SSC17-VII-01

Big Data Downlink Enablers for Next Generation Tactical U.S. Army Applications

Jon Watkins, Tyrel Newton, Daniel Reuster, Matt Hicks
Tethers Unlimited, Inc.
Bothell, WA, 98011; 425.486.0100
jwatkins@tethers.com

Mark Ray, Billy E Johnson
US Army Space and Missile Defense Command
Huntsville, AL, 35898; 256.955.3629
mark.e.ray.civ@mail.mil

ABSTRACT

Small satellites do not necessarily lack the capability to collect large quantities of relevant data. The real limitation in fielding large constellations of small satellites is the inability to efficiently downlink large quantities of collected data. Ground station assets and high-throughput communications subsystems that close the radio frequency (RF) link for large numbers of point-to-point "tight-beam" links are not yet available to support LEO constellations of small satellites. This paper summarizes emerging solutions to meet the demand for high data rate downlinks to support the 'big data' volumes enabled by large constellations of small satellites. These solutions utilize software-defined radio (SDR) platforms employing multi-band S-, X-, and Ka-band transceivers capable of closing SATCOM links in excess of 300 Mbps to small, tactically-placed ground stations. Key enabling technologies discussed include: three degree-of-freedom (3DOF) steering of small high-gain apertures; existing and in-development X- and Ka-band RF frontends with greater than 500 MHz of instantaneous bandwidth; baseband processors with greater than 500 MHz of modulation bandwidth; and baseband processors capable of streaming significant quantities of data to and from external high-density storage subsystems. This paper will then address applications to the operational relevance of the next generation of tactical U.S. Army small satellites and the viability of creating point-to-point, high bandwidth, 'over-the-horizon' communication links for remote users.

INTRODUCTION

In response to the increasing need for higher data transmission rates on a small satellite platform, the US Army Space and Missile Defense Command (SMDC) in conjunction with Tethers Unlimited Inc. (TUI) has developed the SWIFT® software defined radio (SDR), a modular plug-and-play radio platform that allows for multiple sub-system configurations. The SWIFT lineup includes Base2 software defined radio core and various RF frontend daughterboards, as well as the SWIFT COBRA™ Gimbal. The Base2 SDR core is a baseband processor that is highly programmable, power efficient and developed specifically for small satellites. It is the core building block of the SWIFT radio platform. The daughterboards include the SLX radio, which is an S-band transceiver consisting of an S-band transmitter, and both L-band and S-band receivers. The SWIFT-SLX is TUI's core telemetry, tracking, and command (TT&C) radio. The XTX and XRX radio cards provide an X-band transmitter and an X-band receiver, respectively. The KTX and KRX are TUI's K-band transmitter and receiver radio cards. One or more of these daughterboards can be paired with the Base2 processor to create a wide variety of radio configurations. Figure 1 shows such a configuration with a fixed antenna attached directly to the radio.

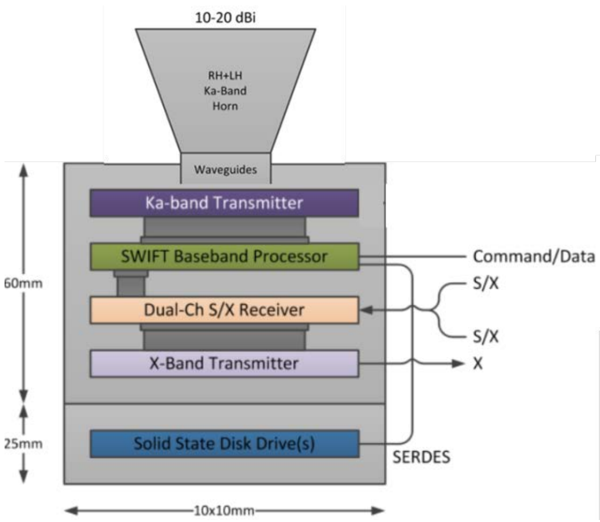

Figure 1: SWIFT Transceiver Configuration.

