TN-nnn: BEB Current Draw Estimates

1. Introduction

Among other functions, the EFW Boom Electronics Board (BEB) provides the floating ground driver (FGND), and the bias, usher, and guard (BIAS, USHER, and GUARD) drivers required to power the EFW preamps and bias the sensor and surrounding photoelectron control surfaces during nominal operations. These drivers have a moderate bandwidth (few hundred Hz historically) to allow them to follow the low-frequency voltage excursions of the EFW sensor, while allowing the floating supply or bias circuits to produce stable DC-offset voltages relative to that low-passed reference signal.

The driver signals shall be conveyed from the main spacecraft to the preamp and associated bias surfaces via a long (≈50-m) custom multi-conductor cable (cross-section of basic design shown in Figure 1). There is a significant (≈100 pF/m) capacitance between each of the seven (7) individual insulated conductors (A) and the (grounded) conductive outer braid of the cable (D), and so it is important to evaluate the impact of the charging and discharging currents that will flow in response to the finite bandwidth of the driver circuits for the signal amplitudes that flow down from the RBSP-EFW measurement requirements (DOC-REF):

- The RBSP-EFW shall measure E-fields with amplitudes up to 1 V/m at frequencies from DC to 300 Hz (MRD).
- The RBSP-EFW shall measure E-fields with amplitudes up to 400 mV/m at frequencies from 1 kHz to 12 kHz (MRD).
- The RBSP-EFW shall measure E-fields with amplitudes up to 30 mV/m (TBR) at frequencies from 10 Hz to 400 kHz (EFW-EMF MOU).

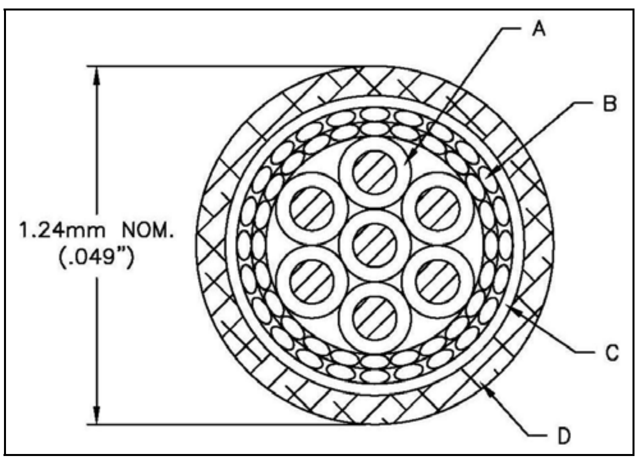

Figure 1: Schematic cross section of RBSP-EFW wire boom multi-conductor cable. (A) indicates one of the seven AWG-36 single conductors; (B) indicates the Kevlar load-bearing braid; (C) indicates the aluminized Mylar underwrap of the outer shield; (D) indicates the silver-plated copper outer braid. (C) and (D) together make up the electrical surface called the outer braid.

A frequency-domain model of the driver circuits, their frequency response, and the currents that will flow in the driver lines (both the total in the output stages, as well as those that will return via the outer braid circuit) is described below. While the total magnitude of the currents involved is relatively small (few mA maximum; see Section 3), these currents will need to be supplied by the HV output stage (±225-V) of the driver circuits, and so may represent a significant increase in required peak power for the RBSP-EFW-BEB relative to earlier designs (THEMIS-EFI, POLAR-EFI, CLUSTER-EFW, etc.).

2. Analytical Model

Examples of the actual floating ground and bias driver circuits from the THEMIS-EFI BEB are included in Section 4. From these actual circuits, the simplified driver circuit model shown at the bottom of Figure 2 was derived. This driver circuit model does not include the impact of the DC offset circuitry on the bias driver (BIAS, USHER, GUARD) channels. It also handles the effect of the “divide and multiply” trick used by the bias driver circuits by normalizing the total voltage gain across the input filter by the DC value of that voltage gain (≈1/24 on THEMIS-EFI-BEB).

Essentially, each driver circuit consists of a single-pole passive input filter, a buffer to the HV output stage (used as a diff amp and as the input stage of the actual driver circuit), the HV output stage itself, and a single-pole passive output filter. The values of the five components that set the frequency response are collected in Table 1, and are taken directly from the THEMIS-EFI-BEB Flight Schematic (rev C). These component values should be taken as the baseline, but still TBR for the RBSP-EFW-BEB design.

