Distributed SATCOM On-The-Move Terminal Open Standard Architecture Architectural Details

Jeff Hoppe, Tat Fung, Syed Akbar, and Tom Rittenbach

***Abstract*—The U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC), with a consortium of industry partners, is developing the Distributed Satellite Communications (SATCOM) On-The-Move (SOTM) Terminal (DST) Open Standard Architecture (OSA). The DST OSA is a nonproprietary, open architecture for the engineering design of a SOTM terminal with distributed antennas integrated on a tactical ground vehicle. The open standardized interfaces between system components are intended to increase market competition and reduce acquisition and life-cycle costs for DST components. Furthermore, the modular architecture defined in the DST OSA will enable research and development efforts to be more efficient and lower risk by focusing on the component level. Modular component development will in turn increase the speed and frequency of system technology refresh and new deployment. Current developments in system architecture are described in this paper.**

***Index Terms*—antenna, distributed, modular, open architecture, SATCOM, standards, terminal.**

TABLE I
DST OSA CONSORTIUM INDUSTRY MEMBERS

Member Company	Point of Contact
Alico Systems, Inc.	Syed Akbar
Ball Aerospace & Technologies Corp.	Wes Pickens
FIRST RF Corp.	Tim Meenach
General Dynamics	Stuart Williams
Harris Corp.	Tom Saam
L-3 Linkabit	Dave Leung
Mercury Systems	Brian Kimball
Northrop Grumman Corp.	John Featherston
ThinKom Solutions, Inc.	Bill Milroy
Toyon Research Corp.	Ryan Strader

I. INTRODUCTION: DST OSA CONSORTIUM

The Distributed Satellite Communications (SATCOM) On-The-Move (SOTM) Terminal (DST) Open Standard Architecture (OSA) is under development by a joint consortium of government agencies and industry partners with a common goal of modularizing and standardizing interfaces for distributed antenna SOTM terminals. The DST OSA consortium, which began in March 2015, currently consists of a U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC) government team that includes U.S. Army and Navy representation and members from 10 industry partners (see Table I).

The mission of DST OSA is to reduce the system costs of distributed SOTM terminals by increasing competition among SATCOM terminal developers for the component products delineated by the architecture interfaces. The modular architecture logically identifies each component along functional lines, which will allow companies to invest and innovate with confidence. DST OSA will be an open-source product wholly owned by, and initially managed by, the U.S. government. As such, it can be assured that all U.S. government contractors will have access to the standard.

The DST OSA consortium has used modular open systems architecture (MOSA) techniques to achieve a modular framework that allows the realization of flexible and robust DST systems that are generally platform, frequency band, and modem agnostic. Simultaneously, each OSA system component needs to be compatible, interoperable, and interchangeable, such that uniform test and evaluation can be used to speed integration to fielded systems.

The DST OSA carefully weighs this dichotomy of requirements to achieve a natural balance between reduced system life-cycle costs for the military and increased market share for companies with the best solutions.

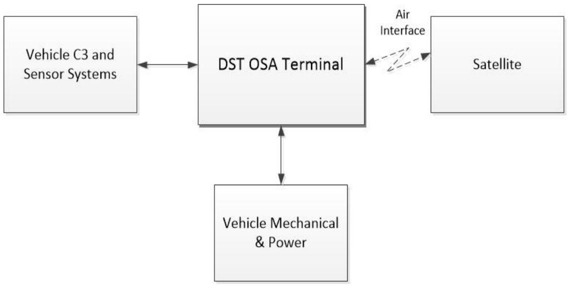

Fig. 1. DST OSA Terminal and external system interfaces.

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Fig. 1 illustrates the DST OSA Terminal and the interfaces to external systems. Fig. 2 illustrates the components in the DST OSA. The OSA Specification Level identifies the component-level interfaces defined in the DST OSA.

Comparison of Fig. 1 and Fig. 2 shows that while components such as the vehicle Installation Kit, Vehicle External Interfaces, and Satellite Air Interface are not part of the DST OSA Terminal hardware, they are necessary external components/systems with which the DST OSA Terminal must interface.

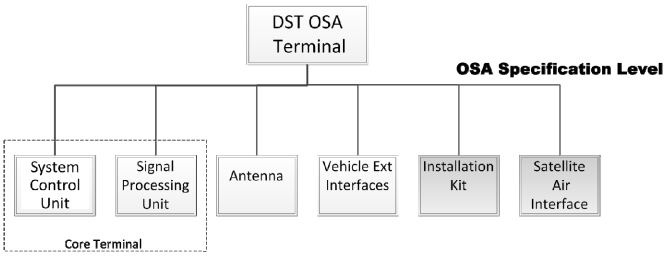

Fig. 2. DST OSA component-level architecture.