A solid state disk drive (SSD) utilizing a serializer/deserializer (SERDES) connection adds the ability to source and sink high-speed data directly on-board the satellite. A second, more capable, configuration utilizing TUI's COBRA Gimbal along with the SWIFT transceiver is shown in Figure 2. The COBRA Gimbal is a beam steering platform allowing three degree-of-freedom (3DOF) steering of small high-gain apertures and providing continuous pointing without inducing cable twist/wrap. Utilizing this key technology, the COBRA gimbal, SWIFT RF frontends, and the baseband processor, TUI's SWIFT radio transceivers are capable of SATCOM links in excess of 300 Mbps.

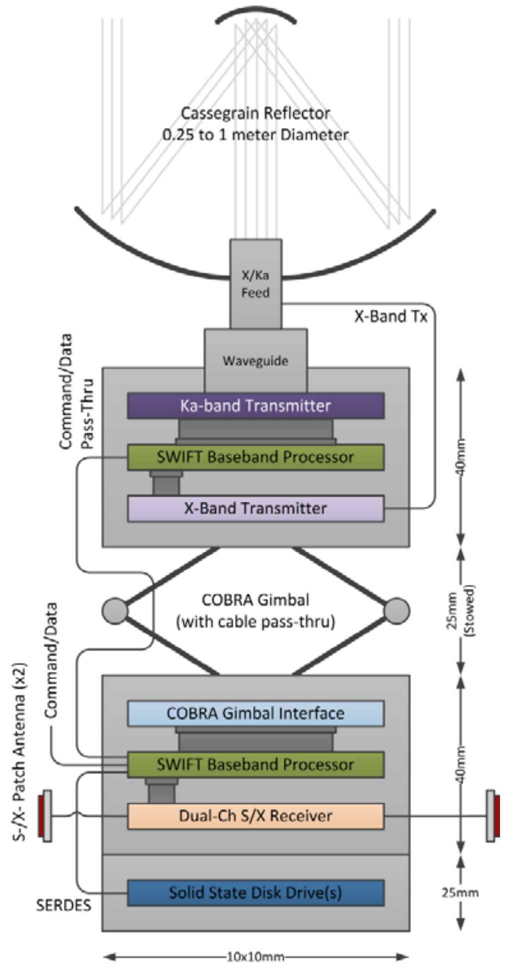

Figure 2: SWIFT Transceiver Configuration *with integrated antenna pointing.*

KEY TECHNOLOGY

Baseband Processor

At the center of the SWIFT radio platform is the Base2 baseband core processor. The baseband processor is a highly programmable, power efficient SDR platform specifically designed for small satellites. A single high-density FPGA is connected to high-speed analog converters and significant onboard RAM and ROM. A PLL-based clock synthesis and distribution chip provides low jitter analog sampling clocks and programmable reference clocks for other modules in the system. Modular RF frontends allows the baseband processor to operate on signals from arbitrary frequency bands. Figure 3 shows a block diagram of the baseband processor.

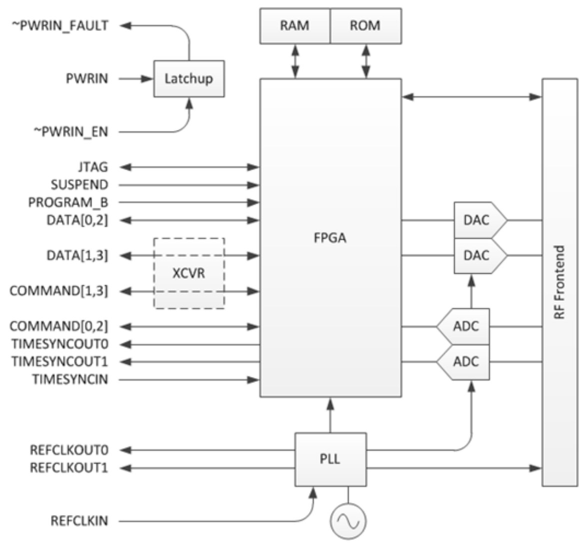

Figure 3: Simplified Block Diagram of the Baseband Processor

The current SWIFT baseband processor has roughly 50 MHz of linear modulation bandwidth, which is enough to create 50-100 Mbps class downlinks in X-band using the XTX RF frontend.

