C-Band Missile Telemetry Test Project

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ABSTRACT

The physics associated with transmitting and receiving a telemetry signal at a frequency greater than an octave above the current operating band is such that an end-to-end evaluation of the complete data link system (both the transmit and receive side) is required. In 2012, Airborne Instrumentation Systems Division (AISD), Naval Air Warfare Center Weapons Division (NAWCWD) was sponsored by the Office of the Secretary of Defense (OSD) to develop a couple of short-range air-to-air missile platforms that use a specially-designed warhead-replaceable telemetry section incorporating three data links: (1) an S-band link to transmit Time-Space-Position Information (TSPI), (2) an C-band link, and (3) an additional S-band link where the latter two are transmitting the same pseudo-random bit sequence at the same effective radiated power level.

Flight testing will consist of a series of captive tests conducted over land and water. The tests will be performed under a variety of conditions to induce potential issues caused by multi-path, atmospheric ducting, fast-slewing of the tracking antenna, and large propagation losses. Flight testing will culminate with the live-fire of a missile over a military land range.

This paper describes the continuing efforts of this test program from these series of flight tests, thus quantifying the performance of C-band telemetry data transmission as compared to the S-band.

KEY WORDS

Augmentation, C-Band, and Missile Telemetry

BACKGROUND

The Airborne Instrumentation Systems Division (AISD), Naval Air Warfare Center Weapons Division (NAWCWD) is responsible for the design, development, and fabrication of state-of-the-art telemetry and instrumentation systems for a variety of airborne platforms, primarily used for missile applications. The repurposing of the 1755 to 1850 MHz telemetry band is foreseeable by 2014, as part of the National Broadband Initiative. AISD is taking preemptive actions to assess the impacts to the programs currently supported by the division. While a majority of our systems are currently operating in the 2200-2290 MHz band, one primary concern is the highly probable increase in congestion within this band as others vacate the 1755-1850 MHz band. Another concern is the potential need to vacate the 2200-2290 MHz band in the out years. This concern is currently being studied for possible sell-off to the commercial telecommunications industry. To mitigate this issue, AISD is investigating the possibility of using lower- and mid-C-bands (4400-4940 MHz and 5091-5150 MHz, respectively) for its aeronautical telemetry designs.

Some of the military test range personnel are augmenting a small number of their ground based telemetry tracking antenna systems to track and receive telemetry signals operating within the C-band. The principal method for doing so is by adding a Dichroic reflector to the current L- and S-band prime-focus feed assembly and installing a Cassegrain feed at the center-line of the parabolic reflector, either forward of the dish vertex or directly behind it. Initial tests conducted both at Edwards, Air Force Base (AFB) and Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD, used fixed, ground-based C-band resources and rotary aircraft.[1,2] Although results from tracking the rotary aircraft and ground based equipment yielded good results, it is unknown if similar results will be observed while tracking a very high-speed, small-diameter, highly agile missile.

PROBLEM STATEMENT

The physics associated with transmitting and receiving a telemetry signal at a frequency greater than an octave above our current operating band is such that an end-to-end evaluation of the complete data link system (both transmit and receive side) is required. As the carrier frequency of a radio frequency (RF) signal increases, there is also an increase in the power loss within the link due to atmospheric attenuation and insertion loss within RF cabling. The efficiency of the transistors used in the design of power amplifiers incorporated within RF transmitters decrease significantly as the carrier frequency increases. The efficiency of the transmitter may not be a problem for a majority of aircraft platform applications, but it is a major concern for most missile platforms where space is extremely limited. Adequate heat transfer is always a concern due to the relatively high temperatures that instrumentation systems must function under. As the efficiency decreases, the amount of self-generated heat increases. Additionally, the current draw increases, placing an additional load on the electro-chemical thermal battery used to power the instrumentation system following separation from the launch platform.

