Test Results of the LEDA Beam-Position/Intensity Measurement Module*

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Abstract. This paper describes progress in the design and testing of the log-ratio-based beam-position/intensity measurement module being built for the Low Energy Demonstration Accelerator (LEDA) and Accelerator Production of Tritium (APT) projects at Los Alamos National Laboratory. The VXI-based module uses four, 2 MHz if inputs to perform two-axis position measurements and one intensity measurement. To compensate for systematic errors, real-time error-correction is performed on the four input signals after they are digitized and before calculating beam position and intensity. Beam intensity is computed by using the average of the four log-amplifier outputs. This method provides a better off-axis intensity response than the traditional method of summing the rf power from the four lobes. Several types of test data are presented including results of the real-time error correction technique, a working dynamic range of over 80 dB, and achievable resolution and accuracy information.

INTRODUCTION

This paper reports progress on the design and testing of the LEDA beam-position/intensity module reported earlier (1). Key areas are the real-time error-correction technique, showing results with more complete data than was presented earlier, and an improved method of performing the intensity measurement. A block diagram of the module is shown in Figure 1. The position-measurement technique is based on the log-ratio transfer function which has been described by several authors (2,3,4). The log-ratio technique is defined in Equation 1:

$$V_{\log ratio} = \log(T) - \log(B) \tag{1}$$

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where T and B represent the power in the intermediate-frequency (if) signals for opposite top and bottom lobes of a beamline probe. Subtraction is easier to perform than division and can be done either by digital or analog techniques.

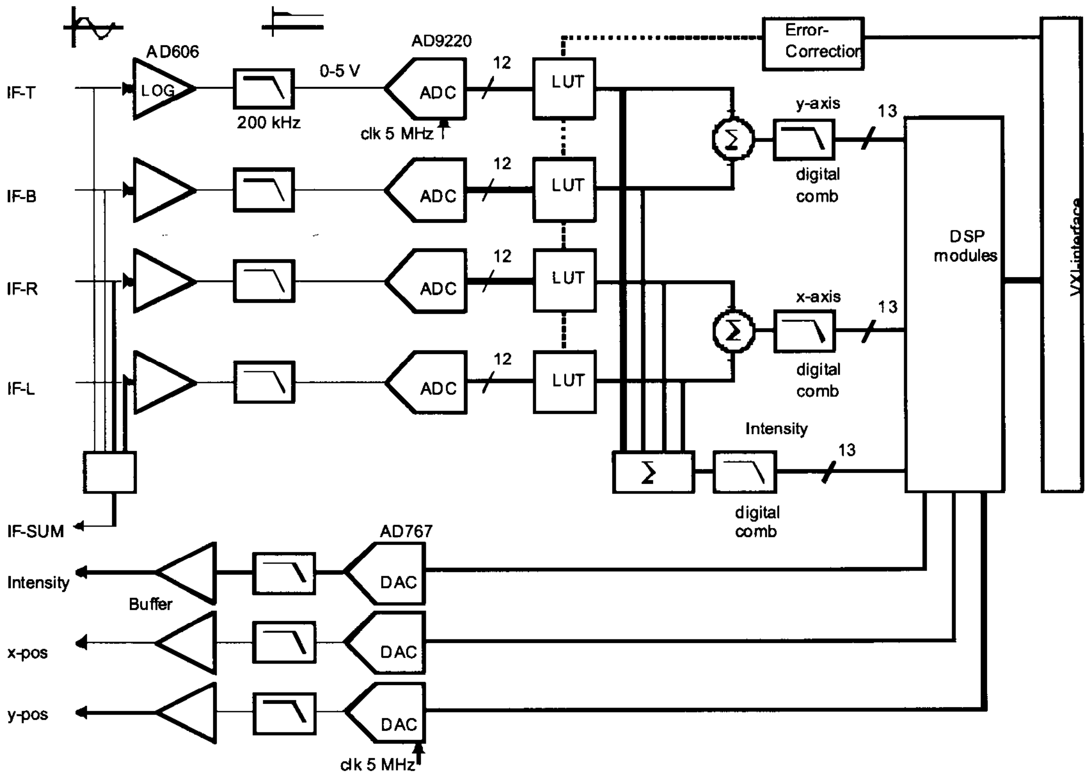

FIGURE 1. Block diagram of the LEDA Beam-Position/Intensity measurement module.

Referring to Figure 1, the 2 MHz if inputs are digitized at a 5 MHz sampling rate, digitally corrected, subtracted, filtered, and passed to the DSP modules for further processing. Three separate DAC channels provide front panel signals for monitoring. For a more detailed explanation of the module's operation, the reader is referred to Reference 1.

