DUAL-CHANNEL RECEIVER PERFORMANCE USING BEST-CHANNEL SELECTION: FIELD TEST RESULTS

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ABSTRACT

Best-Channel Selection (BCS) uses real-time data quality metrics (DQM) to select the best demodulated bits from Channel 1, Channel 2, and the Combiner of dual-channel receivers. Laboratory testing has demonstrated a substantial reduction in bit error rate (BER) relative to individual channels (including the Combiner) under some synthesized link conditions, with no degradation in BER under the remainder of tested link conditions. This paper extends those results to real-world flight tests.

INTRODUCTION

Dual-channel receivers provide receive diversity by combining two different copies of one transmitted signal. A pre-detection maximal-ratio combiner performs optimally if the only channel impairment is attenuation of the transmitted signal [1]. However, signal strength is not always the limiting factor in aeronautical telemetry links [2,3].

The BCS concept arose from the need to improve dual-channel receiver performance in those cases where the Combiner does not perform optimally, and especially those cases where the Combiner underperforms either of the individual received channels. Laboratory testing has demonstrated remarkable potential for performance improvement under controlled though arguably contrived conditions, but field-test results have been limited [4]. So, how does the BCS fare in the real world?

BEST-CHANNEL SELECTION

Let's start by reviewing BCS operation. Figure 1 shows a typical telemetry receiver with diversity inputs from right-hand (RH) and left-hand (LH) circularly polarized antenna feeds:

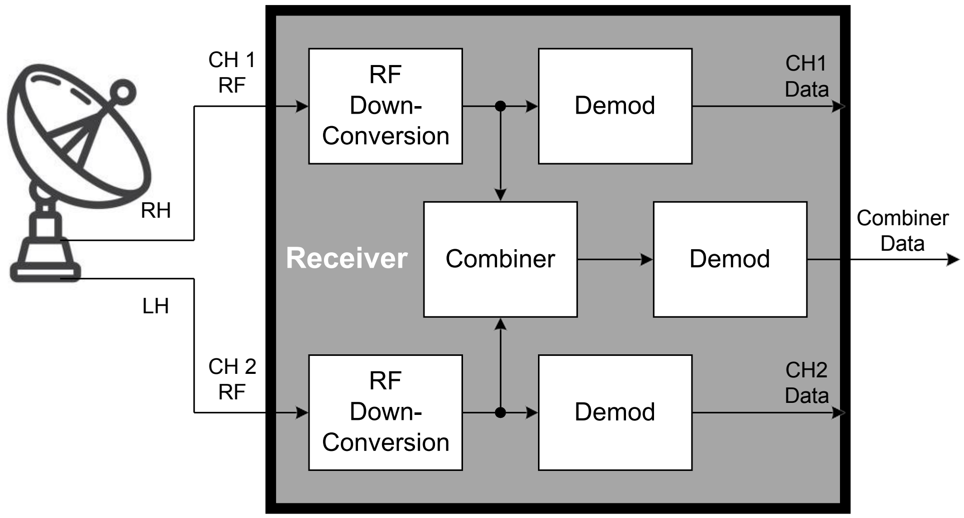

Figure 1 Dual-Channel Receiver.

Note the two radio-frequency (RF) input signals become three data output signals. The third data stream is demodulated from the combined RF signals. Since the Combiner provides optimal performance for weak received signals, the Combiner data output is often the only data used in a mission. But if the received signals are corrupted by multipath, interference, or other channel effects, the Combiner is no longer optimal, and the Combiner data output may have more errors than the Channel 1 (CH1) or Channel 2 (CH2) data outputs.

Figure 2 shows the same receiver with the addition of a BCS:

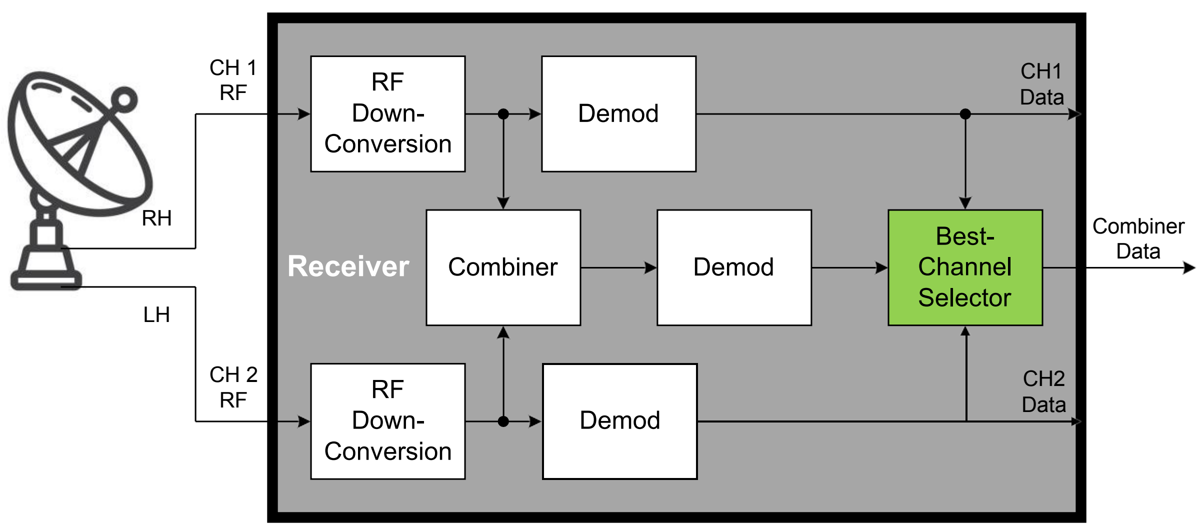

Figure 2 Dual-Channel Receiver with Best-Channel Selector.