SWIFT High Bandwidth (HB)

To reach the requested 300 Mbps and above, the next generation of SWIFT baseband processor is required. It will increase the instantaneous bandwidth by an order of magnitude without breaking the current form factor. The new baseband will include the ability to source and sink high-speed data to and from a Solid State Disk Drive (SSD). The SWIFT HB processor will enable a new class of total data volumes for small satellite missions. The high-performance SWIFT baseband processor will provide two key features:

- Linear in both gain and phase modulation bandwidths more than 250 MHz
- High-speed serial digital interfaces for connecting to external storage arrays

Another key feature is the use of high-speed serializer/deserializer (SERDES) signaling. The high-speed SERDES interface is the host spacecraft interface where large amounts of data can transfer between radios via Gigabit Ethernet, SATA/SAS, Fiber Channel, etc. Figure 4 shows a block diagram of the next generation baseband SWIFT HB processor.

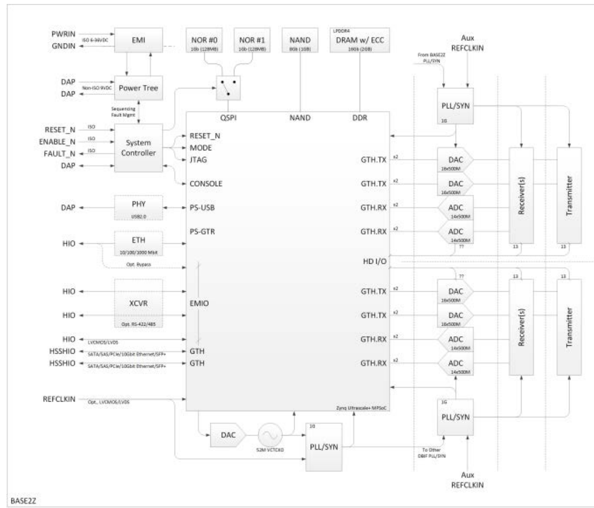

Figure 4: Block Diagram of the SWIFT HB *baseband processor*

The SWIFT HB will be both electrically and mechanically compatible with the existing RF front end daughterboards.

SLX Transceiver Daughterboard

One common instance of the SWIFT architecture is the SWIFT-SLX, which combines the Base2 processor with a SLX transceiver daughterboard. The SLX transceiver (Figure 5) is a frequency and waveform agile, coherent S-band transmitter and dual L- and/or S-band receiver unit. Originally designed to interoperate with the AFSCN, the transceiver is flexible enough to be used with any S-band ground station network, including NASA's NEN, TDRS, DSN, and any commercial S-band ground station with the only difference being the loaded firmware[1]. Key features include:

- >2W S-band Tx w/ 10 MHz bandwidth
- 1.7-2.7GHz Tx frequency coverage
- Independent receivers w/ 10 MHz bandwidth
- 1.0-3.0GHz Rx frequency coverage
- 1 dB receiver noise figure
- Arbitrary waveform/modulation/coding
- Typical LEO max.: 5Mbps down, 1Mbps up
- 100% on-orbit re-programmable with fail-safe boot modes
- Optional diplexer for full-duplex S-band ops

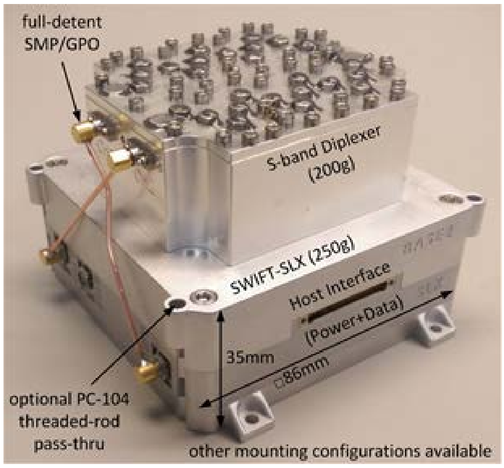

Figure 5: SWIFT SLX Transceiver.

Higher Speed Data Downlinks (XTX and KTX Daughterboards)

For higher data downlinks, the SWIFT SDR platform can integrate both an X-band transmitter (XTX) as well as a K-band transmitter (KTX) option. The SWIFT-XTX provides small satellites with a reconfigurable and reprogrammable architecture for creating high-performance X-band datalinks. Applications for both include 100 MHz data downlinks for remote sensing, multi-antenna satellite cross links and command/telemetry links for deep space missions. The XTX RF daughterboard is shown in Figure 6.

