THE ADVANTAGES OF USING A DATA QUALITY ESTIMATE FOR ANTENNA TRACKING

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ABSTRACT

An Antenna Control Unit (ACU) has historically used the AGC signal from receivers to select the best signal to use for antenna tracking. Using the AGC, the biggest signal, likely the signal with the best Signal-to-Noise Ratio (SNR), is selected as the tracking reference. But often, due to signal impairments and interfering signals, **the biggest signal is not always the best signal**. This can cause a breakdown in antenna tracking. A similar problem is solved for a Correlating Best Source Selector (BSS) by using a Data Quality Estimate (DQE) as the metric for best source selection. The DQE not only includes SNR but also includes the effects of signal distortion and interference. A modern ACU uses the DQE to provide superior antenna tracking performance. This paper discusses the improvements in antenna tracking performance using a DQE versus the AGC. Specific conditions include the tracking of the signal with the best DQ, and the avoidance of tracking a reflected or an interfering signal.

BACKGROUND

Historically an ACU uses the AGC from a receiver to determine the best signal to track. Typically, receivers are connected to both right- and left-hand antenna feeds from multiple antennas. The receivers provide their AGC to the ACU and the ACU uses the AGC levels to select the best signal to track. Conical scan antennas create a small Amplitude Modulation (AM) on the received signal at the antenna scan rate as the antenna is rotated slightly off axis. The AM signal is recovered in a receiver and supplied back to the ACU where it is correlated with the antenna servo scan control. Using the recovered AM the antenna pointing direction is adjusted to minimize the AM amplitude. Traditionally the receiver sends the ACU both the AGC and the recovered AM. The AGC is used by the ACU to pick the strongest received signal, for example the signal from right- or left-hand circular antenna feed, and the ACU uses the AM from the selected signal to determine the optimal antenna pointing angle for tracking.

Since the AM is recovered by the receiver, the receiver AGC time constant must be slow enough to pass and not filter out the AM. However, to track signal dynamics and optimize receiver data recovery performance, that is, to minimize the data Bit Error Rate, a fast receiver AGC time constant works better. As a result, compromises are made in receiver design and in receiver performance, or a separate tracking receiver, not the data receiver, is used for antenna control.

This time constant paradox was resolved a few years back when TCS developed the technology to extract the AM directly from a receiver's AGC. With this technique the receiver operates with a fast AGC time constant, data recovery performance is optimized, only one signal, the AGC, is needed from the receiver, and the recovered AM-to-servo control correlation is optimized.

The ACU uses the AGC to pick the biggest signal because the biggest signal likely is the desired signal and probably has the best SNR. The signal's SNR is important because the better the SNR, the more accurate and stable the antenna tracking. However, **the biggest signal is not always the best signal**. Sometimes a reflected, multipath corrupted signal can be bigger than the desired direct signal. When this happens the ACU will select the reflected signal, the antenna will attempt to track the reflected signal, the reflected signal will likely vanish, and the antenna will need to reacquire the direct signal. A similar event may occur with an interfering signal, if the interferer produces a bigger signal at the receiver, the antenna may temporarily attempt to track the interfering signal, again resulting in degraded tracking performance and degraded receiver data recovery.

So what to do? Back in the early 21st century GDP in conjunction with PAX river NAS, developed an enhanced metric for the newly introduced Best Source Selector [1]. The BSS faced a similar problem, that **the biggest signal is not always the best signal** and should not be selected as the best data source. This led to the creation of Data Quality (DQ) as the decision metric. The DQ not only includes SNR but also factors in interfering signals, signal distortion (due to, for example, multipath), phase noise, jitter, etc. Over the years this metric, (often referred to as EbNo) has been vetted and proven to provide the optimal selection of the best data source for telemetry data processing. The same source selection pitfall occurs in a receiver's diversity combiner, **the biggest signal is not always the best signal**, so the DQ metric was added to the GDP receiver's diversity combining algorithm.

