Proof of Concept Effort for Demonstrating an All-Digital Satellite Communications Earth Terminal

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ABSTRACT

The Space and Terrestrial Communications Directorate of the U.S. Army’s Communications- Electronics Research, Development and Engineering Center is executing a proof of concept program to develop and demonstrate an All-Digital Satellite Communications Earth Terminal. The Future Advanced Satellite Terminal (FAST) program initially focuses on the satellite terminal’s receive component of the satellite link. The two main efforts under FAST are a multi-carrier wideband digital downconverter and a wideband multi-carrier advanced signal processor. The downconverter is designed to simultaneously capture at L-band Intermediate Frequency (IF) all of the signals in a selectable 125 MHz-wide transponder bandwidth of the Wideband Global SATCOM (WGS) satellite and convert them into a digital in-phase and quadrature signal. This digitized signal is then passed over an American National Standards Institute (ANSI) VMEBUS International Trade Association (VITA) 49 interface to the wideband multi-carrier advanced signal processor, which will simultaneously process at least eight communications signals. Future plans for a complete transmit and receive terminal capability and a potential migration path from fixed frequency division multiple access (FDMA) carriers to a more dynamic process for allocating bandwidth, decentralized power monitoring and control, and remote terminal control are also discussed.

INTRODUCTION

Current DoD requirements call for an Enterprise Earth Terminal to be capable of supporting up to 48/96 (threshold/objective) transmit and 56/112 (threshold/objective) receive communications carriers. A single Teleport/standardized tactical entry point (STEP) site can consist of five or more terminals operating in several frequency bands. Even when using block up and down converters, a STEP/Teleport requires a complex Intermediate Frequency (IF) switch matrix subsystem to connect antennas to modems and to support monitoring and control functions.

By moving digital conversion as close to the antenna as possible, a number of efficiencies in performance, scalability, integration and ease of operation can be achieved. The expensive analog IF switch matrix can be eliminated and replaced with a lightweight digital distribution system. Without the need for an analog front end, the modem functions can be consolidated into a multi-card enclosure, where several carriers can be implemented on a single programmable processor card. And the monitoring and control function can have lossless access to the same digital information as the communications channel.

In addition, computerized control of the Configurable Basestation Processor and converters and the ability to simultaneously observe the Wideband Global SATCOM (WGS) downlink in transponder-width (125 MHz) segments, enables rapid terminal and network reconfiguration, decentralized power monitoring and control, and supports remote terminal control and hybrid waveform concepts like frequency division multiple access (FDMA) mesh networking. Collectively, these capabilities have the potential to dramatically increase satellite network efficiency and improve utilization of expensive satellite communications assets.

The United States Army’s Communications-Electronics Research, Development and Engineering Center
(CERDEC) has an effort in place to leverage commercially available technology and existing standards in order to demonstrate the practical feasibility of an all-digital SATCOM terminal. This paper discusses that effort, discusses some of the advanced capabilities enabled by an all-digital terminal, and discusses a migration path that enables an incremental roll-out of those features.

ALL-DIGITAL TERMINAL DEVELOPMENT AND DEMONSTRATION

Under a program called Future Advanced SATCOM Terminals (FAST), CERDEC is developing and will demonstrate an all-digital, multi-carrier receive capability integrated into a SATCOM terminal. Under separate contracts, CERDEC is developing a Direct L-Band Converter (DLBC) and a Configurable Basestation Processor (CBP), which will be connected with a standard interface. Use of a standard interface permits the CBP and the DLBC to be provided by different vendors but still interoperate. Figure 1 depicts the envisioned all-digital terminal architecture and compares it to a conventional terminal architecture.

The receive side of the DLCB will digitize the L-band output of a block down converter into its digital representation in In-Phase and Quadrature (I & Q) format. This digital I & Q signal will then be sent over a standard 10 GigaBit Ethernet physical connection in a VITA-49 digital IF data format to the CBP. The CBP will process the 125 MHz bandwidth of digital I & Q samples to ultimately demodulate all of the individual carriers operating within that bandwidth. Transmitting operates in reverse, with the individual transmit streams being processed into the appropriate digital I & Q representation in the CBP, then being sent over the interface to the DLBC and converted into an analog input to the L-band block up converter. A receive demonstration of the CBP and the DLBC integrated into an earth terminal is planned for late Fiscal Year 2011. A complete transmit and receive demonstration is also planned, but the schedule for that demonstration is still under development.