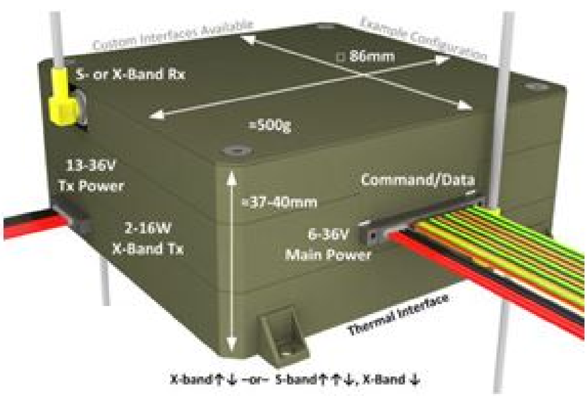

Figure 6: SWIFT XTX Software Defined Radio

The SWIFT-KTX provides even higher throughput downlink in the K-band with an optional uplink in any other band between UHF and Ka. The waveform and coding agility of the software defined radio enables a wide range of link margins to suit multiple missions and multiple mission profiles. Key features include:

- >1W K-band Tx w/ >100 MHz bandwidth
- 17 to 40 GHz K-band Tx frequency coverage in multiple sub-bands
- Arbitrary waveform/modulation/coding

High-order modulation schemes, such as {Q,8,16A,32A}PSK, combined with >100 MHz of instantaneous bandwidth and high-efficiency puncture and turbo codes enable real data rates in excess of 300 Mbps. A significant amount of onboard memory and processing enable high-throughput/low-latency packet processing. Figure 7 shows an example of the SWIFT KTX radio with waveguide-to-coax adapters.

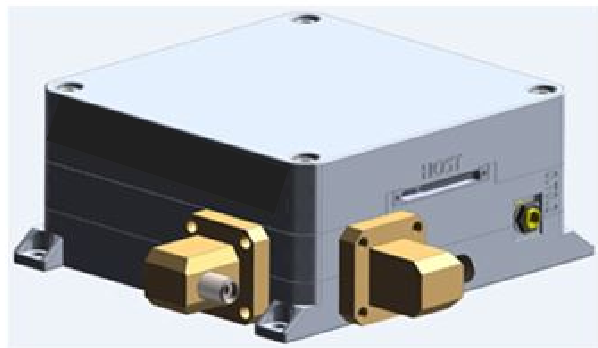

Figure 7: SWIFT KTX Software Defined Radio *with waveguide-to-coax adapters.*

High Performance Uplink (XRX and KRX)

In addition to higher data downlinks, the SWIFT SDR platform also can integrate both an X-band receiver (XRX) as well as a K-band receiver (KRX) for higher data uplinks. When paired with a transmitter, applications can range from high-throughput multi-receive communications links and command/telemetry links for deep-space missions. Both the XRX and KRX radios provide >100 MHz of bandwidth.

Ka-band Transceiver SDR

The RF technology development presented in the previous sections is designed to reduce fabrication costs, but it also allows for locating complex digital circuitry closer to the antenna[2]. This in turn reduces the overall size and weight of the transceiver subsystem, which are critical attributes for small satellites.

Figure 8 and Figure 9 show the possible instantiation of a Ka-band transceiver that is tightly integrated to a pair of horn antennas and a digital baseband processor with a 1Gbit Ethernet interface housed in a 6U satellite vehicle.