In the mid-2010s, recognizing the benefit of DQ for best source selection, the RCC/IRIG independently developed a Data Quality Estimate. The RCC/IRIG DQE takes the data quality and develops a Bit-Error-Probability-Estimate, BEP, based on the signal's modulation, FEC, etc., and uses this BEP as the basis for best signal selection. As a result, there are presently two DQ metrics in use to determine the best quality signal.

So, the premise is that: a modern ACU can provide significantly better, more reliable, tracking performance by using a DQ metric instead of the classic AGC. That, by using DQ, an antenna can protect against tracking the wrong signal, a signal with a lower data quality such as a multipath corrupted signal or an interferer. Sounds good, but can these benefits be realized in practice? The answer is yes, as explained by the results of the following tests.

TESTS SETUP

The tests were conducted at the rear parking lot of the TCS facility in Chatsworth CA. Conditions were far from ideal: there were many high-power interfering signals nearby. There was a SiriusXM repeater occupying about 8MHz around 2.34GHz in the direction of the test sources, a train station Wi-Fi across the street to the left and numerous business Wi-Fis along the right at 2.4GHz, and cell data from everywhere at around 2.1GHz. Despite the conditions, stable, repeatable test results were obtained.

The test configuration used is shown in Figure 1. The signal sources used were changed for each test and are shown in Figure 2.

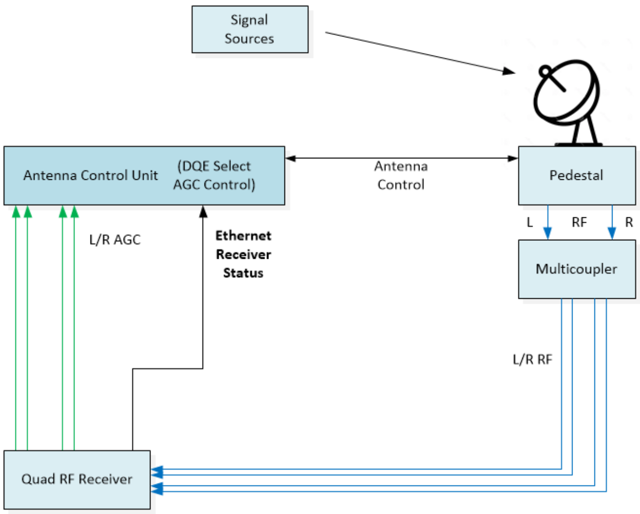


Figure 1– Test Set Up

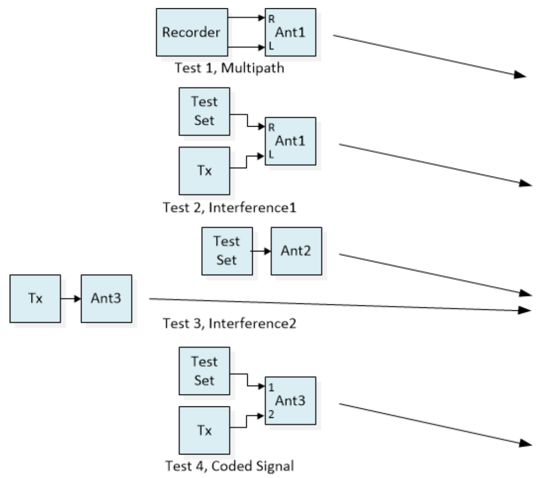


Figure 2 – Signal Sources

The receive antenna was the TCS Model 1800-6, a 6-foot S-Band Tracking Antenna. The ACU was the TCS ACU-M1. These are shown in Figures 3 and 4. The multicoupler was from TCS and the receiver was the GDP 4426 Quad Receiver/Combiner configured as two dual channel combiners.