As the signal frequency viewed by the receiving antenna increases, the beamwidth becomes more narrow. So, it becomes more of a challenge for the tracking antenna to acquire and remain locked onto the signal which could cause system to track on its antenna sidelobe rather than its main beam. To mitigate this effect, the tracking control loop for the receiving antenna must be tightened. Doing so further exacerbates the problem of acquiring and tracking a signal (especially when dealing with a relatively small, high-speed missile platform).

Another concern involves the design of conformal antennas for missile platforms. With the shorter wavelength 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 used and the time constant of the automatic gain control circuitry (AGC) within the tracking receiver, this variation in signal strength could be interpreted as antenna pointing error, thus resulting in instability in tracking or complete loss of acquisition. 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 the tracking signal will be equivalent to 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. While this issue could certainly exist for signals operating in both L and S bands, it can be more prominent in C band if the antenna pattern gain variation is not minimized. Additional engineering is required to phase the radiating elements of the transmit antenna in such a manner as to greatly reduce this variation and thus making the pattern more uniform.

As telemetry tracking antennas become modified to accommodate C-band, test vehicles are needed to verify and validate their operation not only in C-band, but in L and S band as well due to the possible degradation by the implementation of a dichroic reflector. Although preliminary tests can be performed using ground-based and aircraft systems, high-speed missile platforms are needed where conformal antenna designs can be tested in the air and the ground-based antenna systems can be fully exercised when trying to track a high-speed, relatively small, and highly agile missile when the slew rate of the pedestal is approaching its maximum angular rate.

PROJECT OBJECTIVES

In order to address known concerns and discover any other potential issues that may arise when working within the C-band frequencies for missile telemetry applications, AISD has been funded (by the Office of the Secretary of Defense) to develop and fabricate a couple of flyable test assets that could be captive-carried on a variety of aircraft, then eventually air or ground-launched. This will involve developing a conformal wrap-around antenna that operates within the two frequency bands known as lower and mid C-band. These test assets would be designed to provide not only a C-band signal for assessing link and tracking performance, but a concurrent S-band signal for comparison purposes. Flight tests are to be structured to determine the limitations of augmented tracking systems in terms of acquisition and tracking of a high-speed test vehicle, assess relative link quality, and evaluate the effects of multipath as a function of frequency and data rate over various terrains.

FLIGHT TEST OBJECTIVES

The primary flight test objectives objective of the C-Band Missile Telemetry Test Project is to compare the link performance for a telemetry data stream transmitted in the C-band with the data stream transmitted in the S-band. The secondary objective is to compare the ground based tracking performance between the C- and S-Bands. A total of three captive-carry flights and one missile air-launch will be conducted as part of this baseline study.

FLIGHT TEST PLANS

Currently, only eight-foot-diameter, tri-band tracking systems are available to support this series of tests. A minimum of two systems are required at any given time, and this test plan assumes that only two will be available. If additional systems become available in time to support this test, they will be used in a completely passive mode where the flight test plan will not be modified to accommodate the presence of these additional assets. All flight test geometries and slant ranges relative to the tracking antennas are based on preliminary gain-over-system noise temperature (G/T) values. Once the actual G/T values are measured for each tracking antenna system, these metrics may be adjusted accordingly.

For the purpose of this document, a tracking system is defined as a self-contained, auto-tracking telemetry antenna mounted on a dual-axis pedestal and equipped with a minimum of two dual-channel telemetry receivers (one for C-band and the other for S-band, with Right Hand Circular Polarization (RHCP) and Left Hand Circular Polarization (LHCP) inputs for each), a diversity combiner for each receiver, a bit synchronizer for each diversity combiner output (internal or external), and a data multiplexer interface to tie into the range data network. Bit clock and data from each bit synchronizer will be sent to and recorded at a central data collection site over a secure network along with the tracking system controller metrics. Each antenna system will normally track from the C-band signal and provide data and clock from the C-band baseband data, the S-band high speed data stream, and from the S-band low speed TSPI data stream. However, during certain passes, the tracking controllers will be configured to switch between C-band and S-band tracking.

