Ultra Wideband Technology for
Aircraft Wireless Intercommunications Systems (AWICS) Design

Aitan Ameti, Robert J. Fontana, E. J. Knight and Edward Richley

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Aitan Ameti, Robert J. Fontana, E. J. Knight and Edward Richley

Multispectral Solutions, Inc.
Germantown, MD (USA)

Tel: (301) 528-1745 Email: (aameti, rfontana, ejknight, richley)@multispectral.com

ABSTRACT

Current intercommunications system (ICS) designs for military, multi-crew aircraft utilize lengthy, encumbering cords to physically attach the crewmember's helmet or headset to a distributed audio intercom system. Typical ICS long-cords are approximately 100 feet in length and allow crewmembers to maintain communications as they move about the aircraft while performing their mission duties. These cords also allow the crewmembers to maintain communications with the aircraft when disembarked, as when they are controlling aircraft during engine startup. Unfortunately, the current wired topology significantly reduces mission effectiveness, impedes crewmember movement and greatly increases the crewmember's risk of injury. These drawbacks are more pronounced onboard military rotary winged aircraft (helicopters) where several crewmembers have been injured or killed during emergencies requiring the aircraft to ditch at sea. During ditching, crewmembers often became entangled in their lengthy ICS cord, preventing or delaying aircraft egress.

The present paper discusses the development of an aircraft wireless intercommunications system (AWICS) which utilizes ultra wideband (UWB) technology to address mission requirements for these multi-crew, military aircraft. UWB offers unique advantages in this application – multipath mitigation, low probability of detection, low probability of interference to onboard legacy systems, and high throughput in a multiuser environment.

1. INTRODUCTION

The Department of the Navy has long recognized the limitations and dangers of tethered, long-cord intercommunications onboard its Navy and Marine Corps helicopters [1]. During the mid 1990's, the Navy began to investigate candidate technologies for a wireless ICS link replacement. A conventional spread spectrum system was tested onboard a CH-53E helicopter flown by the U.S. Marine Corps (see Figure 1).[1] The CH-53E is the largest helicopter in the U.S. military inventory, employing three large T64-GE-416A jet engines (lift capacity of 73,500 lbs) and a seven blade main rotor system with a diameter of 79 feet.

Figure 1. CH-53E *Super Stallion* Helicopter

With the spread spectrum waveform, multipath signal degradation was prevalent within the confines of the aircraft fuselage[2]. Deleterious multipath effects were also encountered in communications between an internal base unit and a remote user standing outside of the aircraft while the rotor system was engaged and turning. In the latter case, the degradation was found to be caused by multipath reflections from the large rotor system. The receiver essentially encountered a self-jamming situation from its own signal reflections.

After an initial exploration of spread spectrum, UWB eventually emerged as a leading candidate technology for AWICS applications.

2. REQUIREMENTS AND SYSTEM DESIGN

To meet Navy operational requirements, AWICS had to satisfy a number of stringent technical requirements. Among these requirements were the support for eight (8) simultaneously transmitting (i.e., "party line") mobile users. Quality of Service had to be sufficient to guaranteed reliable communications from all eight users within the fuselage of the aircraft without dropouts due to multipath or from onboard electromagnetic interference, either to or from the UWB transceivers. Systems

[1] Technical discussions with Naval Air Systems Command, Air Combat Electronics (PMA-209) relating to Phase II SBIR contract N68335-00-C-0425.

[2] For another example of the performance advantages of ultra wideband over spread spectrum in severe multipath, see [2,3] which describes a UWB tagging system designed for locating assets within a Navy ship cargo hold.

sensitive to electromagnetic interference included the automated flight control system (AFCS), electronic engine control systems, Global Positioning Satellite (GPS) system, and other navigational aids including TACAN, VOR, ILS and DME.[3] In addition, the UWB transceivers had to exhibit a low probability of detection (LPD) capability, which would prevent unauthorized electromagnetic intercept.

