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Dynamic Compensation of the Solid-State Driver for the 197 MHz Power Amplifier in RHIC

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Introduction

A lot of modifications on the QEI solid-state driver had been performed to solve the problems including transistor failures during the initial operating period of the RHIC. Since then the driver stations worked fine. Recently, however, we found that the RF power outputs in some station are not clean, i.e., side bands of around 1 MHz appeared in the spectrum of the outputs. The magnitudes and frequencies of these sidebands vary with the output power level of the solid-state driver station, and inconsistent from station to station. This kind of harmonics, after the amplification of the tube amplifier, put extra thermal stress on the cavity window and affects the quality of the cavity gap voltage. This problem was investigated extensively and the major cause was found to be in the regulated power supply stage. The circuit has been modified to compensate the voltage regulation loop, and some other modification on the whole station is also carried out to improve the output of the RF Driver module. The modification on one station has been running in the tunnel for months stably.

Problem Identification and solutions

Initially the problem was though to be the bad match in the QEI rack. We tried to adjust the input match of the splitter but it did not help much. Then we checked individual modules and found that the module oscillated by itself even with a regulated dc input (commercial dc power supply) and a 50 Ohms dummy load. This isolated the problem to the module itself. After a lot of experiments, we found that the 5 Ohms resisters, which were put in during the modification performed before and was in series with the 15 uF decoupling capacitors (C2 in Fig. 1), had something to do with the oscillation. The oscillation would be gone if we short the resistors out. So, we decided to take the resistors out. A whole set of modules was test on the test bench with commercial power supply and standard dummy load. No problem was found on the bench.

However, after we put the modules in the rack, oscillation still happened, but at different frequency (around 30 kHz). Although the magnitude of the sideband can be depressed to certain extend by fine-tuning the splitter, obviously this did not fix the problem completely.

While trying to identify the root cause of the problem, we monitored the regulated voltage of each module while it was installed in the rack. We found there were unacceptable ripples on the regulated 50 volts bus of most modules. Thus we checked the dynamics of the regulation loop of the power supply for the module. And found there was a deep phase sag from around 30 kHz to 70 kHz. The worst point is very close to 180 degree, as shown in Fig. 2. Thus the regulation loop is potentially unstable.

