A MULTI-CHANNEL DIRECT CONVERSION DIGITAL UPLINK RECEIVER

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Abstract

The design details of a direct block-down-converting receiver which provides simultaneous demodulation of up to seven uplink channels is presented. The overall architecture is that of a block down converting receiver utilizing a fixed-tuned RF front end and a single conversion. The bandwidth of interest is complex down-converted to baseband into I and Q channels, and sampled by a high speed analog-to-digital converter. The digitized I and Q data is then input to a Fast Fourier Transform (FFT) processor to perform coarse channelization. Finally, filtering, channelization, and demodulation is performed within a digital signal processor (DSP) dedicated to each channel. The design approaches that of an all-digital radio implemented with off-the-shelf components selected for their suitability for use in the space environment.

Introduction

The design details for a direct block-down-converting receiver used on the ORBCOMM™ Constellation spacecraft is presented. Each ORBCOMM™ receiver allows for simultaneous demodulation of up to seven uplink carriers. Each of the seven uplink carriers is Symmetric Differential Phase Shift Keyed (SDPSK) at 2.4 kbps in the specific application, however, the hardware can support multiple modulation formats with simple software changes.

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The design approaches that of an all-digital radio, where traditionally analog functions are replaced by software, providing an easily reconfigurable platform for different modulation, data formats, and receive frequencies. The reduction of analog componentry enhances the reproducibility of the receiver. Only wideband filtering is performed in the analog domain, and the more demanding channelization filtering is performed in the digital domain where high performance linear phase filters are easily synthesized. A more digital approach to the receiver design also minimizes the effects of parametric variations due to component tolerances, environmental conditions, and aging. Additionally, a modular design was pursued in order to enhance testability, manufacturability, and expandability.

Commercial off-the-shelf (COTS) components selected for their suitability for use in the space environment are used in the design where required, with additional circuitry and software employed to mitigate the effects of single event upsets in those devices that have been deemed to be susceptible. The selective use of COTS componentry allows the latest high performance signal processing devices to be utilized in the design thus producing a digital receiver that rivals the electrical performance of a high-quality analog receiver, but with a fraction of the mass and volume.

Design Considerations

The ORBCOMM™ satellite constellation provides a commercial bidirectional data service for remote and mobile users. The ORBCOMM™ constellation makes use of a secondary frequency allocation for subscriber uplink services in the 148-150.05 MHz band on a non-interference basis with existing terrestrial users of the band under Footnote US323 of the Radio Regulations. The ORBCOMM™ uplinks must operate in the presence of dramatic interference due to the terrestrial users of the band. Therefore, the receivers must maintain exceptional linearity and selectivity to make optimum use of the available unused spectrum at any instant. A novel receiver band-scanning approach is used to identify unused channels which are then assigned to terrestrial users for uplink under the Dynamic Channel Activity Assignment System (DCAAS). In addition to the electrical performance considerations, the radiation environment was also considered to minimize single event effects.

Hardware Description

The block diagram for the analog portion of the receiver is shown in Figure 1. The antenna is followed by a diplexer filter, a low noise amplifier (LNA), an image noise reject filter, attenuators, and an RF amplifier (RFA). The variable attenuator allows for a shift in dynamic range from optimum noise figure to optimum interference rejection. The ORBCOMM™ subscriber uplink receiver covers the frequency band of 148-150.05 MHz, but other 2 MHz wide frequency bands could be received with simple modifications. The RF signal is then downconverted to in-phase (I) and quadrature-phase (Q) baseband components with a low phase noise 149 MHz local oscillator. The oscillator has a phase noise specification of -110 dBc/Hz at 5 kHz to prevent interference due to large adjacent channel interferers. The I and Q baseband signals are then analog filtered, amplified, and digitized. The receiver gain, noise figure, and intercept point distribution is shown in Figure 2.