Due to severe restrictions on available space and mounting points, antenna placement also became a critical parameter. In addition, mobile units were required to be of a physical size that could easily be worn and carried in a standard military survival vest. An 8-hour operational lifetime for mobile units required careful attention to UWB transceiver power management issues.

The basic system concept is illustrated in Figure 2 below. As shown, both pilot and copilot remain tethered, whereas crewmen are permitted to be mobile.

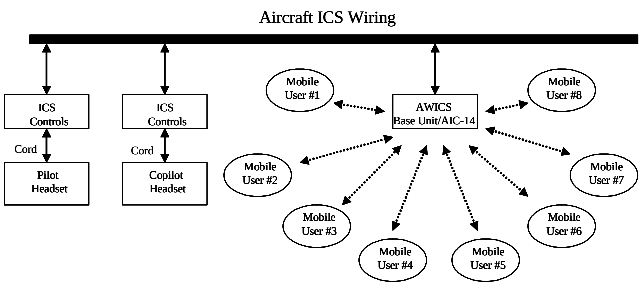


Figure 2. AWICS Conceptual Design

In consultation with representatives from the Naval Air Systems Command, Air Combat Electronics (PMA-209) and flight crews of the United States Marine Corps, MSSI developed the specification for the UWB AWICS system. It was required that the UWB electronics for the base unit be integrated into an existing ICS junction box (AIC-14) onboard the CH-53E and CH-46E aircraft. The AIC-14 junction box hardware was redesigned by its manufacturer to accommodate the integration of MSSI's AWICS transceiver. The redesigned AIC-14, prior to integration of the AWICS transceiver, is illustrated in Figure 3. Essentially, the redesign consisted of removing all mechanical switches and replacing the existing wiring harness with an additional circuit board which freed up sufficient space for the UWB transceiver (right hand cavity in Figure 3).

[3] Additional test results of the compatibility of UWB emissions with onboard avionics equipment were provided under the DARPA *NETEX* (Networking in the Extreme) program [4].

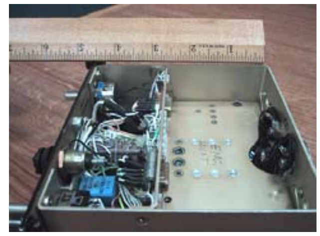
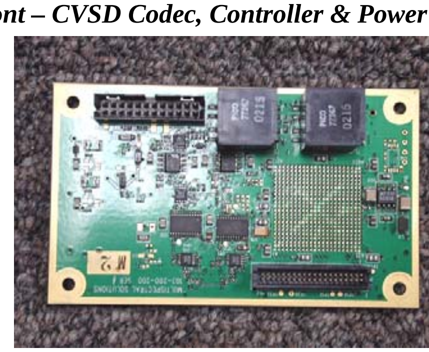


Figure 3. AIC-14 Redesign to Accommodate AWICS UWB Transceiver

As shown in Figures 4 through 6, the UWB transceiver was designed as a two board stack, containing UWB RF, digital, power and audio interface electronics. A separate broadband antenna (consisting of a dielectrically loaded wideband helix structure) was mounted on the front panel of the AIC-14 housing.

Figure 4. AWICS UWB Transceiver Module ($3^{5}/_{8}$ x $2^{3}/_{8}$ x 1 inches)

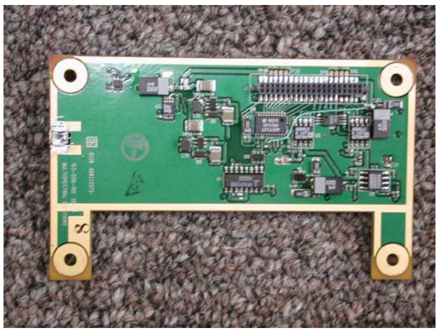
(a) Front – CVSD Codec, Controller & Power Supplies



(b) Rear – Audio Interfaces

Figure 5. AWICS Digital/Audio/Power Board

(a) Front – UWB Transmitter and Receiver



(b) Rear – T/R and RF Control Electronics

Figure 6. AWICS RF Board

A simplified block diagram is illustrated in Figure 7 below.