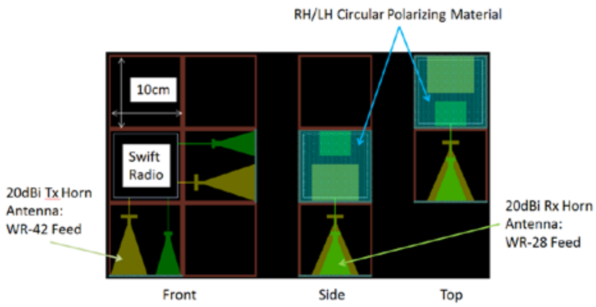

Figure 8: Possible Integration of a Ka-band transceiver *in a 6U satellite vehicle.*

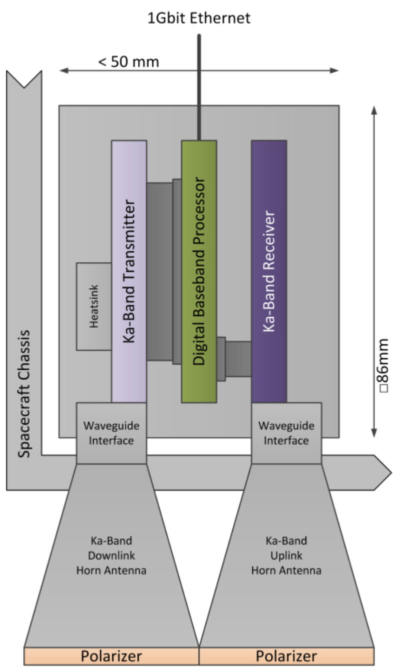

Figure 9: Possible Integration of a Ka-band transceiver *connected to a pair of horn antennas with circular polarizers*

The tight coupling of microwave components and FPGA-based digital frame processing enables a very small transceiver to implement a high-level of 'packet-to-RF' abstraction, as outlined in the block diagram of Figure 10. Figure 10 shows UDP-based frame processors and QoS-prioritized frame multiplexers directly connected to software-defined modulation and coding transmit and receive paths.

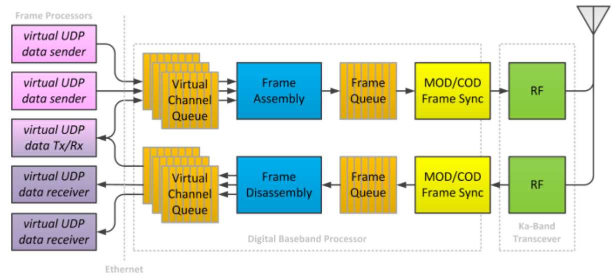

Figure 10: Possible Integration of a Ka-band transceiver *connected to a pair of horn antennas with circular polarizers*

COBRA Gimbal

To improve data links even further, the pointing of a high gain antenna aperture is achieved through the use of a gimbal. TUI's COBRA gimbal is a three degree of freedom gimbal capable of continuous full hemispherical-plus pointing with accuracies better than 0.5 degrees, and supporting slew rates of greater than 30 degrees per second. The carpal-wrist joint architecture of the COBRA gimbal, adapted from the "Canfield Joint" mechanism originally developed by Dr. Stephen Canfield of the Tennessee Tech University, also allows for continuous rotation without the need for failure-prone and costly slip rings or rotary joints. This provides a significant reduction in system risk and complexity. These capabilities make the COBRA gimbal an ideal solution for small satellite antenna pointing applications and provide significant improvements over state-of-the-art gimbal mechanisms.

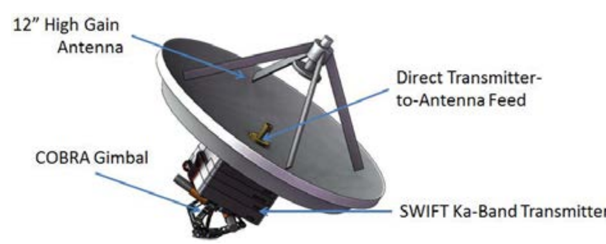

Figure 11: COBRA Gimbal with SWIFT Ka-band Transmitter and High Gain Antenna

Utilizing the SWIFT KTX transmitter, from the SWIFT SDR line, a 12" Cassegrain feed reflector and the COBRA gimbal (Figure 11), greater than 100 Mbps K-band downlinks are achievable. Alternate architectures to provide forward links as well as return links are readily integrated given the modularity of the SWIFT SDR architecture.

RADIO INTEGRATION SCHEMES

Due to the small form factor and plug-and-play stack-up of the SWIFT radio platform, there are a wide variety of configuration examples (Figure 12).

