Performance and Design of a Precision RF Signal Chassis at Los Alamos Neutron Science Center

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Abstract

Accelerator low-level RF (LLRF) systems have demanding requirements on signal distribution circuitry. The RF feedback control paths from the cavity are not corrected for error and demand a high level of attention to performance. This chassis allows the frequency dependent (805 MHz or 201.25 MHz) circuits to be separated from the modular frequency independent digital low level RF system. The same digital system hardware is used throughout the linear accelerator (LINAC) with RF cavity type dependent software. The prototype of this chassis suffered from too much RF crosstalk between the cavity and reference signals. This paper reviews the challenges associated with this chassis, the updates that were made from the prototype to the production version, and the decision for one chassis to contain the frequency dependent circuits. We also review the requirements for temperature stability of the chassis, cavity, and reference signals. Performance testing of the chassis is reviewed including the design process for automating the test procedures which allows for quick and efficient testing of the chassis, resulting in significant time savings throughout the process.

LLRF Upgrade at Los Alamos Neutron Science Center

Los Alamos Neutron Science Center (LANSCE) is located at Los Alamos National Laboratory in Los Alamos, New Mexico, USA. The LLRF systems are currently undergoing an upgrade from the original analog LLRF systems of the late 1960s and early 1970s to modern digital systems. In 2015, the first digital systems became operational. As of 2022, 30 of the 53 LLRF systems are upgraded. The analog system was increasingly difficult to maintain with many obsolete parts making repairs and maintenance challenging. It should be noted that the analog system was incredibly robust and was working reliably since 1972.

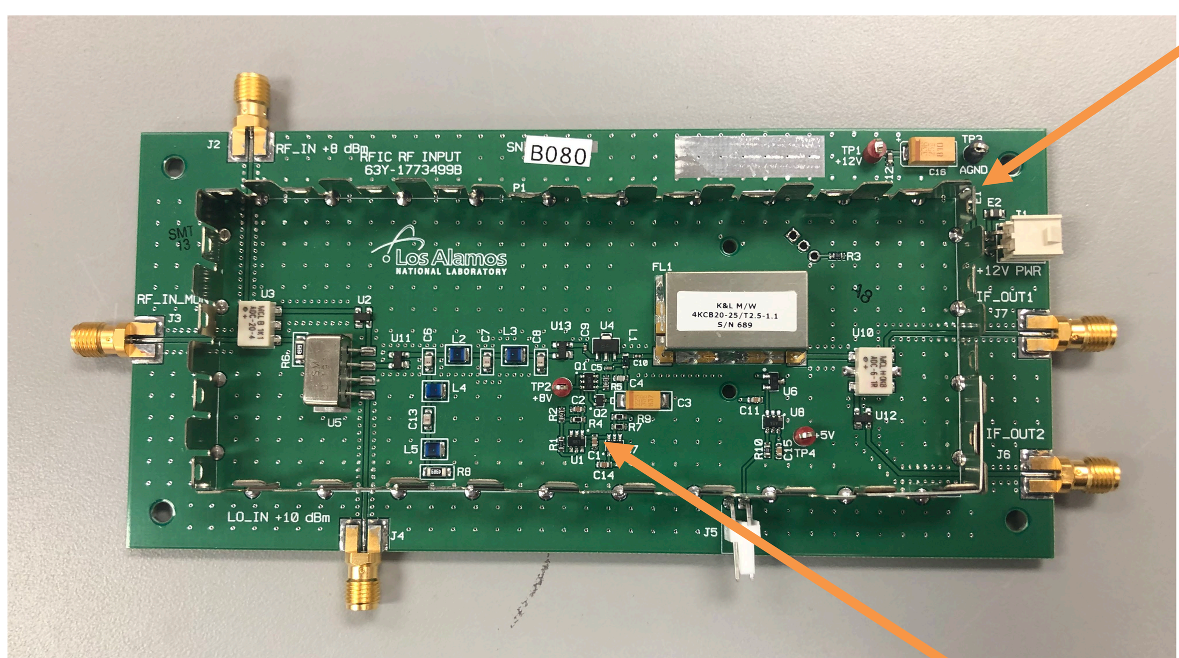

Figure 1. RFIC RF Input Board for RFIC Chassis

Testing Automation

To reduce the amount of time needed for testing the RFIC PCBs and chassis, multiple LabVIEW programs were designed, tested and implemented. These automated test programs have a significant time savings for the LLRF team, a reduction from one day to two hours. After automation of this chassis and the resulting times savings, several other processes were automated.

Future Installations

Currently, 30 of the 53 systems have been installed and all systems are scheduled to be updated by end of 2024. All 201.25 MHz RF systems have been updated and 26 of the 44 805 MHz RF systems have been updated. The systems yet to be updated include the remaining 805 MHz RF systems, the Low Energy Buncher Transport, and the Proton Storage Ring.

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RF Interface Chassis

The RF Interface Chassis (RFIC) is the chassis within the digital LLRF which contains most of the frequency dependent components. LANSCE has several frequencies within the LLRF systems, including 2.8 MHz, 16.77 MHz, 25.15625 MHz, 176.09375 MHz, 201.25 MHz, 779.84375 MHz, and 805 MHz. By having one chassis contain the frequency dependent circuits, it makes adapting to a different frequency straightforward as there is only one chassis and a few components in the tunnel that need to change.