The Range Control Center (RCC) is defined as the central collection site of all data sent from the individual tracking systems as defined in the previous paragraphs. Each telemetry data stream along with the tracking system metrics and the aircraft radio communications shall be recorded at RCC onto an IRIG-106 Chapter 10-compliant data recorder. In addition, GPS timing and Joint Advanced Missile Instrumentation (JAMI) TSPI Unit Message Structure (TUMS) data from the JAMI Ground Station computer is to be recorded as well. If it is not possible to record tracking system metrics remotely, then a local recording can be made if the recording is time-stamped using GPS time to properly correlate this data with the rest of the data recorded at RCC.

For tests conducted to evaluate tracking performance, the antenna control unit (ACU) of each tracking antenna will be configured to track off of either the S-band signal or C-band signal. The data from each link will be recorded simultaneously regardless of which signal is used for tracking. For tests comparing link quality between S- and C-band, the ACU will be configured to track only on the C-band signal. In addition to these two principal pseudo-random data streams, the low data rate TSPI data will need to be collected along with the elevation tracking error angle, the azimuth tracking error angle, the elevation pointing angle, the azimuth pointing angle, GPS time, RHCP receiver AGC from both links, and the LHCP receiver AGC from both links. During post-mission data processing, each of the two pseudo-random data streams will be fed to a link analyzer to measure instantaneous bit error rate, cumulative bit errors, data link availability, pattern-loss-seconds, and severely-errored-seconds as a function of time.

Testing will be performed in five separate phases – a static test, a captive flight test over land, a captive flight test over water to assess general tracking and link quality, another captive flight test over water for assessing multi-path performance and the use of Low Density Parity Coding (LDPC) forward correction at low signal to noise (E_b/N_0) values, and a ballistic missile air launch.

For all flight tests, elevation will be maintained within ± 50 feet of that specified in the test procedures; velocity within ± 10 KTAS; and distance within ± 0.1 nautical miles (nmi).

A No-Test for any given test run is defined as any of the following conditions:

a. A loss of TSPI data.

b. A failure of any of the missile data links.

c. An out-of-tolerance condition for specified flight altitude, velocity, or distance as described above.

d. Either of the two 8-ft tracking systems (including the receivers) at the land range malfunction (Test Phases I, II, and V).

e. The 8-ft. portable TSC tracking system (including the receivers) at the sea range malfunctions (Test Phases III and IV).

f. A data recorder malfunction.

The flight test phases are described as follows:

Phase I- Static Testing: Test Objective to ensure all tracking assets, instrumentation systems, data receiving and recording equipment are functioning properly prior to conducting flight testing.

Phase II - Captive Test, Land Range: The test objectives are to assess general tracking and link performance over land at both high and low altitudes relative to the tracking antennas systems and to assess the integrity of the tracking loop when slewing up to 90% of the maximum angular rate of the antenna.

Phase III - Captive Test, Sea Range, General Tracking and Link Quality Assessment: The test objective is to assess general tracking link performance over the sea range at various altitudes.

Phase IV - Captive Test, Sea Range, Low Signal to Noise Ratio and Low Grazing Angle Tracking: The test objective is to assess tracking performance when receiving very weak signals in the presence of multi-path and to determine the link margin improvement when utilizing LDPC forward error correction.

Phase V - Missile Live Fire: The test objectives are to perform an actual live fire demonstration of a short-range air-to-air missile employing a C-Band telemetry data link and to compare the tracking performance of the antenna systems modified for C-Band reception to S-Band counterparts. As a byproduct of this demonstration, the C-Band data link performance will also be compared to that the S-Band data link transmitting the same data from the same platform.