The BCS automatically selects the best data from CH1, CH2, and the Combiner. This selection happens in real time, on a bit-by-bit basis, so the best available data is always output on the Combiner's data output. With the BCS, it is therefore safe to use only the Combiner output data for a mission. But how do we know this data is always best?

DATA QUALITY METRIC

DQM, as defined in IRIG 106-17 Appendix 2-G [5], provides the information required to make optimal source-selection decisions in a best-source selector (BSS) [6]. DQM effectively encodes the probability of any bit in a data quality encapsulation (DQE) block being errored.

If this bit error probability (BEP) accurately reflects the actual bit error rate (BER), then source selection based upon DQM will reduce the BER of the selected data stream. Because Combiner errors are correlated with CH1/CH2 errors, the BCS simply selects the data with the lowest BEP. Thus, accurate DQM estimation is directly intertwined with and essential for BCS performance.

Early testing of DQM accuracy [7] showed good promise across a wide range of impairments. Since that time, substantial improvements in DQM estimation have been achieved, as measured in the lab. Ultimately, though, real-world performance is all that matters.

FLIGHT TESTS

Intermediate frequency (IF) recordings have been made for several flight tests in recent years. Using these recordings, it is possible to measure BCS performance, even for testing that occurred before the BCS was conceived.

Flight test recordings are available spanning a broad range of environments and configurations. For brevity, this paper examines just a few of the results from three selected test scenarios:

- Aircraft testing of telemetry link performance under common flight conditions
- Rocket launch
- Helicopter testing of problematic link conditions

These tests were conducted using several technologies, including:

- Binary phase-shift keying (BPSK)
- Shaped offset quadrature phase-shift keying (SOQPSK)
- Advanced range telemetry (ARTM) continuous-phase modulation (CPM)
- Space-time coding (STC)
- Low-density parity check (LDPC) forward error correction

Many portions of a flight may yield consistent, good performance, both from the individual receive channels and from the Combiner. However, these stretches are often punctuated by errors and dropouts. These are the areas of primary concern for reliable telemetry, and the focus of the results that follow.

FLIGHT TEST RESULTS

These results show accumulated bit errors as well as link availability ($\frac{T^M - \sum SES}{T_M}$) during the measurement interval T_M. In this analysis, a severely errored second (SES) is defined as a one-second interval with a BER exceeding 1×10^{-5}. Link availability is the truest measure of performance: it indicates the net usefulness of a channel, which can be high despite a large number of accumulated errors as long as those errors occur in a small number of bursts.

Circle, 50° Bank, ARTM CPM, Single Antenna In this test, an airplane flies in a circle at a 50° bank angle. Altitude is chosen to avoid ground multipath, and range is well within the link budget. Therefore, the primary channel impairment is shading and reflections from the aircraft.

Figure 3 and Figure 4 show performance during this test:

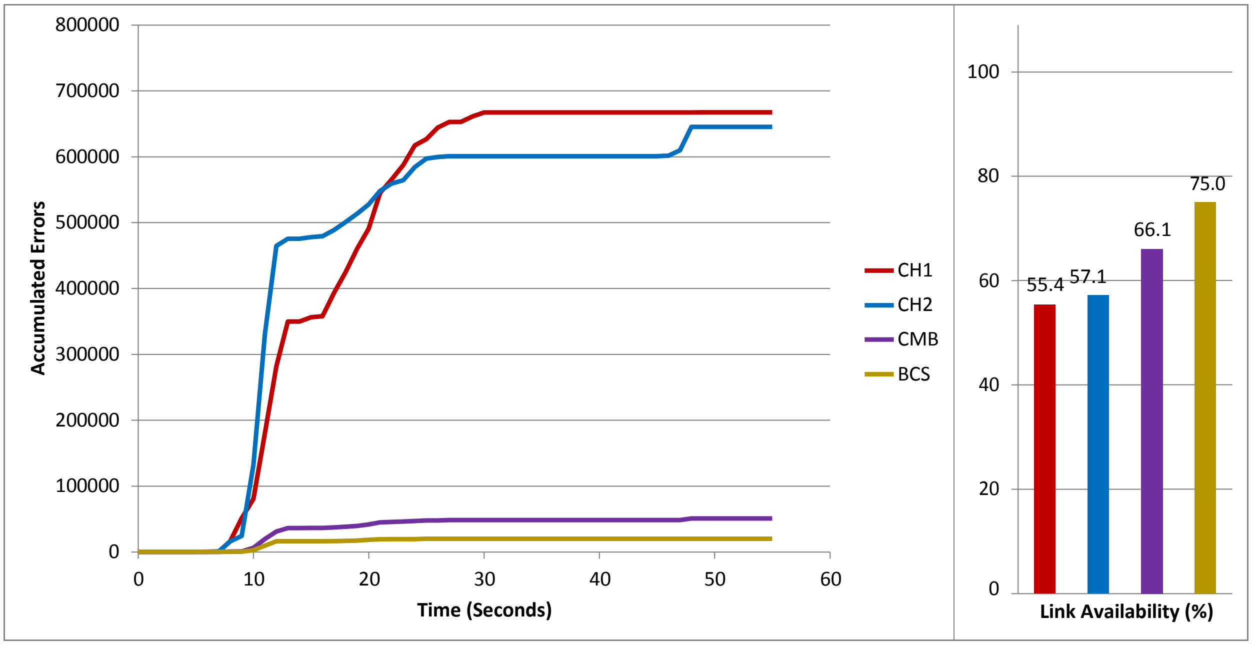

Figure 3 Circle Test Results, 50° Bank, ARTM CPM, Single Antenna.

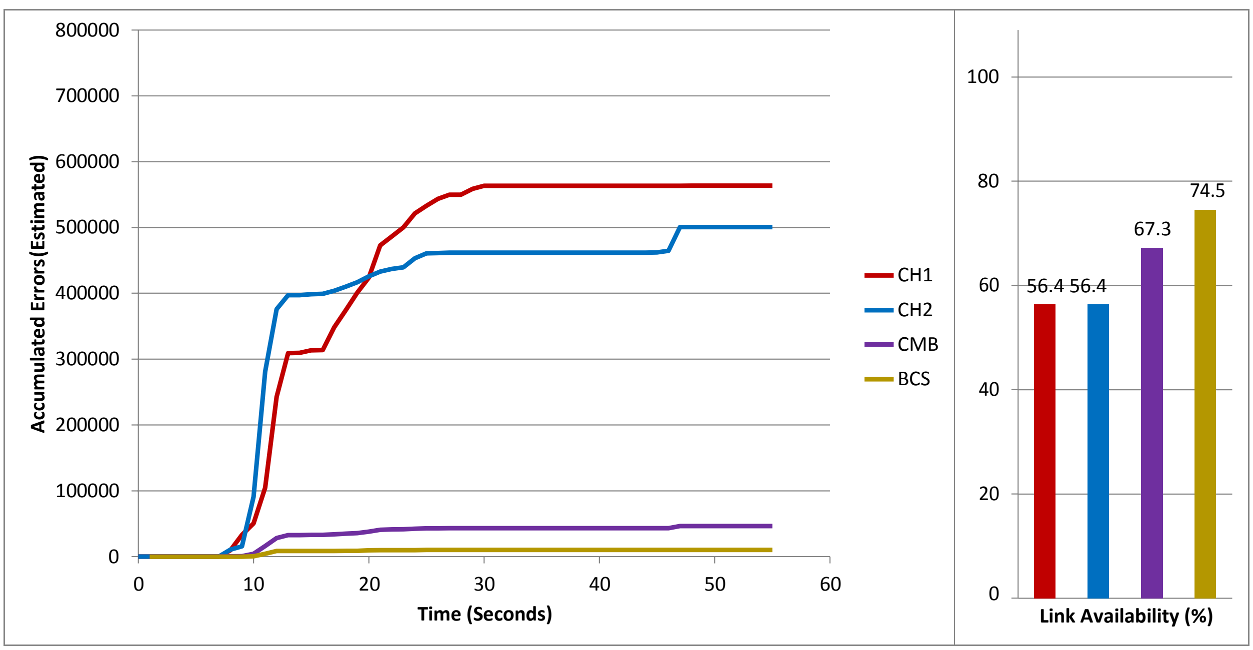

Figure 4 Circle Test Results, 50° Bank, ARTM CPM, Single Antenna – Estimated from DQM.

At first glance, it appears the same figure has been duplicated. Actually, Figure 3 shows performance as measured by a bit-error-rate tester (BERT), and Figure 4 shows calculated performance as estimated by DQM. These results are typical in several ways.

First, and perhaps most importantly, these figures demonstrate that DQM is an extremely accurate predictor of link performance. The largest error is approximately a factor of 2 in accumulated errors for the BCS. At the average BCS BER for the test, this equates to only 0.25 dB effective error relative to the theoretical BER curve for ARTM CPM. While accuracy varies across cases, the overwhelming trend across all field data is solid performance prediction by DQM. In fact, it is fair to conclude that, in cases where user data is unknown or encrypted, DQM can be used in place of BER measurement to monitor telemetry performance. This result also bolsters the expectation that the BCS will perform equal to or better than the Combiner (or CH1/CH2).

Second, under stressful link conditions, the Combiner often performs better than CH1 or CH2 individually. Still, by selecting data from the underperforming channels at appropriate times, the BCS manages to decrease accumulated errors and increase link availability significantly compared to the Combiner alone.