II. DST OSA System Architecture

Fig. 2 identifies the six major components of the DST OSA:

- System Control Unit (SCU);
- Signal Processing Unit (SPU);
- Antenna;
- Installation Kit (IK);
- Vehicle External Interfaces;
- Satellite Air Interface.

The SCU and SPU make up the central core terminal subsystem of the DST. The SCU's prime responsibility within the core terminal is to monitor and control the system. The SPU's prime responsibility is to combine signals from the DST's multiple antennas into a coherent receive (Rx) signal; this function is necessitated by the use of multiple antennas with varying levels of performance at various look angles to the satellite. The combining function will smooth out the performance variation of the distributed antennas. Ideally, combining will provide a seamless hemispheric performance of the antenna subsystem.

Along with transmitting and receiving the communications signal, the antenna component has the key role of satellite acquisition and tracking. The tracking system must compensate for movement and vibration of the tactical vehicle.

The three remaining components are considered external systems of the DST OSA Terminal. They are not vehicular platform, modem, and frequency agnostic; as such, the interfaces described for these components are specified only by requirements in the DST OSA document.

The first is the IK component. This component provides the vehicle-specific cables, mechanical mounting adapters, and connectors needed to install the DST OSA Terminal on a vehicle. The second is the Vehicle External Interfaces component, which identifies the additional equipment necessary for DST operation. This is equipment typically found on ground tactical vehicles, as they prove necessary for other vehicular functions. Lastly, the Satellite Air Interface is a major component that must be specified for operation of the DST OSA Terminal.

The interconnecting interfaces between the aforementioned six components define the DST OSA standard. These interfaces will be specified via formal Interface Control Documents (ICDs), which will be nonproprietary and open to the U.S. government and U.S. Department of Defense (DoD) contractor community.

III. Architecture Component & Subcomponent Definition

The DST OSA consortium used a MOSA process to ensure the completeness and functionality of the DST OSA. The consortium process began with a functional decomposition of a DST OSA Terminal shown in Fig. 3. From this functional decomposition, a reference implementation was developed utilizing that architecture. Finally, the reference implementation was used to determine and describe the necessary interfaces between the components.

It should be noted that only the component-level interfaces are described in the OSA (see "OSA Specification Level" in Fig. 3). Subcomponent interfaces are not described, as they will be implementation specific and potentially proprietary. The OSA requires interface compliance only at the component level.

IV. OSA Component: System Control Unit

The primary role of the SCU component is to monitor and control the DST. From a hardware perspective, the SCU contains the primary processing and data storage capabilities of the system. The SCU also includes two Ethernet switches (Fig. 4), making the SCU the primary communications hub for the terminal. The processing, storage, and communications capabilities of the SCU make this component ideal for monitoring and control.

The SCU's Terminal Controller (TC) performs the monitor and control function. The TC controls the systems as a finite state machine. The state of each DST component is coordinated by the TC by advertising the state transitions to each component. The TC then utilizes a state-specific command set for each component. The TC monitors the system via distributed Built-in Test (BIT) functions in each component of the DST. Each BIT is designated to operate initially, on command, or continuously during operation. The BIT commands also utilize a prioritization and acknowledgement scheme to ensure they are dealt with in order of importance and in a timely fashion.

Another TC function is to install, provision, and configure the terminal. To accomplish this, the TC needs to develop and store data files and must have the ability to modify those files via interaction with the end user. While the end user interface