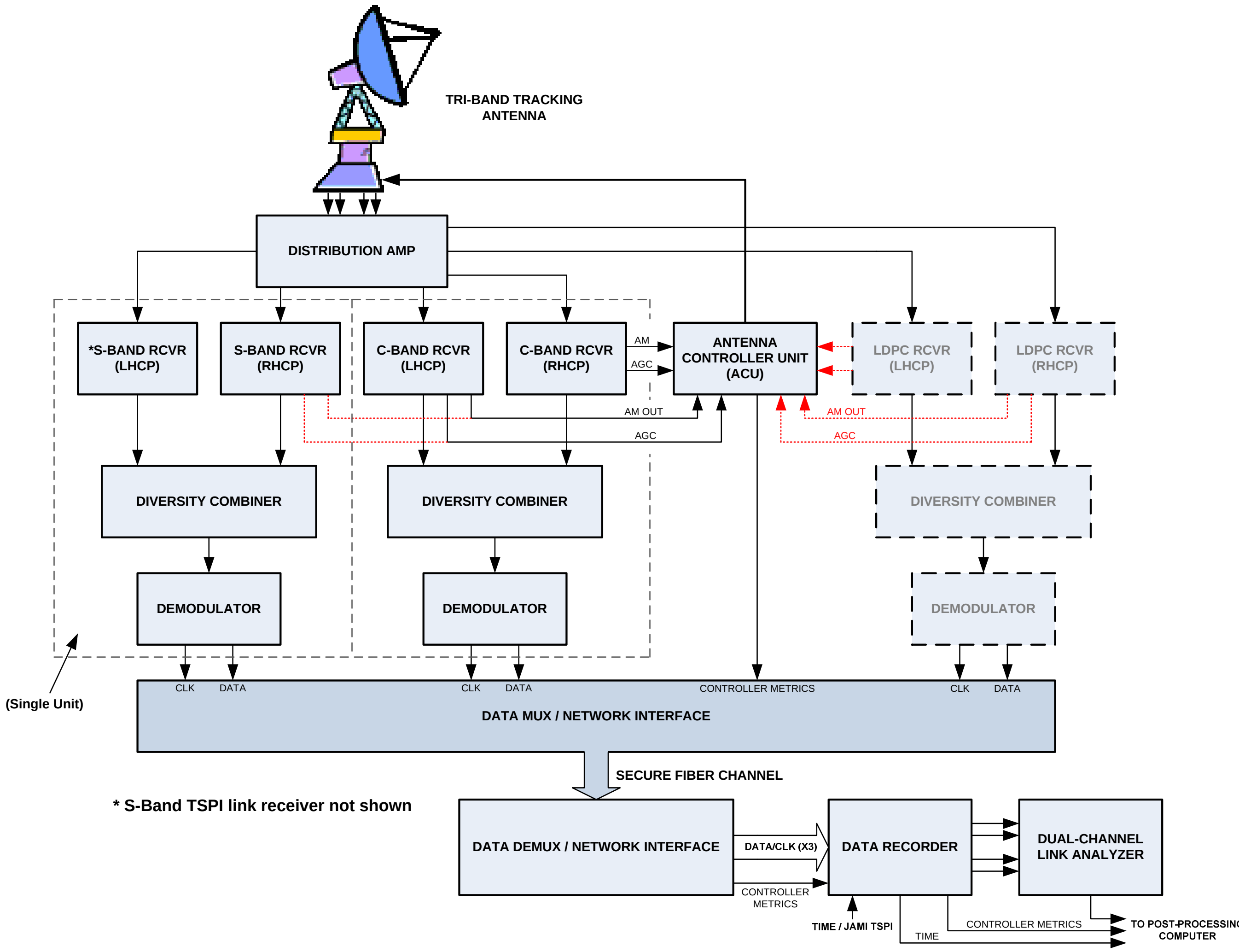

Figure 1. Antenna tracking system configuration and data flow diagram.

SUMMARY

The developmental phases of the C-Band Missile Telemetry Test Project have been completed. The telemetry units were fabricated and the various phases of the test flight plans have been documented. Once flight clearance is granted, the various missile test flights will be conducted. The results of these test flights will be presented in the 2014 proceedings of the International Telemeter Conference (ITC).

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