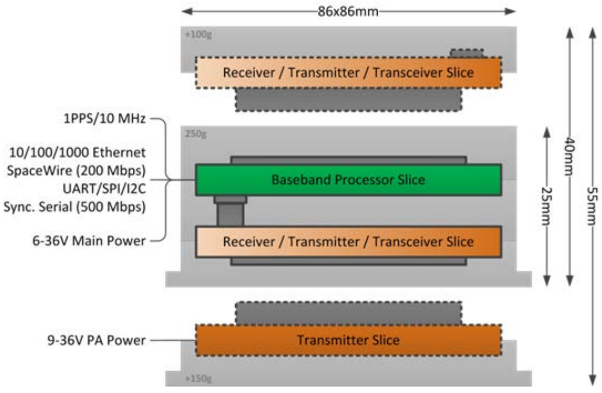

Figure 12: Generic SWIFT Radio Configuration

Pairing the baseband radio with the different RF modules, a wide variety of configurations are possible, from a radio with a single transmitter to one utilizing 4 receivers and 2 transmitters (see Figure 13). Some examples of the different possible stack-ups are as follows:

- SLX Radio
  - Baseband Radio
  - SLX Transceiver
- XTS Radio
  - SLX Transceiver
  - Baseband Radio
  - XTX Transmitter
- KTS Radio
  - SLX Transceiver
  - Baseband Radio
  - KTX Transmitter

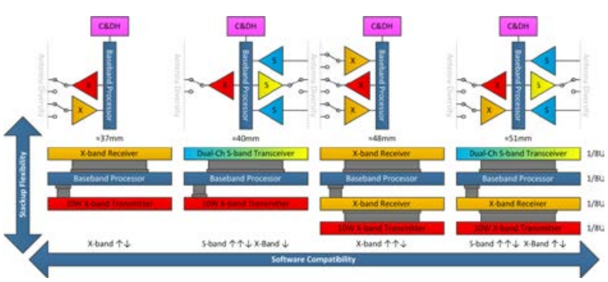

Figure 13: Possible XTS Radio Configurations

MILITARY COMMUNICATIONS

Military utility of LEO small satellites for low bandwidth voice and data communications have been demonstrated with Space and Missile Defense Command – Operational Nanosatellite Effect (SMDC-ONE)[5], Soldier Nanosatellite Program (SNaP)[1] and others. Technology and demonstration activities are naturally trending towards increased capability and higher complexity. The agile SWIFT SDR design provides flexibility for a variety of missions.

A noted trade of operating in LEO is that many satellites are needed to provide comparable coverage due to constellation motion and the relatively low field-of-view compared to GEO. Additionally, tracking requirements, including angular, range, range rates, and Doppler distortion for ground terminals become significant. However, these effects and short revisit time can be desired mission features in certain applications.

Mission Data Downlink

Today's mission payloads (e.g. remote sensing) have the capability to collect large quantities of relevant data which must be downlinked to the user. For LEO satellites with short access times and multiple revisits it is highly desired to downlink as much payload data as quickly as possible. SWIFT-HB is expected to provide large amounts of data to enable these applications.

Legacy Tactical Networks

Ka-band Transceiver SDR is applicable for tactical networking applications. Legacy tactical networks operate in Ka-band utilizing vehicle-mounted mechanically steered on-the-move (OTM) antennas and modems to communicate through satellites in GEO. LEO satellites have the opportunity to augment and supplement the GEO capability but only if the concomitant challenges of LEO can be addressed. Army SMDC is partnered with TUI to address these challenges in a technology demonstration program.

Next-Generation Data Links

As the Army moves toward an increased expeditionary mission command capability, the prospect of employing LEO orbits as a solution becomes even more attractive. Expeditionary forces, which may lack access to traditional SATCOM will have a complement of services in any local – provided there are satellites in an appropriately chosen set of orbits.

SUMMARY AND CONCLUSION

The highly programmable, power efficient SWIFT SDR family is developed specifically for small satellites. The daughtercard architecture supports a variety of mission ready configurations. The ability to highly integrate the baseband, radio and antenna is critical for small satellite adoption where volume is critical.

The technology advancements described above combined with recognition of military utility of small satellites in LEO and the insatiable appetite for SATCOM[1] taken together represent an opportunity for a disruptive innovation, creating new value propositions for the US Military and other communications customers.

References

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