Circle, 10° Bank, SOQPSK, Dual Antenna This test is the same as the first test, but at a shallower bank angle, using SOQPSK modulation with a typical dual antenna configuration. Therefore, the primary channel impairment is signal self-interference from the two antennas.

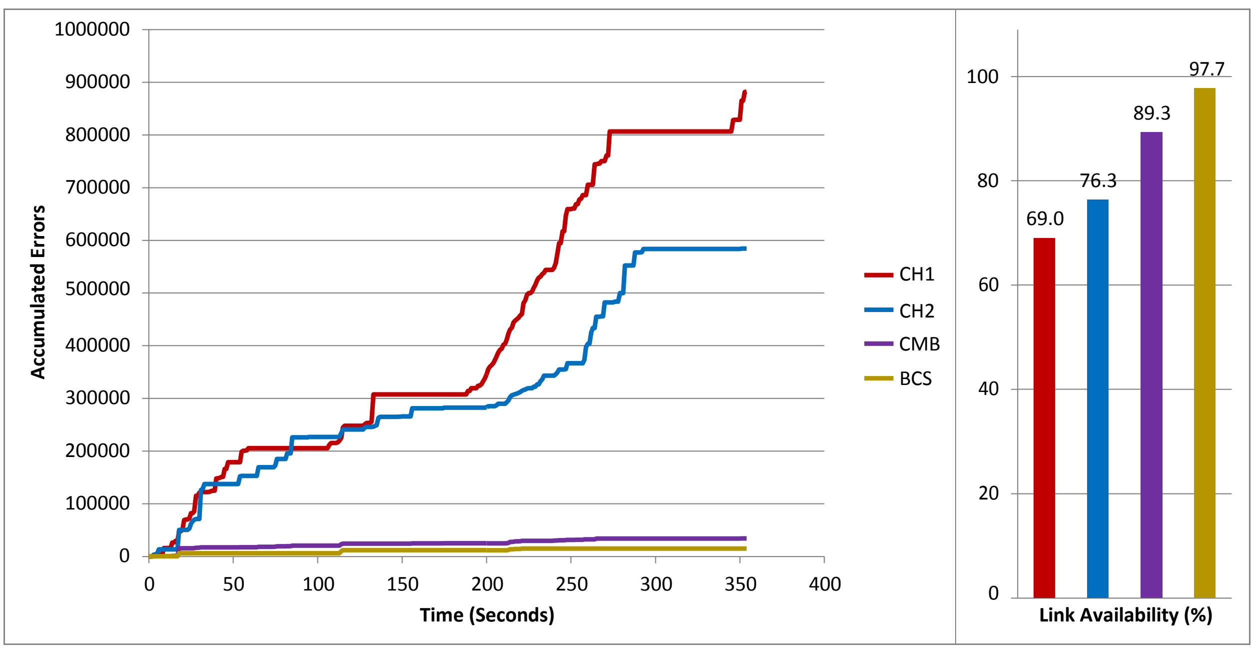

Figure 5 Circle Test Results, 10° Bank, SOQPSK, Dual Antenna.

These results show a repetition of the previous themes, but greater improvement for the BCS relative to the Combiner. It is specifically worth noting the gain in link availability. In this case, the BCS reduces severely errored seconds from 10.7% to just 2.3%, a substantial improvement.

<u>Circle, 10° Bank, STC, Dual Antenna</u> This test is the same as the second test, but with STC encoding.
and
<u>Multipath Corridor, STC, Dual Antenna</u> This test is a straight east-west flight over mountainous and flat terrain known to exhibit both short- and long-delay multipath at various points.

Figure 6 and Figure 7 show performance during these tests:

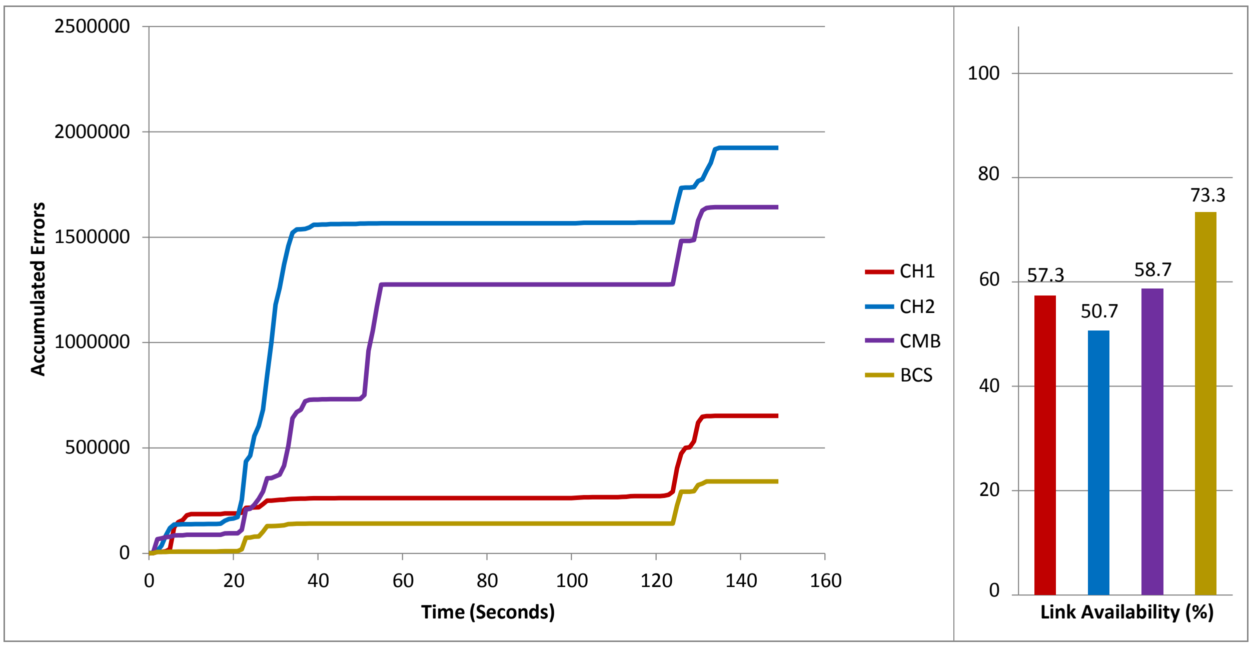

Figure 6 Circle Test Results, 10° Bank, STC, Dual Antenna.

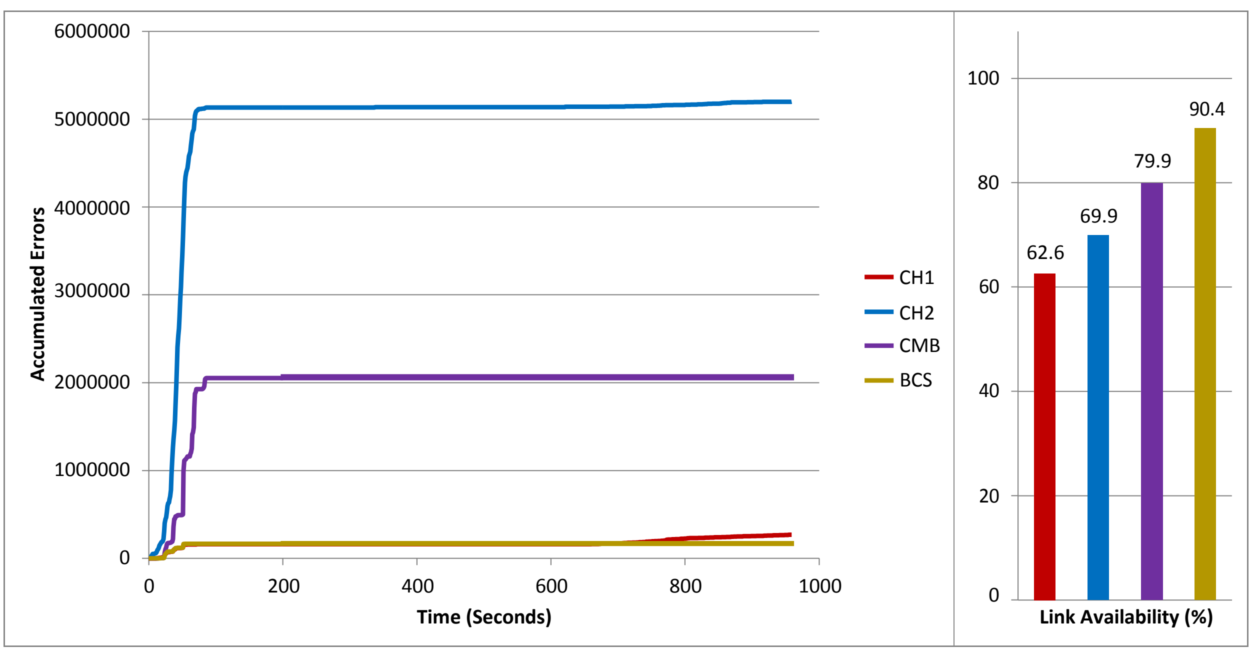

Figure 7 Multipath Corridor Test Results, STC, Dual Antenna.

These results demonstrate less common cases in which the Combiner accumulates more bit errors than another channel (CH1, in both cases), though its link availability remains higher than both individual channels. Had the Combiner been the only data output in use, its BER would have been correspondingly poor. These cases are good examples of why the BCS was initially developed.

Rocket Launch, BPSK In this test, a rocket is launched and accelerates toward the horizon. The primary impairments are multipath prior to and immediately following launch, and antenna shading and plume effects after launch.

