Statement of Work | APS Upgrade

Solid-State Upgrade
LLRF Analog Front Ends

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Table of Contents

1 Introduction....3
2 Scope of Work....4
3 AFE Requirements....5
4 Acceptance Testing....6
4.1.1 Down-Converter Phase Noise Test....6
4.1.2 Down-Converter Amplitude Noise Test....7
4.2.1 Up-Converter Phase Noise Test....8
4.2.2 Up-Converter Amplitude Noise Test....9
5 Deliverables....10
6 Schedule....11
7 Special Instructions....12
8 References....12

1 Introduction

The APS is planning to replace its Storage Ring RF system amplifiers from klystrons to solid-state amplifiers. As part of that APS Solid-State Upgrade project, the existing analog LLRF systems will be replaced with digital LLRF. This will require the use of analog front ends (AFE) to convert to/from the RF frequency from/to the intermediate frequency (IF) that is digitized by the digital LLRF system.

Fermilab has existing AFE products that can be used for this project. These products include both an up-converter chassis [1] and a down-converter chassis [2]. The up-converter chassis is used to up-convert an IF signal coming from a Digital-to-Analog Converter (DAC) to the RF signal which drives an RF system. The down-converter chassis performs the opposite operation, it down-converts the RF signal to an IF signal. The IF signal output from the up-converter AFE can then be sampled with an Analog-to-Digital Converter (ADC) in the digital LLRF receiver.

Fermilab has already developed, produced, and used both of these designs for their Proton Improvement Plan II (PIP-II) project. Both designs support an IF of ~20MHz which is compatible with the Solid-State Upgrade LLRF frequency plan.

Through this statement of work, the APS will contract the purchase of the PIP-II style AFEs to Fermilab for their use in the Solid-State Upgrade LLRF systems.

Fermilab will be responsible for fabrication, testing, and delivery of the AFEs according to this statement of work.

The APS will be responsible for contract management, receipt, and final acceptance testing of the AFEs according to this statement of work.

2 Scope of Work

- **Production Quantities**

Fermilab will produce the following units:

Table 2.1: Converter types and quantity

Type	Qty
352MHz Up-converter (see Sect. 3.1)	2
352MHz Down-converter (see Sect. 3.2)	2

- **Parts Ordering**

Fermilab shall be responsible for ordering and acquiring all parts to fabricate the units, except as noted in the below paragraph. Fermilab shall identify any replacement components that are required to tune the PIP-II designs to accommodate the frequencies requirements given in Sections 3 through 5. Fermilab is also responsible for coordinating acquisition and assembly of the printed circuit boards.

Upon Fermilab and the APS together identifying the output K&L Microwave bandpass filters required for use in the up-converters, APS shall be responsible for ordering and acquiring the K&L Microwave bandpass filters for the up-converters. These are the only parts which the APS will be responsible for acquiring.

- **Fabrication and Testing**

Fermilab shall be responsible for fabricating and testing all units. Measurement reports from both the board check and the chassis check of each unit shall be supplied.

3 AFE Requirements

3.1 352 MHz Up-Converter

The up-converter fabricated for Booster shall have the specifications listed in Table 3.1.1.

Table 3.1.1: Booster Up-Converter Specifications

Parameter	Value
IF signal input frequency (nom.)	19.6 MHz
RF output frequency (nom.)	351.93 MHz
LO input frequency (nom.)	332.38 MHz
LO input signal level (nom.)	0 dBm
Number of RF outputs	4
Full Scale IF I/Q input signal level (nom.)	-2 dBm each
Full scale RF Output signal level (min.)	+ 10 dBm (+/- 1dB)
Output Linearity	+/- 1%
Channel-to-Channel Crosstalk	< -80dB
Residual Phase Noise (1Hz-100kHz BW)	< 2 mdeg rms
Residual Amp. Noise (1Hz-100kHz BW)	< 0.02% rms

3.2 352 MHz Down-Converter

The down-converter fabricated for the Booster shall have the specifications listed in Table 3.2.1.

