A-UR- 93-1881

Title: **MEASURED PERFORMANCE OF THE GTA RF SYSTEMS**

Author(s): P. M. Denney and S. P. Jachim

Submitted to: 1993 Particle Accelerator Conference
Washington, DC
May 16-20, 1993

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Los Alamos
NATIONAL LABORATORY

Measured Performance of the GTA RF Systems*

Peter M. Denney[†] and Stephen P. Jachim
MS-H827, Los Alamos National Laboratory, Los Alamos, NM 87544

Abstract

This paper describes the performance of the RF systems on the Ground Test Accelerator (GTA). The RF system architecture is briefly described. Among the RF performance results presented are RF field flatness and stability, amplitude and phase control resolution, and control system bandwidth and stability. The rejection by the RF systems of beam-induced disturbances, such as transients and noise, are analyzed. The observed responses are also compared to computer-based simulations of the RF systems for validation.

I. INTRODUCTION

In recent months, an experiment was performed on GTA which resulted in the successful commissioning of the 3.2 MeV accelerator [1]. The measured performance of the RF control systems with and without beam disturbances will be presented.

II. RF SYSTEM DESCRIPTION

Much has been written in the literature regarding the design of the RF control system for GTA [2-5]. For ease of understanding the measurements, however, a brief explanation of important concepts is in order.

Figure 1 shows a block diagram of the "bare-bones" RF system operating in closed loop control. Additional modules can be incorporated for improved performance [6-10], however, that is beyond the scope of this paper.

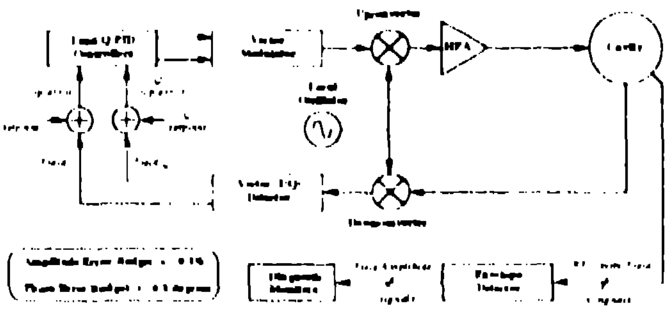

Figure 1. Block Diagram of the RF Control System

The implementation used to achieve the +/- 0.5% and +/- 0.5 degree error specification relies on the control of the in-phase (I) and quadrature phase (Q) components of the cavity field. These orthogonal components, "Field I" and "Field Q", are baseband signals which are regulated independently via the I Controller and Q Controller, respectively. Regulating the "Field I" and "Field Q" vectors implies that the RF cavity field vector is regulated to the same degree. This assumes, however, that the transfer function of the sense loop (cable between the cavity and Downconverter, the Downconverter, and the Vector Detector) remains constant. Since the phase stabilized cable has not been implemented thus far [6], long term phase stability can not be assumed. Thus, all the measurements presented in this paper will address short term stability. The "Field Amplitude" and "Field Phase" stability can be derived using the following simple equations.

$$\text{"Field Amplitude"} = \text{SQRT}\left(\text{"Field I"}^2 + \text{"Field Q"}^2\right) \quad (1)$$

$$\text{"Field Phase"} = \text{ArcTAN}\left(\text{"Field Q"} / \text{"Field I"}\right) \quad (2)$$

As an independent verification of the "Field Amplitude" stability, cavity field signals from various pick up loops were measured by Envelope Detectors producing "Field Amplitude" signals, as well. To avoid confusion, however, "Field Amplitude" measurements will be identified as Envelope Detector or Vector Detector measurements.

III. TEST RESULTS

A. Waveform Digitization Measurements

In order to analyze various control parameters including noise rejection, a waveform digitizer was employed. The digitizer possessed 4 synchronous data channels which allowed beam data and RF data to be measured simultaneously. The sampling rate was 5 MSamples/sec and its resolution was 12 bits (although its effective resolution was only 9 bits due to noise). This provided measurement capability of 2.5 MHz bandwidth and +/- .4% resolution of a full scale signal. Since the "Field I" and "Field Q" measurements needed to be resolved to within +/- .1% for noise analysis, this was clearly a limiting factor. Fortunately, however, the "I Loop Error" and "Q Loop Error" signals were magnified by a factor of 10 before being sent to the digitizer so the "Field I" and "Field Q" signals could be derived to +/- 0.04 % using the following equations.

$$\text{"Field I"} = \text{"I Setpoint"} - \text{"I Loop Error"} \quad (3)$$

$$\text{"Field Q"} = \text{"Q Setpoint"} - \text{"Q Loop Error"} \quad (4)$$

Figure 2 shows synchronously taken data of the RFQ "Beam in", the RFQ "Field Amplitude" and "Field Phase Error". The RF data was derived from the Vector Detector signals. Table 1 summarizes the characteristics of the "Field Amplitude" and "Field Phase" characteristics for both the RFQ and DTL-1 RF systems.