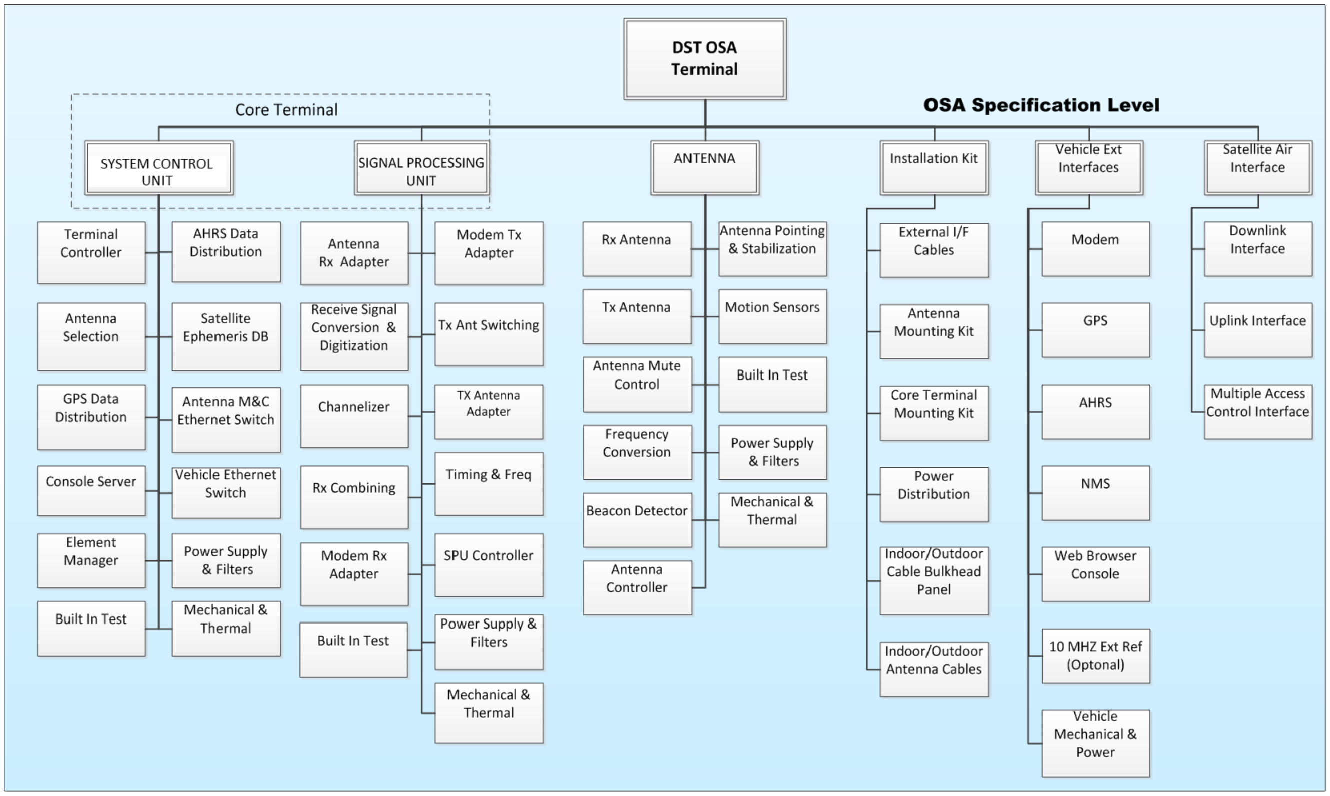

Fig. 3. DST OSA components and subcomponents.

to the DST is revealed through the Web Browser Console and/or Network Management System (NMS) external equipment, the SCU's Console Server hosts this function and provides a wired Ethernet network interface to these systems.

The storage capability of the SCU provides access to the files necessary to install, provision, and configure the terminal. These files include the Satellite Ephemeris Database, Antenna Mounting and Configuration files, and platform No Transmit Volume (NTV) files. (Note: NTVs identify volumetric regions on the platform where the transmitting antenna is blocked or where antenna radiation would endanger the safety of vehicle personnel.)

The SCU's processing and communications capabilities make it the logical selection for the transmit (Tx) Antenna Selection function. This function needs significant processing power to support a real-time pointing vector algorithm, along with the communications input from antennas and external equipment (e.g., Attitude and Heading Reference System (AHRS), Global Positioning System (GPS), modem, etc.). The Antenna Selection function will likely be implementation and SCU specific and will include a vendor proprietary algorithm that allows the DST to dynamically select the transmitting antenna. Antenna Selection algorithms are an example of an area in which the OSA encourages vendors to innovate and mature the system with proprietary solutions.

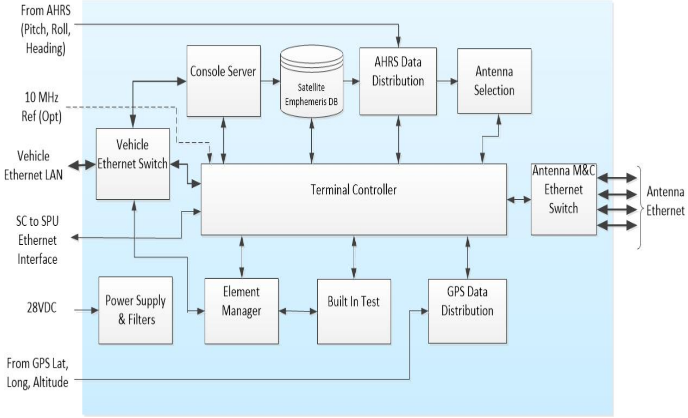

Fig. 4. SCU notional block diagram.

