

White Paper: DVB-S2X for Next Generation C4ISR Applications

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Abstract

Increased use of SATCOM on C4ISR fronts has created a need for High Throughput Satellite technology. Recently ratified, DVB-S2X standard offers an increase in spectral efficiency and operating range (-10 dB to 20 dB $\frac{E_s}{N_0}$). Although DVB-S2X standard is targeted for satellite communications, it can support other C4ISR links such as bent pipe and direct connections with airborne assets. In this paper, we discuss the key advances in DVB-S2X and demonstrate the performance of our DVB-S2X core, the 4709 E2IQ. Using the new Ettus X310 SDR platform with our E2IQ core, our results show low implementation loss and a maximum data rate of 324 Mb/s. Given this base SDR design and implementing the highest order modulation, the modem is capable of 432 Mb/s. To the best of our knowledge, we are the first to implement and demonstrate DVB-S2X on an SDR platform. Through these efforts, it is our objective to demonstrate the performance advantages of using DVB-S2X in next generation C4ISR systems. If this technology is interesting to your program, we would like your specific requirements for a more a detailed proposal.



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DVB-S2X for Next Generation C4ISR Applications

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I Introduction

With the increase in additional surveillance capabilities, and battle-fronts to monitor and defend, Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) has become proportionally more dependent on SATellite COMmunication (SATCOM). Consequently, commercial SATCOM provides 80% of the Department of Defense (DoD)'s total capacity [1]. To this end, High Throughput Satellite (HTS) SATCOM has become a key interest. Ratified in October of 2014, Digital Video Broadcast-Satellite Second Generation Extension (DVB-S2X) offers a next generation increase in capacity and spectral efficiency [2]. Although DVB-S2X standard is targeted for satellite communications, it can support other C4ISR links such as bent pipe and direct connections with airborne assets. Figure 1 shows examples of C4ISR communications links suitable for DVB-S2X.

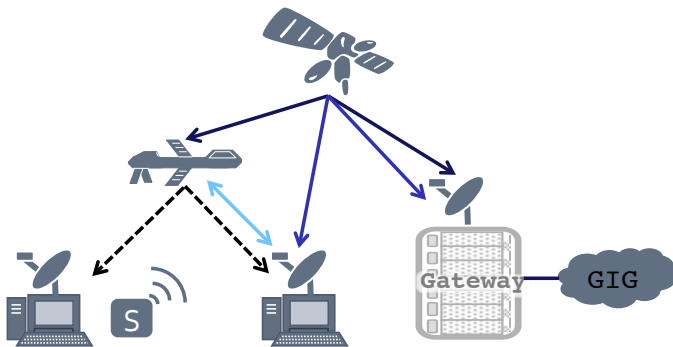


Fig. 1. Point-to-point applications for DVB-S2X in C4ISR communications links.

Thus, with the new capabilities of this standard, we seek to educate and demonstrate the performance benefits of DVB-S2X to the C4ISR community. To demonstrate the performance benefits of DVB-S2X, we implement our design of the DVB-S2X standard, the 4709 E2IQ Core, on the Ettus X310 [3] Software Defined Radio (SDR). Using this SDR platform and our E2IQ Core, we show performance of a real modem in the Additive White Gaussian Noise (AWGN) channel. To the best of our knowledge, we are the first to implement the new DVB-S2X standard onto an SDR platform. Through these efforts, it is our objective to demonstrate to C4ISR users the flexible adaptability of using our E2IQ core in next generation systems.

Our paper is organized as follows. We begin our paper, in Section II, where we summarize the key advances in DVB-S2X

that increase spectral efficiency. In Section III, we describe our hardware configuration of the DVB-S2X modem using the Ettus X310. After describing our hardware configuration, we describe our implementation of DVB-S2X, the 4709 E2IQ [4], in Section IV. In Section V, we describe our hardware performance experiment and present our results. We close our paper in Section VI with a summary of our work. At the end of our paper, we provide the reader with a summary of the AHA Products Group along with our capabilities and services.