As a practical matter, the image rejection of the complex downconverter is limited to about 45 dB which is less than the 80 dB required to prevent interference from the largest terrestrial emitters in the band. The image rejection of the downconverter is limited by amplitude and phase errors introduced by the LO, the mixer, and the baseband filters. A software I/Q balance algorithm dynamically corrects for the downconversion errors and restores the image rejection to the required 80 dB.

Once the +/- 1 MHz of complex baseband data is digitized, the channelization and demodulation of the 2.4 kbps data signals is performed completely with digital signal processing firmware and software. A block diagram of the digital section of the receiver is shown in Figure 3. A FFT processor computes 256 point complex FFTs, the results of which are transferred to the seven ADSP-2181 processors. Each 2181 filters and demodulates a single 2.4 kbps modulated carrier out of the entire 2

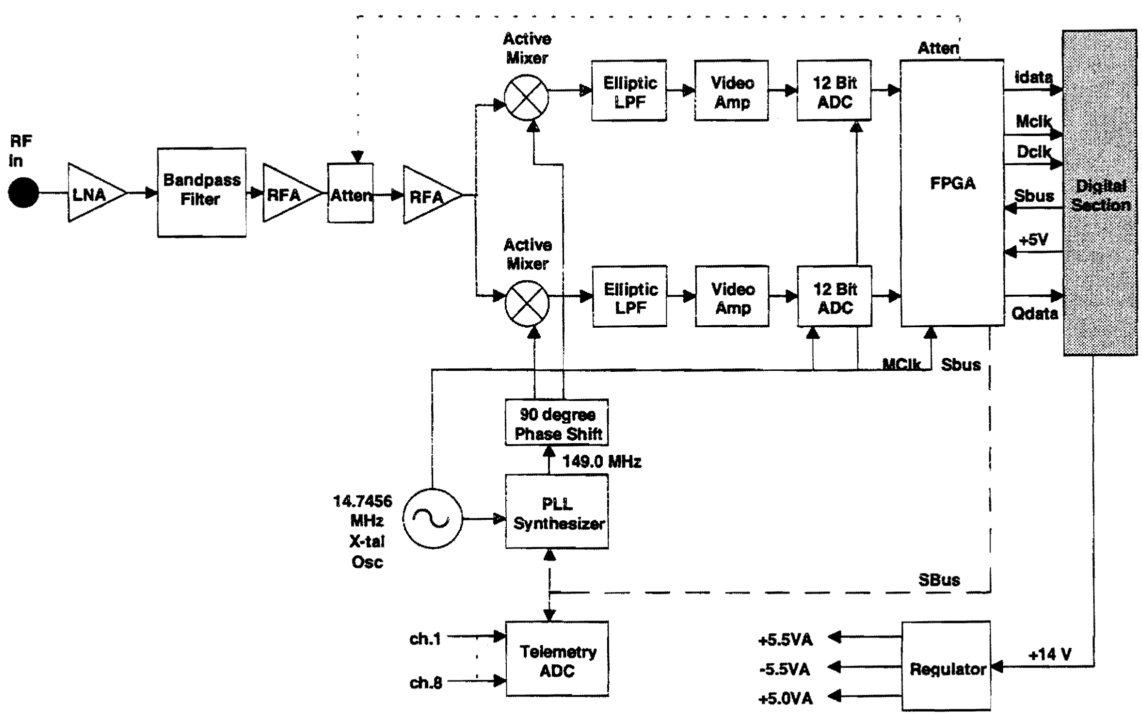
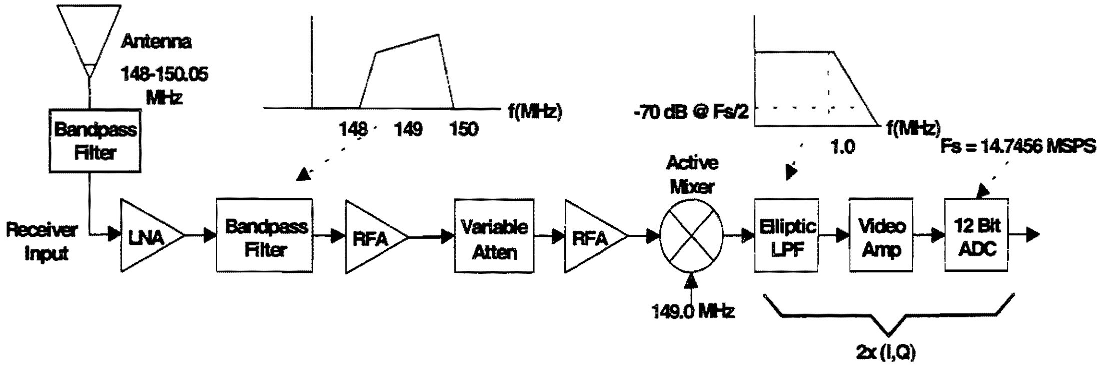