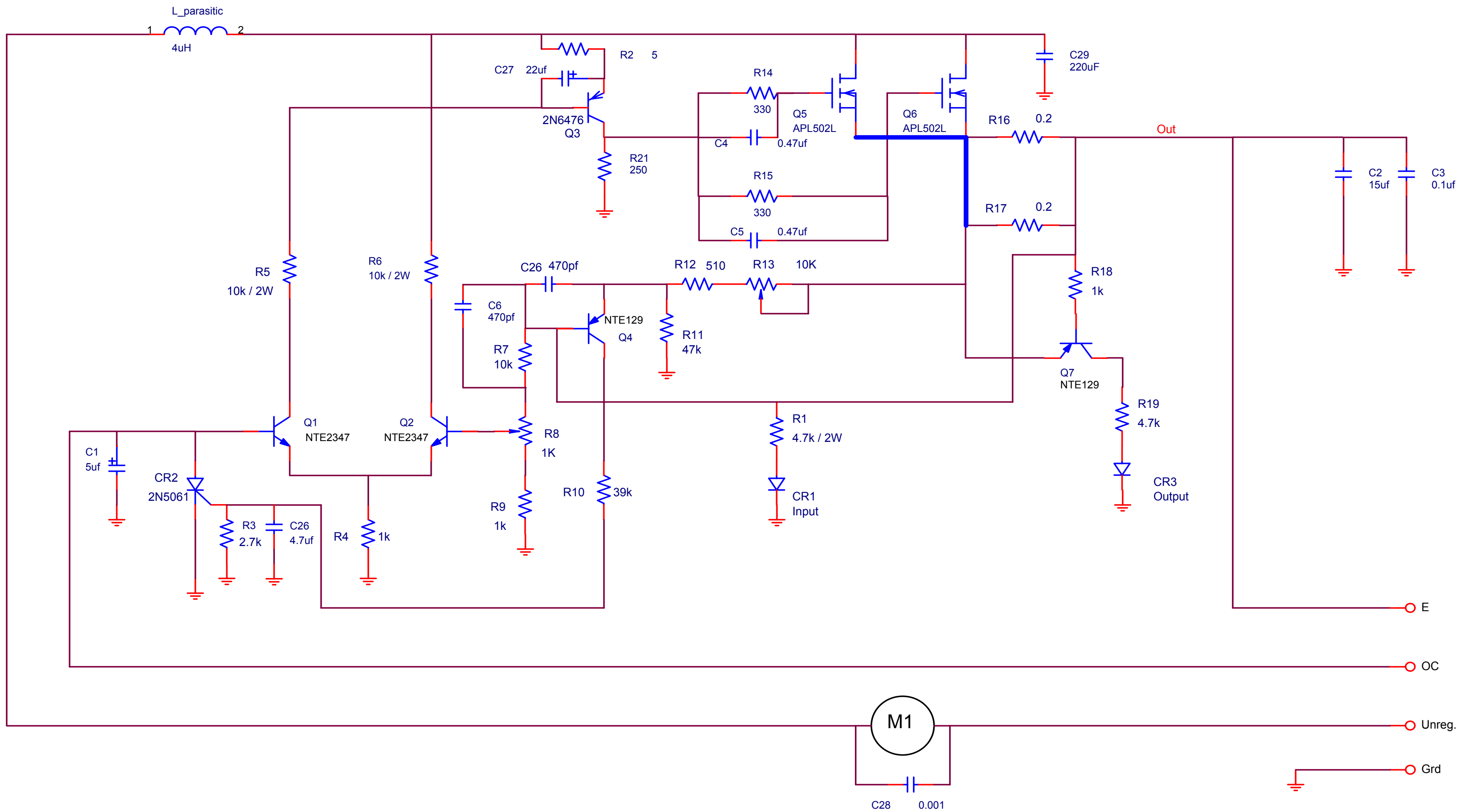

Fig. 1 The voltage regulator after modifications.

PSPICE simulation was performed to analysis the dynamics of the circuit. The reason for the phase sag was identified to be the parasitic inductance of the wire transmitting the unregulated dc voltage from the cap bank of the rack (L-parasitic in Fig. 1), the front-end capacitor, and the RF decoupling capacitor at the power supply output side. The voltage regulation MOSFET (Q5 and Q6 in Fig.1) connects the components in the unregulated and regulated side. They form a high-order circuit and interact with each other. While it is not practical to eliminate the phase dip completely, appropriate compensation can be employed to improve the phase margin.

Lead-lag compensation was applied to the loop and the dynamic response was improved. In terms of the circuit modification, this compensation can be easily implemented by adding several capacitors to the circuit

Modifications

Eventually the circuit was modified as following:

1) Remove two 5 ohms resistors from the RF decoupling capacitors (C2 in Fig 1).

   This is done by shorting the resistor or taking out the resistor and sold the capacitor to the ground plane directly.

2) Add 470 pf capacitor (C6 in Fig. 1) in parallel to a resistor (R7 in Fig. 1) in the feed back loop.

   This is done by sold the capacitor on the legs of the resistor.

3) Add 0.47 uf capacitors C4-5 in Fig. 1) to the gate resistors (R14-15 in Fig. 1) of the MOSFET;

   This is done by sold the capacitor on the legs of the resistor.

4) Change the front-end capacitor to 220 uf (C29 in Fig. 1), this provides a better ac ground for the voltage regulator circuit.

