Spectrum Access R&D (SARD) Program:
Conformal C-Band/Multi-band Antenna Project

Scott Kujiraoka, Russell Fielder, and Maxim Apalboym
NAVAIR-Point Mugu and China Lake, California

ABSTRACT

The Conformal C-Band/Multi-band Antenna project will support the AWS-3 auction by providing the technology to integrate C-Band or multi-band telemetry (TM) antennas on test articles such as missiles, weapons, or aircraft. These test articles would then provide C-Band or multi-band TM data to ground station receivers that are relocated to the C-Band frequency range through the AWS-3 Spectrum Relocation Fund program. This project would advance the technology of antennas in the C-Band region for test article TM integration. Successful use of C-Band and Multi-Band antennas for aeronautical mobile telemetry (AMT) on test and training ranges is dependent on the advancement of key technologies. This paper will detail the technology areas being matured by this project as well as the capabilities to be demonstrated.

KEY WORDS

C-Band Telemetry, Conformal Wraparound Antennas, Spectrum Access, Spectrum Selloff.

BACKGROUND

The Spectrum Access Research and Development (SARD) Program is a $500 million Program created out of the spectrum selloff to commercial wireless companies. It was created to support the transition of Government Test Ranges to operate in the C-Band frequency range. The Conformal C-Band/Multi-band Antenna Project will be one of the many projects funded by the SARD Program. This project is separated into five subprojects to be detailed in the following paragraphs.

BROADBAND CONFORMAL C-BAND MISSLIE WRAPAROUND ANTENNAS

Background: This project would advance the technology of conformal antennas in the C-Band region for test article TM integration. The C-Band/Multi-Band Antenna project would lead to commercial-off-the-shelf antennas that could be acquired by Government or weapon manufactures who are developing test article TM kits for integrated applications. Prevalent use of C-Band and multi-band antennas that can meet
performance requirements will reduce the demand on L-Band TM/Video and contribute to the availability of spectrum in other bands.

Scope: Based on lessons learned from a recent T&E/S&T SET project entitled “C-Band for AIM9 Telemetry”, the following issues require further development/investigation: 1) Efficient operation over the entire lower and mid C-Band frequency range (4400-5150 MHz). 2) Stabilization of the variability in the omni-directional antenna radiation patterns over this frequency range (preferably less than 5-8 dBi). Initially this effort will address small diameter missiles and then will progress to investigating larger diameter missiles. 3) Execute additional captive carry test flights using the test missile developed under this previous C-Band S&T effort over the water to further characterize the effects of multipath on C-Band TM reception. 4). Using data retrieved from these test flights flying close to the surface of the water, conduct multipath mitigation studies and develop algorithms to mitigate the effects of multipath on telemetry reception. 5). Investigate the impact of different antenna feed technologies (E-scan vs conical scan) as well as active beam-forming antenna technology in the mitigation of multipath effects in C-Band.

BEAM SWITCHING ARRAY ANTENNAS

Background: With narrower wavelengths associated with the C-Band frequencies, more variation in the gain pattern is expected (i.e., more ‘peaks’ and ‘nulls’). As the aspect angle of the missile relative to the tracking antenna changes, these variations in gain will result in variations in received signal power. Depending on the type of feed being employed and the time constant of the Automatic Gain Control (AGC) circuitry within the tracking receiver, this variation in signal strength could be interpreted as antenna pointing error, thus resulting in an instability in tracking or loss of acquisition altogether. This issue is compounded for rolling airframes whose roll rate is close to the nutation rate of tracking antennas employing conical scan feeds. Any variation in roll-pattern gain will result in amplitude modulation of the tracking signal, the frequency of which will be the missile roll rate. This will be interpreted as pointing error where the control loop will try to null-out this amplitude modulation, forcing the antenna pedestal to modulate from boresight. One could argue this issue could also exist for signals operating in both L and S-Bands, but this issue is expected to be much more prominent when operating in C-Band. As such, additional engineering is required to phase the radiating elements of the transmit antenna in such a manner as to greatly reduce this variation to make the pattern much more uniform. This variation can be mitigated over a relatively narrow band, but becomes much more of a challenge for broadband conformal antennas.

Scope: In a rolling missile, it is desirable to be able to steer the telemetry beam. This would allow for the maximizing of the antenna gain and directivity. As a result this would provide for the following benefits. One benefit would be the use of lower transmitter power and therefore help with the issue of transmitter heat dissipation. Another benefit would be the increased capability of receiving the TM signal at a great distance. The design approach would be to take the inertial measurement (IMU) data from on-board rate sensors and accelerometers to determine the attitude of the missile
at all times. Using this information, turn on and off the power to the various antenna elements so as to steer the TM signal. Next, develop a prototype system to achieve TM beam steering with the following variable design parameters: Missile Roll Rate and Missile Diameter.

**MULTI-BAND CONFORMAL ANTENNAS FOR AIRCRAFT APPLICATIONS**

*Background:* Due to a diminishing and increasingly crowded RF spectrum, airborne telemetry antennas that are capable of delivering comparable performance across the L, S & C-Bands are needed to allow Department of Defense (DoD) instrumentation groups to support flight test programs that may need to efficiently switch telemetry bands between missions. These assets can reduce test costs by eliminating the need to install multiple telemetry antennas and will reduce the complexity of flight clearances.