Table 1: Model filter component values.

Channel	Filter Component Values				
	RA [ohm]	RB [ohm]	CB [F]	Ro [ohm]	Co [F]
FGND	51.1k	None	10n	221	1.0n
BIAS	1M	41.7k	10n	20k	1.0n
USHER	1M	41.7k	10n	1M	1.0n
GUARD	1M	41.7k	10n	51.k	1.0n

The model for determining the impact of the capacitance between the single conductors in the wire boom cable and the grounded outer braid is shown in the upper part of FIG_REF. Each single is tied to the outer braid via a 5-nF capacitor (50-m cable length; 100 pF/m; based on initial testing and mechanical design (DOC-REFS)), and the outer braid is tied to boom unit chassis ground via a 330-kohm grounding resistor (value TBR; THEMIS-EFI value).

Also shown, but not used in this analysis, is the node to the outer braid marked “Plasma and Photoelectron Currents;” this node is a stub that shows that the outer braid is exposed to both sunlight and the ambient plasma environment, and thus additional currents may be injected at that node. The magnitudes of these currents are expected to be in the few uA range, and so are not significant for the purposes of this analysis (few tenths to a few percent of the peak currents found in the model results).

Note that there is inter-single capacitance of similar magnitude to the single-to-braid capacitance between each of the single conductors and the rest of the singles in the cable. The effect of the inter-single capacitance on driver output stage current is not computed in this model. One can expect that because all the singles in the cable are being driven off of similarly-filtered versions of the sensor output voltage that the impact of the inter-single capacitance will be greatly reduced relative to that of the single-to-braid capacitance. The impact would be proportional to the difference in voltage gains between channels at a given frequency.

The results of the analytical frequency-domain model for voltage gains, admittances, and the magnitude of current flow in the HV output stages and from the singles to the braid and to chassis ground are shown in FIG-REF. These results were computed using IDL 6.3, using the procedure, "**rbsp_efw_beb_current_estimates_revA.pro.**"

The upper right panel gives the legend for the channels in each of the plots (FGND is red; BIAS is magenta; USHER is dark blue; GUARD is cyan). The upper left panel shows the magnitude of the total voltage gain across each driver channel (input filter and output filter) as a function of frequency from 0.01 Hz to 1 MHz, and is used to determine the voltage of each single with respect to ground.

The lower left panel shows the magnitude of the admittance between any given single and ground as a function of frequency in uS (uA/V).

The center two panels show the magnitude of current for the low-frequency (≤ 100 Hz (TBR)) measurement requirements of a 1V/m external field, a 100-m tip-to-tip boom system, and a boom shorting factor of 1.0 (no shorting; measured field = applied field), for both the branch leading through each single, coupling to the outer braid, and then to chassis ground via the grounding resistor (top panel), as well as the total magnitude of the current that has to be supplied by the HV output stage (bottom panel).

The total required currents peak out at just over 100 uA (0.1 mA) for all the driver circuits. Note that the peak values for the BIAS and GUARD occur for applied frequencies in the 1-10 kHz range, and so represent an over estimate (by about a factor of 2.5) of the required current since the measurement requirement is lower above 100 Hz (400 mV/m, instead of 1 V/m). The plateau in the total current above a few hundred Hz in the bias channels is due to the dominance of the admittance of Co over that of the braid at those frequencies. This effect is not seen in the FGND channel due to the much higher roll-off frequency of the FGND output filter (≈720 kHz).

The currents flowing to ground through the outer braid are of similar magnitude to the total currents, peaking out at just over 100 uA (0.1 mA) for all the channels, in the 100 Hz to 1 kHz band.

This model does not include several other effects at this time:

1. Actual frequency response of the sensor-preamp-cable assembly -- contributes a factor of 2 attenuation above ≈300 Hz, and cuts off response above 400 kHz.
2. Plasma sheath impedances and current flows on the sensor (BIAS), outer braid, and other biasable surfaces (USHER, GUARD) – tens of Mohm impedances to plasma.
3. Floating supply currents – different supply than the HV output supply, but similar analysis can be applied.