Table 3.2.1: Booster Down-Converter Specifications

Parameter	Value
RF signal input frequency (nom.)	351.93 MHz
IF output frequency (nom.)	19.55 MHz
LO input frequency (nom.)	332.38 MHz
LO input signal level (nom.)	+5dBm
Number of RF inputs and IF outputs	8
Full scale RF Input signal level	+ 10 dBm
Full scale IF Output signal level	+ 5 dBm (+/- 1dB)
Output Linearity	+/- 1%
Channel-to-Channel Crosstalk	< -80dB
Residual Phase Noise (1Hz-100kHz BW)	< 2 mdeg rms
Residual Amp. Noise (1Hz-100kHz BW)	< 0.02% rms

4 Acceptance Testing

Test reports for all units shall show evidence that all channels meet the requirements in Sect. 3 except for the phase and amplitude noise which will be measured at Argonne per Sect. 4.1 and 4.2 below.

4.1 Down-Converter Testing

4.1.1 Down-Converter Phase Noise Test

The general setup of Fig. 1 will be used at Argonne to measure the residual phase noise of the down-converters. Since the down-converter is a frequency translation device, the residual phase noise is measured between two channels of the down-converter. The LO and RF signals will originate from a common frequency source. A phase shifter is used on one of the RF input signals to adjust for quadrature conditions at the mixer used to compare the IF outputs from the down-converter. The output of the mixer is fed through a low-pass filter (LPF) which is then amplified using a Wenzel BPAA-1000 audio amplifier. The output of the audio amplifier is then fed to a Stanford Research Systems SR785 which estimates the power spectral density through fast fourier transform (FFT) analysis.

All channels will be measured. The integrated phase noise of each channels over a 1Hz to 100kHz bandwidth shall be less than 2mdeg rms for the 352MHz units and less than 10mdeg rms for the 1408MHz units.

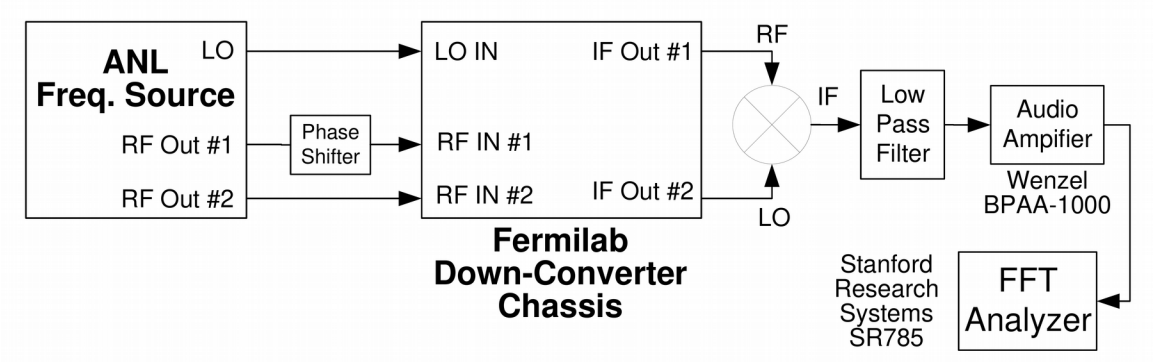

Figure 1: Down-converter residual phase noise measurement test setup

4.1.2 Down-Converter Amplitude Noise Test

The general setup of Fig. 2 will be used at Argonne to measure the amplitude noise of the down-converters. The LO, RF, and clock (CLK) signals will originate from a common frequency source. The down-converter will convert the RF signal to the IF signal which will then be measured with a digital LLRF receiver based upon the Vadatech DAQ523 MicroTCA module. The integrated amplitude noise of this setup for each channel over a 1Hz to 100kHz bandwidth shall be less than 0.02% rms for the 352MHz units and less than 0.05% rms for the 1408MHz units.

