Q705 will turn on, sourcing current through the yoke and the current sense resistor R710. If the second stage output rises above about .7V, the emitter approximately equal to it, turning Q706 on, sinking current through the yoke and current sense resistor R710. For intermediate values, both transistors are weakly on, and the net current imbalance goes through the yoke, but due to the high gain of the circuit and the feedback mechanism this is not a stable state in practice.

For the third stage, increased input voltage results in more current being sourced (positive current), so it is a non-inverting stage. The cascade of the three stages (inverting, inverting, non-inverting) results in a net non-inverting gain through the amplifier. Thus, when the input voltage rises, the current through the yoke rises, and the voltage across the current-sense resistor rises, and stabilizes the output. This is the behavior we expect from the circuit, so all is well with the world.

## 4 Input Protection Circuitry

Well, that is to say, all is well with the world until something goes wrong. The biggest problems with the 6100 occur when the X and Y voltages coming from the game PCB get wacky. Although the spot killer circuitry takes care of shutting down the Z amplifiers when the beam stops moving to prevent screen burn, there is nothing built into the P314 (original revision) deflection board to prevent runaway voltages from damaging the deflection circuits. If the input voltage goes either too high or too low, the biasing for the input stage gets thrown off, and sends extreme voltages into the later stages, resulting in unfavorably high currents in through the driver transistors. In this section, I'll discuss various ways Atari tried to rectify this.

### 4.1 The Zener Hacks

This modification was included in the Star Wars to Empire Strikes Back documentation as well as in other Atari tech notes. It is shown in Figure 5.

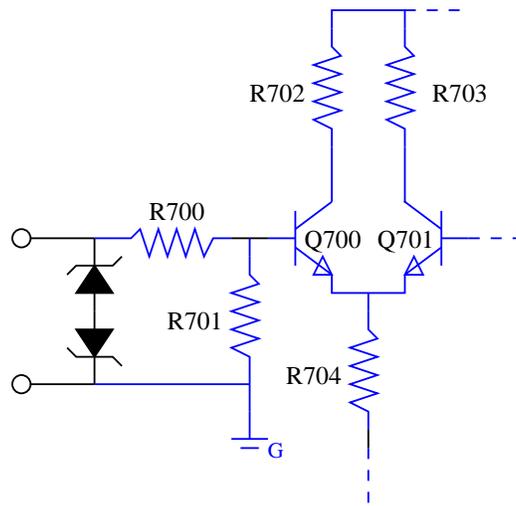


Figure 5: Atari Zener diode input protection mod

This is the simplest of the input protection schemes. Normal diodes conduct at about .7V forward voltage, and inhibit reverse current until they breakdown. Zener diodes are designed to break down at a predictable voltage for a given amount of current (which is why they were used in the original low-voltage power supply). With the diodes placed back to back, if the input voltage strays from ground by more than the Zener voltage plus .7V, the diodes will conduct and clamp the input. Atari used 1n754 6.8V Zeners on the Y axis (-7.5V to 7.5V clamping) and 1n756 8.2V Zeners on the X axis (-8.9V to 8.9V clamping). The actual clamp voltages are approximate, since the Zeners aren't reverse biased at their specified current of 20mA, which gave rise to the following improvement.

Frank the Crank from Play Meter magazine wasn't to be outdone so he designed the hack in Figure 6. This is essentially no different from the Atari modifications, except the Zener diodes are properly biased using resistors to the rails, and 1n914's are dropped into the circuit to clamp the input to the within the  $\pm 8.2V$  from the 1n4737 Zeners.

## 4.2 P314 Input Protection PCB

The next revision of the input protection circuit was sent out as an add-on PCB for the P314 deflection boards. It is almost identical to the circuit used on the Amplifone (but Atari recommended the mainly redundant Zener modifications for the Amplifone anyway). The half circuit for this board is shown in Figure 7.

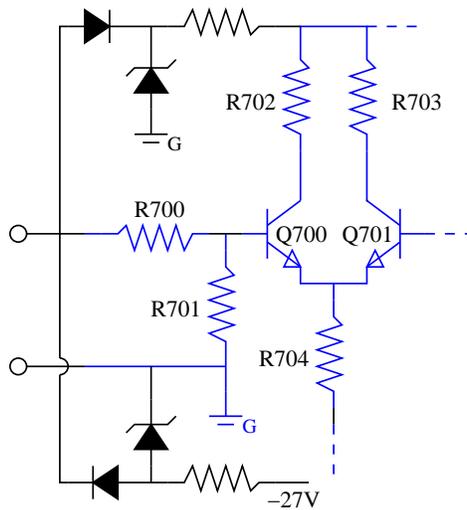


Figure 6: Frank the Crank's Zener diode input protection mod

Let's start with the simple part of this circuit. As we've seen before,  $R_g$  biases the Zener diode at about 5.1V, so if the input to Q700 rises above 5.8V,  $D_a$  turns on and clamps it. The rest of the circuitry is designed to cut off the bias currents to the first and second stages when the average DC voltage is too low.

