Data Collection Via Aircraft Powerlines

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ABSTRACT

Advances in physical layer interface technologies have led to the ability to establish a virtual IP network over powerlines. Raw data packet transport speeds of over 10 Mbits/s have been achieved. The powerline is a dynamically changing electromagnetic environment completely unlike the stable, steady state environment of coaxial cables or twisted wire pairs. A special interface technique called adaptive Orthogonal Frequency Division Multiplexing (OFDM) is used to overcome the rapid and dynamic changes in transfer function and noise floor of the powerline. This paper describes the technique being used to implement a fast data collection network over aircraft powerlines that is being developed by the 46th Test Wing at Eglin Air Force Base under the CENTS Program.

Introduction

Advances in physical layer interface technologies have led to the ability to establish a virtual IP network over powerlines. This virtual IP network can be used to facilitate the transfer of data in test aircraft from the (several) units under test to a recording or telemetry device without adding orange wire to the aircraft. The Common Event Network test-instrumentation System (CENTS) is a Technology Test and Demonstration (TTD&D) program under development by the 46 Test Wing Instrumentation Division at Eglin Air Force Base in Florida. The intent of the project is to develop and demonstrate a new method data collection and processing for use on advanced air vehicles (F-22, JSF, UCAV & Comanche Helicopter).

Common Event Network Test-instrumentation System (CENTS)

The Common Event Network Test-Instrumentation System (CENTS) develops a new open architecture system for use on advanced air vehicles providing for common instrumentation data acquisition interfaces and transducers that conform to a commercial standard. CENTS is an event-oriented system built on a publisher-subscriber model that l monitors data from items under test via "instrumented coupled" connector interfaces. These "instrumented coupled" connector interfaces eliminate the need to add many of the traditional data acquisition boxes to the severely space limited air test vehicle. Additionally, these interfaces provide full commonality between test vehicles and minimize aircraft installation/downtime since many of the data acquisition boxes are replaced by the "instrumented coupled" connector interfaces. The transducers provided by this development are smart sensors, which along with the "instrumented coupled" connectors will place data on the network in the event of a data limit or trip point condition. The CENTS hardware architecture differs from traditional Time Division Multiplex (TDM) data encoding by the use of variable length data packets and packet telemetry protocols. Bandwidth is reduced to a minimum since traditional sampling and/or associated fixed frame encoding is not employed.