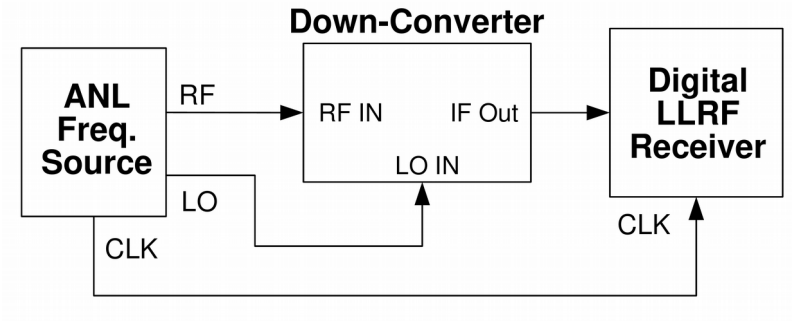

Figure 2: Down-converter amplitude noise measurement test setup

4.2 Up-Converter Testing

4.2.1 Up-Converter Phase Noise Test

The general setup of Fig. 3 will be used at Argonne to measure the residual phase noise of the up-converters. Since the up-converter is a frequency translation device, the residual phase noise is measured between two channels of the up-converter. The LO and IF signals will originate from a common frequency source. A phase shifter is used on one of the IF output signals from the up-converter chassis to adjust for quadrature conditions at the mixer used to compare the phase of the IF outputs. The output of the mixer is fed through a low-pass filter (LPF) which is then amplified using a Wenzel BPAA-1000 audio amplifier. The output of the audio amplifier is then fed to a Stanford Research Systems SR785 which estimates the power spectral density through fast fourier transform (FFT) analysis.

All channels will be measured. The integrated phase noise over a 1Hz to 100kHz bandwidth shall be less than 2mdeg rms.

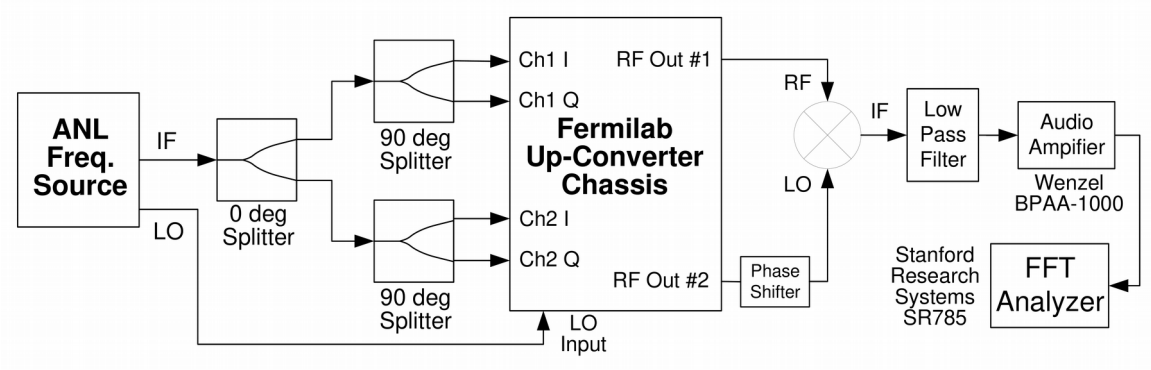

Figure 3: Block diagram of up-converter residual phase noise measurement test setup

4.2.2 Up-Converter Amplitude Noise Test

The general setup of Fig. 4 will be used at Argonne to measure the amplitude noise of the down-converters. The LO, IF, and clock (CLK) signals will originate from a common frequency source. The up-converter will convert the IF source signal an RF signal which will then be down-converted back to an IF signal which will then be measured with a digital LLRF receiver based upon the Vadatech DAQ523 MicroTCA module. The integrated amplitude noise of this setup for each channel over a 1Hz to 100kHz bandwidth shall be less than 0.03% rms for the 352MHz units and less than 0.07% rms for the 1408MHz units. For the 352MHz units the 0.03% rms is greater than the 0.02% rms of Table 3.1.1 and Table 3.3.1 since a down-converter is used in the test setup. Hence we allow the noise of the combination to be less than the rms sum of the two devices. Similar logic gives the value for the 1408MHz units.

