DESIGN AND EVALUATION OF A BROAD BAND microTCA.4 BASED DOWNCONVERTER

N. Gan[1,2], R. Liu[1], X. P. Ma[1], Y. L. Chi[1]
[1]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China.
[2]University of Chinese Academy of Sciences, Beijing, China.

Abstract

Modern low-level RF (LLRF) control systems of particle accelerators are designed to achieve extremely precise field amplitude and phase regulation inside the accelerating cavities, the RF field signal is usually converted to an intermediate frequency (IF) before being sampled by ADC. As the down-conversion is an important procedure of the digital signal processing in LLRF system, designing a high performance and broad band downconverter compatible with various accelerators will be significant. In this paper, the design of a MicroTCA based downconverter is presented, the major design objective of this module is wider operating frequency range and more flexibility in application. Several performance evaluations on different frequency points of this module have been conducted and the module presents a good performance in the operating frequency range.

INTRODUCTION

Modern accelerator facilities require precisely controlled radio frequency (RF) fields for beam acceleration. The field parameter control is performed by a low-level radio frequency (LLRF) control system, which should ensure the regulation accuracy is typically better than 1% for the amplitude stability and 1° for the phase stability. The new generation accelerators need much higher RF field accuracy and stability in cavity. Accelerators such as the Europe X-ray Free Electron Laser (XFEL) and 3 GeV Energy Recovery Linac (ERL) require an accuracy up to 0.01% and 0.01°[1]. These high performance requirements bring great challenges to the LLRF system.

The RF front-end is an important part in LLRF system. The primary function of the front-end is to down convert the signal from the cavity to the intermediate frequency, and the performance of it will directly influence the accuracy of the LLRF system. To meet the growing requirements of regulation accuracy in accelerators, we have designed a multi-channel broadband downconverter module based on MicroTCA.4 standards. The MicroTCA is a new standard which offers better stability, modularity and maintainability compared to traditional hardware standard. This standard has been widely adopted in many recent accelerators, include the ADS Injector I project [2].

DESIGN OF THE DOWNCONVERTER

Board Overview

The down-converter is packed as an RTM board, which will down convert the high frequency RF signal into an intermediate frequency. The downconverter has 9 RF input channels and 1 LO channel, and the input RF frequency range of the module is from 300 MHz to 5GHz. The simplified downconverter scheme is shown in Fig.1

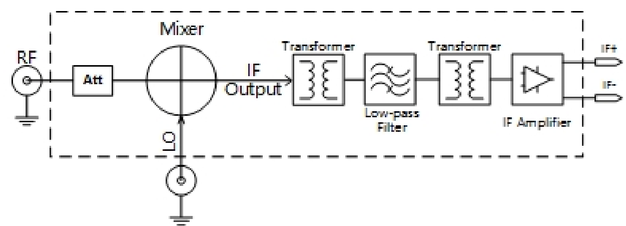

Figure 1: Brief schematic of down-converting unit.

The first stage of the down-converting unit is an attenuator to set the proper operating level depending on the input RF level. The second stage is a mixer (LTC5577), which converts the RF signal to the IF. The mixer incorporates a high linearity double-balanced active mixer optimized for wide bandwidth applications, and the internal buffer allows LO operates in the range of 0 dBm. The IF signal is low-pass filtered to suppresses unwanted mixing products. In the last stage the filtered IF signal is amplified by an ADC driver to operate the ADC at full scale. The differential IF signals are transmitted through the Zone-3 connector to the digitizer. Several baluns are placed between stages to implement impedance match and unipolar signal to differential signal conversion. The input LO signal is split into 9 branches to down-converting units using surface mount Wilkinson power splitter chip. The total LO power consumption of the module is 12 dBm.

The downconverter has RTM management unit, trigger distribution unit and I2C bus on the board besides the down-conversion unit. The RTM management unit is compliant to PICMG MicroTCA.4 specifications, responsible for the implementation of RTM hot-swap and monitoring of sensor data.

PERFORMANCE EVALUATION

To estimate the performance of the downconverter, the harmonic suppression, channel-to-channel isolation, output linearity and the 3rd order input intercept point

Copyright © 2016 CC-BY-3.0 and by the respective authors

ISBN 978-3-95450-147-2

(IIP3sys), phase and amplitude stability of the downconverter were measured at different RF frequency points [3]. The input impedances of the RF and LO port are optimized at specific frequency point before the module been tested. After the optimization, the S11 parameters of the RF and LO ports are in the rage of -15 dB to -20 dB.

Linearity Measurement

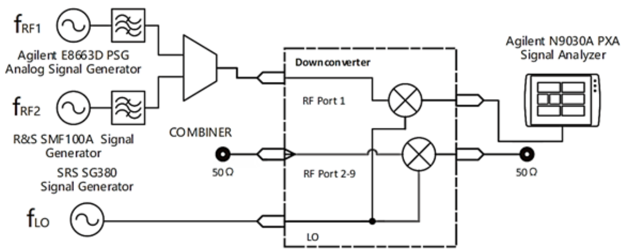

Figure 2: Setup for linearity measurement.