Figure 1. Receiver Analog Section Block Diagram.



	LNA	BPF	RFA	Var. Atten	RFA	Mixer	LPF	Video Amp	12 Bit ADC	Total
Noise Figure (dB)	1.2	4.5	1.2	8.2	2	10.1	3	14	37.3	3.3
Gain (dB)	16	-4.5	16	-8.2	14	-10.1	-3	20	0	39
IP3 (dBm)	19	60	19	60	40.5	23	60	53	60	
IP3 @ Input (dBm)	3	3	-9	-9	-9	-9	-9	-10	-10	-10

Figure 2. Gain, Noise Figure, and Intercept Point Summary.

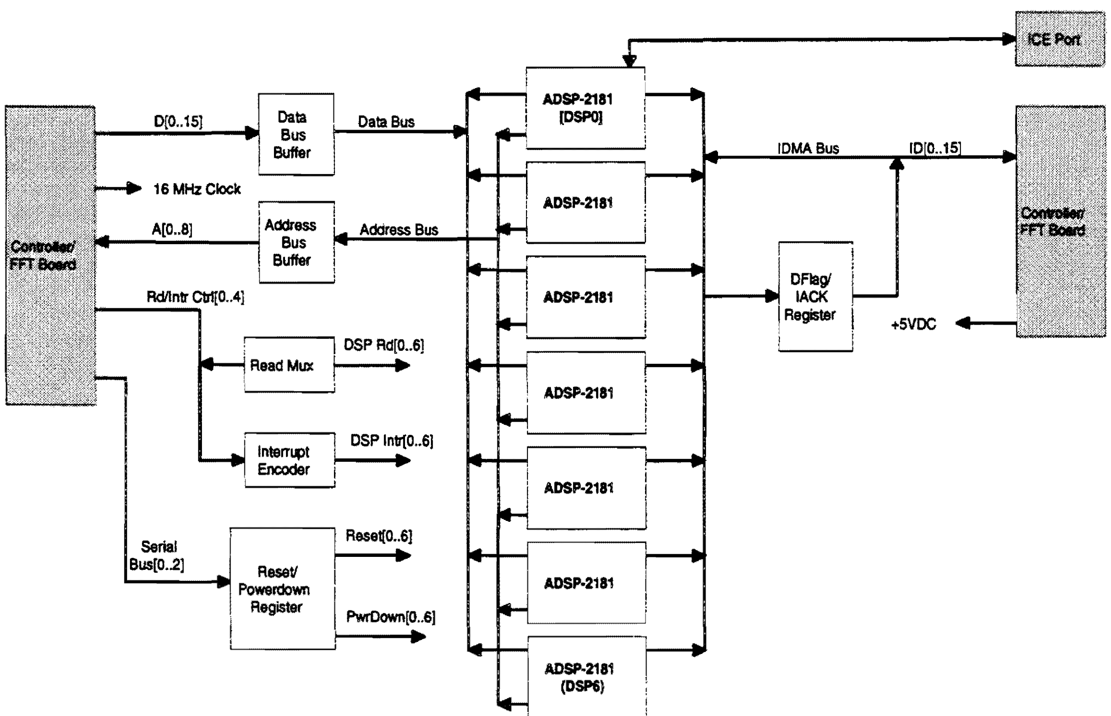


Figure 3. Receiver Digital Section.