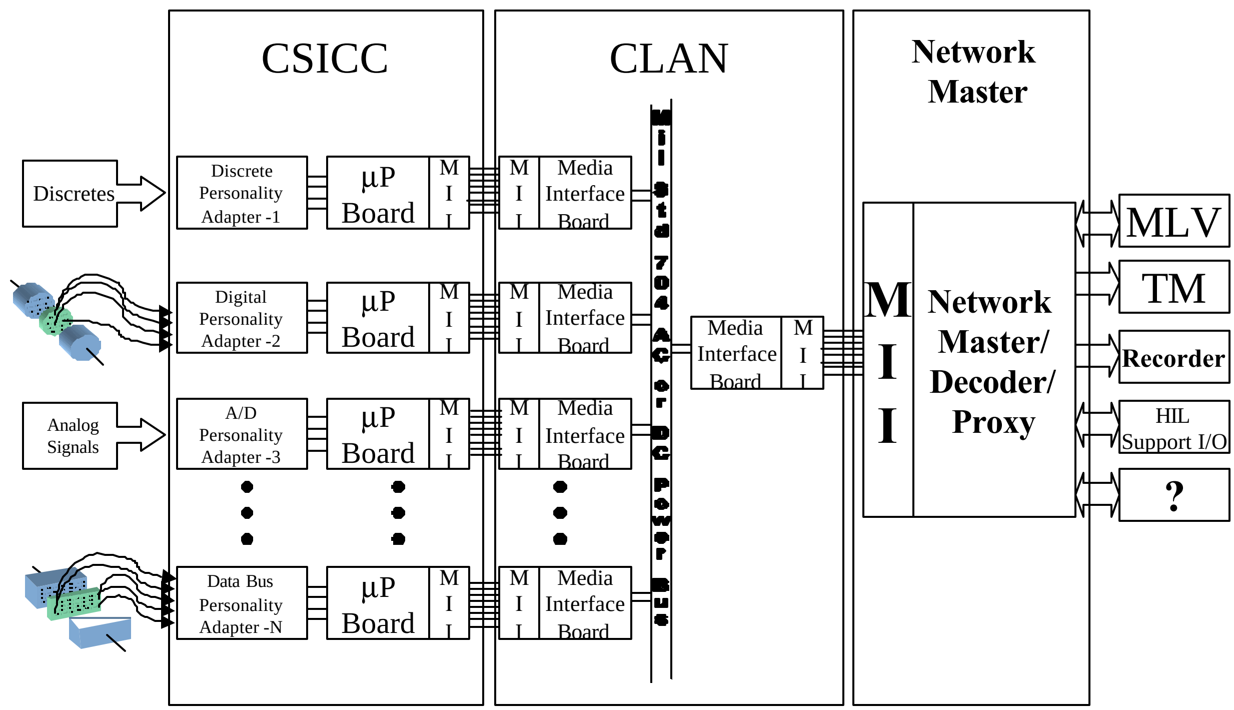

Figure 1 CENTS Block Diagram

The three building blocks of CENTS are the CENTS Local Area Network (CLAN), the CENTS Smart Instrumented Coupled Connectors (CSICC) and data Decoder as depicted in Fig 1. The CLAN will be a “virtual network” and will be implemented by superimposing data on the existing Aircraft/UAV power lines. At the lowest layer the CLAN will provide for utilization of existing TCP/IP protocols and will allow for remote wireless applications. CSICC’s are the second building block of CENTS providing for direct interface to all "data producing” hardware. CSICC’s connect directly to the existing Aircraft/UAV Input/Output (I/O) connectors and will only transfer data in the event of a change of state or trip condition. CSICC’s shall provide for built in test capability and be automatically configured for the data type and expected values over the CLAN. The third component of the CENTS is a Decoder/Network Master, which is used to demodulate the superimposed data for onboard recording/ telemetering. A picture of CENTS module (a single node) is shown in figure 2.

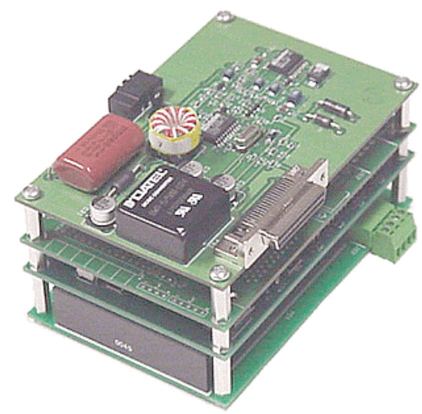

Figure 2 A CENTS Node

The work on the CLAN has been completed and is presented in this paper.

CENTS Local Area Network (CLAN)

The challenge of the CLAN is to superimpose data on the aircraft powerlines reliably and at sufficient bandwidth/transfer speeds to allow realistic data transfer rates. The goal set at the outset of the effort was 1 million bits per second (1 Mbits/sec), which is approaching the data rates of some current systems.

Survey of Powerline Networking Developments

Unlike lines designed to be balanced, such as coaxial or shielded twisted pairs; the transfer function of the powerline changes rapidly over time. Instruments that draw power have start up transients and some components actually generate noise "spikes" during their operation that could be seen as jamming in an ordinary communications environment. Attenuation can be high and in some cases is not even proportional to path length. The lines are typically unterminated in an RF sense and foster a large amount of multipath. In spite of the RF environment the powerline is an attractive medium because of its ubiquitousness.