*Work supported and funded by the US Department of Defense, Army Strategic Defense Command, under the auspices of the US Department of Energy.

† Industrial Partner - Grumman Corporation

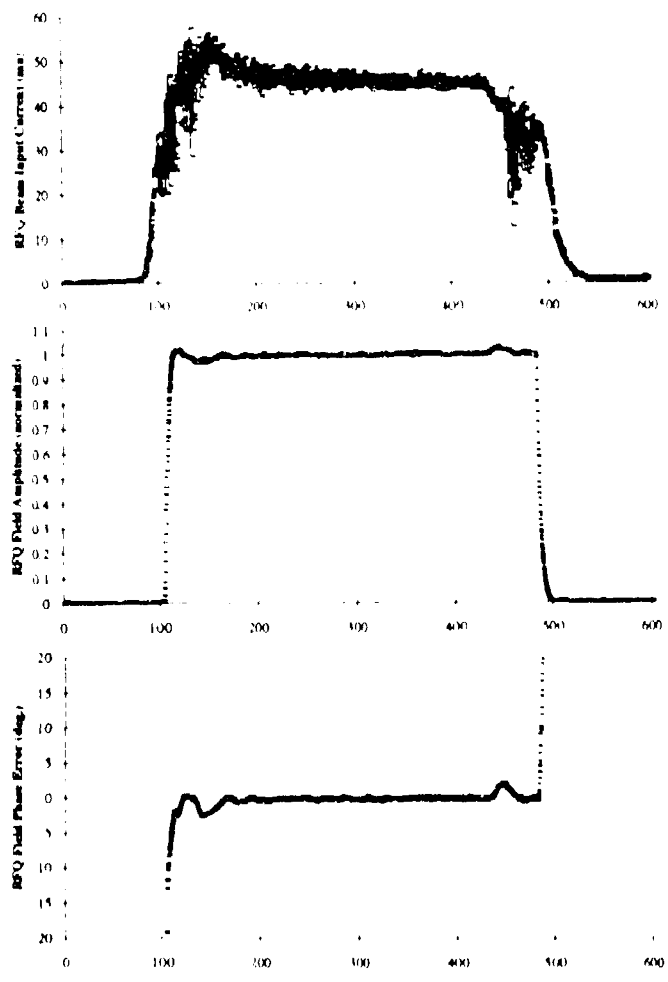

Figure 2. Synchronous Waveforms of the RFQ "Beam IN" (converted to ma), "Field Amplitude" and "Field Phase".

Table 1. Characteristics of RFQ and DTL1 RF systems

Measurement	RFQ	DTL1
Cavity Fill Time (us)	6	5.2
Cavity Fill Overshoot (%)	2	6
Beam Induced Overshoot (%)	4	2
Beam Induced Overshoot (deg)	[illegible]	1

Figure 3 expands the waveforms of figure 2 from 200-400us. Clearly, the amplitude and phase signals contain noise at frequencies of 50 - 100 KHz. The beam signal clearly contains high frequency noise but, by inspection, it is not obvious whether there is any correlation between the beam and RF. Cross spectrum analysis was performed which indicated some correlation at 50 KHz. Figure 4 shows "Field Amplitude" and "Field Phase Error" waveforms without beam. The noise is reduced considerably, however, the same frequency components are present. Open loop tests did not reveal any noise at these frequencies, but the sensitivity was only +/-1%. Table 2 shows measured disturbance rejection of the RFQ and DTL1 closed loop systems. Interestingly, the RFQ control system is most sensitive to noise at 25-100 KHz[4]