Note that the currents arising from similar effects on the axial boom cables will be approximately 40-60 times smaller, due to the shorter multi-conductor cables used in the AXB units (6-8 meters, instead of 50 m for the wire boom systems), as well as the shorter tip-to-tip length of the axial sensors (12-16 m, instead of 100 m for the wire boom systems), and so those currents can be neglected for the purposes of this analysis.

3. Conclusions

The peak magnitude of the currents flowing in the output stages of the floating ground and bias driver circuits on the BEB are on the order of 150 uA per channel, peaking in the 100 Hz to 1 kHz band. Since each spin plane channel consists of four (4) driver channels (FGND, BIAS, USHER, GUARD), and that there are four (4) spin plane wire boom channels, and that the current consumption of the axial drivers is significantly less than that of the wire boom drivers, one can place the peak required current draw on the HV (±225-V) output stage supply at around 5-6 mA.

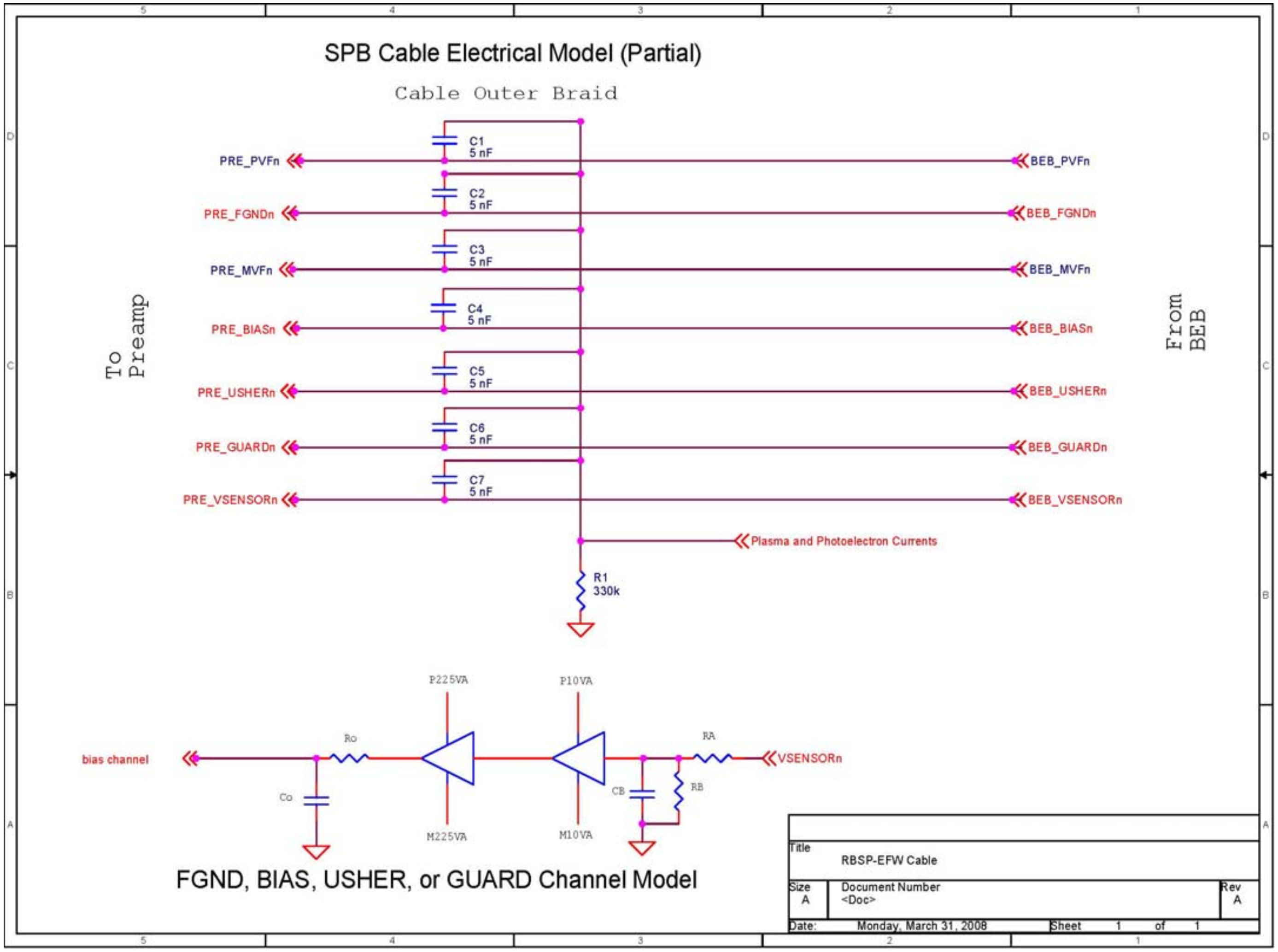

Figure 2: Schematic of simplified SPB cable and driver electrical models.

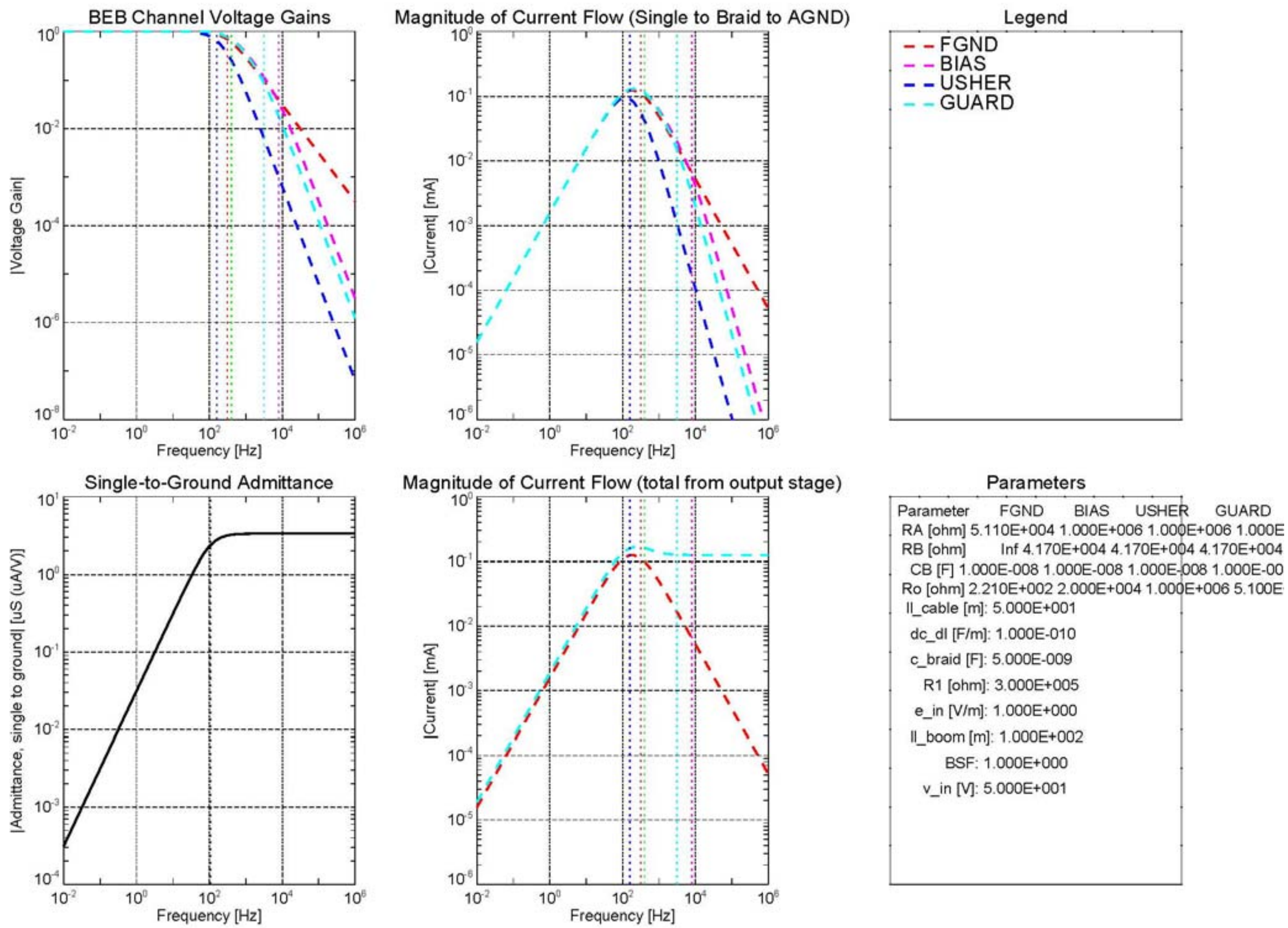

Figure 3: Analytical model results for floating ground and bias driver circuits.