MHz of digital data bandwidth. Once the packet data is recovered by the ADSP-2181 processors, a MC68302 processor transfers the data to a downlink transmitter or to message storage for later transmission.

Software Description

A block diagram of the DSP software functionality is shown in Figure 4. The software in the DSP processors takes the signal information from the FFT processor and then performs channel selection by means of a frequency-domain filtering, a fine

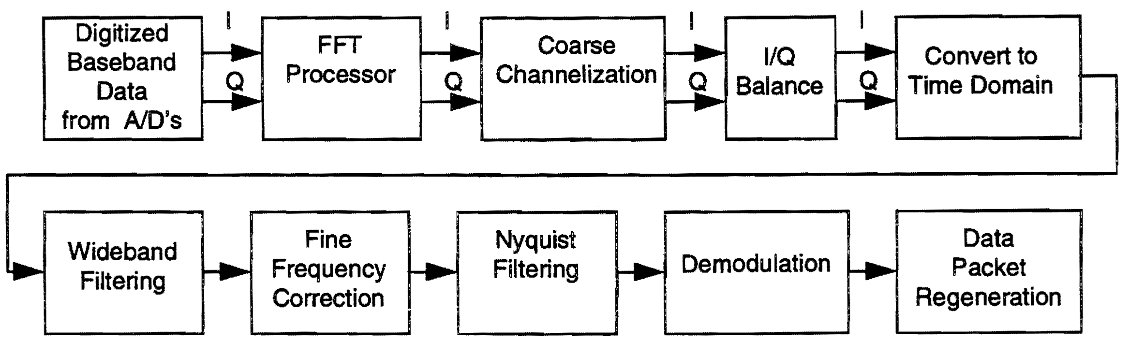


Figure 4. DSP Software Algorithm Flow.

frequency correction to baseband, and a channel low-pass filtering process. Finally, the Nyquist filtered signal is demodulated to produce a data packet output to the 68302. The digital finite impulse response (FIR) filter has excellent selectivity and exact linear phase. In addition, each filter is identical in performance, unlike crystal bandpass or analog lowpass filters. The ADSP-2181 software was written in assembly code to maximize code efficiency, thus allowing for approximately 90% processor loading for each of the seven DSP processors.

The ORBCOMM™ communications protocol includes four independent modes as shown in Figure 5. Each mode has different optimum filtering and demodulation parameters. Acquire and Communicate modes operate in a common, slotted fixed length frame. During the acquire part of the frame, the receiver processes short identification bursts from subscriber communicators. The remainder of the frame is used to process fixed length slotted communications packets. The DCAAS mode is used as a spectrum analyzer function to identify unused frequencies to be allocated for uplink. All modes share a common set of functions that are used to reconstruct a baseband time series from the FFT data. With a DSP receiver approach, the same hardware simply runs different code for each mode, whereas an analog implementation would require four different combinations of signal and loop filters to optimally process the uplink signals. The DSP approach easily allows for changes in demodulator operation, even on-orbit, by simply developing and uploading new software to the receiver.

The digital filters used in the receiver provide the exceptional selectivity required for optimal performance in the presence of multiple large interferers. The filter response of the baseband filter common to the communicate, reservation, and DCAAS modes is shown in Figure 6. Additional roofing filtering is provided earlier in the signal flow to reduce the net sideband response.