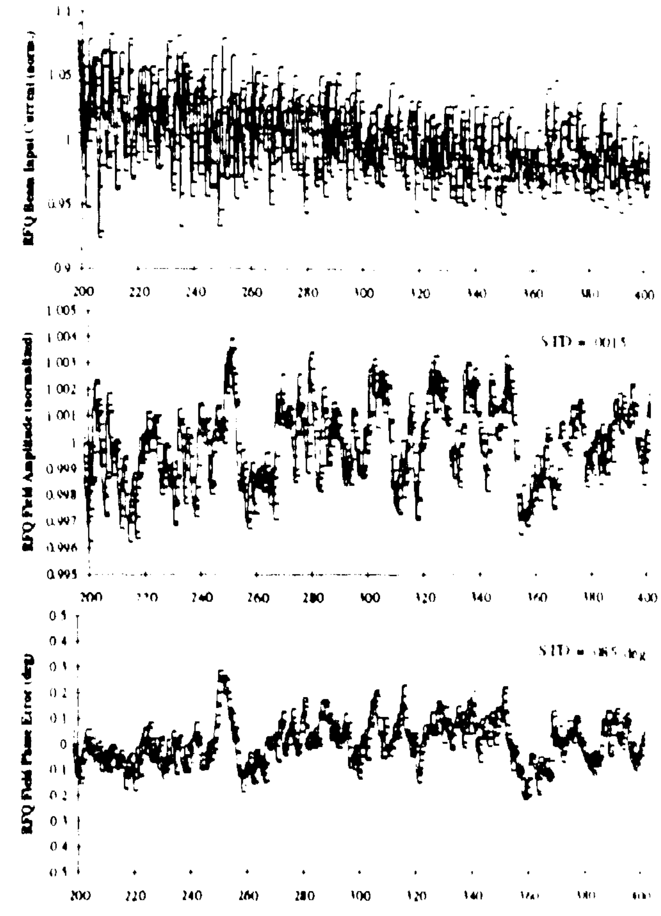

Figure 3. Data from figure 2 expanded from 200-400us

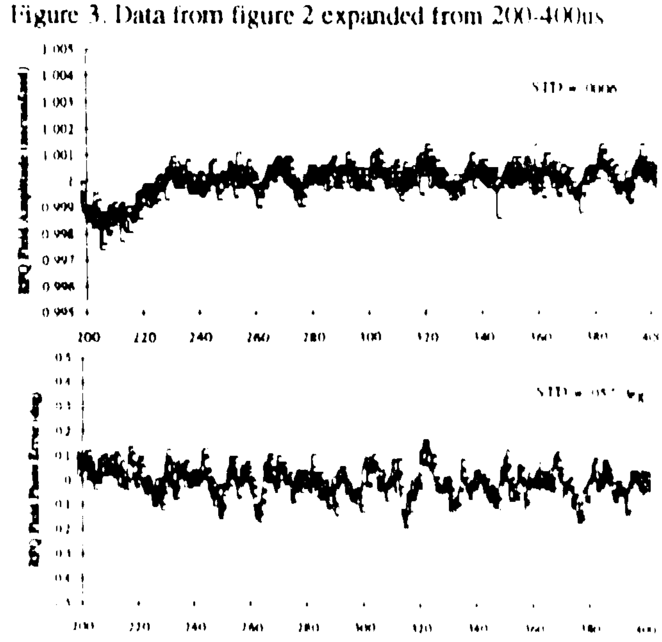

Figure 4. RFQ "Field Amplitude" & "Field Phase" w/o beam

Table 2. Disturbance Rejection of RFQ & DTL1 vs. freq

RF System	10 KHz	[illegible]	[illegible]	75 KHz	100 KHz	[illegible]
RFQ	15.1 dB	[illegible]	2.1 dB	3.4 dB	6.6 dB	[illegible]
DTL1	[illegible]	[illegible]	10.2 dB	[illegible]	[illegible]	[illegible]

B. Single Sample / Pulse Measurements

Equipped with 12-bit A/D converters on the Vector Detector and Envelope Detector Modules, the "Field I", "Field Q", and various "Field Amplitude" signals were synchronously sampled at a single point during the RF pulse. A single snapshot consisted of 15 consecutive pulses. By incrementing the timing along the RF pulse, the field flatness was measured. Figure 5 shows the flatness of the DTL1 "Field Amplitude" without beam as measured from the Envelope Detector. The statistics are summarized in Table 2 for all 4 RF systems. Please note that the amplitude values are normalized and the mean values are relative to the setpoints. Since the Envelope Detector readings were normalized to the mean value, its mean is equal to unity. Also, STD represents standard deviation. Table 3 gives the statistics with beam.