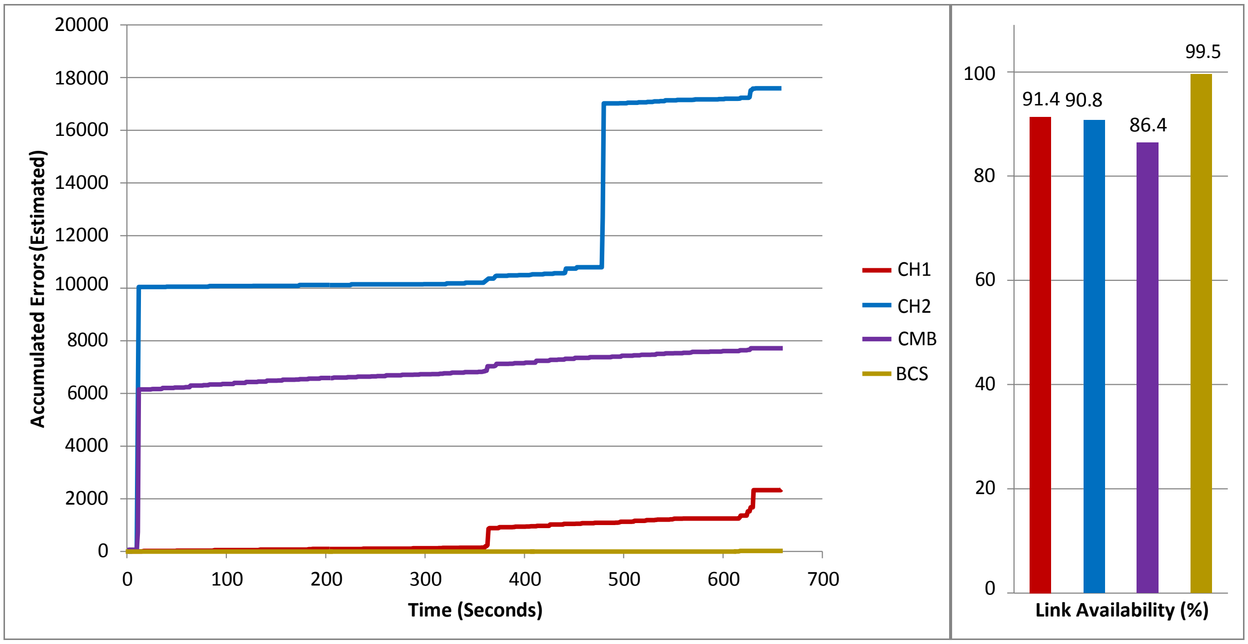

Figure 8 Rocket Launch Test Results, BPSK.

These results show the Combiner underperforming CH1 in BER and underperforming both CH1 and CH2 in link availability. Though all channels display steady accumulation of errors post-launch, the BCS manages to maintain nearly perfect link availability.

Up/Down Runway, SOQPSK/LDPC In this test, a helicopter hovers above a runway and proceeds back and forth along it. Therefore, the primary channel impairment is severe ground and rotary-wing multipath.

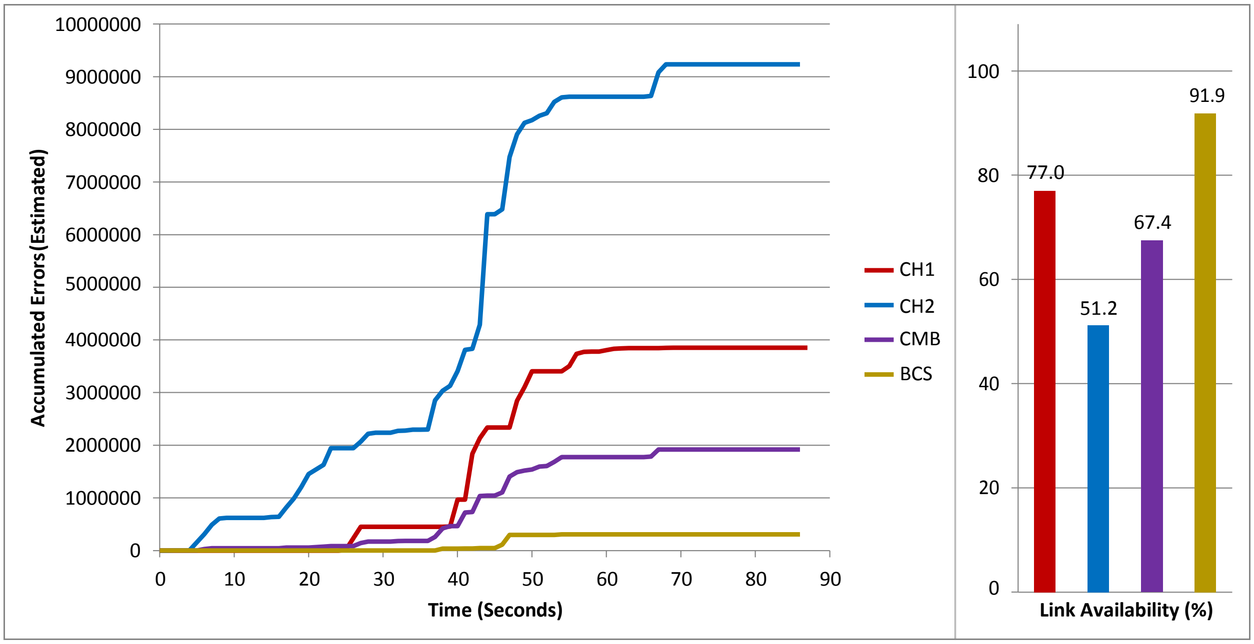

Figure 9 Up/Down Runway Test Results, SOQPSK/LDPC.