The SCU, in addition to selecting transmit aperture, is responsible for preparing the antenna system for transmission; i.e., when the system control software determines that the current transmitting antenna is no longer the best Tx aperture, the SCU commands another Tx aperture to power up its power amplifier to transmit. Once the Tx aperture switchover has been completed, the previous Tx antenna powers down its power amplifier until its next transmission.

Finally, the SCU must interface with a large variety of currently deployed and commercially available external equipment (AHRS, GPS, NMS, modem, satellite, etc.). To ensure this compatibility, the DST OSA document strays from its conventional bit-level interface descriptions and provides interface requirements only to external equipment. An example of these requirements is the use of Ethernet or Serial Protocol for the external interfaces identified in Fig. 5.

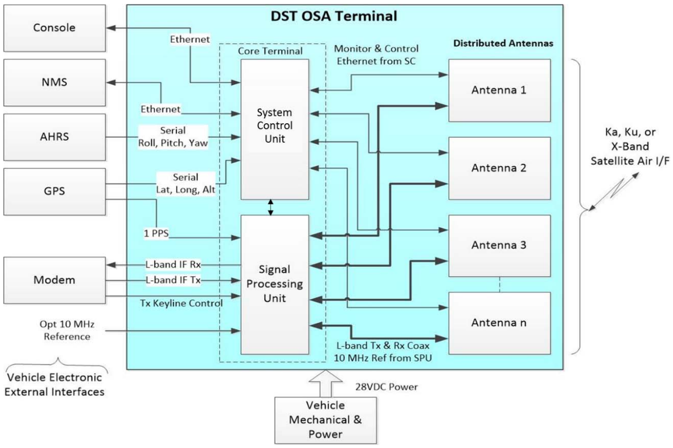

Fig. 5. DST OSA hardware interface diagram.

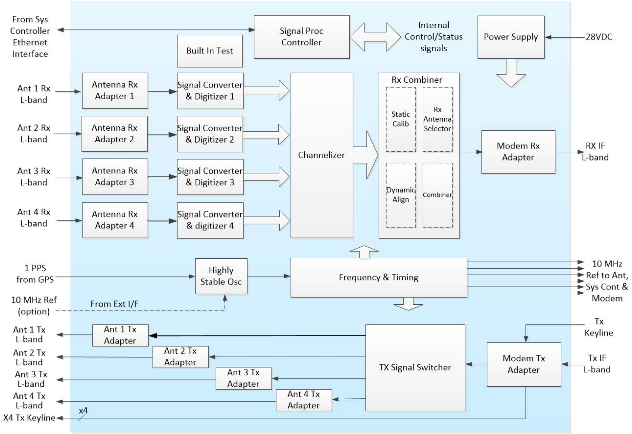

Fig. 6. SPU notional block diagram.

V. OSA COMPONENT: SIGNAL PROCESSING UNIT

The SPU component notionally comprises a single board computer (SBC), a field-programmable gate array (FPGA)-based beam combiner, a modem interface adapter, a clock distribution module, and various input/output and filtering elements.

For the receive path (from antennas to modem), the primary function of the SPU is to combine the analog intermediate frequency (IF) signal from each of the receive antennas to a single coherently combined IF analog signal for the modem. However, there are several technical challenges in executing this function. First, the satellite communications signal arrives at different times at each antenna, and the time interval between the signals changes due to the movement (including vibration) of the platform. Second, the signal arrives at a different amplitude due to the angle of arrival to a (typically) flat-panel phased-array antenna and different propagation paths. Third, the lengths of electrical cable that route the signal from the antenna to the SPU are arbitrary (i.e., unknown prior to signal arrival). This can be due to antenna spacing changes at integration and/or real-time cable heating/cooling.

To coherently combine signals in this environment, a level of flexibility is needed in the system to account for these variables. As a result, the primary method for coherent combining for tactical platforms is to digitize the receive signal prior to coherent alignment in the time domain.

