RADIO FREQUENCY OVERVIEW OF THE HIGH EXPLOSIVE RADIO TELEMETRY PROJECT

Roger Bracht
Los Alamos National Laboratory
ESA-MT

Jeff Dimsdle
Dave Rich
Frank Smith
AlliedSignal Federal Manufacturing & Technologies*

ABSTRACT

High explosive radio telemetry (HERT) is a project that is being developed jointly by Los Alamos National Laboratory and AlliedSignal FM&T. The ultimate goal is to develop a small, modular telemetry system capable of high-speed detection of explosive events, with an accuracy on the order of 10 nanoseconds. The reliable telemetry of this data, from a high-speed missile trajectory, is a very challenging opportunity. All captured data must be transmitted in less than 20 microseconds of time duration. This requires a high bits/Hertz microwave telemetry modulation code to insure transmission of the data within the limited time interval available.

KEY WORDS

Quadrature amplitude modulation (QAM), radio frequency (RF) modulation, bandwidth, bit error rate (BER).

INTRODUCTION

The available time for sending explosive wavefront timing information is such that 64 channels of information must be transmitted at an equivalent transmission rate of approximately 100 Megabits per second. For this application, a polar differential-phase/absolute-amplitude 16 QAM modulation technique has been chosen. Use of QAM allows for a lower symbol rate than would be required with BPSK or QPSK. Other advantages are that QAM data compression makes it easier to maintain the frequency spectrum within the telemetry band. The polar format makes it easier to minimize constellation distortion, and thus maximize efficiency, when operating near amplifier compression. Finally, differential encoding is desirable in the event that coherent

detection is impossible due to loss of preamble synchronization or frequency variations in the signal. A Xilinx field programmable gate array (FPGA), with sophisticated logic programming, is used to control the system. Inphase (I) and quadrature (Q) modulation method is used, allowing for a significant amount of system flexibility.

HARDWARE CONFIGURATION

Sixty-four optical signal inputs are connected into the package, by way of fiber optics, to allow interfacing from the time of arrival signal detectors to the multi-chip module. This module contains the optical to electrical converters and the FPGA. Each detected signal is monitored by the FPGA, which determines time delay between events. The information is then placed into memory and is simultaneously polled and formatted for output. The output format, from the FPGA, is in the form of eight bits of I and eight bits of Q data. The I and Q data is then converted to a set of analog signals. These two base band signals are filtered by 15 MHz, 5th order, linear phase, low pass equi-ripple filters. This output is then applied to the modulation inputs of an RF Microdevices 2422 vector modulator integrated circuit. A very accurate Sawtek developed RF source, operating at 2,229.5 MHz, is connected to the RF input port of the modulator. The modulated output signal is then amplified and buffered to the module's output port. A block diagram of this setup is shown in Figure 1. Details of the optical interface are beyond the scope of this paper. Of particular interest are details concerning the logic design and modulation formats.
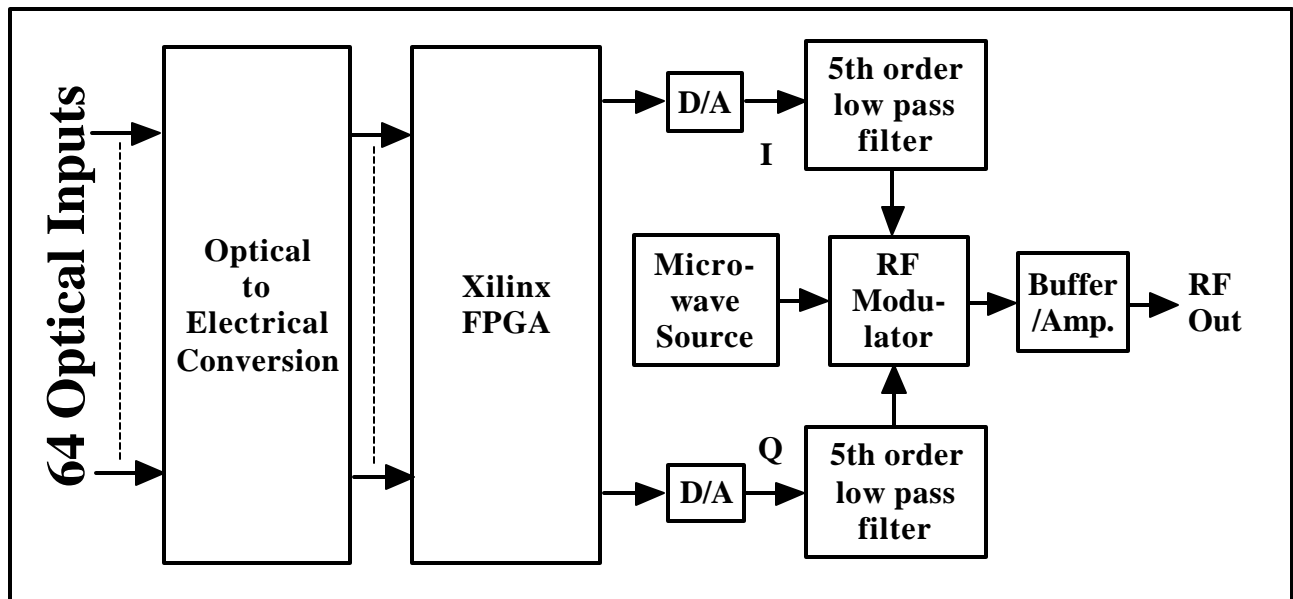

Figure 1. Block Diagram of HERT Module.