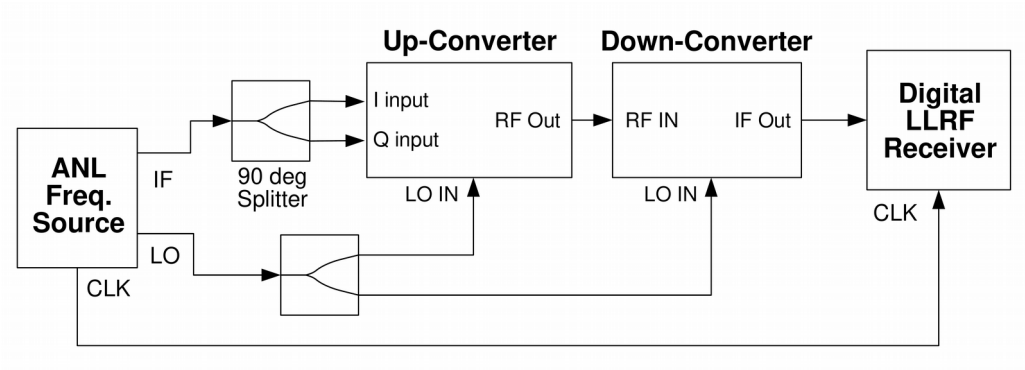

Figure 4: Up-converter amplitude noise measurement test setup

5 Deliverables

1. A total of 2 up-converters:

2. A total of 2 down-converters

3. Test reports for each unit according to the below:

    - For the up-converters the reports shall include
        i. RF out vs. IF input for all channels
        ii. Output linearity
        iii. monitor levels for all channels
        iv. channel-to-channel isolation between all channels
        v. current draw at +6V.

    - For the down-converters the reports shall include
        i. IF out vs. RF input for all channels
        ii. Output linearity
        iii. monitor levels for all channels
        iv. channel-to-channel isolation between all channels
        v. current draw at +6V.

4. Schematics

5. PCB files

6. Parts Lists

7. Chassis Drawings

6 Schedule

Table 6: Schedule

Item	Description	Quantity	Earned Value	Due Date
Order all Parts	*Place orders for all parts except for the K&L filters which APS is responsible for*	*N/A*	*10%*	*4 weeks ARO*
Fabrication: Down-Converters	*Fabricate and test 352MHz Down-converters*	*N/A*	*N/A*	*25 weeks ARO*
Ship: Down-converters	*Ship 352MHz Down-converters*	*2 Down-Converters*	*45%*	*26 weeks ARO*
Fabrication: Up-converters	*Fabricate and test 352MHz Up-converters*	*N/A*	*N/A*	*27 weeks ARO*
Ship: Up-converter	*Ship 352MHz Up-converters*	*2 Up-Converters*	*45%*	*28 weeks ARO*

7 Special Instructions

Until parts are ordered, Argonne reserves the right to call regular weekly meetings via teleconference for technical discussions and to track progress including requesting effort hours spent on the tasks listed in Sect. 6.

Fermilab will give a bi-weekly update via email, including work status and effort hours spent on the tasks listed in Sect. 6. Once a month, Fermilab will provide a total of M&S and efforts spent on the tasks listed in Sect. 6. To accommodate timing of month end accounting, these monthly totals may require a 1 to 2-week forecast.

If any re-work is required to pass Fermilab internal tests, Fermilab shall discuss with Argonne before proceeding. If the units do not pass APS-U acceptance tests and are found to be unacceptable, Fermilab shall remedy the situation under APS-U direction.

8 References

[1] Fermilab PIP-II 325 MHz 4-Channel Up-Converter Rev D Datasheet
[2] Fermilab PIP-II 325 MHz 8-Channel Down-Converter Rev D Datasheet