In normal operation for this circuit, transistor  $Q_c$  is conducting and is pulling one end of  $R_f$  up to ground to provide the bias voltage for Q702 and Q704. (Previously,  $R_{706}$  provided the current to generate these biases). At the input of this circuit  $R_a$  and  $R_b$  form a resistive divider, which is low pass filtered by  $C_a$ . This voltage is then applied to the bases of transistors  $Q_a$  and  $Q_b$ . If the base of  $Q_b$  falls below  $-0.7V$  (ie, an average input below  $-3.7V$ ),  $Q_b$  turns on and pulls its emitter up toward ground, eventually turning  $Q_c$  off, so that  $R_e$  and  $R_f$  pull down the Q702 bias to the negative rail, cutting off the current sources.  $Q_a$  simply provides bias current passing through  $R_d$ , to generate a quiescent base voltage for  $Q_c$  to keep the base voltage of  $Q_c$  from being pulled down to the negative rail when  $Q_b$  is off.

This circuit is doubled for the X axis circuitry (with a change in the resistor divider values, since the X axis is allowed greater swings), so that the amplifiers for both axes are disabled when either input goes below the allowable range. This circuit seems a little bit excessive to me, since Zener clamping the input from going too far negative would achieve roughly the same results. Q700 can be cut off when if the input drops too low, causing its collector to be pulled up to the positive supply, thereby cutting off Q703 entirely, and stressing Q704, so this may be the reason behind this

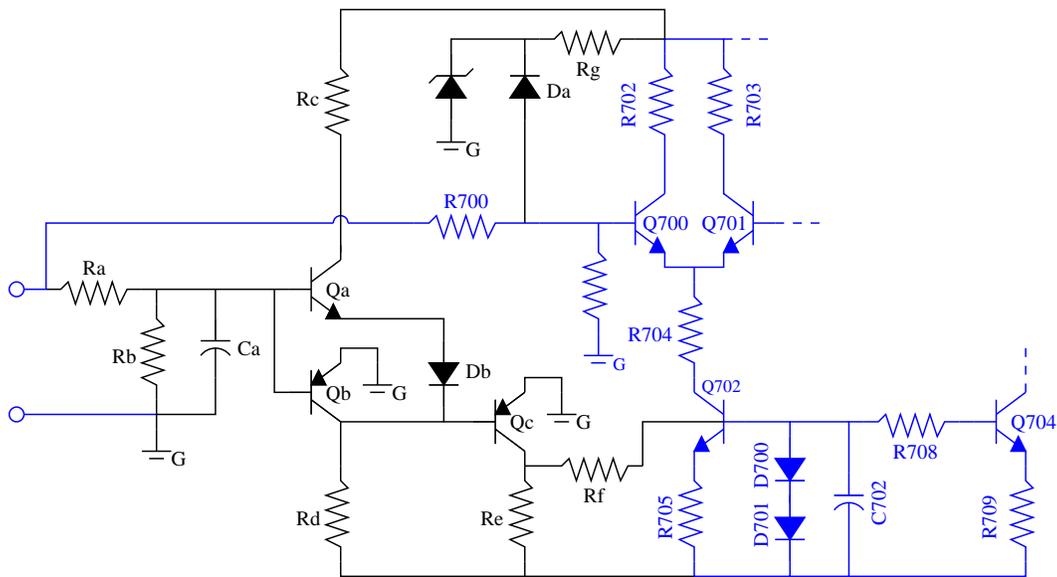


Figure 7: P314 input protection PCB half circuit

approach.

When this input protection circuit kicks in, the inputs of the chassis transistors are no longer driven, so there is no yoke deflection, and the spot killer circuit will trip and turn off the Z amps to prevent screen burn.