Figure 3 - TCS S-Band Tracking Antenna Model 1800-6

Figure 4 - TCS Antenna Control Unit ACU-M1

The right- and left-hand antenna feeds were supplied to the multicoupler which produced two copies of each signal. From the multicoupler the left-hand signal was sent to receivers 1 & 3 and the right-hand signal was sent to receivers 2 & 4. Each receiver processed its input signal to recover the data, measure the BER, determine the signal EbNo, calculate the IRIG BEP and embed the BEP in the DQE. Receivers 1 & 2 supplied the signal to combiner 1 and receivers 3 & 4 supplied the signals to combiner 2. Each receiver provided an AGC to the ACU. The Quad receiver was controlled over ethernet by its GUI, provided recovered data over 218-20 TMoIP, and provided a composite status message, containing EbNo and DQE for each receiver, to the ACU over multicast ethernet.

For the 6’ dish antenna the far field for 2250MHz starts around 165’. Due to the physical constraints of the test sight the test signals were transmitted from boresight antennas placed about 83’ from the receive antenna, about half the distance to the far field. Fortunately, this did not have an impact on the tests. The 6’ dish has a 3dB half power beamwidth is 4.9 degree. At 83’ this is about 7.1’ or 3.55’ for half of the 3dB beamwidth.

Figure 5 - Circularly polarized boresight antenna

Figure 6 – Dipole in a cup boresight antennas

The 1st two tests used a crossed dipole in a cup boresight antenna with its pluming set up to produce both a right- and left-hand circularly polarized signal as shown in Figure 5. For the 3rd test, the two crossed dipole in a cup boresight antennas shown in Figure 6 were used to transmit two signals at different frequencies. The antennas were separated by about 3.5’, the receive antenna’s half 3db beamwidth. One was 8’ high and the other 7’ high. For the 4th test the 7’ high boresight was used to transmit the two signals at different frequencies.

TEST 1 - MULTIPATH

The 1st test used a 2325MHz, 5Mbps PCM/FM signal and a multipath corrupted version of the signal to verify that the ACU can use a DQ metric to choose the best quality signal for tracking.

When a right-hand circularly polarized signal is reflected it becomes left-hand polarized. The reflected signal is often composed of multiple reflections and can be stronger than the direct signal. Using signal size as a metric an ACU may attempt to track the reflected signal instead of the direct signal, if however, the ACU uses DQ as a metric, the signal with the best signal quality, the direct signal, will be tracked. To verify this a 5Mbps PCM/FM signal was fed to the GDP multipath simulator to create the direct signal and a multipath corrupted version of the signal. Both signals were recorded on a Wideband RF recorder model DRS 9300. The recorded signal was played back with the direct signal applied to the right-hand polarization of the boresight antenna and the multipath version applied to the left-hand polarization with 10dB higher power. The receive antenna left-hand signal was supplied to the GDP receiver channel 1 and the right-hand signal to receiver channel 2. The spectrum of each signal is shown on the receiver GUI in Figure 7.