Besides these module modifications, we also found that the driver module, which used to be running in class AB, incurred harmonics that causes the QEI station oscillation if the input splitter is not carefully tuned. Since we found the oscillation was fix when we used a commercial class A power amplifier instead of the driver module, it looks like the problem was due to the harmonics generated by the driver module. Mr. Spitz came up with a great idea to use an output module running in class A in place of the driver module, and it works great. It is easy to change an output module from class AB to Class A by adjusting the bias voltage of the FETs. However, a lot of works need to be done to provide a pre-driver and associated circuitry for the modified class A driver.

The voltage regulator after modifications is shown in Fig.1, and improved dynamic response is shown in Fig. 3.

Summary

Modifications on both the QEI module itself and the pre-driver are performed. The problem of oscillation of the 197 MHz QEI solid-state driver stations is fixed. This note documents the modifications.

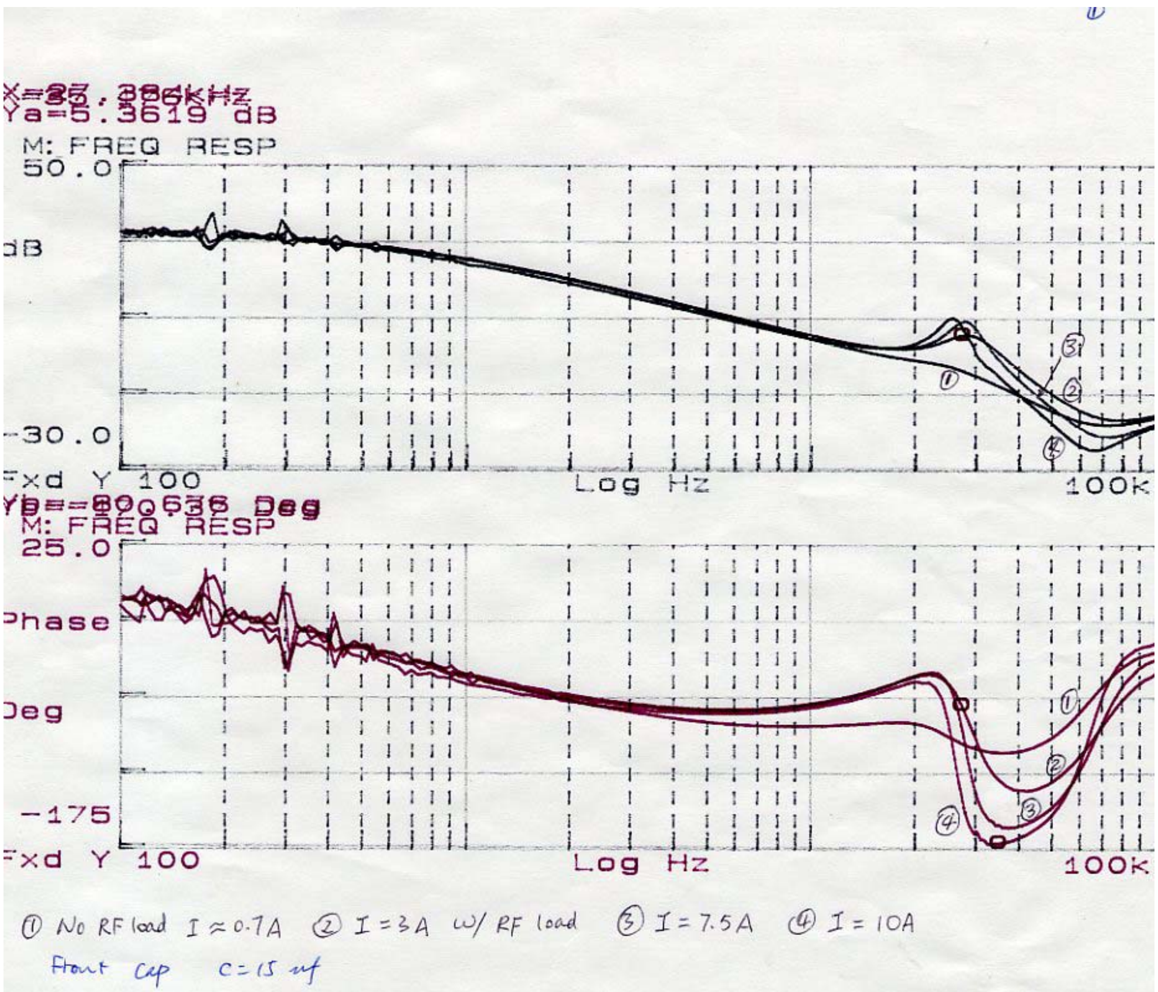

Fig. 2 The dynamic response of the voltage regulator before modifications.