The Fig.2 shows the setup for linearity evaluation, the linearity operating range and the IIP3 of the system has been measured. The RF input of the downconverter is the combination of two RF signals which have 1 MHz frequency shift between them. From the magnitudes of IF and third-order intermodulation product corresponding to each input level, the IIP3 and IF output linearity can be evaluated. During the test, the downconverter could maintain good linearity in a range of more than 30 dBm, and the IIP3 of the module at 325 MHz input frequency was 25.6 dBm.

Noise Measurement

The Fig.3 shows the IF noise measurement setup, a frequency synthesizer is used to generate LO signal and clock signal, the frequency of the reference signal is 325MHz.

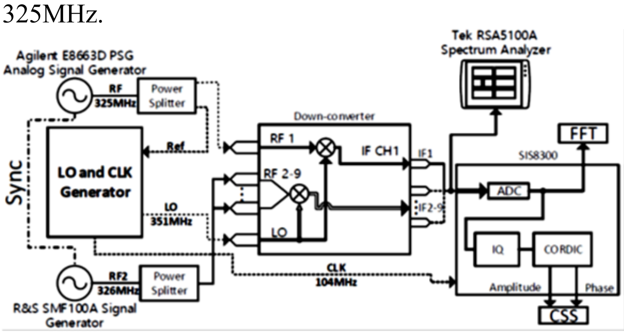

Figure 3: IF noise measurement setup.

In order to analysis the spectrum of IF signal, the downconverter was installed in the MicroTCA.4 chassis and operated with the SIS8300 digitizing board [4]. Then the SIS8300 card digitized the IF signal under a sampling frequency of 125 MSPS and processes the signal using fast Fourier transform. As shown in Fig.4, the main noise component presents as second-harmonic with a level below -65 dBc.

During the test, the phase noise of the IF signal was also measured. As shown in Fig.3, the IF signal was analyzed by a spectrum analyzer. The measurement result is presented in Fig.5, the close-in phase noise of the IF signal is below -97 dBc/Hz.

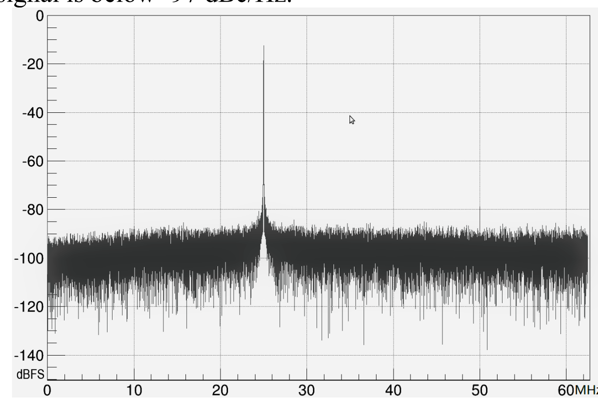

Figure 4: 65536 samples IF Signal FFT Spectrum. The IF frequency is 25 MHz.

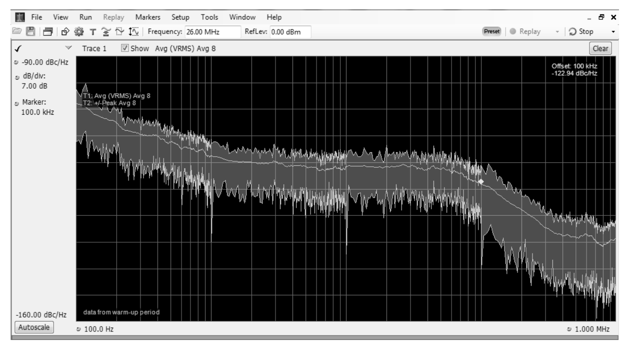

Figure 5: Phase noise measurements over the bandwidth [100 Hz - 1 MHz].

Isolation Measurement

As isolating input and output channels is essential for the downconverter since the unwanted signal leaking through the device will mix with the desired output signal, converted into intermodulation products which may be difficult to filter out. During the test, the cross-talks between RF, LO, IF ports were measured under an RF frequency of 325 MHz, the level of RF signal was 0 dBm, and the level of LO signal was 6 dBm. The measurement result is shown in Tab.1.

Table 1: Cross-talk Between RF and LO Ports (in dB)

IN / OUT	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	RF9	LO
RF1	×	-77	-78	-79	-79	-82	-81	-83	-83	-86
RF2	-79	×	-81	-79	-82	-82	-83	-85	-84	-82
RF3	-79	-81	×	-75	-78	-80	-84	-84	-86	-80
RF4	-83	-82	-80	×	-78	-78	-82	-82	-84	-79
RF5	-82	-79	-80	-77	×	-76	-79	-80	-81	-81
RF6	-81	-81	-80	-78	-80	×	-80	-79	-82	-80
RF7	-82	-81	-82	-81	-79	-78	×	-78	-80	-78
RF8	-81	-83	-84	-81	-82	-80	-79	×	-80	-75
RF9	-82	-83	-81	-82	-80	-80	-81	-77	×	-76

As shown in the table, the isolations between RF ports and LO port are around 80dB. For further tests, the RF signal was connected to one channel, other channels were

ISBN 978-3-95450-147-2

Copyright © 2016 CC-BY-3.0 and by the respective authors

disconnected. Then the SIS8300 will sample IF crosstalk signal from the disconnected channel, as shown in Fig. 6. The level of crosstalk signal is -87 dBFS, corresponding to a -12 dBFS IF level as shown in Fig.4, which indicate the isolation between IF channels is about 75 dB. The crosstalk measurement results show that the RTM downconverter can achieve a comparable isolation to a traditional RF front-end in a smaller dimension [5].