The module is divided into three sections: first, the analog front-end; second, the digital-to-analog section; and third, the DSP, error-correction, and VXI-interface section. Some of the important specifications of this module are listed in Table 1.

ERROR-CORRECTION PERFORMANCE

Each logarithmic amplifier exhibits some non-ideal behavior in the form of small perturbations in its transfer function, DC offsets, and distortion effects at the upper and lower ends of the dynamic range. By using digital error-correction, non-ideal performance in the log amps and other system non-linearities can be removed from the overall system transfer function. The signal level range at the input of the ADCs is 0–5 V. The ADC resolution in mm depends on the specific probe sensitivity in dB/mm or other suitable units.

TABLE 1. General Requirements for the LEDA Beam Position/Intensity Module

Item	Value	Units
Frequency input (if input)	2.00	MHz
Maximum input signal power	10	dBm
Input impedance	50	Ω
number of if inputs	4	each
number of axis measurements/module	2	each
Range, *x*-, *y*-axis outputs	±10	V
Range, intensity output	0 –10	V
Measurement bandwidth	≥ 180	kHz
Measurement resolution	0.03	dB
ADC resolution	12	bits
ADC sampling rate	5	MHz

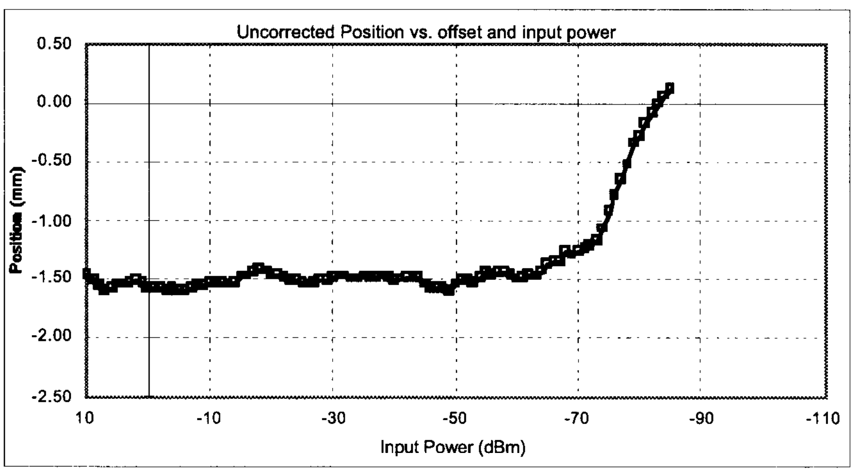

FIGURE 2. Plot of single-axis uncorrected position data for 5 dB offset inputs.

Digital data streaming from the four ADCs are the addresses to the look-up tables (LUTs). Corrected data are output from the LUTs and are used in the subtraction and intensity measurement processes. Figure 2 shows uncorrected position data for a 5 dB offset input ratio performed on the if-T and if-B input channels.

The probe sensitivity is assumed to be 3.484 dB/mm. Circuit offsets and other non-linearities cause the plot to be shifted slightly downward and exhibit significant ripple. Over the useable dynamic range of +10 to –70 dBm the mean is –1.493 mm, and the standard deviation is 0.069 mm. The same input offset, 5 dB, and power range using error-correction is shown below in Figure 3. Again, the same probe sensitivity value of 3.484 dB/mm is used to plot the data. The corrected position from +10 to –70 dBm has a mean of –1.437 mm, and standard deviation of 0.016 mm, a significant improvement over that of the uncorrected response. The data plotted in the above two figures is taken with input signals at the beam-position/intensity module if inputs and do not include other system components such as the beamline probes, down-converters, and cabling. These data serve as a useful baseline of the best possible performance from the system.