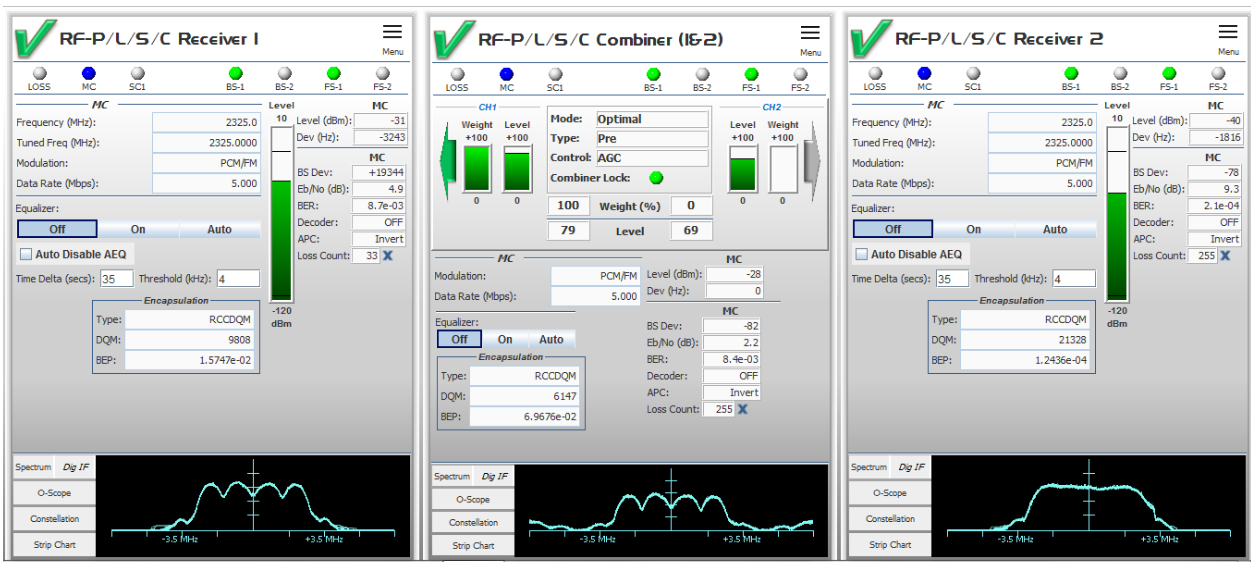


Figure 7 - Using the AGC metric the bad signal is weighted at 100%

Examining the GUI several observations are made: the multipath signal is about 10dB higher than the direct signal, the EbNo of the multipath signal is about 5dB worse than the direct signal, the BER of the multipath signal is almost two orders of magnitude worse than the direct signal, and the DQM of the multipath signal is less that half the DQM of the direct signal. Also note that the combiner is using the AGC as the weighting decision metric and is picking the multipath corrupted signal as the best signal.

To focus on the tracking metric, only the center portion of the TCS ACU GUI is shown in the following figures. The GUI displays the AGC levels in the central green horizontal bars with the length of the bar indicating the relative strength of the signals. The numbered tabs on the left column indicate which receiver is selected for tracking. When AGC is selected as the decision metric the Auto tab on the upper left is illuminated orange. When EbNo or DQE is selected as the metric, the selection, and the value of the selected parameter, is shown in the column to the left. Looking now at figure 8 it is seen that, when using AGC as the tracking decision metric, the stronger signal from receiver 1, the multipath corrupted signal, is selected for tracking.

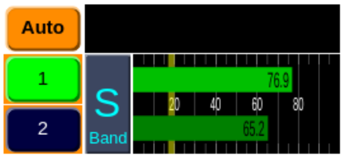


Figure 8 – Auto AGC

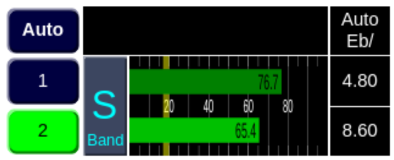


Figure 9 – Auto EbNo

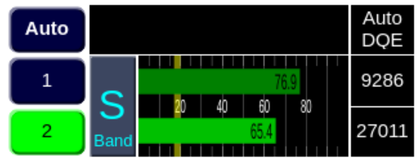


Figure 10 – Auto DQE

In figure 9, the ACU's tracking decision metric is switched to EbNo and now the better-quality signal, signal 2, is tracked. The same is true using IRIG DQE as shown in figure 10, the better-quality signal is used for tracking.