4. Appendix: BEB Driver Circuit Schematics (THEMIS_BEB_SCH_001C)

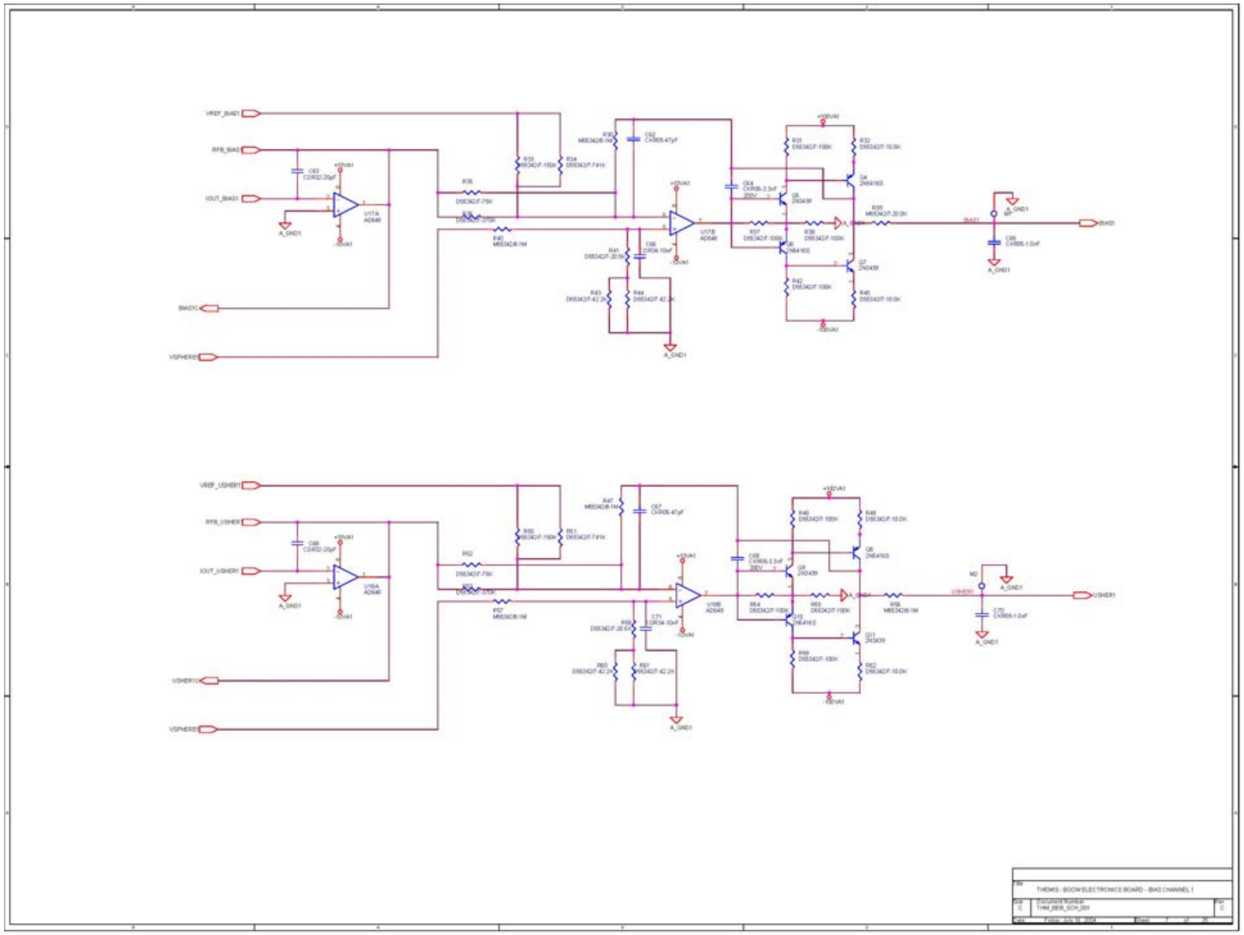

Figure 4: THEMIS-EFI-BEB BIAS and USHER driver circuits.

