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Title: HIGH EXPLOSIVE RADIO TELEMETRY (HERT) SHOCK MEASUREMENT SYSTEM

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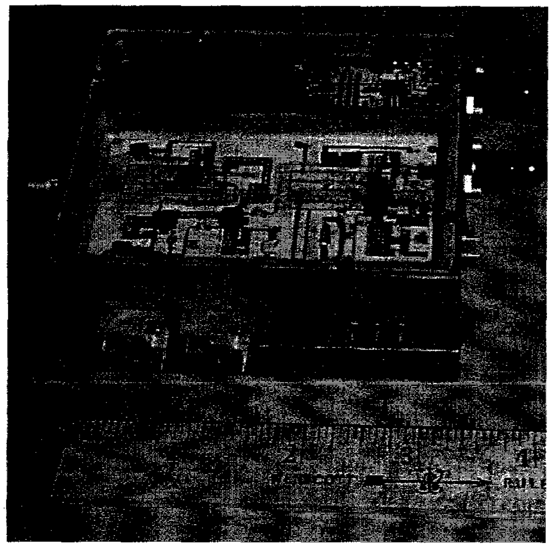
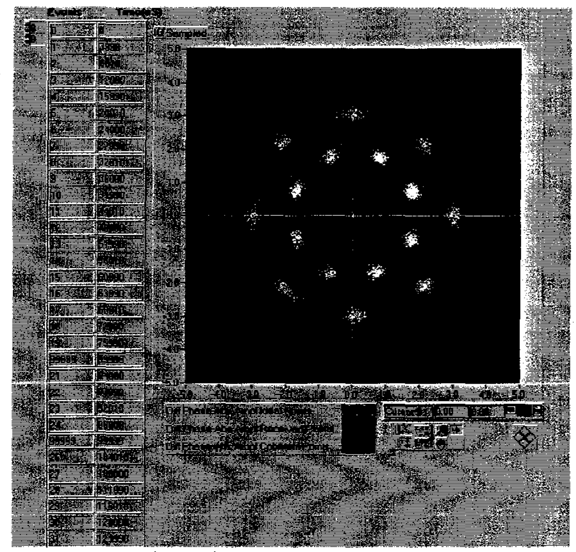
Introduction



HERT Mark II unit, Figure 1.



HERT received data and constellation, Figure 2.

High Explosive Radio Telemetry (HERT) is a measurement system being developed Los Alamos National Laboratory (LANL) and the Honeywell FM&T, Kansas City Plant (KCP) to capture late time flight data on high explosive performance of a test article late in flight. Severe limitations on time of survival of the HERT instrumentation require new and innovative methods to capture this data and transmit the data to a ground station for capture.

There are several parts to the HERT measurement system. The sensor array will detect the shock arrival of the HE detonation and deliver this shock arrival time to the HERT module. The HERT module will detect the sensor's signal and determine the time of arrival of that signal and other signals. This time of arrival information will be put into a digital format and transmitted using LANL and KCP custom digital differential Quadrature Amplitude Modulation technique. This technique allows the data to be transmitted at a rate 4 times faster than traditional Pulse Code Modulation – Frequency Modulation (PCM-FM) for a given bandwidth. The data is transmitted using the vehicle's antenna ports and is collected at one or several ground stations. At the ground stations, the signal(s) are detected and down-converted from the RF frequency to an intermediate frequency, a trigger signal is generated and a high-speed digital waveform recorder captures the signal(s). The captured date is analyzed post-event with custom software, to produce the in-flight high explosive performance data. In addition there will be a self-check system to interrogate the number of valid sensors and general status of the rest of the measurement system. This can be activated at anytime just before the detonation of the high explosives.

HERT has been extensively tested in non-explosive, explosive, and flight tests with very successful results.

General Features and Parameters

HERT can measure 64 channels of data with 10 nano-seconds of resolution for each channel. The signals can all arrive at the simultaneously or be spread out by many microseconds. HERT will start transmitting upon the detection of any of the 64 channels and then time all other signals from that first detection reference. HERT weighs about 1.25 pounds in its present configuration. This includes the optical detection, logic, RF source, modulation, and power amplifier systems. It consumes about 6 watts of electrical power. HERT is based upon a burst mode rather than a continuous mode of data transmission. This is highly efficient in the consumption and dissipation of electrical power. This efficiency also reduces the size of the battery, heat sinking, and associated masses. The present HERT unit is about 1 ¾ x 2 ½ x 3 ½ inches in size. Future designs will be smaller and lighter.

