WEP023

12th International Conference on Accelerator and Large Experimental Physics Control Systems, Oct 12-16, 2009, Kobe

Correction of Phase and Amplitude Error of RF Modulator and Demodulator

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Abstract

Construction of the XFEL/SPring-8 project is in progress. In this accelerator, very high stabilities are required of the rf amplitude and the phase of the accelerating cavities. In the most severe case, stabilities of the amplitude and the phase of a C-band cavity voltage are required to be better than 0.01% and 0.1 degree in rms, respectively. To make such a stable rf field, we developed a high-speed DAC and an ADC, an IQ (In-phase and Quadrature) modulator and a demodulator to control and detect low level rf signals. High setting and detecting accuracies of the modules are preconditions to achieve good stability. However the developed modules had some errors such as offsets and gain errors due to the requirement of high-speed operation. These errors degrade the performance of the feedback control processes used to stabilities the rf amplitude and the phase. We have thus developed a calibration procedure of the IQ demodulator. By using this procedure we could reduce the amplitude and the phase errors of the IQ modulator at 5712 MHz from 10% to 0.7% and from 6 degree to 0.3 degree in p-p, respectively. Once we obtain a calibrated demodulator, we can calibrate the IQ modulator up to the same accuracy of the demodulator by using a similar procedure.

Introduction

XFEL/SPring-8 : delivery of coherent and intense X-ray to users.

X-ray is generated by SASE process using low-emittance & high-peak current electron beam, 0.7πmm mrad, 3kA , E=8GeV, width Δt~30 fs.

Requirements of rf field stabilities of accelerating cavities
amplitude < 0.01% rms , phase < 0.1 deg rms @ most sever case.

IQ modulator/demodulator, high-speed DAC/ADC were developed.

If there were errors such as
- non-linearity in amplitude and phase
- cross correlation between amplitude and phase,

they degraded performance of feedback control loops.

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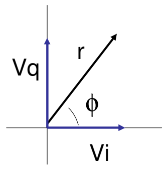
To reduce errors, it is necessary to calibrate those modules.

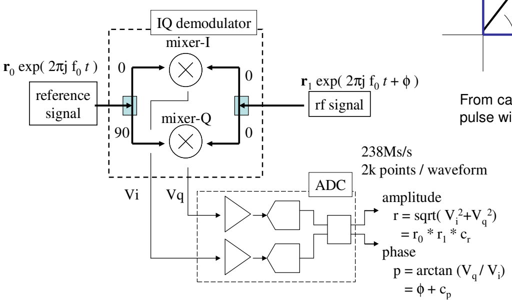
RF Demodulator

Configuration of the demodulator

$(r, \phi) \rightarrow (V_i, V_q)$



From cavity, pulse width ~ 2.5us



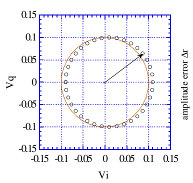
Errors in amplitude and phase

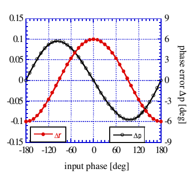
amplitude error $\Delta r = r / (r_1 * r_0 * c_r) - 1$,

phase error $\Delta p = p - \phi - c_p$,

Error sources
- offsets of amplifiers,
- gain errors of amplifiers, mixers,
- phase error between I and Q axis from 90deg

Numerical example; r=100mV, offset=10mV in Vi

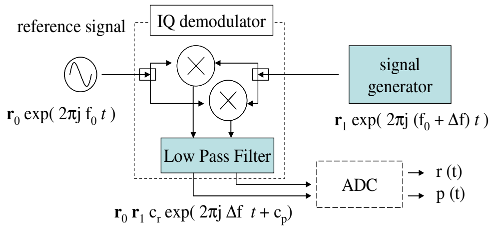




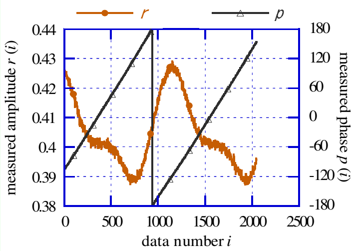
amplitude error ±10%, phase error ±6deg

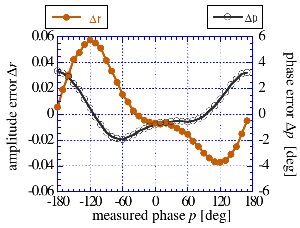
Detection of errors

measurement of $\Delta r(\phi)$, $\Delta p(\theta)$ at a fixed r_1
by feeding a frequency shifted signal from SG



Phase of rf signal $\phi = 2\pi\ \Delta f\ t$





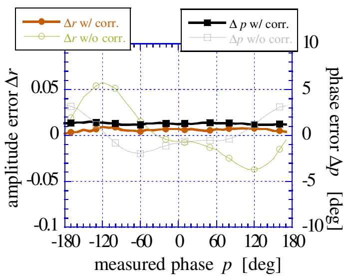
amplitude *r* and phase *p* measured by using ADC
2kpoints/waveform 238Ms/s

calculated errors of amplitude Δr and phase Δp

Correction of errors

Δr and Δp have periodic change in *p*
→ Approximation with Fourier series

Result of Discrete Fourier Transform shows coefficients of 1st (offset) and 2nd (Gain error and/or tilt of IQ axis) are dominant.



	w/o corr.		w/ corr. using DFT coeff.
amplitude error	±6%	→	±0.5%
phase error	±3deg	→	±0.15deg

Once the calibration of IQ demodulator is done, calibration of IQ modulator can be done with similar procedure.

Summary

We developed a calibration procedure for an IQ demodulator. The systematic error of the IQ demodulator was measured by feeding a frequency-shifted signal, which was equivalent to a scan of the input rf phase. From the values of the amplitude and the phase sampled by an ADC with a fixed time interval, the systematic errors of the amplitude and the phase were calculated. The errors were expressed with a small number of DFT coefficients. By using these coefficients, the systematic errors of the amplitude and phase were reduced from 10% to 0.7% and from 6 degree to 0.3 degree in p-p, respectively. The phase error could be reduced to be smaller than the target value. The amplitude error was somewhat larger than the target value. By using the calibrated reference IQ demodulator, an IQ modulator can be calibrated with a similar procedure. Further reductions of the errors, a performance test combining the calibrated modules, such as the modulator/demodulator and the DAC/ADC, are our next step.