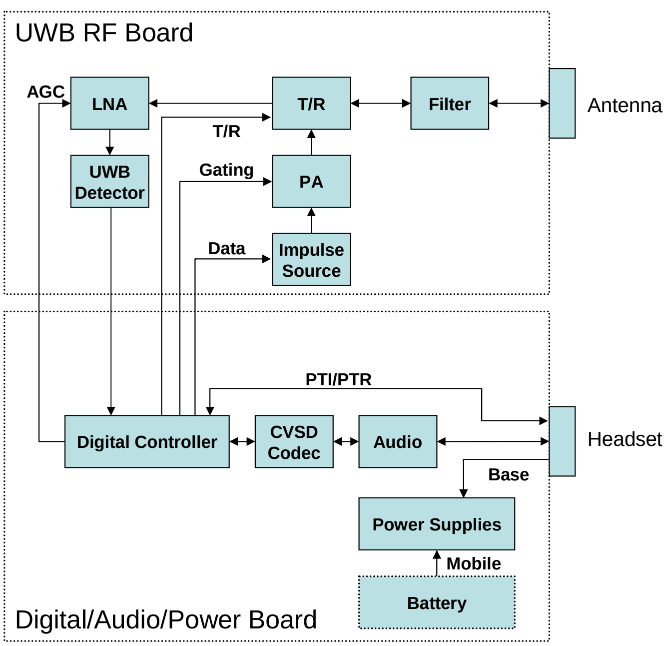


Figure 7. Simplified AWICS System Block Diagram

The system operates at L-band with an instantaneous -3dB RF bandwidth of 400 MHz (i.e., 2.5 ns burst waveform) and an Effective Isotropic Radiated Power of approximately +26 dBm. The transmitter utilizes bias control gating of the output power amplifier to lower the average battery drain requirement. With a receiver noise figure of approximately 5 dB (-83 dBm thermal noise floor), the system can accommodate a path loss of between 96 and 100 dB. A tunnel diode detector is used in the UWB receiver to permit single pulse detection, particularly important for reliable performance in severe multipath.

In order to accommodate eight simultaneous mobile users, a time division multiple access (TDMA) protocol is used, in which the UWB burst rate is 2.048 MHz (i.e., 488 ns interpulse arrival times). A 64 kb/s continuously variable slope detection (CVSD) codec is utilized for digital voice transmission, providing high quality audio reproduction. Each UWB packet consists of an 8 byte synchronization preamble followed by a 64 byte CVSD voice segment, 1 byte ID (with privacy bit and spare fields) and 10 byte Reed Solomon forward error correction (FEC) parity block. Synchronization is reestablished on each packet burst (83 bytes at 2.048 MHz for a total packet duration of approximately 324 μs), further improving multipath performance. The synchronization preamble also contains a short training sequence for establishing the optimum receiver gain setting (Receiver Signal Strength Indication, RSSI). TDMA time slots are established on 500 μs boundaries, with a super frame duration of 32 identical time slots to accommodate up to 31 simultaneous users and a single base station. For the AWICS prototype, only the first 9 TDMA slots are used.[4]

3. PROTOTYPE TEST RESULTS

Navy specifications required that the system maintain reliable communications within the fuselage of the aircraft, without dropouts due to structural interference or other blockage, while the mobile units were worn by crewmembers performing all required mission tasks. The harsh operational requirements of military aviation also required that the units be water resistant, as well as shock and G-force tolerant. The prototype mobile unit is shown in Figure 8 below. Physical dimensions are 5.25 inches long by 3.5 inches wide by 1.5 inches thick. A ruggedized, waterproof enclosure was designed composed of Delrin®, an extremely tough and heat resistant polymer, which appeared to be ideally suited for the AWICS application. A separate pouch was added to the upper left front quadrant of a standard, summer issue, flight jacket to hold the mobile transceiver during use. In

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[4] In another application for secure intra-boat communications, three sets of 8 simultaneous users, for a total of 24 users, were accommodated. In this system, additional voice encryption was incorporated using a 128-bit Advanced Encryption Standard (AES) algorithm embedded in an FPGA. See, for example, http://csrc.nist.gov/CryptoToolkit/aes/.

this configuration, the UWB antenna was located at the upper left chest area.