Norweb (a power utility company) in the UK began demonstrating data networking technology in the early 90's. Speeds were limited and the goal was to provide an alternate to toll call dial up network connections. In the late 90's efforts began for the CEBus, targeting mainly the US consumer electronics market. Concurrently efforts involving automotive electronics based on the CAN bus standard were picking up steam. Several companies began demonstrating and marketing systems that operated under these standards at speeds of around 1 Mbit/s raw data rate. When bus and protocol overhead were added these devices were little better than 9600 baud. The use by some vendors of broader band Spread Spectrum Carrier waveforms helped push the raw rate to near 2 Mbits/s.

A consortium of companies came together to create the "Home Plug" standard. Under this arrangement several vendor companies were competitively to develop a baseline technology with a raw data rate above 10 Mbits/s. The winner of that competition demonstrated in a very large number of homes in the US and Europe a robust system with raw rates in excess of 13 Mbits/s under a variety of conditions. The technique used by the winning vendor is called adaptive Orthogonal Frequency Division Multiplexing (OFDM).

OFDM General Description

OFDM is essentially the simultaneous transmission of a large number of narrow band carriers, or subcarriers. Each of the subcarriers is modulated at a low data rate, but the sum of the rates can be a very high data rate, depending on the bandwidth and the number of subcarriers.

The history of OFDM reaches back to 1966 when R.W. Change published a paper on “Band Limited Orthogonal Signals for Multichannel Transmission” in the Bell System Technical Journal. In 1971 S. B. Weinstein and P.M. Ebert used the Discrete Fourier Transform (DFT) for the base band modulation and demodulation. There work included guard space to solve a multipath problem of intersymbol interference. Then in 1980 A. Peled and A. Ruiz introduced the cyclic prefix to the guard space, which helped maintain orthogonality.

Standard OFDM has been adopted as the modulation standard in Europe for terrestrial and satellite audio broadcast with Eureka 147 Digital Audio Broadcast (DAB). It is also in use for terrestrial Digital Video Broadcast (DVB). The decision to select OFDM was largely due to OFDM’s ability to mitigate multi-path reflections while making efficient use of the available spectrum. The DVB standard provides for net data rates up to 31.67 Mbps in a channel only 8 MHz wide for distances exceeding 50 miles (using OFDM/64-QAM).

The basic idea of OFDM is to divide the available spectrum into many narrowband, low data rate carriers (or subcarriers). To obtain high spectral efficiency the frequency response of the subcarriers are overlapping and orthogonal, hence the name OFDM. Each narrowband subcarrier can be modulated using various modulation formats where BPSK, QPSK and QAM (or the differential equivalents) are commonly used.

Since the modulation rate on each subcarrier is very low, each subcarrier experiences flat fading in a multi-path environment and is easy to equalize. The need for equalization can be eliminated by using differential QPSK (DQPSK) modulation where the data is encoded as the difference in phase between the present and previous symbol in time on the same subcarrier. Differential modulation improves performance in environments where rapid changes in phase are possible.

OFDM modulation is generated by an FFT processor, which encodes M bits of data onto N subcarriers in the frequency domain. Note that

$M=NxB$ (1)

where B is the number of bits per modulation symbol. In the case of QPSK or DQPSK B = 2. An IFFT converts the symbol to the time domain where the length of time for the OFDM symbol is the reciprocal of the subcarrier spacing. Normally this is very long compared to the data rate. Demodulation is, of course, just the reverse of the modulation process.

Line Sensing and Adaptation

A unique feature of the OFDM technique used for the CENTS Local Area Network is the line sensing and adaptation. Essentially this is just the adaptation of the tone map to the unique set of RF characteristics of the powerline in use at the time. During establishment of the link between individual transmitters and receivers all subcarriers are transmitted and evaluated on both ends of the link. The nodes agree on a tone map, or the allocation of subcarriers across the frequency band based on signal to noise ratio (SNR) or bit error rate (BER) criteria. These criteria are selectable and allows for the dynamic configuration of the tone map during data transfer. The adaptation process is illustrated in fig. 3. This equates to a frequency mapping capability and also allows the OFDM waveform to be adapted to regulatory and mil-standard requirements.

