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IMPROVING CAVITY PHASE MEASUREMENTS AT LOS ALAMOS NEUTRON SCIENCE CENTER*

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Abstract

Control stability of the phase and amplitude in the RF accelerating cavity is a significant contributor to beam performance. The ability to measure phase and amplitude of pulsed RF systems at the accuracies of +/- 0.1 degrees and +/- 0.1 percent required for our systems is difficult and custom designed circuitry is required. The digital low level RF upgrade at the Los Alamos Neutron Science Center (LANSCE) is continuing to progress with improved cavity phase measurements. The previous generation of the cavity phase-amplitude measurement system has a phase ambiguity, which requires repeated calibrations to ascertain the correct phase direction. The new phase measurement system removes the ambiguity and the need for field calibration while improving the range and precision of the cavity phase measurements. In addition, the new digital low level RF systems is designed to upgrade the legacy system without significant mechanical, electrical or cabling changes. Performance data for the new phase measurement system is presented.

BACKGROUND

The low level radio frequency (LLRF) system at LANSCE is currently undergoing an upgrade from the original analog control systems to digital control systems. The upgrade began in 2014 and currently 30 of the 53 systems have been upgraded to digital control systems. As part of this upgrade, a new system for the measurement of the cavity phase and cavity amplitude signals is needed as the analog system is incompatible with the new digital systems. The requirements for the error of the LLRF system at LANSCE are 0.1 degrees for phase and 0.1% for amplitude. There have been multiple designs of the digital phase-amplitude measurement system.

CURRENT VERISON

The current version of the digital cavity phase-amplitude measurement system, as seen in Fig. 1, has an 180 degree phase ambiguity. The main integrated circuit (IC) used in the measurement of the phase is the Analog Devices AD8302 IC and the design of the phase measurement system is based on this IC. The AD8302 compares the phase of two input RF signals and determines the difference between the two input signals as voltage. The output is scaled to 10mV per one degree of phase difference. As seen in Fig. 2, a positive 90 degree and a negative 90 degree phase difference have the same voltage output, leading to the ambiguity in the current system. This ambiguity must be accounted for at each module to determine if the phase slope is positive or negative. The calibration is completed by looking at sign of the predetermined conversion factor. For each calibration that is completed, the phase slope must be checked to ensure that the phase is located on the correct slope. If the phase is on the wrong slope, then the measured voltage is the correct value, but the phase is incorrect, causing issues with beam acceleration. The amplitude measurement system uses an Analog Devices ADL5511 IC which determines the amplitude of the input cavity amplitude signal as a voltage output.

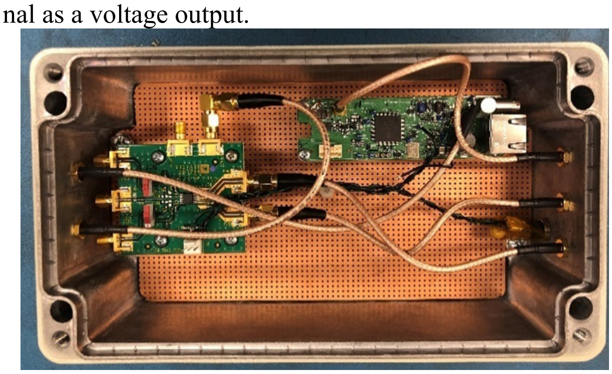

Figure 1: Current phase-amplitude measurement system.

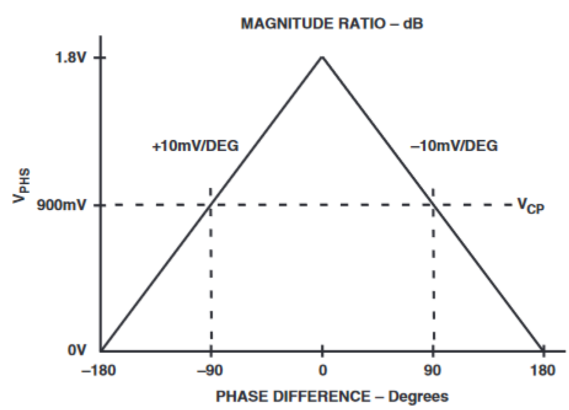

Figure 2: Output of AD8302.

NEW DESIGN

To remove the phase ambiguity of the current phase-amplitude measurement system, a new design was implemented and a prototype printed circuit board produced. The major difference between the current version and the new design is two AD8302 ICs are used, instead of only one. The cavity and reference lines are split into two and one of the cavity input signals is phase shifted by 90 degrees. To keep the phase shift consistent across various boards, thephase shifted is completed by lengthening the RF trace on the printed circuit board. Any commercially available phase shifter has some variation in the exact phase shift

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between different modules, leading to an inconsistent phase shift. The addition of the phase shift and an integrated dual channel analog to digital converter (ADC) allows the digital system to determine the phase and remove the need for manual phase slope calibration. The new design has an algorithm to compare the relationships of the AD8302s output voltage levels to determine the quadrant (-180° to -90°, -90° to 0°, 0° to 90°, 90° to 180°), as seen in Fig. 3, of the phase. This allows for the unambiguous phase measurement.

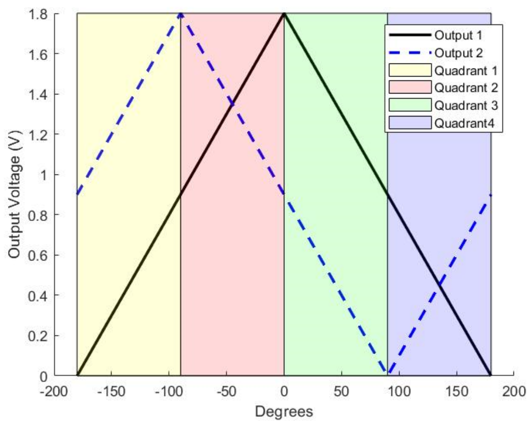

Figure 3: Quadrants.