II Key Advances in DVB-S2X

Extensions to DVB-S2, DVB-S2X, were ratified in 2014 [2] and added two main advancements in order to increase spectral efficiency, data rates, and Signal to Noise Ratio (SNR) operating range. First, DVB-S2X added more options for roll-off factors of the pulse shaping Nyquist filter. DVB-S2 offered roll-off factors of 30%, 25%, and 20%. DVB-S2X now supports additional roll-off factors of 15%, 10%, and 5%. These new roll-off factors can create an increase in spectral efficiency by reducing spectral bandwidth. Figure 2 compares the spectral bandwidth of an DVB-S2X 8 Msps carrier at these different roll-off factors.

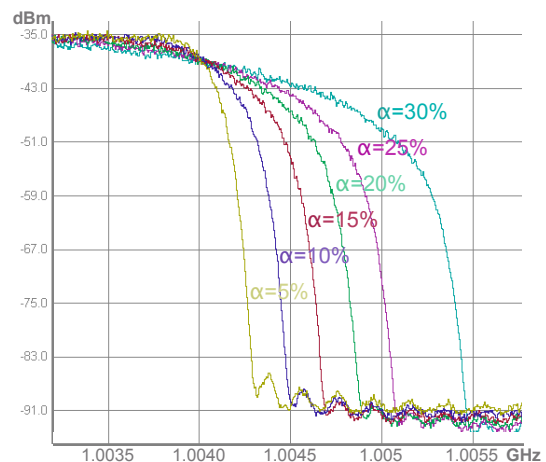


Fig. 2. Comparison of carrier roll-off factors, α , for an 8 Msps DVB-S2X channel centered at 1 GHz. DVB-S2X supports additional roll-off factors of 5%, 10%, and 15% for more narrow spectral bandwidth.

In addition to lower roll-off factors, DVB-S2X offers a wider array of available MODulations and CODings (MODCODs) for Adaptive Coding and Modulation (ACM). An illustration of the most spectrally efficient MODCODs is shown in Figure 3. The wider variety in the available number

of MODCODs provides improvements in three key areas. First, lower order modulations (i.e., Binary Phase Shift Keying (BPSK)) with low code rates (as low as 1/5) enable operations in Very Low SNR (VL-SNR) regions (-10dB to -3dB $\frac{E_s}{N_0}$). The purpose of the VL-SNR is to support applications with extreme path loss such as: airborne/aviation internet access, small/high frequency VSAT terminals, or deep fades caused from humidity i.e., tropical zones [2].

Second, finer granularity of MODCODs improve spectral efficiencies by providing more optimal coding and modulation combinations for mid-range SNR values. Threshold differences between mid-range values for DVB-S2X average 0.4 dB compared to 0.7 dB of S2. Additionally, gain improvements from optimizing MODCOD values in this region can be as much as 2.3 dB when compared to S2. Third, with the addition of higher order modulations i.e., 64-Amplitude Phase Shift Keying (APSK) to 256-APSK, the standard supports higher throughput capabilities into an Extended SNR (E-SNR) range (15dB to 20dB $\frac{E_s}{N_0}$). The E-SNR ranges offer increases in spectral efficiency by more than 50% for channels with high SNR.

With a wider range of MODCOD values, C4ISR applications can increase throughput of communication links at a wide range of SNR values. In the VL-SNR range, DVB-S2X can endure deep fades or interference and continue operating. At mid-range values, more granular and optimal MODCODs enable higher throughput through increasing spectral efficiency. Finally, applications at high SNR are capable of increasing data throughput in the E-SNR range. These ranges are overlaid and emphasized in Figure 3.