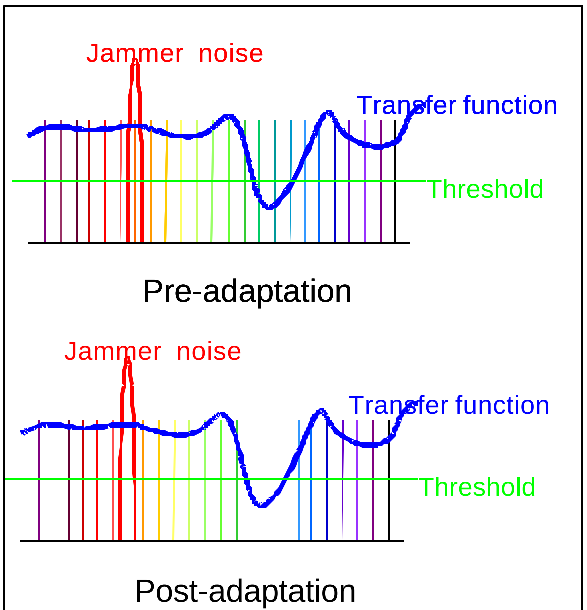

Figure 3 Adaptive OFDM

Demonstration

During Phase 1 of the CENTS program a demonstration was accomplished using the powerlines of two different F-15 fighters as the transfer medium for the CENTS Local Area Network. Two test computers were used to monitor Bit Error Rate (BER) and signal metrics and raw data transfer speeds. Interface to the aircraft was accomplish through the use of existing AIM-9 Short Range Missile electrical disconnect. Personal Computers were interfaced to the 28 VDC and 115 VAC 400Hz AIM-9 connector power pins on wing weapon station 2A and 8B an F-15C and F-15E aircraft.

On the F-15E, tail number 185, tests were completed on both the 115 VAC 400 Hz powerlines as well as the 28 VDC powerlines. The aircraft was powered by a ground cart, all avionics systems (RADAR, Radios, Armament Computer, etc) were powered and checked for their effect on data transfer rates and dropped data packets. With different systems being turned on and off to generate start up transients and powerline noise data rate transmission speeds were monitored and recorded. The raw data transfer speed varied from a minimum of 6 Mbits/s to a maximum of 13 Mbits/sec.

The worst case came when using the 400 Hz AC line with the RADAR going through start up. The best cases were every configuration of the 28 VDC where high rates were recorded for every test. An anomaly to the test was an asymmetry observed when using the 400 Hz AC lines. In that configuration, higher network speeds were noted when transmitting from station 8b than were seen transmitting from station 2a. This case usually occurs when the one of the devices of a network pair is closer to a noise source than its companion.

On the F-15C, tail number 101; tests were conducted using the aircraft's engines. Again the AIM 9 connectors at stations 2a and 8b were employed. However, tests were conducted on the 115 VAC 400Hz powerlines only, as these had been the worst case of the previous testing. In this testing an asymmetry was again noticed, in that transmission from station 8b to station 2a was noticeably better that vice versa. However, in this case the difference was not as pronounced as in the previous testing. During this set of tests the minimum raw data rate observed was 11.7 Mbits/s while the maximum was observed to be 13.3 Mbits/sec. A video teleconference was established between the test computers and full motion video (and audio, but we couldn't hear it with the engines going) was passed between both computers. During this testing spectrum analyzer traces were plotted and evaluated for bandwidth use. Figure 4 is a spectrum analyzer trace from a maximum throughput test. The video streaming was found to take less than 10% of the available bandwidth.