The CBP started as a Small Business Innovative Research (SBIR) Phase I study effort with Welkin Sciences in 2006. It proceeded to a SBIR Phase II effort in 2007, and was selected as a Commercialization Pilot Program (CPP) in 2010. The CBP performs the functions of:

- Packet former/parser for transmitting digital IF content between the CBP and the DLBC
- Channelization to/from the individual communications streams
- Digital Switching/Routing
- Modulation/Demodulation
- Control, Monitor and Alarm (CMA)
- Spectral Monitoring & Power Control
- Terminal Management
- Performance Monitoring and Test Subsystem (PMTS)

Key features of the current CBP effort include the capability to support at least eight simultaneous carriers (expandable to 112 carriers), support for representative Military Standard 188-165 waveforms, a graphical user interface for control and status, a mechanism to measure and report signal-to noise ratio (SNR) and bit error rate (BER), and support for redundant and fail-safe architectures. The CBP will also have a pass-through capability to enable it to interoperate at the digital I & Q level with an external modem. This will enable integration of existing modems with proprietary waveforms into an all-digital terminal with the least effort.

The objective of the DLCB is to be capable of synthesizing and digitizing an instantaneous bandwidth of up to 1 GHz, in intervals of 125 MHz, with a control feature such that the individual bands can be enabled or disabled. The initial implementation of the DLBC will be capable of supporting multiple carriers (48 threshold, 96 desired), in the range of 1000 – 2000 MHz, where individual carrier data bandwidth will range from 32 Ksps to 60 Msps. The initial DLBC will support simultaneous reception of at least two selectable bands, or 250 MHz total. The DLBC transmit and receive will be designed to comply with all applicable specifications in MIL-STD 188-165.

The interface between the CBP and DLBC will be sized to support 1 GHz of RF bandwidth, with the delivered interface able to support at least 250 MHz of RF bandwidth using three single mode 10 Gigabit Ethernet
(Gbe) fibers. The interface will be able to support upgrade to 40 Gbe fiber optic modules to support the 1 GHz bandwidth. It is anticipated that 40 Gbe Fiber standard shall be available by the time of the DLBC Critical Design Review.

A full-duplex interface is needed to pass the digitized signal representations between the CBP and the DLBC. The data streams are segmented in time into VITA 49 IF Data packets. The signal data for the transmit frequency bands (denoted A and C) generated by the CBP pass over the interface from the CBP to the DLBC. The signal data for the receive frequency bands (denoted B and D) captured by the DLBC pass over the interface from the DLBC to the CBP. A VITA 49 IF Context packet defines the associations between the frequency bands A, B, C and D with eight fixed 125 MHz wide sub-bands (1.000–1.125 GHz, 1.125–1.250 GHz, 1.250–1.375 GHz, 1.375–1.500 GHz, 1.500–1.625 GHz, 1.625–1.750 GHz, 1.750–1.875 GHz and 1.875–2.000 GHz).

The physical CBP to DLBC interface is comprised of three point-to-point single-mode duplex fibers. One of these fibers (denoted “FO Link 1”) carries the signal data stream associated with frequency band A from the CBP to the DLBC and carries the signal data stream associated with frequency band B in the DLBC to the CBP. A second fiber (denoted “FO Link 2”) carries the signal data stream associated with frequency band C in the CBP to the DLBC and carries the signal data stream associated with frequency band D in the DLBC to the CBP. The third fiber (denoted “FO Link 3”) carries parity data from which corrupted packets on FO Link 1 or FO Link 2 may be reconstructed.

The CBP-DLBC interface cannot tolerate the latency of an error control scheme relying on packet retransmission. Instead, the CBP-DLBC interface uses a forward error control (FEC) mechanism that reconstructs dropped Ethernet packets based on redundant parity data. The FEC mechanism employs two parity-checking schemes to provide a fault-tolerant and error-tolerant CBP-DLBC interface. One scheme, called “Inter-Link Forward Error Control”, uses FO Link 3. The second scheme, called “Intra-Link Forward Error Control”, uses parity-checking on the layer 2 Ethernet packet level. Figure 2 illustrates how these two schemes work together. Notice that VITA 49 IF Context packets are sent only from the CBP to the DLBC. The DLBC does not use acknowledge reception of a VITA 49 IF Context with a responding VITA 49 IF Context packet. That acknowledgement is implicit in the State and Event Indicators field of the trailer word in the VITA 49 IF Data packets sent from the DLBC back to the CBP.

Figure 2: FEC Mechanism Based on Two Packet-Level Parity-Check Schemes.

**POTENTIAL APPLICATIONS**

The CBP and DLBC together will replace the modems and the IF switch matrix in an earth terminal. This will eliminate the need for the complex and expensive L-band IF switch matrix, while providing an exact copy of the digital I & Q samples to the terminal control, monitor and alarm (CMA) function. Initial fielding can be accomplished in parallel with existing terminal hardware, so that new capabilities can be incrementally fielded. Use of MIL-STD 188-165 waveforms and the capability for interfacing external modems with the CBP enables over-the-air compatibility with existing terminals. And an interface with the L-band infrastructure within a terminal would enable the all-digital capability to be integrated into an existing terminal in parallel with the legacy equipment.