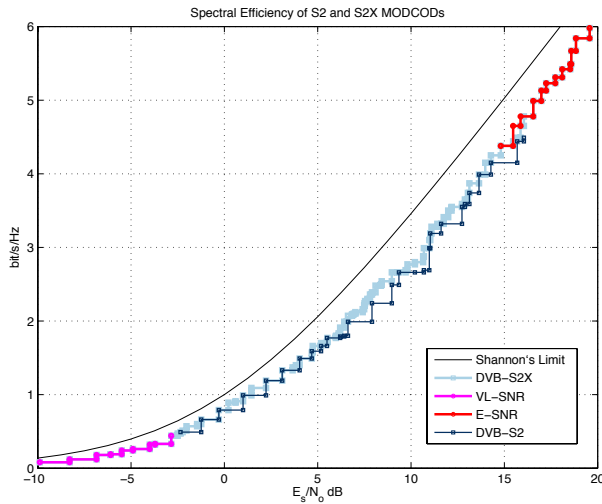


Fig. 3. Spectral efficiency envelope of DVB-S2X and DVB-S2 under the AWGN channel model and packet error rate of 10^{-5} . VL-SNR, E-SNR, are overlaid in magenta and red, respectively.

III Hardware Configuration

Our implementation is built using the Ettus X310 SDR platform [5] and the SBX-120 daughter board. A diagram showing our hardware configuration is captured in Figure 4. The SBX-120 daughter-board provides the RF front end, which includes the local oscillators, mixers and attenuators for the RX and TX paths. At the interface between the SBX-120 and

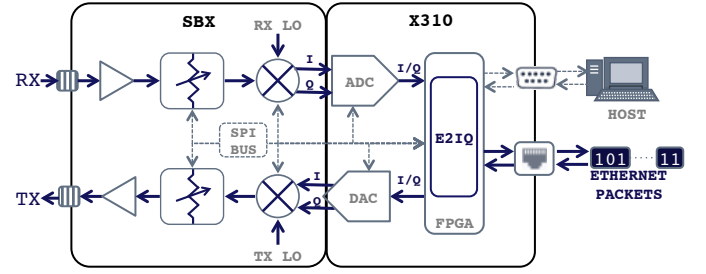


Fig. 4. Hardware block diagram of X310 and SBX-120 SDR

X310, analog I/Q samples are processed in/out of the X310. On the Ettus X310, our design comprises the Xilinx Kintex-7 Field Programmable Gate Array (FPGA), Digital to Analog Converter (DAC), and Analog to Digital Converter (ADC). The core of our modem design, the E2IQ, is placed on the FPGA. Our host, via the Serial Peripheral Interface (SPI) bus, calibrates and configures the DAC, ADC, and the SBX-120 front end. For external data and control to the FPGA, we use the Ethernet and RS-232 interface, respectively.

IV E2IQ Architecture

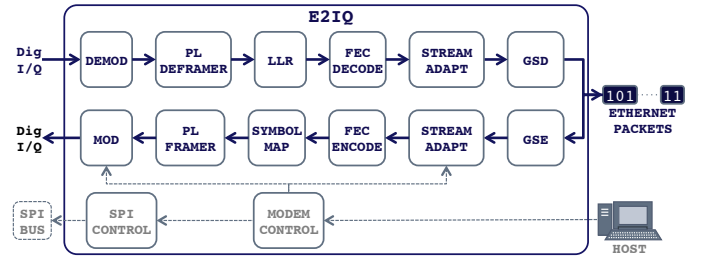


Fig. 5. Block diagram of our DVB-S2X implementation, E2IQ

Our E2IQ design comprises two main parts: the control and data flow. A block diagram of our E2IQ core is shown in Figure 5. Driven by the host, the purpose of the control flow is to configure and calibrate the encoder, modulator, and RF front end. The modem control block design is built on the Zynq CPU (ZPU), which is a small embedded processor. Leveraging the ZPU, the modem control block is able to perform algorithms required for ACM, gain control, and other real-time functions. To this end, the modem control block instructs the stream adaptation block which MODCOD to use for transmission. Additionally, modem control configures the modulation block to use the appropriate symbol rate. The stream adaptation block passes down MODCOD information to the subsequent modules to indicate block size, code rate, and modulation to use for the transmission. Finally, the center frequency and transmit power level may be configured via the SPI bus using a modem control algorithm or by the host.