These results show yet another case in which the Combiner underperforms in link availability. Despite mediocre performance on all channels, BCS link availability is reasonably good.

Up and Away, STC/LDPC In this test, a helicopter flies along a preselected path with points known to produce dropouts.

Figure 10 and Figure 11 show performance during this test:

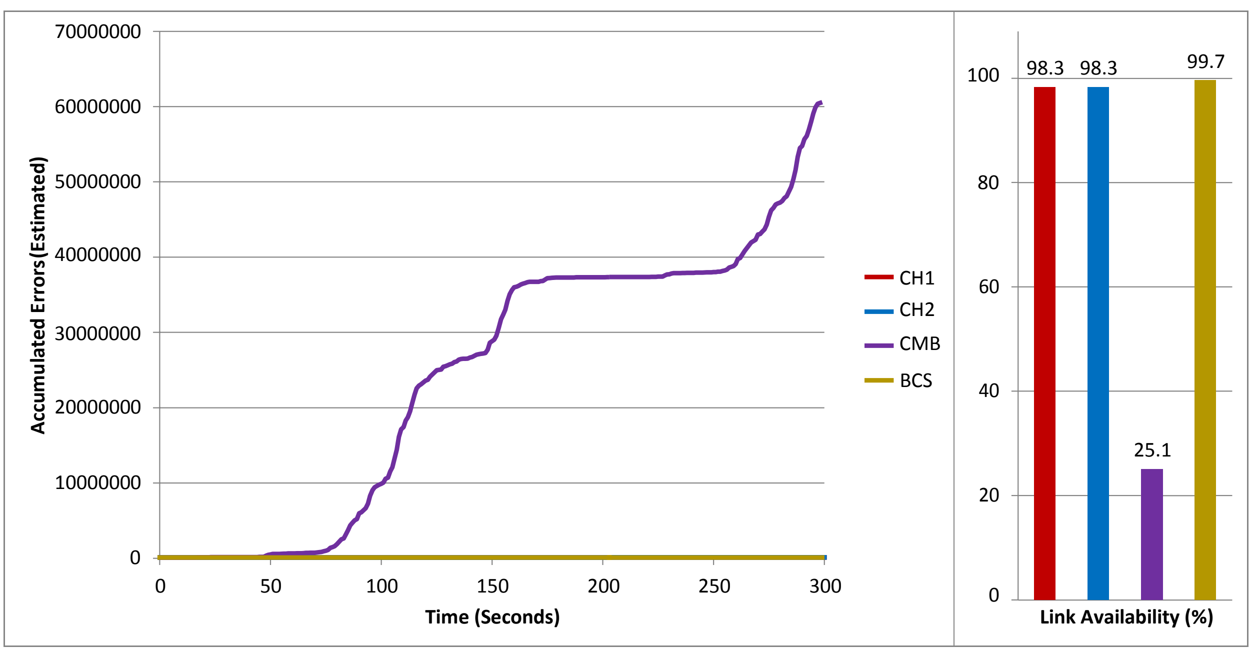

Figure 10 Up and Away Test Results, STC/LDPC.