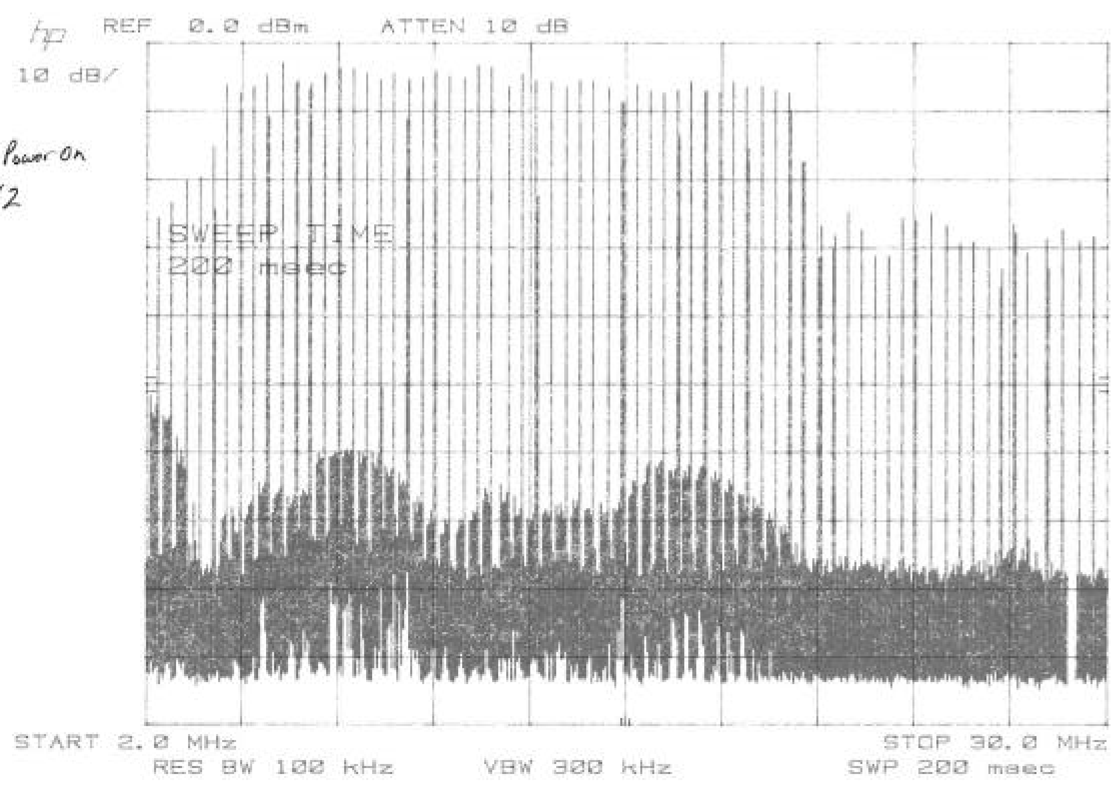

Figure 4 OFDM Transmission over F-15C Powerline
(Station 8 to Station 2)

Note on the raw data bandwidths that when network overhead is added for a standard protocol such as Ethernet the data transfer speed is reduced to about 4 Mbits/s. An evaluation of all the tests taken using F-15 Aircraft in the loop showed that the minimum ethernet equivalent transfer speeds varied from a minimum of 2.7 Mbits/s to a maximum of 4.075 Mbits/s. The median of this data was 3.8 Mbits/s.

Additionally during the demonstration engineers tested various test benches and avionics support laboratories in an attempt to demonstrate the system under various conditions. It was found that the system can be swamped by noise, particularly in a very dirty laboratory power environment. Electrical fans that are found in many test benches have proved to be a particular problem for SNR requirements of the system. The effects of swept noise sources, such as an airport RADAR, were found to be of little to no effect.

Conclusion

Eglin's 46TW has employed a novel approach to achieve a high bandwidth data transfer network for test systems. The CENTS LAN backbone uses an OFDM waveform to establish a network on standard aircraft powerlines. The OFDM technique is a classic communication method that has been successfully adapted to the challenging RF environment of aircraft powerline wires. Measured raw data speeds of up to 13 Mbits/s have been demonstrated on two different F-15 aircraft. CENTS is considered to have a Moderate Implementation Risk with a High Process Savings Payback. Potential Process savings payback is rated high due to the tri-service application of the CENTS, the substantial reduction in aircraft wiring/downtime, the quick reaction instrumentation capability, the built-in-test and reduced manning supportability provided by CENTS installations.