There are two different printed circuit board versions, one for 805 MHz and one for 201.25 MHz, where the RF trace on the printed circuit board has been lengthened to match the phase adjustments. In addition, the new design has been integrated into an existing printed circuit board in the digital LLRF system, removing the need for a separate chassis to contain the phase-amplitude measurement system. There will still be analog outputs of the AD8302 and ADL5511 ICs for ease of use and viewing on an oscilloscope. The amplitude portion of the phase-amplitude measurement system has not changed from the current version to the new design, although the output is also feed into the ADC. The block diagram of the new design can be seen in Fig. 4 and the new phase-amplitude measurement system printed circuit board can be seen in Fig. 5.

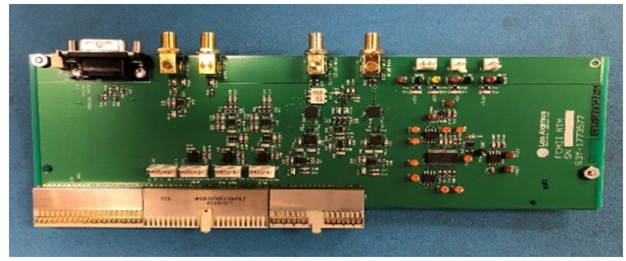

Figure 5: New design of phase-amplitude measurement system integrated into an existing board within the digital LLRF system.

RESULTS

Figure 6 shows the two phase outputs from the board. The voltage difference between the two outputs in the linear section is 0.8V of difference, which corresponds to a phase shift of 80 degrees. Although designed for 90 degrees, the shift of 80 degrees will not be a problem. A measure of the noise generated by each channel was taken and the histogram feature of the oscilloscope was used. The noise, on channel one, was the standard deviation was 3 mV and 95% of the noise was within two stand deviations. On channel two, the standard deviation of 3.5 mV and 95% of the noise was within two standard deviations, showing consistency between the channels. The algorithm takes advantage of oversampling to reduce the noise.

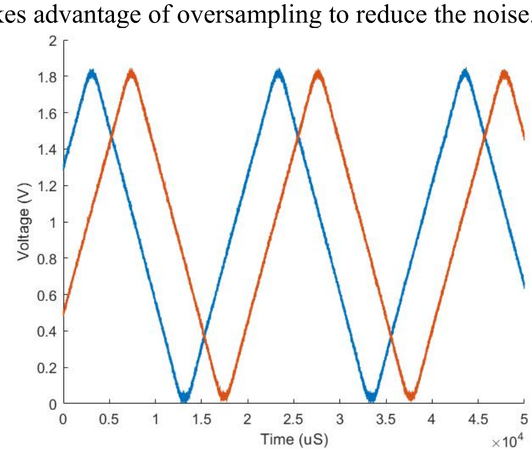

Figure 6: Output of the new design.

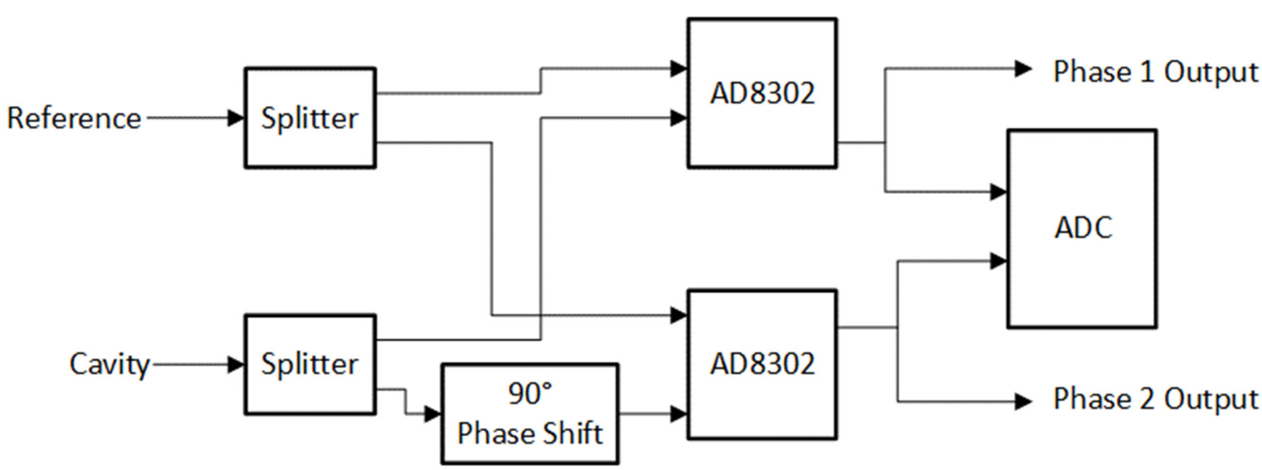

Figure 4: Block diagram of the new design.

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FUTURE

There are several endeavors for the new phase-amplitude measurement system which have yet to take place. Including temperature testing, to see how the phase-amplitude measurement system varies with temperature. The production version of the new board will have some modifications with part changes due to the supply chain issues of several parts on the board and current lack of availability. The phase shift will be adjusted from 80 degrees to 90 degrees.

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