Parts Selection and Radiation Effects

Digital receivers similar in functionality to the one presented have been developed recently for terrestrial applications. The unique design of this receiver has been optimized for the required functionality as well as for reliable use in the space environment, and also to minimize mass, volume, and power consumption. Established reliability

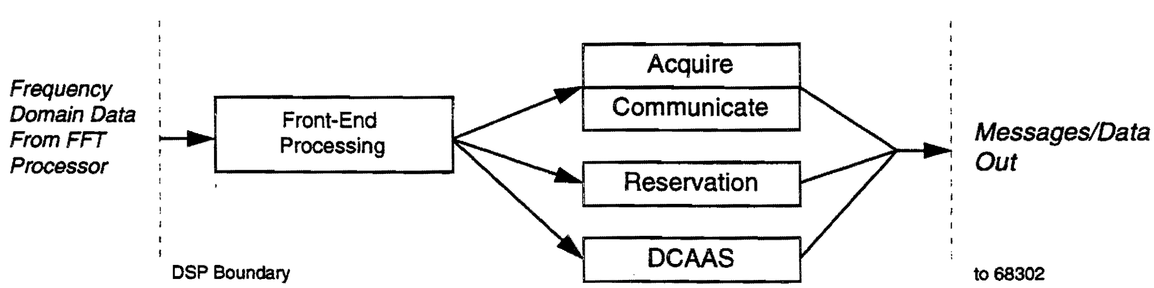


Figure 5. Demodulator Modes.

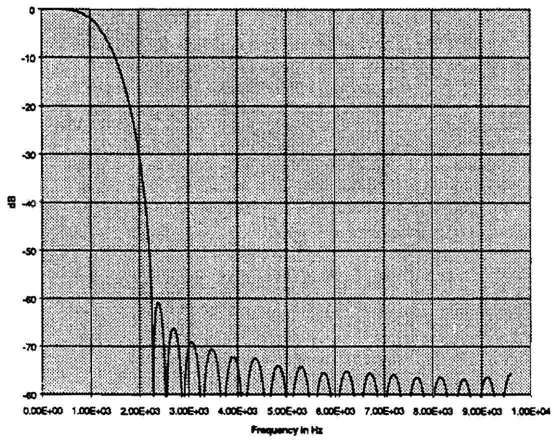


Figure 6. Baseband FIR Filter Response.

Table 1. Receiver Specification Summary.

Specification	Value
Noise Figure (at nominal variable attenuator setting)	3.3 dB
Input 3^{rd} order intercept point	-10 dBm
Input 1dB compression point	-40 dBm
Phase Noise @ 5 kHz	-110 dBc/Hz
Channel bit rate	2400 bps
Modulation	SDPSK
Demodulator Impairment (relative to theory @ 10^{-5} BER)	1.7 dB
Dynamic range of received signal	50 dB
Interference Rejection	80 dB
Mass	2.1 lbs
Size	7.25" L X 2.6" W X 4.25" H

and screened parts were used throughout the design wherever possible. The selective use of COTS DSP hardware allowed for state-of-the-art DSP performance and high performance density. Use of the COTS components required a careful review of the radiation tolerance and reliability of each part. In addition to selecting parts which exhibited adequate Total Ionizing Dose (TID) ratings, those devices which were measured to be susceptible to latchup were protected by an automatic latchup reset circuit. Devices that exhibited destructive latchup were not used. The reliability of the COTS components are further assured by a process of thermal cycling, burn-in, and extensive testing.

Receiver Performance Specifications

The performance summary of the ORBCOMM™ multi-channel digital receiver is shown in Table 1. The combination of the high performance analog front end and the optimized DSP filtering and demodulation produce receiver specifications rivaling the best of all-analog receivers, but with higher packaging density and greater repeatability.

Summary

The multi-channel direct conversion digital uplink receiver developed for the ORBCOMM™ program provides excellent electrical performance with high mass and volumetric efficiency by means of a high performance analog front end and selective use, qualification, and screening of state-of-the-art COTS digital signal processing hardware. The design is also highly adaptable to different frequency bands, modulation formats, and protocols.