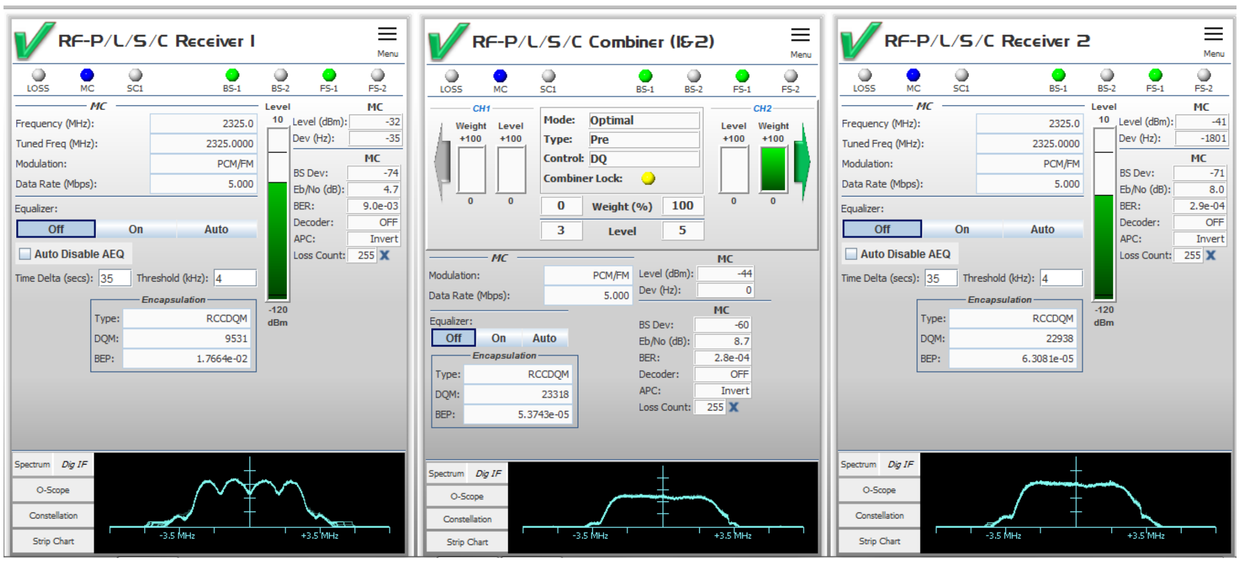


Figure 11 - Using the DQ metric the good signal is weighted at 100%

The ACU results are similar to the combiner's results as shown in figure 11. When the combiner's weighting decision metric is switched to EbNo, the combiner picks the better quality, lower power signal for the combiner's output. This is clearly shown by the combiner's spectrum where the direct signal, not the corrupted signal is now displayed.

TEST 2 – INTERFERENCE 1

For the 2nd test, antenna 1, is again used to test tracking in the presence of a same frequency interfering signal. The right-hand signal was a 5Mbps PCM/FM signal from an Emhiser S-Band transmitter and the left-hand signal was a CW signal from an SRI model RM-6300 RF Test Set. Both signals were at 2325MHz. The received signal parameters are shown in figure 12.