The OSA functional decomposition (Fig. 3) identifies the functional components necessary for digital signal conversion, coherent combining, and digital to analog conversion for the modem (via the Modem Rx Adapter). These functions include Receive Signal Conversion, Channelization (discussed later), Rx Combining, and Modem Rx Adapter. The SPU notional block diagram (Fig. 6) identifies the signal flow through blocks of similar names.

The SPU Rx Combining function is an implementation-specific, and likely proprietary, algorithm for each DST. The SPU Rx aperture combining function is responsible for analyzing the received signal characteristics from all of the distributed Rx antennas and applying the appropriate signal adjustments to each such that the four received signals can be combined into one coherent Rx signal of sufficient signal-to-noise ratio that the modem may process it.

For coherent combining, and stable frequency conversion throughout the terminal, it is necessary to have a single highly accurate timing and frequency reference for the system. For conversion, this ensures that all multiples of this frequency have a common phase relation to each other. The SPU receives a timing reference (1PPS) from the platform GPS and uses this to tame its local oscillator. The SPU then distributes this common timing reference to the antennas and modem for the same purpose. The DST OSA SPU includes provisions for an external frequency reference if GPS is not available.

Finally, tactical SATCOM systems often are required to perform a dual-use function. Specifically, it may be necessary for the system to act simultaneously as a hub (i.e., relay a signal) and as a user (i.e., receive its own signal). As a result, the system must support noncontiguous banded frequency segments, in between which there is only noise.

The SPU Channelizer allows the system designer to choose the appropriate architecture for the SPU to process the required IF bandwidth. In some cases, a single analog-to-digital (A/D) conversion system is most effective in meeting the desired Size, Weight, and Power – Cost (SWaP-C) constraints. In others, several tunable band-pass filters and converters may be more effective.

For the transmit path (from modem to antennas), the primary purpose of the SPU is to route the signal to the proper antenna chosen by the SCU. The OSA supports two primary methods for this function.

The first method is analog switching. In this method, the Tx Signal Switcher is synchronized to a modem key-line function implemented via an RS-422 level discrete signal that starts at the modem and runs through the SPU and to the antennas. In this method, there is no buffering of the transmit signal. When the modem key-line is on, the communications signal flows from the modem through the Modem Tx Adapter (which provides analog signal power adjustment and filtering), to the analog Tx Signal Switcher (which is always preset by the SCU), and to the appropriate antenna for transmission.

The second method is digital switching. This method may be preferable for time division multiple access (TDMA) modems, where time delays due to signal combining on the receive end require that the transmit signal incorporate the same time delay to synchronize the TDMA receive and transmit time slots.

In the second method, the modem interface adapter takes the analog IF and converts it to digital IF, and the Tx Signal Switcher not only switches the signal to the appropriate antenna but also includes a time delay circuit to synchronize the transmit signal.

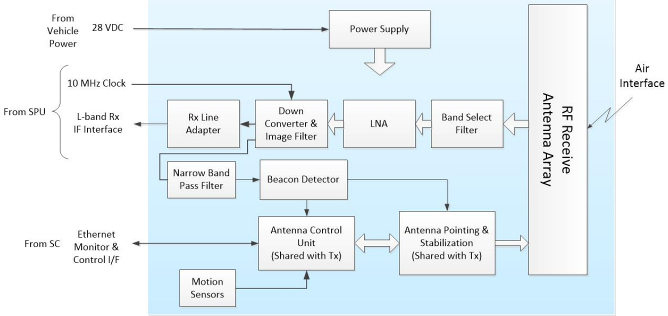

Fig. 7. Notional transmit antenna block diagram.

The role of the modem adapter in both transmitting and receiving is to condition the signal as necessary to work with the modem prescribed for the intended application. DST OSA does not define the modem interface, only interface requirements, because the modem is an external device where are many commercial and legacy military types. Two requirements of note are: The transmit and receive IF interface frequency shall be within 1500 ± 500 MHz, and the modem shall provide a transmit key-line signal. This second requirement is essential for DST systems, as it enables these terminals to manage the critical vehicle resource of consumed power.

VI. OSA Component: Antennas

The OSA recognizes that a multitude of antenna types will be necessary for various applications of DST. That being said, the DST distributed antenna system will consist of several distributed Tx/Rx antennas integrated around the vehicle platform. An assumption of the current OSA is that Tx/Rx aperture pairs are collocated in a common assembly such that they are non-separable. While this assumption simplifies the safety requirement of determining if a transmit aperture is blocked, it also restricts the development and integration of DST antennas. If deemed prudent for DST systems integration, future versions of the OSA can remove this assumption.