FPGA LOGIC

Most of the computational work is accomplished by the use of a XILINX 4036XL FPGA clocked at 100 Megahertz (MHz). This device is the equivalent of approximately 36,000 gates and provides a flip-flop rich environment along with wide-edge decoders, abundant routing resources, and high performance random access memory (RAM). The programmed logic consists of event timers, an input polling machine, a poll FIFO, an output multiplexer and checksum generator, differential encoding, and an output FIFO.

Each channel uses a 14 bit counter clocked at 100 MHz. When a channel signal goes low, all of the counters start running. When another channel signal goes low, it's respective counter stops running. As a result the very first event triggered indicates a zero time on the counter and all other event time values are relative to this first event.

The polling machine continuously scans the 64 channels looking for new events. The time and channel number, of each event, is sent to the poll first-in-first-out (FIFO) registers once a new event is found. A mask is then set to avoid placing this information into the poll FIFO again.

The heart of the poll FIFO is a 64x20 bit RAM implemented to hold the time and channel number data. This FIFO is designed to pack the RAM with time and channel data, but to never empty. The FIFO also uses two read data pointer counters. One counter, which has higher priority, allows reading the most recent data that has been stored. The secondary counter allows for repeating data during long dwell times or when all data has been written into the FIFO and sent out at least once.

The checksum block adds a simple 4-bit checksum using the time and channel number data. The multiplexer divides up the time, channel, and checksum data into 4-bit slices to be differentially encoded symbols.

The 4-bit time and channel data slices are then differentially encoded using a unique algorithm developed by AlliedSignal FM&T. This produces a gray encoded differential polar QAM format that will be discussed later in this paper.

Finally, the 8-bit I and Q values, from the differential QAM generator, are stored in the output FIFO and sent at a 25 MHz symbol rate. The output FIFO is also pre-loaded with a three word real time correlator trigger data that is used to reliably trigger the recording device at the ground station.

RF MODULATION

While programmable, the initial HERT RF modulation is a two amplitude level 16 QAM differential-phase/absolute-amplitude polar format. Setting the number of states to 16 is convenient for reasonably high bit to symbol packing density. A higher number of QAM modulation states would mean that more signal-to-noise ratio is required for reliable signal recovery.

Polar QAM format appears to offer significant advantages over rectangular QAM for this application. The polar format is less sensitive to constellation distortion due to amplifier compression. Furthermore, the polar format allows phase to be directly differentially encoded. With phase differentially encoded, loss of a coherent carrier is less catastrophic, since the data can still be non-coherently recovered.

For the HERT implementation, all data is encoded into differential phase transitions and absolute amplitudes. The particular method used has two amplitude levels with 8 phases at each level. All states are uniformly and uniquely separated in phase by multiples of 22.5 degrees. Two amplitude levels are superior to three for this differential method since the effective "reference" for each symbol is the previous symbol, and the average amplitude for this effective "reference" is greater for the two amplitude level case. This means the signal to noise for the "reference" is greater with two amplitude levels.

For each symbol, the amplitude can be compared to the amplitude of the previous symbol. If the ratio is within a certain band, the present symbol amplitude is an outer circle amplitude value and the previous symbol is an inner circle amplitude value. These values can be incorporated into a running weighted average for tracking and compensation of scaling and compression. The gray coded differential-phase/absolute-amplitude constellation state assignments are shown in Figure 2.

PERFORMANCE

This modulation scheme has been extensively simulated under various conditions. The Eb/No vs. BER simulation results for various modulation methods is shown in Table 1. Significant points concerning this chart are summarized as follows:

The results shown for the non-coherent differential-phase/absolute-amplitude 16QAM is for non-optimal decision state assignment regions, just "closest to" in the differential-phase/absolute-amplitude "quasi" IQ constellation. The Eb/No at BER=1E-4 for coherent differential-phase/absolute-amplitude 16QAM is 1.58 dB worse than the absolute version of that constellation and 2.54 dB worse than conventional absolute rectangular 16QAM. Of course, a total absolute scheme, not just coherent, would require some special code
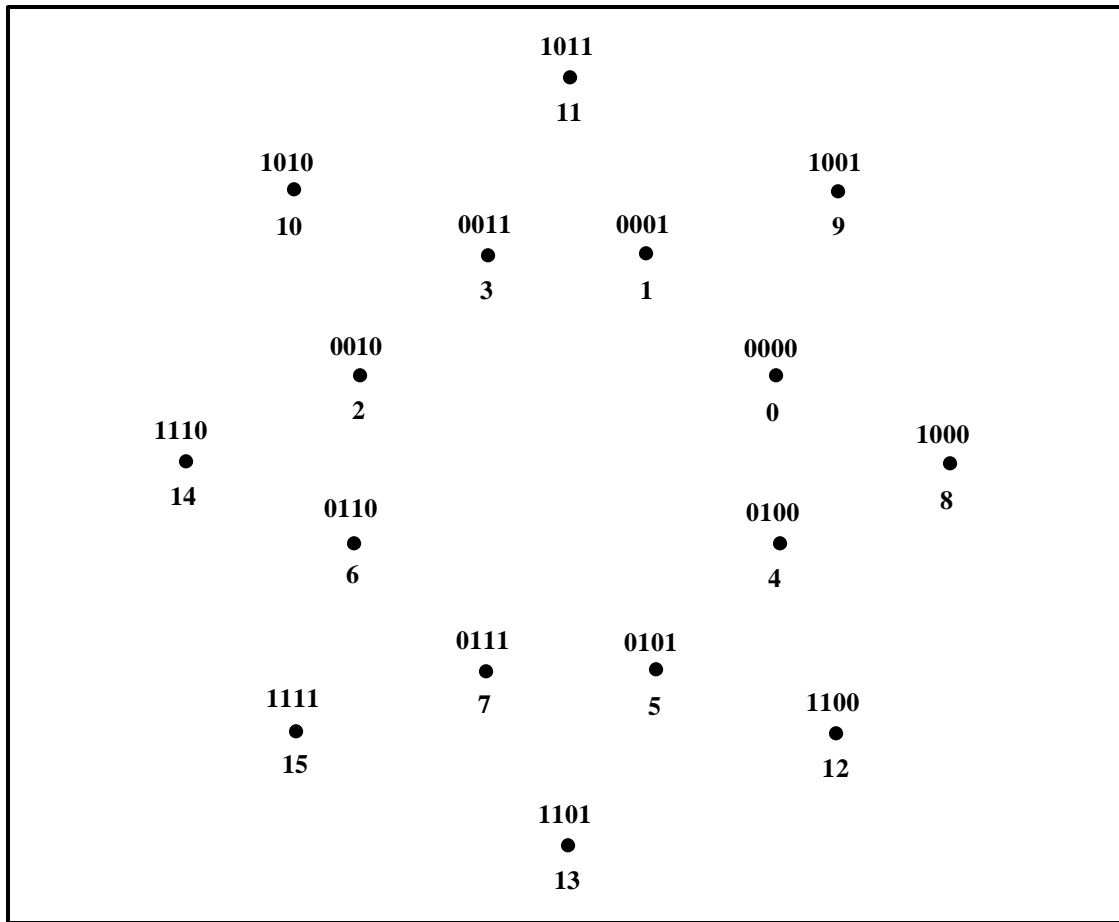
Figure 2. Differential phase and absolute amplitude QAM symbol number assignments.

word to resolve the discrete angle ambiguity and if for some reason the carrier cannot be coherently recovered the data could not then be recovered non-coherently, as is possible with the differentially encoded phase case.

The non-coherent differential-phase/absolute-amplitude 16QAM BER vs. Eb/No is 0.7dB worse at BER=1E-4 (less with more optimal decision regions) than non-coherent 8DPSK, but with the data rate of conventional 16QAM, while still retaining both continuous phase and amplitude referencing.

For differential-phase/absolute-amplitude 16QAM, comparing the coherent to the non-coherent result shows about a 0.6dB improvement in required Eb/No at a BER=1E-4 for the coherent differential versus non-coherent differential demodulation (Eb/No=14.7 dB vs. 15.3 dB) with a two symbol window. The improvement is about 1dB at higher BERs. Increasing the window size for coherent differential demodulation would provide a greater improvement over non-coherent differential demodulation.

Modulation	Eb/No at BER=1E-4
Non-coherent differential-phase/absolute 16QAM	15.34
Coherent differential-phase/absolute 16QAM	14.68
Absolute coherent 2-amplitude polar 16QAM	13.10
Absolute coherent rectangular	12.14
Non-coherent differential 8DPSK	14.62
Absolute coherent	11.66

Table 1. Eb/No vs. BER simulation

CONCLUSION

In conjunction with AlliedSignal FM&T, a small, modular data acquisition, high speed measurement, and fast telemetry unit has been developed using state-of-the art miniaturization techniques and innovative RF modulation methods. Complex, miniaturized, optical channels have been integrated along with fast analog interfaces, sophisticated real time processing, a high order logic design, state-of-the-art RF integration and filtering, all brought together into one low power module. This new module size is on the order of the typical standard JTA telemetry modulator/transmitter unit by itself and has less than 5 watts of power consumption. Overall, significant progress has been made towards our future understanding of flight dynamics of explosive systems.

ACKNOWLEGMENTS