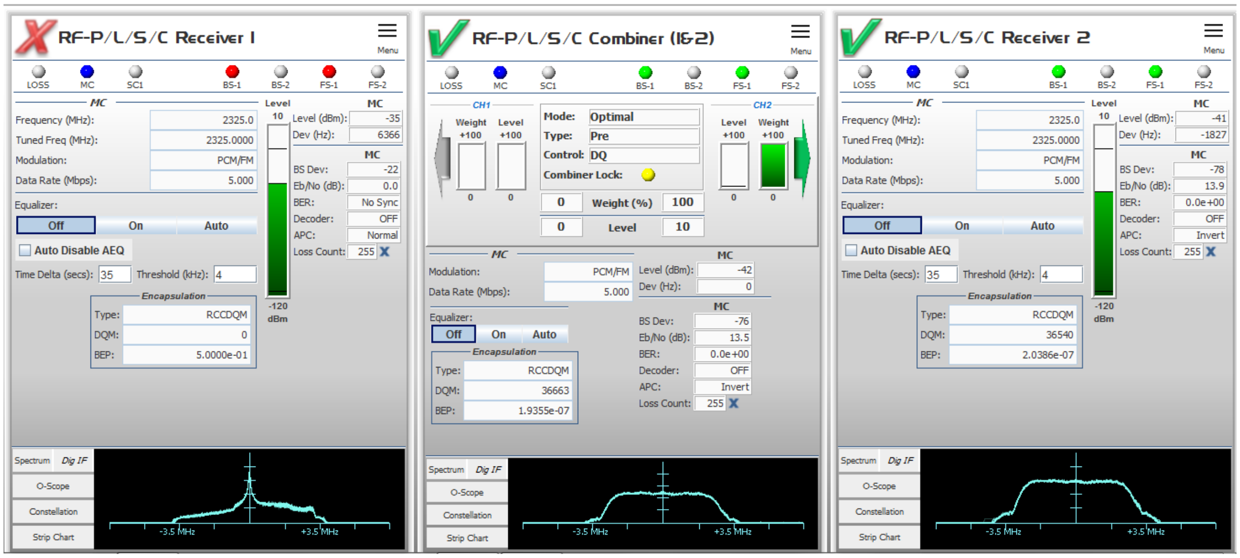


Figure 12 – Same frequency interfering signal

Examining the receiver GUI several observations are made: the interfering signal is stronger than the desired signal, the EbNo and DQE of the desired signal are both good, and the EbNo and DQE of the interfering signal are both zero. Also note that the combiner is using DQ as the weighting decision metric and as a result is not picking the biggest signal but is picking the best signal as the source.

Looking now at the TCS ACU GUI tracking metric, it is seen in figure 13, that when using AGC as the tracking decision metric, the stronger signal from receiver 1, the interfering signal, is selected for tracking. But when the ACU's tracking decision metric is switched to EbNo, figure 14, or DQE, figure 15, the better-quality signal is selected for tracking.

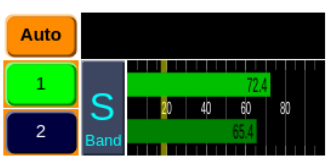


Figure 13 – Auto AGC

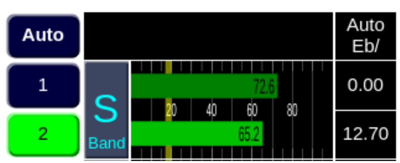


Figure 14 – Auto EbNo

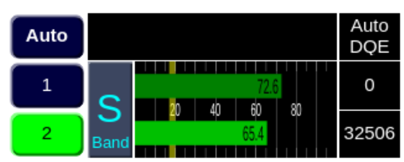
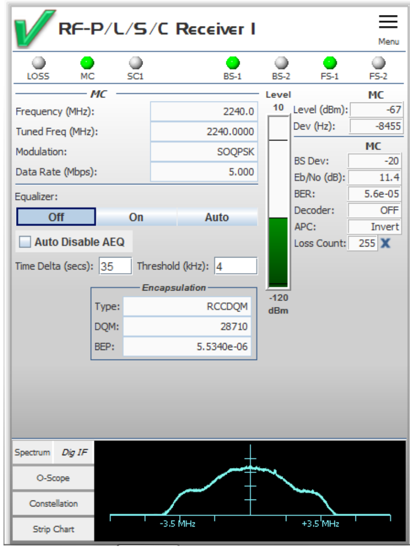
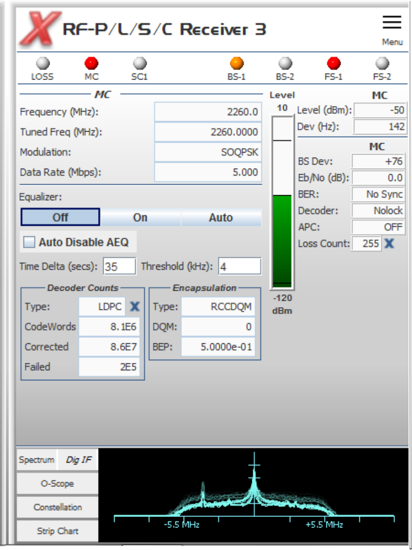