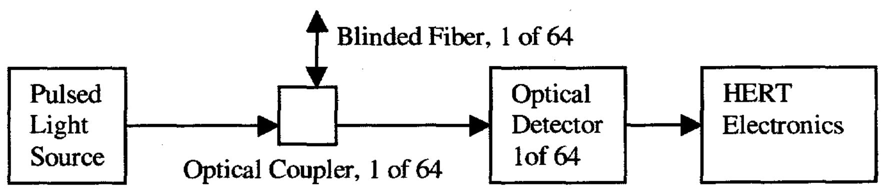
Sensor System

HERT is a fiber based measurement system. At the present time there is a development process with KCP and LANL for a blinded high shock, about 1 Mega-bar, sensing optical fiber. Fiber sensors have the advantages of being lightweight, small, no electrical charge, and no electro-magnetic interference into the HERT electronic systems. The high shock fiber sensor will self-illuminate upon a high pressure impacting it. This self-generated light will be detected by the optical detection system to give a time of arrival. The fiber has a diameter of about 0.005 inches with a blinding coating of 0.010 inch diameter and 0.040 inches long. This fiber sensor can be located in many places.

HERT can measure low-shock, about 100 Kilo-bar, events with electro-contact pins. The electrical output of this type of pin is converted to an optical signal and then the optical signal is deliver to the HERT optics and electronics. Future plans call for development of a low-shock fiber sensor to replace the electro-contact pins.

Self-Check System

One critical question that must be answered is "Are the sensors and HERT electronics operating properly?" The self-check system answers this question. Figure 3. shows the basic function. A light source is launched into a high efficiency optical coupler, the light travel to the end of the blinded fiber and returns to the coupler. The detector leg of the coupler sends the light to one of HERT inputs and is detected. HERT will start transmitting data upon the detection of the first light pulse to the ground station. With this scheme all element will be tested and the status of the HERT measurement system will be known. This self-check system can be activated at any time HERT needs to be tested, including just before the detonation of the HE.



Self-Check Diagram, Figure 3.

Optical Detection System

HERT's optical detection will have an optical threshold of about 200 microwatts. The time jitter for detection will be well within the 10 nano-second resolution of HERT. The sub-miniature 1 x 16 optical detectors are shown in figure 1 as aluminum blocks on the case. The high shock sensors will connect to these four blocks. 1 x 16 fiber arrays inside HERT will transmit the optical signals to the optical detectors. These detectors are custom built by KCP to be very rugged and very small. Each 1 x 16 array is about 1 x 0.3 x 0.1 inches. Ongoing designs at KCP will reduce the volume by a factor of 3. They are electrically close coupled to the logic system for maximum speed.

Logic System

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 buffer.

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 logic 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.

Radio Frequency and Modulation System

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. Each symbol is gray encoded to enhance data reliability.

Power Amplifier System

The power amplifier, shown in figure 1 at the bottom, provides 10 watts of peak RF power, with 20 db of (a factor of 100) gain. When coupled to transmitting antennas the HERT data can be received at a remote ground station. Calculations and testing indicate a maximum range of at least 1100-Km (nearly 700 miles) for a 33 megabit per second system. The power amplifier turns on only when a RF signal from the modulator system is delivered. This is consistent with the designs for efficient operation.

Ground Station System and Receiver

The HERT receiver is a custom design by LANL. It requires specialized processing due to the wide bandwidth; low group delay variation, and burst mode of the HERT signal. The signal is first filtered by an appropriate front-end filter to eliminate near by interfering signals. It is amplified by a low noise amplifier and then connected to a digitally controlled attenuator, allowing for quick adjustment of signal level. Then the signal is downconverted to 75 MHz along with appropriate buffers and amplifiers.

Normally this output signal is connected a digitzer that captures the signal at a 500 Megasample rate. This digitized signal is then read by a Labview program which processes it and produces the demodulated results of the event timings and event numbers on the screen. It also produces a graphical display of the modulation state space signal along with a standard deviation number from the ideal modulation. This gives a strong indication of the recovery margin of the signal.

An additional feature is the microprocessor that processes the trigger and also sets the automatic gain control (AGC) for each of the received bursts of data. Each burst of data is preceded by 20 microseconds of pure tone at the carrier frequency. This signal is detected by a very narrow band filter and compared to a reference level. If it is higher than the reference signal, a trigger has occurred. This trigger is applied to the interrupt input of a microprocessor, which conditions the trigger signal for the digitizer input. It also reads the input RF level and immediately outputs a corresponding attenuation control signal to the digitally controlled attenuator. This effectively sets the receiver gain to match the incoming RF level of the burst pulse so that it will nether saturate or be to low for the remaining receiver components and the digitizer. In addition, the receiver output signal level is monitored by the microprocessor which uses this information to remove long term drift of receiver components.

Conclusion and Acknowledgments

Both LANL and KCP have developed HERT. KCP's contribution has constituted a large amount to both design and hardware development. The future of HERT will continue to develop into a smaller, lighter, and more rugged unit. Demands that HERT of development has led into advanced technologies at KCP that will benefit future measurement applications. Advancements in fiber sensor technologies are being co-developed at LANL and KCP. As the fiber sensors, optics and electronics advance, the HERT measurement system and spin off technologies will find many applications in the shock measuring community.