The data flow paths transform the digital I/Q into Ethernet packets and vice-versa. A diagram showing the encapsulation of Ethernet packets to I/Q symbols is shown in Figure 6. For the Ethernet to I/Q or transmit flow, Ethernet packets are first received by the modem and framed using the Generic Stream Encapsulation (GSE) protocol [6]. The GSE packets are then framed with a Base Band (BB) header to indicate ACM control, roll-off factor, and other frame control information.

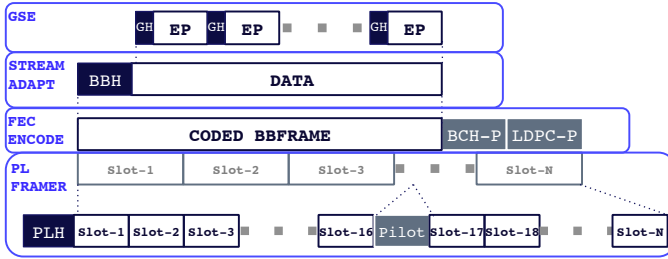


Fig. 6. Illustration of framing from Ethernet Packets (EP) to I/Q symbols used by each functional block of the E2IQ core. (Sizes of frames are not drawn to scale.)

The entire BB frame is sized according to the input block of the MODCOD, which is then passed along to the Forward Error Correction (FEC) encoder. To encode the BB frame, DVB-S2X uses an outer BCH code and with an inner LDPC code¹. After encoding, the FEC frame is mapped to symbols and slots to be processed by the Physical Layer (PL) framer. Through its own header, the PL framer creates the start of frame followed by information used to decode the entire FEC frame. Additionally, the PL framer periodically inserts pilot slots for maintaining synchronization. As the PL processes each symbol, the data is then modulated into a digital I/Q signal and sent to the RF front end.

On the receive path, the demodulator, working with the PL deframer, looks for the start of the PL frame and the PL header to determine the MODCOD and the size of the slotted FEC frame. Signal measurements from detected symbols are then used as an input for the Log Likelihood Ratio (LLR) computation and subsequent decoding of the FEC frame. The stream adaptation block and GSE deframer blocks then remove the BB header and decapsulate back into Ethernet packets, respectively.

V Performance Demonstration of E2IQ and SDR Modem

To characterize performance of our DVB-S2X design we configure a single modem in a loop-back configuration for both the E2IQ FEC core and the Ettus SDR Platform. For performance characterization of the E2IQ core, we create an AWGN channel model on the FPGA and insert the channel between the FEC encoder and decoder core. A known pseudo-random number sequence is then generated and feed into the FEC encoder, which passes through the AWGN channel and back into the FEC decoder. When a statistically significant number of errors and associated data points for SNR values are performed, we calculate the 10^{-5} Block Error Rate (BLER) for all MODCOD [2].

Similar to the characterization of the E2IQ FEC core, the TX of our Ettus SDR is connected to a carrier-to-noise generator, which provides a programmable SNR to evaluate each MODCOD in the AWGN channel model. The RX path is returned to the same modem from the generator. In same way as the FEC characterization, the TX begins sending a known pseudo-random number sequence at incremental SNR values. From these experiments, the corresponding SNR at

¹Bose, Chaudhuri, and Hocquenghem (BCH) codes are a generalization of the Hamming code for multiple-error correction. A low-density parity-check (LDPC) code is a linear error correcting and capacity-approaching code.

10^{-5} BLER is determined. In our Ettus SDR design, we use the mid-range MODCODs for performance comparison. The results of the E2IQ core and the Ettus SDR implementation are shown in Figure 7.