Figure 15 – Auto DQE

TEST 3 – INTERFERENCE 2

For the 3rd test two boresight antennas were used to test antenna tracking in the presence of an interfering signal. The Emhiser transmitter generated a 5Mbps SOQPSK signal from antenna 2 at 2240MHz and the SRI test set generated a higher power CW interfering signal at 2260MHz from antenna 3. For this test four receivers were used, right-hand and left-hand for each frequency. The received signal parameters for receivers 1 and 3 are shown in figures 16 and 17 when the ACU is using AGC as the tracking metric and the antenna is tracking (pointing towards) the interfering signal.





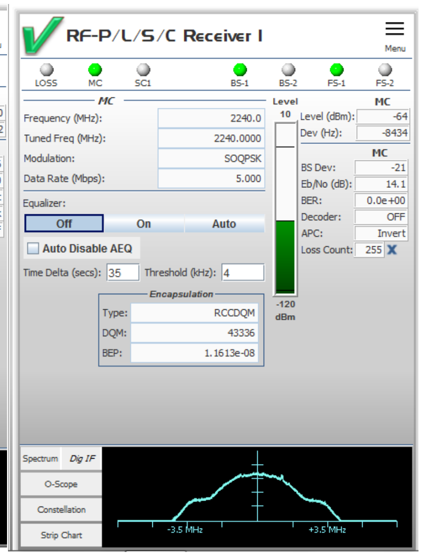
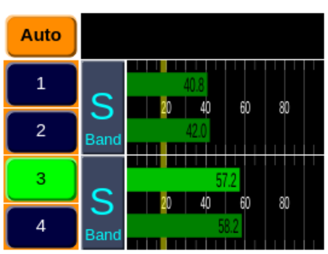
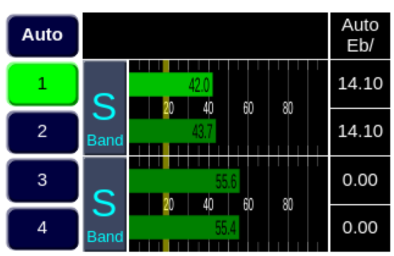


Figure 16 – Desired Signal **Figure 17 – Interfering Signal** **Figure 18 – Tracking Desired Signal**

Examining the receiver GUI several observations are made: the interfering signal is stronger than the desired signal, the desired signal level = -67dBm, EbNo = 11.4dB and DQE = 28k, and the EbNo and DQE of the interfering signal are both zero. In figure 18 the desired signal parameters are again shown, this time when the ACU is selecting the best quality signal and the antenna pointing towards the best source antenna. Note that the desired signal level is now -64dBm, 3dB higher than before. This is because the transmit antennas are separated by the receive antenna half 3dB bandwidth, so that when the receiver antenna is pointed to the interfering source the desired signal is reduced by 3dB.





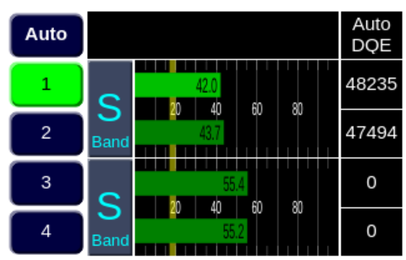


Figure 19 – Auto AGC **Figure 20 – Auto EbNo** **Figure 21 – Auto DQE**

Looking at the ACU GUI tracking metric, all 4 receivers are now available to be selected as the best source. It is seen in figure 19 that when using AGC as the tracking decision metric, the stronger interfering signal from receiver 3 at 2260MHz, is selected for tracking. But when the ACU's tracking decision metric is switched to EbNo, figure 20, or DQE, figure 21 the better-quality signal from receiver 1, the desired signal at 2240MHz, is selected for tracking.