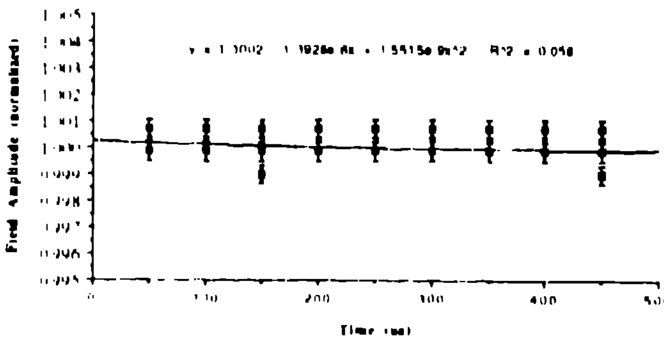

Figure 5. DTL1 Field Amplitude Flatness without beam

Table 1. Statistics of all 4 RF systems without beam

	RFQ	IMSA	IMSB	DTL1
I/Q Detector				
Amplitude Mean	0.9988	0.9993	1.0023	0.9971
Amplitude STD	0.00041	0.00081	0.0012	0.00074
Ampl. min,[max]	[illegible]	0.9972,[1.0028]	1.0014,[1.0063]	0.9964,[0.9979]
Phase Mean (deg)	0	0.04	0.1	0.04
Phase STD (deg)	0.060	0.064	0.161	0.081
Phase min,[max] (deg)	0.24,[0.24]	[illegible],[0.17]	0.74,[0.20]	0.13,[0.13]
Env. Detector				
Amplitude STD	0.00038	0.00048	0.00085	0.00034
Ampl. min,[max]	[illegible]	[illegible]	0.9989,[1.0029]	0.9990,[illegible]

Table 2. Statistics of all 4 RF systems with beam

	RFQ	IMSA	IMSB	DTL1
I/Q Detector				
Amplitude Mean	[illegible]	0.998	[illegible]	[illegible]
Amplitude STD	[illegible]	[illegible]	[illegible]	[illegible]
Ampl. min,[max]	[illegible]	[illegible]	[illegible]	[illegible]
Phase Mean (deg)	[illegible]	[illegible]	[illegible]	[illegible]
Phase STD (deg)	[illegible]	[illegible]	[illegible]	[illegible]
Phase min,[max] (deg)	[illegible]	[illegible]	[illegible]	[illegible]
Env. Detector				
Amplitude STD	[illegible]	[illegible]	[illegible]	[illegible]
Ampl. min,[max]	[illegible]	[illegible]	[illegible]	[illegible]

IV. SUMMARY

To summarize, all RF control systems exceed the performance specification with and without beam present in the cavities. As expected, the amplitude and phase errors are greater with beam present, however, it is unclear as to how much of the added noise is due to beam noise or increased forward RF power. Further testing using more accurate waveform digitizers is necessary, to quantify the correlations. The data presented, however, clearly show that the RF control system behaves as a bandpass filter w.r.t. noise.

Good agreement of the standard deviations was noticed between the RFQ waveform digitization measurements and the single sample / pulse tests. Also, excellent agreement of the standard deviations between Vector Detector and Envelope Detector "Field Amplitude" data exist. This verifies the accuracy of the measurements.

V. ACKNOWLEDGMENTS

The authors would like to thank the following individuals for their assistance and patience along the way: B. Atkins, D. Barr, S. Bowling, R. Cole, C. Geisik, D. Gilpatrick, M. Jenkins, K. Johnson, D. Kerstiens, J. Power, A. Regan, O. Sander, B. Weiss, A. Young, and C. Ziomek.

VI. REFERENCES

[1] K. F. Johnson et al., "Commissioning of the First Drift Tube LINAC Module in the Ground Test Accelerator", *Proc. IEEE Particle Accelerator Conf.*, 1993.

[2] S. P. Jachim, "Some New Methods of RF Control," *Proc. LINAC Conf.*, pp. 573-577, 1990.

[3] S. P. Jachim et. al., "The Los Alamos VXI-Based Modular RF Control System", *Proc. IEEE Particle Accelerator Conf.*, 1993.

[4] S. P. Jachim and E. F. Natter, "Beam Loading and Cavity Compensation for the Ground Test Accelerator", *Proc. IEEE Particle Accelerator Conf.*, pp. 1870-1873, 1989.

[5] A. H. Regan and P. M. Denney, "RF Reference Generation for the Ground Test Accelerator", *Proc. IEEE Particle Accelerator Conf.*, 1991.

[6] S. P. Jachim, et. al., "A Phase Stable Transport System", *Proc. Neutral Particle Beam Tech. Symp.*, 1990.

[7] C. D. Ziomek, S. P. Jachim and E. F. Natter, "Design of a Multivariable RF Control System Using Gain Shaping in the Frequency Domain", *Proc. IEEE Particle Accelerator Conf.*, 1991, pp. 1329-1331.

[8] C. D. Ziomek, "Adaptive Feedforward in the LANL RF Control System", *Proc. LINAC Conf.*, 1992.

[9] J. Eaton, S. Jachim and E. Natter, "An Adaptive Control Technique for Accelerators Using Digital Signal Processing Technology", *Records of the Europhysics Conference on Control Systems for Experimental Physics*, 1987.

[10] C. D. Ziomek et. al., "Results of Adaptive Feedforward on GTA", *Proc. IEEE Particle Accelerator Conf.*, 1993.