PROTOTYPE VERSION

The prototype RFIC was initially designed with functionality and ease of assembly in mind. The design requirements for isolation between the channels was not an initial concern because preliminary calculations indicated more that adequate isolation. Having a single printed circuit board (PCB) simplified assembly, however during operational tests isolation problems between adjacent channels become evident. Measured isolation was ~ 60 dB which was 30 dB less than the required specification of 90 dB. Additional detailed analysis indicated the required isolation would take extraordinary measures to achieve in a single integrated PCB. Additionally noted on this design was the significant phase drift (1-2 ^{0}/^{0}C) of the bandpass filters as a function of temperature as well as the temperature dependent gain variation (0.25 dB/^{0}C) of the RF/IF amplifiers. Temperature variation in the chassis was up to 5 ^{0}C.

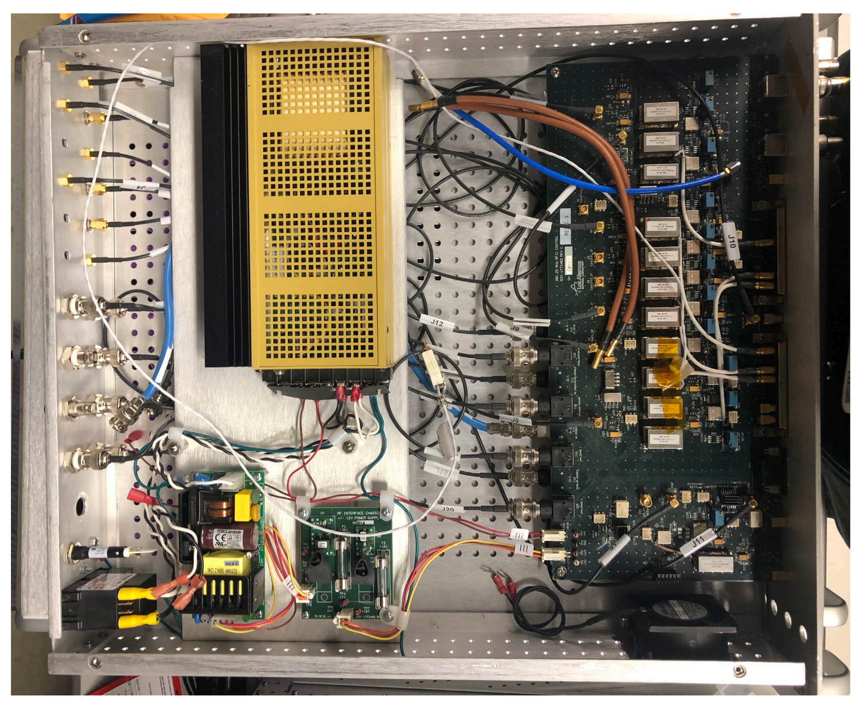

Figure 2. Prototype Chassis

PRODUCTION VERSION

The analysis of the prototype design suggested that the best way to achieve the isolation requirements was through individual PCBs for each channel and signal transport using coaxial cable. Cross talk between adjacent channels was the main culprit for the loss of isolation. To improve isolation, RF shielding covers were added to each board to provide additional noise shielding and isolation. The channel to channel isolation in the newer design is ~ 110 to 120 dB. The phase variation of the bandpass filters was addressed by changing to a lowpass filter and temperature controlling the filter using a oscillator temperature control element to ± 1^{0}C with a RF phase variation of < 0.1^0. The temperature variation of the amplifier gain was improved by adding a current mirror circuit to the input power network and changing the amplifier technology from GaAs (0.04 dB/^{0}C) to InGaP HBT (0.003 dB/^{0}C), improving the overall temperature stability by over a factor of 20.

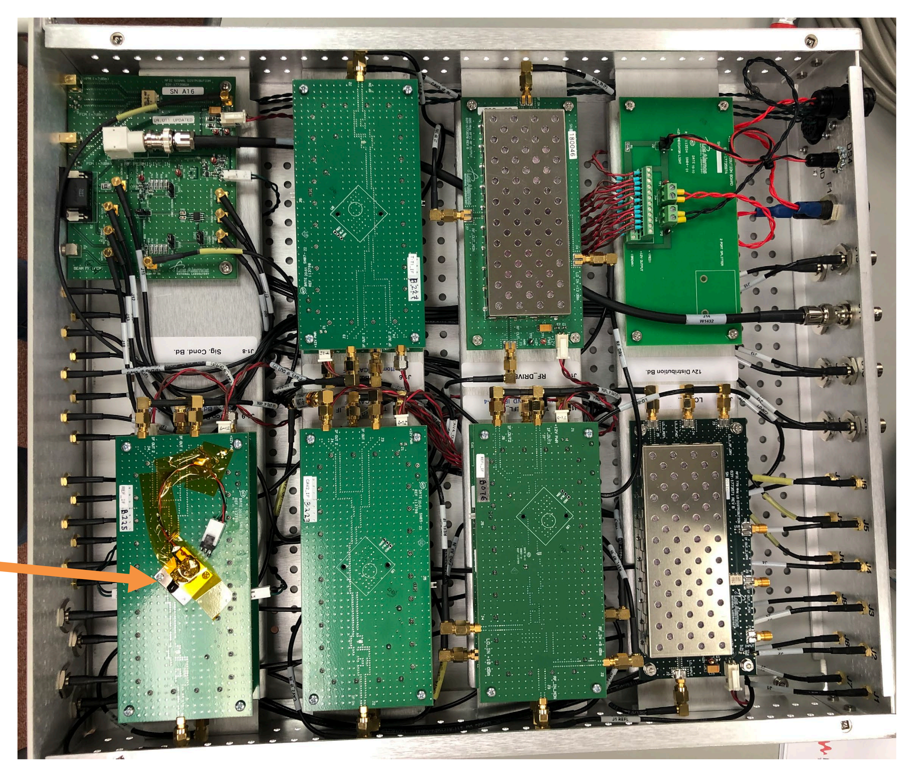

Figure 3. Production Chassis

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