### 4.3 P327 / P339 Input Protection Circuit

For the later revisions of the 6100 deflection board, the input protection circuit changed yet again. Atari probably figured that the P314 input protection board add-on was a bit excessive, and designed a simpler circuit that would alleviate some of the problems with the original Zener diode solutions. The Y half of this circuit is shown in Figure 8. The X half is identical, and either half may clamp the voltages of both halves.

This circuit is actually quite simple. Ra and Ca form a low pass filter to time average the input value. During normal circuit operation, the bases of both Qa and Qb pulled to ground through Rb and Rc, so both transistors are off. Thus the circuit does not affect the deflection amplifier. If the voltage across Ca falls below  $-0.7V$ , Da begins to conduct and the base of Qa falls below ground. When Ca it reaches  $-1.4V$ , the base of Qa is at  $-0.7V$ , and the transistor is full on, and the base of Q700 is clamped back to  $0.7V$  through Qc. Similarly, when the voltage across Ca reaches  $1.4V$ , the base if Qb is at  $0.7V$ , so Qb is full on, clamping the base of Q700 to  $0.7V$  via Qd.

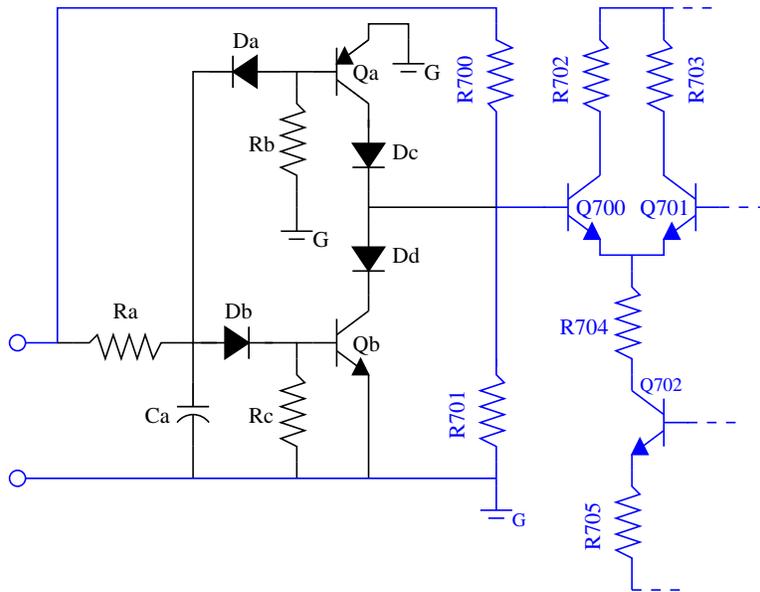


Figure 8: P327/P339 input protection half circuit

This circuit is superior to the Zener circuits since it clamps the input very close to ground during over-voltage conditions, ensuring that excessive currents do not flow through the later stages. It is also much (obviously) simpler and less intrusive to the circuit than the P314 input protection board. No change is needed to the later deflection boards, but some sort of input protection circuit should be added to the P314. Fortunately this circuit can be easily spliced into the existing deflection board by removing R600, R601, R700 and R701 and adding a board which plugs into the 8 vacated holes. Since the PCB area would dominate the cost, it would make more sense to implement the half-circuits separately as I drew them, rather than save the handful of components and use a larger PCB. (If there's any interest, I can make some of these up, but I suspect there aren't all that many P314's left out in the field).

## 5 Conclusion

Well, I think that's all I wanted to write about. I didn't talk at all about the spot killer circuitry, but I can in a later revision if anyone is really interested, but the 6100 manual gives an adequate explanation. I didn't mention the Z amplifiers either, but there's nothing special about them and the 6100 manual (or any raster manual) should give an adequate description. There are quite a few other minor differences between revisions of the 6100 that I could discuss, but I think Woodcock's

document addresses that. Anyway, if anything is unclear (or downright incorrect), feel free to drop me an email and I'll update this doc.

## **A Other resources**

Other vector monitor resources freely available on the internet include:

<http://arcade.ne.client2.attbi.com/~rgvac/monitors>

<http://www.gamearchive.com/video/manufacture/atari/vector/html/monitor.html>

[http://ionpool.net/arcade/tech/6100\\_faq.pdf](http://ionpool.net/arcade/tech/6100_faq.pdf)

## **B Upgrade sources**

Upgrade parts, including cap kits, replacement low-voltage regulators, and input protection PCBs are available from the following sources:

<http://www.therealbobroberts.com>

<http://arcade.ne.client2.attbi.com/~rgvac/layout>

<http://www.diac.com/~jeffh/lv200>