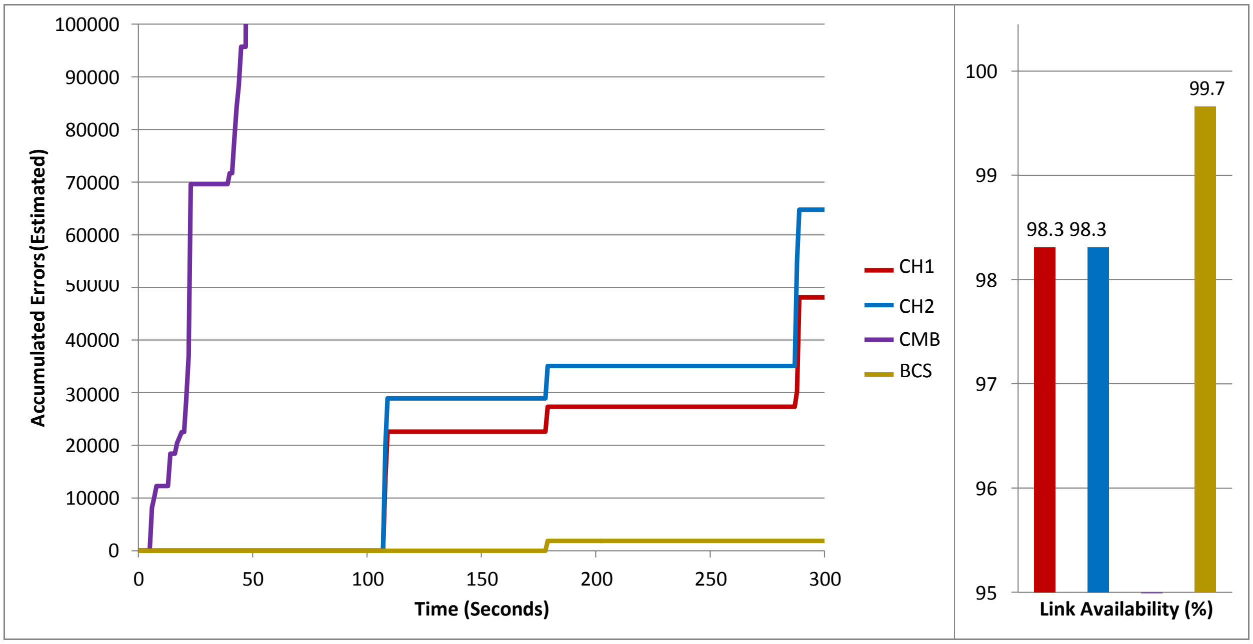

Figure 11 Up and Away Test Results, STC/LDPC – Zoomed to Show Detail.

This test illustrates the ultimate motivation for the BCS. CH1 and CH2 perform admirably, but the Combiner is unable to coherently sum these inputs due to propagation effects that place the orthogonal STC signals exclusively on opposite polarizations [4]:

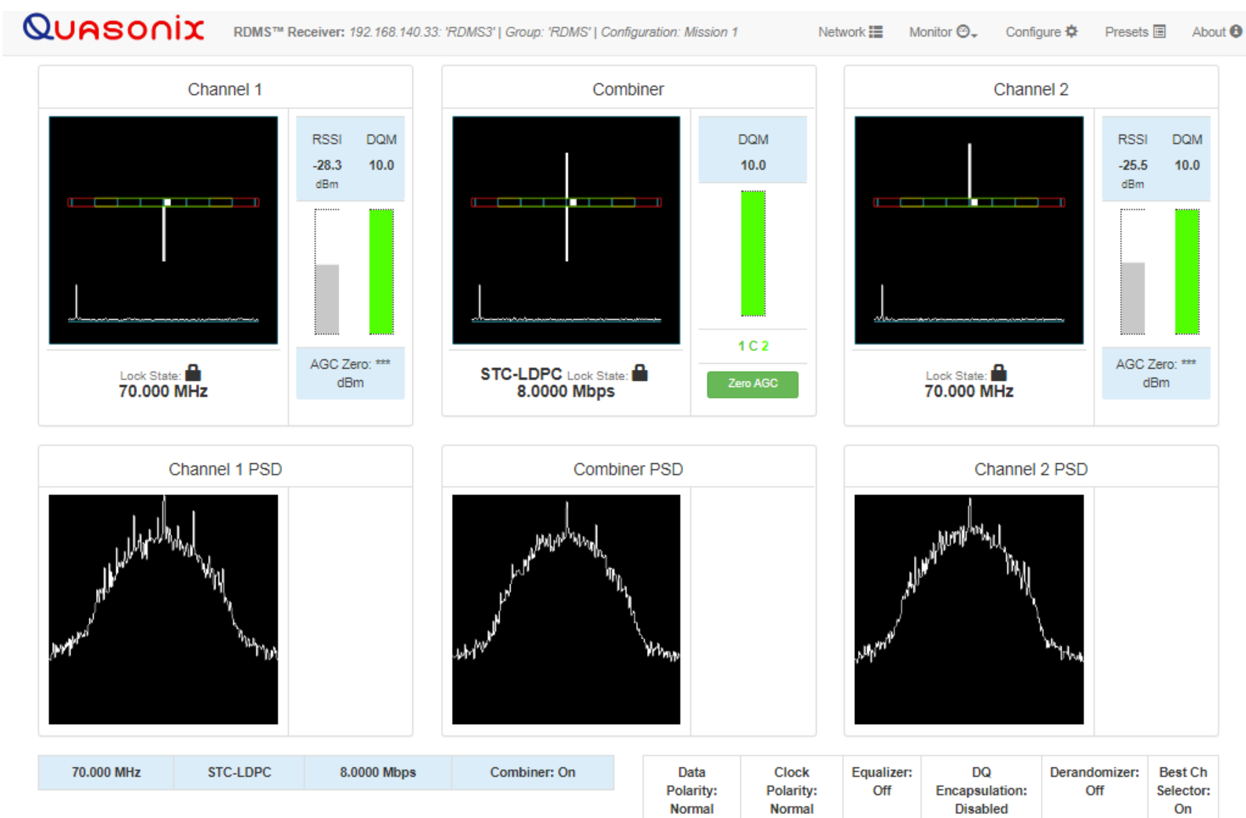

Figure 12 Receiver Status During Up and Away Test.

In this case, the Combiner fails catastrophically, as would the mission if the Combiner output were the only data used. Not only does the BCS alleviate this issue entirely and automatically, it manages to improve link availability well above CH1 and CH2 in the process.

CONCLUSIONS

The BCS performs quite well in the field, as predicted by laboratory testing. In all observed cases, the BCS reduces BER and increases link availability relative to the Combiner and individual channels in a dual-channel receiver, often slightly, but sometimes dramatically. This performance relies on accurate DQM estimation, which has also been verified in the field.

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