Multi-band telemetry antennas are currently available for L, S & C-Bands. However, the observed performance has been inadequate in comparison to dedicated, single-band antennas. While vendor-supplied antenna specifications indicate performance comparable to existing single-band antennas, actual in-flight testing of multi-band antennas has shown degraded performance in the lower L-Band. Further investigation is needed, including in-flight aircraft testing, to evaluate multi-band antenna performance.

*Scope:* The simultaneous operation of GPS and Telemetry (TM) on airborne platforms has caused much interference in the past. Due to size constraints, a multi-band conformal TM antenna system needs to be developed for use in DoD aircraft. Due to its size, a wraparound antenna will not be feasible. Methods such as Space Time Coding will need to be explored due to the close proximity of the antennas. A system approach will be implemented to address the filtering of signals to prevent unwanted coupling of the signals. The following will be investigated: Re-design the existing antenna panels on the top and bottom of the aircraft and replace them with a tri-band (L, S and C) TM antenna. They should be designed to meet the existing specifications of the current antennas. Also the redesign the RF system from the transmitters to the antenna panel (transmitters, RF cables, other required microwave components). Space Time Coding (as defined in IRIG-106-15) will be used to address the issues of antenna nulling caused by the close proximity of the two panels.

**HIGH ALTITUDE ANTENNA PERFORMANCE UNCERTAINTY**

*Background:* This need pertains to the requirement to investigate the coronal effects due to C-Band antenna systems for high altitude vehicles (rockets, and other target vehicles) capable of ionosphere and exo-ionospheric flight (50 to 400 miles) above the surface of the earth. The need centers on the effective design of these RF and antenna systems required to avoid corona discharge effects observed previously in L and S-Band designs.
Scope: The inability to quantify the effects of the coronal ionization discharges due to the use of C-Band, and lack of demonstrated mitigation techniques causes a significant technology gap and risk to using C-Band in place of L or S-Bands for tests where coronal effects have been noted in the past.

Existing capabilities at L and S-Band depend on careful design of RF systems by personnel who have developed working techniques for the varying situations (both atmospheric and exo-atmospheric) encountered in numerous different flight regimes. It is anticipated that similar but more intense efforts will be required for suppression of these possibly exacerbated problems at C-Band.

The phenomenon in question here does not have a ready off the shelf solution. It is a problem that will require some research into the behavior of C-Band frequencies at higher power levels than those currently utilized with L and S-Band transmitters coupled to RF transmission components in the presence of low density gases injected into a vacuum. Varying amounts of atmospheric gases can be expected to be encountered within the ionosphere. The internal design of RF routing and coupling systems to achieve needed return loss for effective delivery of power to the antenna, and the antenna ability to absorb energy and transmit it outside the vehicle rather than reflecting or releasing into the transmitter containment cavity will require investigation. The following tasks will be accomplished: 1). Perform study and investigation into historical coronal effects encountered at L and S-Bands during testing; documenting findings including root causes. 2). Perform analysis of potential coronal effects as a result of C-Band operations to quantify potential effects. 3). If necessary, perform investigations into coronal effects at L and S-Band along with proposed C-Band frequencies using high altitude chamber testing. 4). Develop design methods and approaches which could be implemented in new telemetry system designs to minimize coronal effects due to use of C-Band. 5). Conduct flight testing to validate newly developed methods of reducing C-Band coronal effects.

SMALL, MEDIUM-GAIN MULTI-BAND ANTENNAS

Background: Having telemetry antennas that are capable of delivering comparable performance across the L, S & C-Bands will enable DoD Range Ground Stations to support multiple test programs without having to maintain multiple single-band antenna systems or having to swap antenna feeds between tests.

Relatively large (6’ diameter and up) multi-band ground station telemetry antennas are currently available for L, S & C-Bands. However, for many surface vehicle weapons systems tests, ground station antennas in the 2’ to 3’ diameter range are more suitable. A gain range of approximately 15 to 25 dBi is required across the bands. While vendor-supplied antenna design specifications for 2’ and 3’ dishes indicate performance fairly comparable to existing single-band antennas, actual testing of multi-band antennas in the past has generally shown degraded performance in the lower L-Band.

Scope: There is currently a lack of commercially available small, medium-gain multi-band antennas. Market research has indicated that at least some antenna
manufacturers have designs for 2’ to 4’ multi-band dishes with the major components in hand, but to date, have not actually built any.

Testing of several different single-band (L, S & C) antennas was conducted at Aberdeen Test Center during 2012/13. These tests were conducted while operating an instrumented ground vehicle on a test range with L, S, and C-Band single-band antennas installed and a corresponding small, medium-gain single-band ground station antenna. The evaluation of the data quality was based on observing differences in processed data using a variety of different antenna combinations. This view provided a system-level look at the impact of using different antenna types.

The results showed in general, the telemetry needs for the majority of the ground vehicle surface weapons systems tests could be met by using any one of the single-band antenna configurations. For reasons stated previously, the desire then would be to have similar results for the corresponding multi-band antenna configuration.

The work being accomplished will be: 1). Develop a functional small, medium-gain multi-band ground station prototype antenna. 2). Conduct further investigations, including lab characterization and field testing to evaluate performance and determine the viability of use.

**SUMMARY**

The Conformal C-Band /Multipath Antenna Project is a five year effort funded by the Spectrum Access Research and Development (SARD) Program. Its mission is to investigate and develop C-Band TM antennas for airborne and ground based applications. The goal is to have the antennas developed under this project be eventually integrated and used at the various government test ranges.

**REFERENCES**

Tri-Service C-Band Roadmap Study (TSCRS): Gap Analysis and Technology Shortfalls Report (dated 24 September 2014)