HSCR: High Speed CubeSat Radio

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Abstract
Software Defined Radios (SDRs) are limited by their usable bandwidth, which restricts how quickly they can transmit or receive data. The High Speed Cubesat Radio (HSCR) is capable of transmitting and receiving higher bandwidth signals by combining the bandwidths of several individual SDR transceivers. The HSCR performs phase correction to seamlessly stitch the bandwidths of each individual SDR into a single larger bandwidth.

Introduction
The general approach to this project is shown by the figures below:
1) Gather and shape data from two separate receivers tuned to offset frequencies. Use a custom Nyquist filter to perform the shaping.
2) Shift the signals in frequency in preparation for signal addition
3) Add signals together. Due to offsets in phase between the two signals, the signals may not combine as expected (left figure). To get a valid combination, the phase offset must be corrected (right figure).
4) When phase is not corrected, combining the two signals produces a distorted eye diagram (left figure). When phase is corrected, the eye diagram shows no distortion (right figure).

Method
Using an Analog Devices FMCOMMS5-EBZ transceiver board in conjunction with a Xilinx Zynq-7000 ZC706 FPGA development board, the HSCR combines signals using the algorithm shown in the flowchart to the left. To combine the signals, we first shape the bandwidths of each signal using a carefully designed raised cosine Nyquist filter.
Shaping the signals avoids any magnitude distortion in the combined signal. A phase error control loop removes phase distortions at the overlapping portion of the signals. This loop consists of a complex exponential multiplication, a phase error detector, a loop filter, and a DDS that controls the complex exponential.
The complex exponential shifts each received signal to its proper overlapping position. The signals then enter the phase error detector, which generates a phase error signal that feeds into a proportional plus integral loop filter. The loop filter produces a filtered error signal that controls the DDS. The DDS then makes slight changes in the complex exponential frequency that shift the two received signals. These slight changes remove phase distortion in the combined signal.

Results
The figures above show the signal combination process using actual data gathered from the HSCR at the conclusion of the project. The description of each step is provided below:
1) A test signal was transmitted by the Ettus B205mini-I. The HSCR used two receivers on the FMCOMMS5 board, each capturing one half of the signal.
2) The two received signals were shaped using a raised cosine Nyquist filter.
3) The two shaped signals were shifted to their proper overlapping positions by the phase correction loop, then added together.
4) After performing the phase correction process, the original signal was reconstructed with no distortion in the spectrum. Without using phase correction, magnitude and phase distortion were introduced into the spectrum of the combined signal.
5) The HSCR's combined signal has a slightly higher signal-to-noise ratio (and therefore a lower bit error rate) than a signal received with a traditional high-bandwidth radio. This is because the uncorrelated noise from the two receivers does not coherently combine in the overlapping region.

Discussion
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Conclusions
By correcting for phase and frequency offsets using a phase error control loop, we successfully combined the bandwidths of two separate receivers. The figures shown above were collected from the HSCR after implementing the signal combining algorithm on the FPGA. Any implementation loss is overcome by the reduced signal-to-noise ratio, resulting in better performance than a traditional radio.
This was a proof of concept project aimed at CubeSat communications systems. Ultimately, we hope to use the algorithms developed to create an "all in one" package that is easily reproducible and integratable with CubeSats.
The results of this project are scalable. As a proof of concept, we used only two receivers; however, the algorithm developed here can be implemented on several receivers, and could be easily modified to work for transmitters. This would result in a usable bandwidth that is limited more by processing capability than transceiver capability.

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