Figure 8. Prototype AWICS UWB Mobile Transceiver with Headset

The system was successfully demonstrated in February 2003 onboard both CH-53E *Super Stallion* and CH-46E *Sea Knight* helicopters at Marine Corps Air Station (MCAS) Quantico, VA (see Figure 1 above and Figure 9 below).

Figure 9. CH-46E *Sea Knight* Helicopter

Performance was very robust within the fuselage skin of both types of aircraft. No loss of communications was experienced in any location within the aircraft skin. Testing included having the user lie facedown on the deck of the aircraft, completely smothering the antenna and unit with his body. This was done to simulate a crewmember looking through the access hatch on the deck of the aircraft, which is an operationally routine occurrence on both aircraft. The mobile units were also placed behind spars and other structures within the aircraft to rigorously test blockage potential. No performance degradations were noted throughout internal testing. System capacity was tested with eight simultaneous users with no degradations of system performance.

Notably, communications with a disembarked crewmember were also tested with the engines and rotors engaged on the ground. The external user walked an arc around the aircraft at a range of approximately 50'. The external user did experience very slight pockets of dropout due to fuselage attenuation with the external user at the 12 o'clock position (off the aircraft's nose), the 4-5 o'clock position and the 7-8 o'clock position. In these areas, the direct signal path was obstructed by at least three layers of metallic fuselage structure. In the 12 o'clock area, the signal had to penetrate the nose of the aircraft, the cockpit instrument panel and a metal bulkhead aft of the pilot and co-pilot seats. At the 4-5 and 7-8 o'clock positions, the signal had to penetrate the fuselage and multiple layers of metal on each aircraft sponson, where the external fuel tanks are located. Subsequent system designs will maintain communications in these areas with improved antenna gain on the base transceiver.

The system was also tested with the aft cargo ramp of each aircraft open. Operationally, this is a normal occurrence where crewmen depart the aircraft via the aft ramp while disembarking infantry troops. Communications were maintained out to 200 feet from the aircraft in this disembarked crewman scenario. The external communications distances achieved during testing greatly exceeded the specification requirements under this prototype development.

4. SUMMARY AND CONCLUSIONS

UWB has been shown to have unique performance advantages for wireless transmission within severe multipath environments such as those encountered onboard aircraft. These advantages stem largely from the use of large bandwidth waveforms which, in the time domain, can be resolved from a multitude of multipath returns, provided the channel dispersion is short relative to the UWB pulse interarrival times. In the example shown in this paper, the pulse interarrival times were approximately 500 nanoseconds, corresponding to a free space propagation distance of roughly 500 feet. As this is much greater than the internal dimensions of a helicopter, multipath effects were minimized.

In addition, the correspondingly low average power densities of a UWB waveform have advantages for both low probability of detection and low probability of interference to onboard legacy systems. As illustrated here, the UWB AWICS system operated in L-band and exhibited no interference to onboard GPS receivers.

As shown, the results of prototype testing onboard the Navy and Marine Corps helicopters demonstrated the feasibility of using UWB technology for this application. Designed as a drop-in replacement for an existing wired system, AWICS may be easily interfaced to existing communications equipment onboard a wide variety of military platforms including small boats, fixed wing aircraft, rotary winged aircraft, Humvees, armored personnel carriers (APCs), and tanks.

A C-band version, operating in the 6-7 GHz band, is currently under development for commercial applications including home wireless intercoms, wireless telephones and wireless audio/video distribution systems.

5. REFERENCES

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