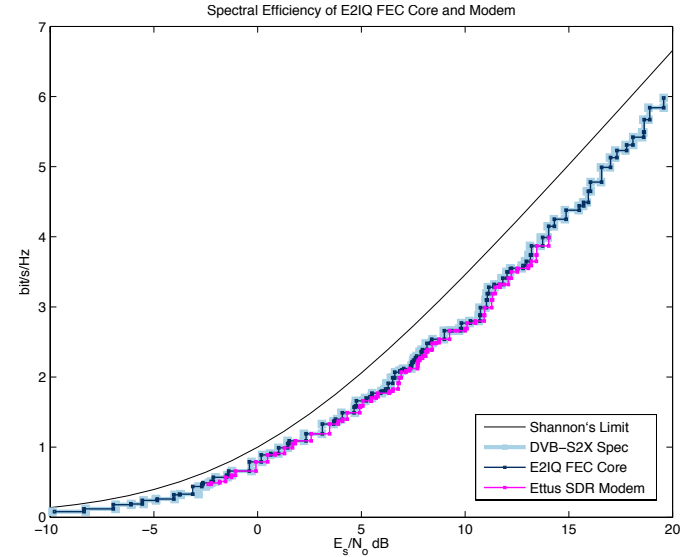


Fig. 7. Comparison of the E2IQ FEC core (dark blue) and the Ettus SDR implementation (magenta) with the DVB-S2X specification (light blue). Both implementations have small performance gaps over the range of tested MODCODs.

As shown in Figure 7, the performance gap between the E2IQ core and the DVB-S2X spec is small. On average, the E2IQ performance gap is 0.1 dB. On the SDR implementation, the average performance gap of 0.29 dB also tracks closely to the DVB-S2X spec. This demonstrates the high quality of the E2IQ core design and implementation on the Ettus SDR. Finally, the designed SDR, the maximum symbol rate and most spectral efficient MODCOD is 72 MSPS and 4.5 bits/s/Hz, i.e., a maximum data rate of 324 Mb/s. Given the base SDR, and implementing the higher order MODCODs, the modem could support a maximum data rate of 432 Mb/s.

VI Conclusion

DVB-S2X offers increases in spectral efficiency through smaller roll-off factors and additional MODCODs that improve performance over a wide range of SNR values. Specifically, DVB-S2X has full SNR range from -10 dB to 20 dB $\frac{E_s}{N_0}$. Through our experiments and results, we have shown that the E2IQ core is a low loss implementation of the DVB-S2X specification. Additionally, given that the Ettus SDR is a multi-purpose platform, the E2IQ core is flexible can be adapted effectively to create a high performance data modem for variety of C4ISR applications. From our performance demonstration, we have shown that C4ISR applications can leverage DVB-S2X advances for increases in operating range and throughput.

Tell Us Your Requirements!

Thanks for taking the time and interest reading our paper. We hope you found it informative and interesting. If you have



a program or project requirements for a related technology, we can provide a more detailed cost proposal for any of our products and services:

- LDPC, DVB-S2X, or Custom FEC core
- Full Digital Data Modem
- DVB-S2X or Custom Modem Design
- Data and Signal Compression Technology
- Data Encryption Technology
- Executive Level Training on FEC Technology

Please contact the paper authors, sales department, visit our website www.aha.com for more information or to begin a conversation with us.

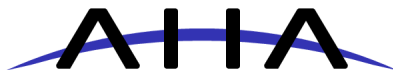
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About the AHA Products Group



The AHA Products Group (AHA) of Comtech EF Data Corporation develops and markets application-specific integrated circuits (ASICs), boards, and intellectual property core technology for communications systems applications. Located in Moscow, Idaho, AHA has been providing leading edge Forward Error Correction and Lossless Data Compression technology for more than two decades. AHA offers a variety of standard and custom hardware solutions for the communications industry. Visit us at www.aha.com.

AHA works closely with our parent company, Comtech EF Data, to develop cutting edge solutions for optimizing satellite communications, networking, storage and other applications. For more information about Comtech EF Data, visit www.comtechefdata.com.



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