All DST distributed antennas consist of Tx and Rx Antenna apertures, an Antenna Mute (i.e., attenuator or power control) unit, a Beacon Detector, a Pointing and Stabilization Unit, a BIT unit, Frequency Converters (i.e., radio frequency (RF) to/from IF), an Antenna Control Unit (ACU), and Motion Sensors (i.e., inertial sensors). The functionality of these subcomponents includes antenna control, health/status, emitted power control, movement and tracking, directional RF reception and radiation, and IF transmission.

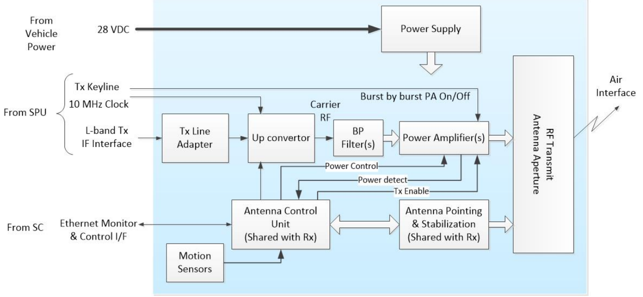

Fig. 8. Notional receive antenna block diagram.

The satellite pointing and tracking function resides in the antenna. While this decision seems counterintuitive for reducing overall system cost (as each antenna must contain the pointing and tracking system), the more intuitive choice of locating a single pointing and tracking system in the SCU would necessitate a high-speed and low-latency interface to account for vehicle vibration (likely a separate, dedicated physical interface with additional costs). The antenna's Pointing and Stabilization Unit uses local motion sensors, normally in the form of a multi-axis accelerometer and gyro, to develop a local pointing vector to track the satellite.

It should be noted that the OSA choice to locate the pointing and tracking system in the antenna is specific to systems and environmental requirements commensurate with the tactical platforms (i.e., small antenna sizes, tracked vehicles, and multiband-capable X, K_u, and K_a systems).

One role of the ACU is to facilitate central control of pointing and tracking. Some antennas can be controlled across three degrees of freedom: two orthogonal coordinate axes and polarization. Some antennas may require more degrees of control, such as a tertiary coordinate axis. Pointing control is implemented through various means, including mechanical mechanisms (such as rotating plates or gimbals) or electrical means (amplitude and phase control devices). As such, the ACU will be implementation specific and vendor proprietary.

The antenna Frequency Converter component includes the means to translate the interfacing IF signals to and from the desired transmit and receive RF signals. This is commonly performed using a block up-converter (BUC) and a block down-converter (BDC). The BUC and BDC require an external reference timing signal, nominally a 10-MHz sinusoidal signal, from the SPU to ensure frequency stability and synchronization.

The DST will be compliant with MIL-STD-188-164B and, as such, must exert positive control over the transmitted power at all times. The SPU and antennas provide a means to adjust power with commands from the SCU. This is accomplished through variable attenuation in the transmit signal chain. The antenna also provides the function to completely mute the Tx signal, as is required by the standard.

The ACU also serves as the primary controller to facilitate all communications from the core terminal to the antenna subsystem. The ACU has the task of monitoring all internal subsystems for health and status and providing timely feedback to the SCU in an anomalous event. The SCU will periodically request status from the ACU, and at that time the ACU will respond with the current state of the compiled subsystems' status.

The OSA considers a number of tracking methods for interface definition. The reference architecture includes one of the more challenging use cases where a bursty communications waveform does not always present the opportunity for closed-loop tracking. In this case, one option is to include a beacon receiver in the antenna. When the beacon signal is detected, the antenna is locked to the satellite location and enables a closed-loop satellite tracking algorithm to operate on behalf of the antenna.

VII. CONCLUSION

The development of DST OSA is a challenging endeavor that requires an innovative, spiral development process with the consensus of the DST OSA consortium members. The consortium is developing a standard that will be followed by the development of several emulators to verify key design elements of the architecture. A key highlight of the architecture is the definition of major components: 1) SCU, 2) SPU, 3) Antenna System, 4) IK, 5) External Interfaces, and 6) Satellite Air Interface. The next most critical part of the standard will be the definition of the interfaces between the six major components in ICDs. These ICDs will be nonproprietary and open to allow product vendors to supply interoperable components. The end objective is increased competition and innovation within each component that can remain proprietary.

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