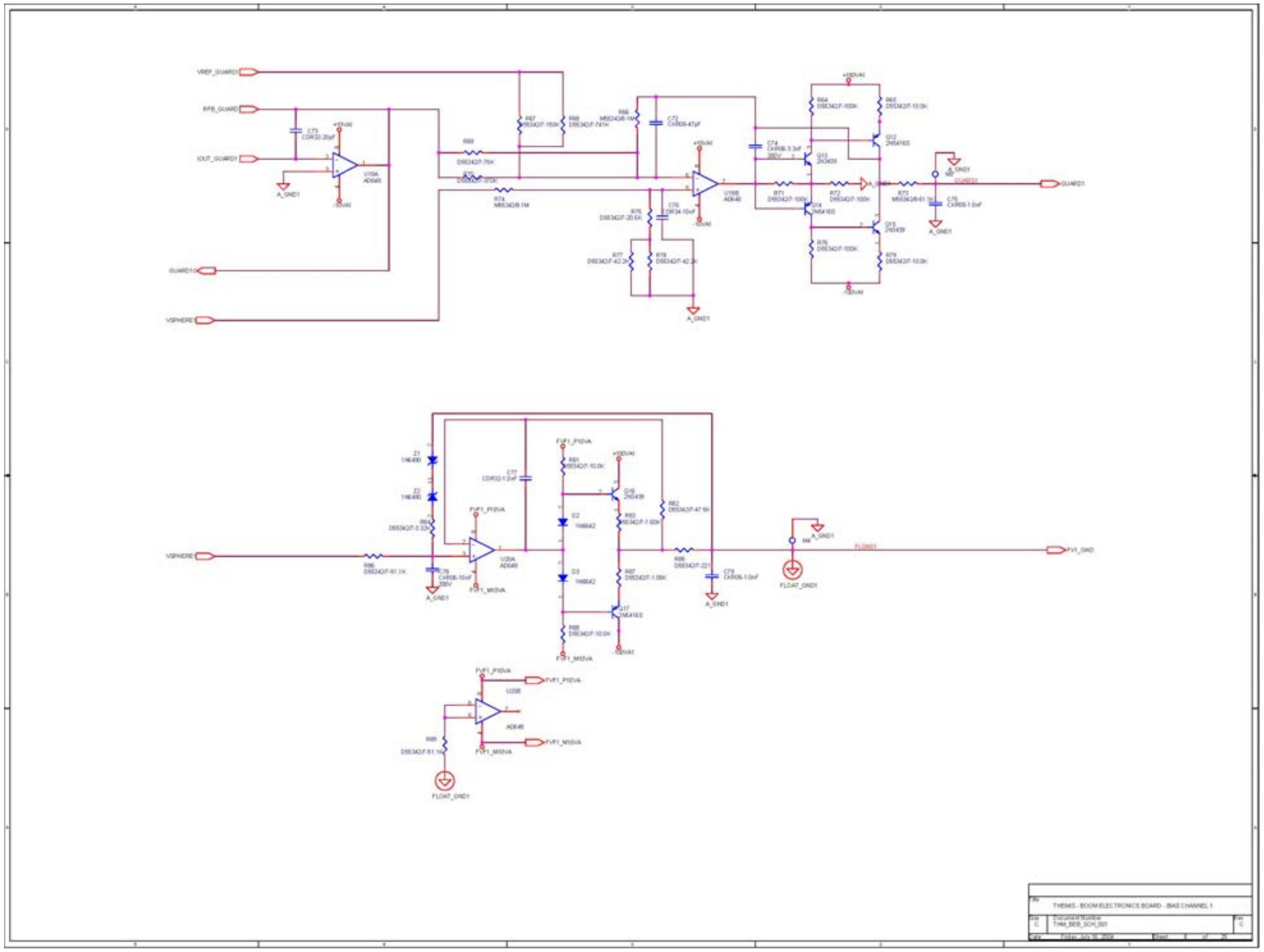

Figure 5: THEMIE-EFI-BEB GUARD and FGND driver circuits.