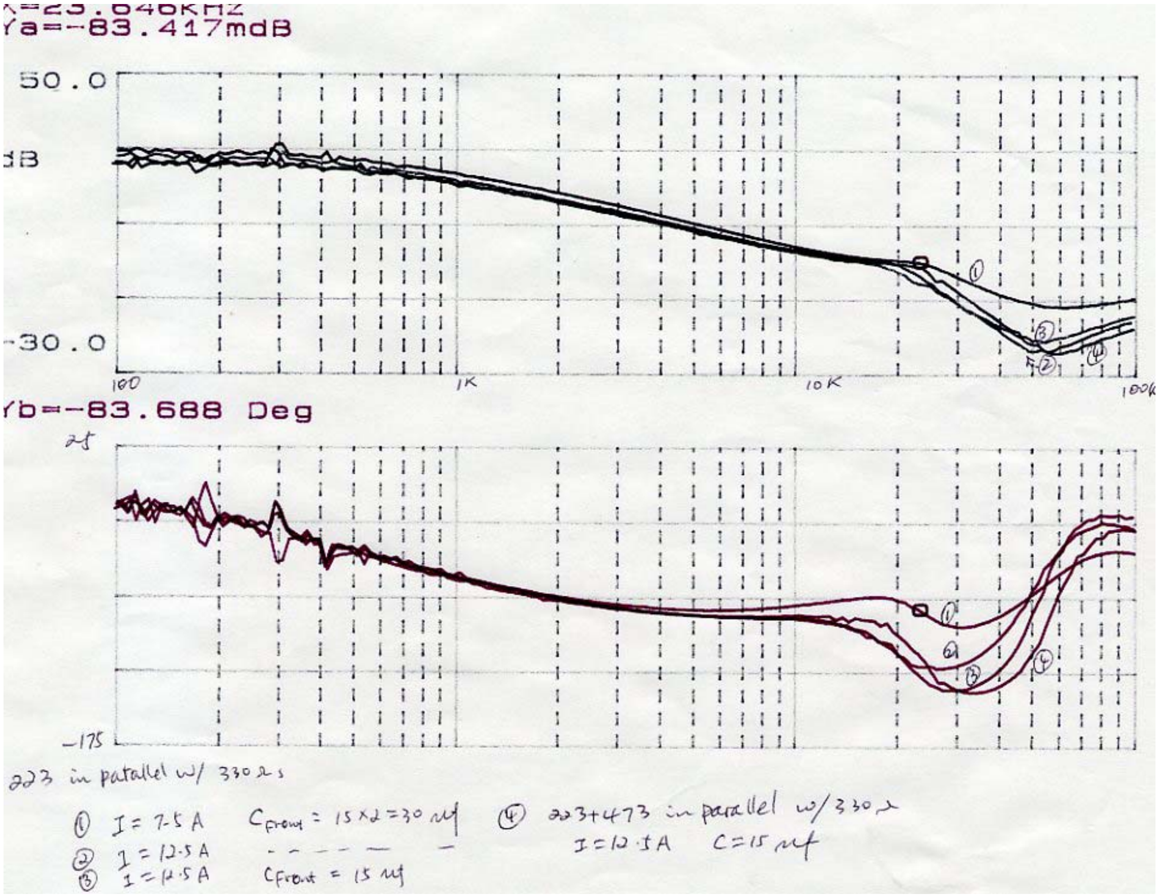

Fig. 3 The dynamic response of the voltage regrlator after modifications.