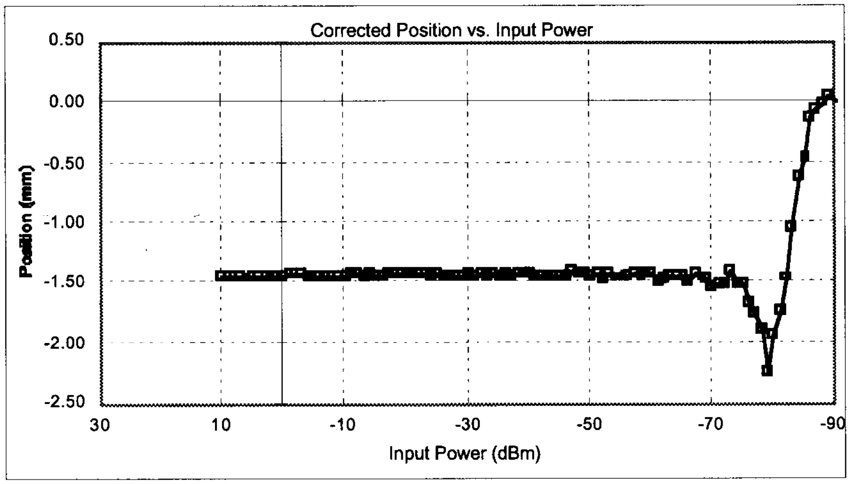

FIGURE 3. Plot of single-axis corrected position data for a 5 dB offset between the inputs.

INTENSITY MEASUREMENT

The original method chosen to perform the intensity measurement was to sum the four if inputs (IF-SUM), present the sum to a log amplifier, and then digitize the log amplifier output and perform digital error correction and calculations on that signal (1). This required a fifth log-amp/ADC channel. However, after examining constraints, such as limited board space, the need to have a fifth channel was eliminated by using a different intensity calculation method, an average of the log inputs (AVG-LOG). The IF-SUM signal is still available to other accelerator systems via the front panel. The IF-SUM and AVG-LOG techniques are defined in general terms as:

$$V_{IF-SUM} = \alpha_1 \log(T + B + R + L) \tag{2}$$

and

$$V_{AVG-LOG} = \alpha_2 \left(\log T + \log B + \log R + \log L\right) \tag{3}$$

where T, B, R, and L represent the input power of the respective lobes. Constants α_1 and α_2 are scaling factors used to normalize the respective responses.

The IF-SUM technique when used with the LANL circular probes yields a very non-linear response as a function of beam position (5). Ideally, the intensity measurement should be independent of beam position. For a centered beam, the IF-SUM technique provides an accurate measure of the beam intensity over a very wide dynamic range. However, as the beam moves off center within the probe, the probe's response distorts the accuracy of the measurement. A better intensity measurement method to use with these probes is the average log (AVG-LOG) technique.

Given the fact that each lobe signal is already digitized on the board, it is simple to sum and average them digitally as shown in Figure 1.

Using Gilpatrick's mathematical model of a LANL 10.25 mm radius probe response (6) and the above mentioned intensity techniques, the responses of the IF-SUM and AVG-LOG techniques are shown in Figure 4. Both curves are normalized to 100 mA beam current.

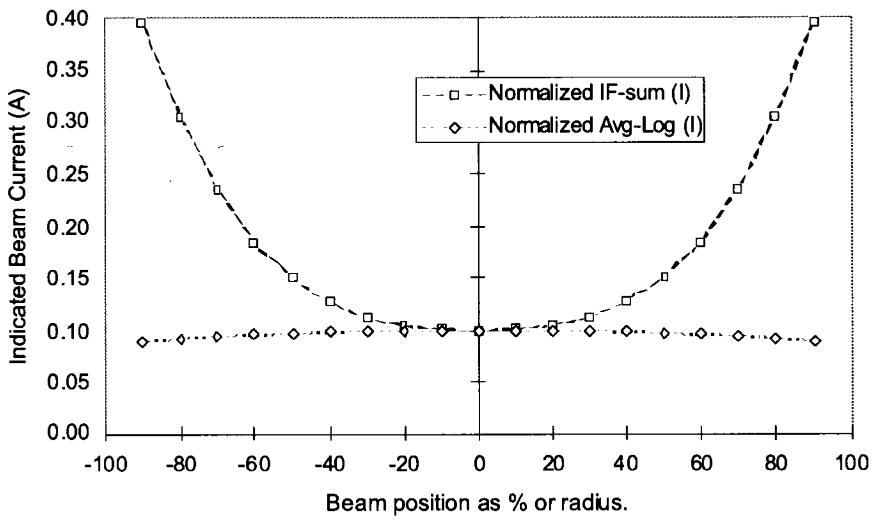

FIGURE 4. Comparison of the indicated current response of two intensity measurement methods: IF-SUM and AVG-LOG.

The AVG-LOG technique provides a response less correlated with position than the if-SUM technique. The *x*-axis in Figure 4 is beam position as a percentage of beam-probe radius out to 90%, and the *y*-axis is indicated beam current.

Even though the AVG-LOG technique still yields a beam-intensity measurement partially correlated to beam position, knowing beam position in *x*- and *y*-space, and indicated intensity, the real beam intensity can be calculated. This calculation is done in the main control system and not in the module.

REFERENCES

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[6] *Ibid.*