Since the CBP and DLBC will be computer controlled, they can be used to enable enhanced terminal configuration, operation, monitoring and control capabilities, which can also be incrementally fielded. Initially, this can be done manually through the CBP / DLBC graphical user interface (GUI). Changes can be time queued for pre-planned future execution. Parsing satellite access authorization (SAA) messages, with or without manual review, can begin a transition to remote automated terminal reconfiguration. Automated terminal reconfiguration can also enable rapid reaction to unforeseen events, as well as preplanned changes. This could potentially evolve into a demand-based reassignment of bandwidth. Since each all-digital terminal in the satellite beam has access to the entire receive band of interest, reassignment of bandwidth could be rapidly accomplished one carrier at a time in a make-before-break pattern, such that there is no break in communications traffic (analogous to defragmenting a hard drive).

Since each all-digital terminal can easily access the entire uplink and downlink bands of interest, all of a terminal’s traffic in a band can be consolidated into one FDMA
carrier. The router in each receive terminal could forward the traffic meant for that terminal and drop irrelevant traffic. This would aggregate all of the FDMA overhead into one carrier per terminal per beam and convert numerous point-to-point links into a mesh network. This concept is presented in Figure 3.

With an all-digital terminal, CMA functions could have ready access to the entire downlink band and have exactly the same picture as the communications function with no loss, via digital copy of the digital I & Q stream. Since the terminal can observe the downlink band of interest directly, it could be programmed to automatically adjust its transmit power levels within a pre-defined policy, subject to monitoring and correction by the CMA function. There is also the possibility of providing some monitoring capability to a Wideband SATCOM Operations Center where it currently can not see the downlink beam directly.

**EFFICIENT USE OF SATELLITE POWER**

Many SATCOM terminals employ some form of power control to mitigate rain fading effects. One of the key advantages of an all-digital SATCOM terminal is its ability to employ adaptive power control in a joint manner among all the links of the all-digital terminal. This joint power control process, which is referred to as the multiple-link approach, can be used to improve the power usage from the satellite. In a conventional SATCOM terminal, power control is accomplished on a single-link basis and the transmit power of each link is adapted without regard to the channel conditions of other links. On the other hand, in a multiple-link approach the transmit power of a particular link depends on the link characteristics of other links. It should be pointed out that the all-digital terminal can easily vary the relative power levels of the links to realize the advantages of a multiple-link approach. For this discussion let us assume that uplink power control is perfect so rain fading is present only in the downlink.

![Figure 4](image)

**Figure 4:** Satellite power under clear sky and rain fading conditions. (a) Single-link approach. (b) Multiple-link approach.

Figure 4(a) shows the satellite power allocated and required under clear sky and rain fading conditions. In clear sky conditions each link is allocated a power margin and the satellite transmits the minimum power required for that link together with the margin. Under rain fading conditions, to support the same coding and modulation rate, the minimum power requirement from the satellite will increase. Under severe rain fading conditions, this minimum power requirement exceeds the allocated power level for that link and this results in a link outage. As shown in the figure, Link 2 is in an outage and Links 1, 3 and 4 have sufficient margin to support the coding and modulation rate. In this single-link approach the additional margin available to Links 1, 3 and 4 cannot be shared with Link 2.

Figure 4(b) shows the multiple-link approach where the power margin is shared by all the links. Under rain fading conditions the required power from the satellite for all the links is still below the total power allocated. So, unlike in the single-link case, a link outage can be avoided for the multiple-link case. As shown in the figure, the multiple-link approach improves the link availability level for the
same total satellite power allocation. Alternatively, in the multiple-link case, the total satellite power can be reduced to achieve the same link availability level as in the single-link case.

![Figure 5: Advantage in satellite effective isotropic radiated power (EIRP) spectral density for the multiple-link approach. Legend denotes the availability level for a single-link system.](image)

Figure 5 shows the results for the advantage obtained in the satellite power for a multi-link approach over a single-link approach. Clearly, because of the larger margins required at higher link availability levels, the advantage improves with the availability level. For example, a terminal with 15 simultaneous links can achieve a satellite power advantage of about 6.5 dB at 99.5% availability level. These results are for a rain fading region comparable to Miami, FL, and this advantage increases for more severe rain regions, such as those in Southeast Asia.

**CONCLUSION**

The demonstration of an all-digital terminal is an important step in simplifying large earth terminal installations and eliminating the complex and expensive L-band matrix switch. The all-digital terminal’s capability for automated/remote control and ability to simultaneously observe entire transponders enables many possibilities to dramatically increase satellite network efficiency and improve utilization of expensive satellite communications assets. Additional study is needed to assess the promise and implications of these changes, examine policy and security issues, and to explore potential fielding increments.

**REFERENCES**