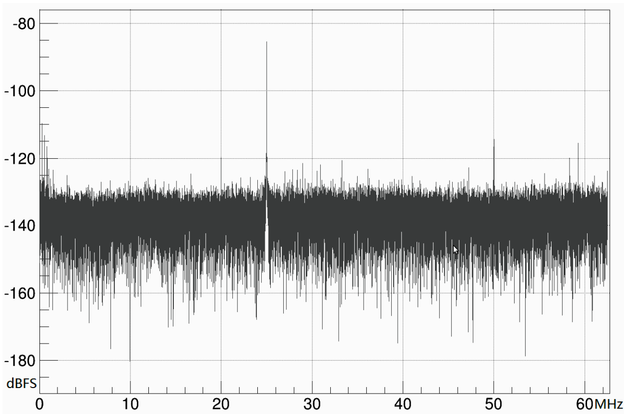

Figure 6: 65536 samples IF crosstalk signal FFT Spectrum.

Amplitude and Phase Stability Test

As the amplitude and phase stability of the down-conversion process directly affects the accuracy of the LLRF system, we conducted a stability evaluation of the downconverter. A block diagram of the measurement setup is shown in Fig. 3. The IF signal from receiver was sampled and processed by a SIS8300 digitizer. The digital IQ sampling method was used to convert IF signal to IQ sequence data, and the CORDIC algorithm was used to calculate the amplitude and phase. The amplitude and phase data were transferred to control system studio (CSS) software via EPICS, and the stability of the downconverter can be characterized from the curve generated in CSS as shown in Fig.7. During the test the system short term amplitude stability was better than ±0.06%, and phase stability was better than ±0.05°.

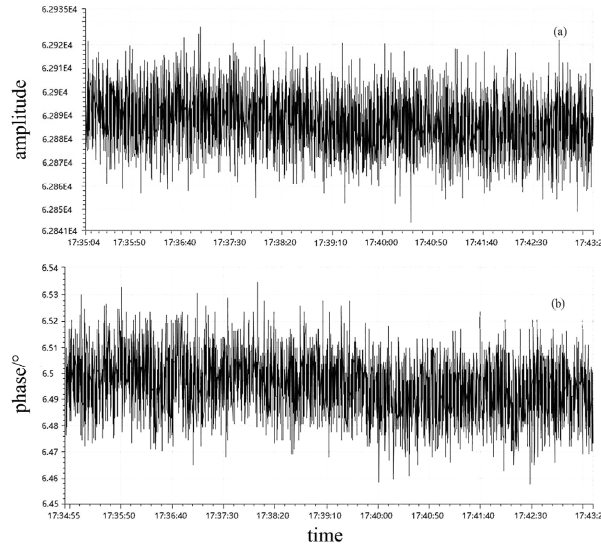

Figure 7: Short term amplitude and phase stability of the system.

SUMMARY

This paper presents the design and test of a MicroTCA.4 compliant LLRF front-end module. Compared with traditional RF front-end and other downconverters based on MicroTCA, this module is designed to operate in a broader operating frequency range (300 MHz and 5 GHz), which makes it cover various operating frequency in general accelerator applications. Detailed performance evaluations of the downconverter have been conducted, showing that the downconverter has a good performance in the operating frequency range. The design and test indicate that this module can be applied in a more flexible and accurate LLRF system.

REFERENCES

[1] S. Simrock, V. Ayvazyan, A. Brandt et al, Conceptual LLRF Design for the European XFEL, in Proceedings of the 23rd International Linac Conference, (USA:JACoW, 2006), p. 559.
[2] R. Liu, et. al, "Design and Commissioning of LLRF System for ADS Project in China", presented at the 7th Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, May 2016, paper WEPOR036, this conference.
[3] M. Hoffmann, F. Ludwig, H. Schlarb et al, Multichannel Downconverter for the Next Generation RF Field Control for VUVand X-ray Free Electron Lasers, in Proceedings of the 22nd Particle Accelerator Conference, (USA: JACow, 2007), p. 2071.
[4] Struck. http://www.struck.de/
[5] U. Mavric, J. Branlard, B. Chase et al, A 96 channel receiver for the ILCTA LLRF system at fermilab, in Proceedings of the 22nd Particle Accelerator Conference, (USA: JACow, 2007), p. 22.

Copyright © 2016 CC-BY-3.0 and by the respective authors