TEST 4 – CODED SIGNAL

It is becoming increasingly common for a target vehicle to transmit more than one signal. To take advantage is this transmit diversity for antenna tracking, the ACU often accepts AGC signals from multiple receivers that process the multiple signals transmitted from the target. Again, this is historically done using the AGC, but now is starting to use DQE to improve performance. However, this is where caution must be used, not all DQEs are suited to the multiple signal scenario. The DQE used must be based directly on signal quality, the signal quality before any forward error correction, and not a derived parameter like BEP. Consider the scenario where one telemetry signal from the target is rate ½ LDPC encoded QPSK, and a 2nd signal is an unencoded QPSK signal. Figure 22 shows the BER of both signals, and the RCC BEP for the encoded signal, versus EbNo. (In the figure a BEP of zero is shown at the bottom of the figure on the 1.0E-08 line for convenience). The RCC DQE is BEP based, so for the encoded signal the BEP is zero when the signal's EbNo is greater than about 1.5dB. This is due to the FEC and not based directly on the quality of the signal itself. If the RCC BEP of the encoded signal at an EbNo of 3 dB, a BEP = 0, is compared to the BEP of the unencoded signal with a 7dB better EbNo of 10dB, a BEP = 4.0E-06, the encoded signal will be declared the better signal even though it has a much worse signal quality. Because the encoded signal has a much worse EbNo it is much closer to its loss threshold and much more prone to a signal loss than the unencoded signal. Based on the RCC BEP the ACU would track the signal with the worse EbNo, a signal much closer to its loss threshold, a signal that will provide a lower quality, noisier AM control signal, and as a result tracking performance would be degraded.

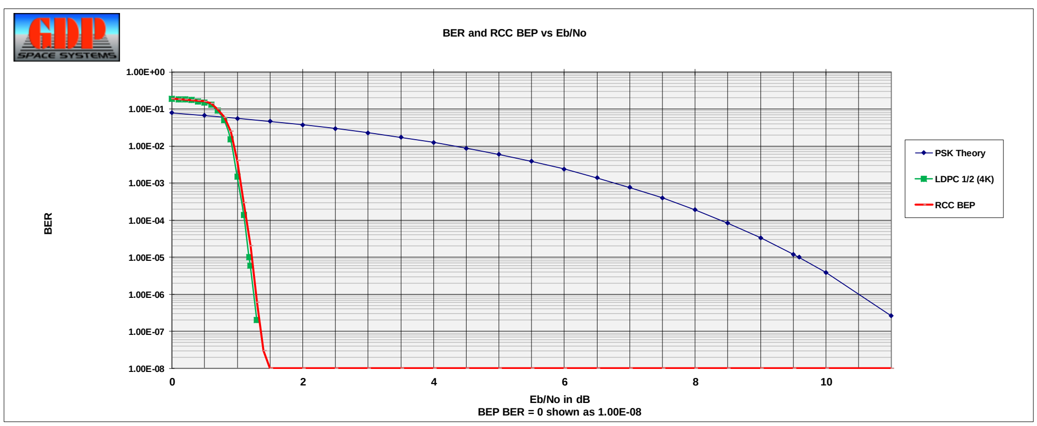


Figure 22 – Encoded and Unencoded BER & BEP vs EbNo

For this test a single boresight antenna was used to emulate two telemetry sources from a single test vehicle. The Emhiser transmitter generated a 5Mbps SOQPSK at 2240MHz and the SRI test set generated a R2/3 LDPC encoded 5Mbps SOQPSK signal at 2260MHz. The two signals were combined at the antenna. For this test four receivers were again used, right-hand and left-hand for each frequency. The received signal parameters for receivers 1 and 3 are shown in figure 23 and figure 24.

Examining the receiver GUI several observations are made: the uncoded signal is the stronger signal with a better EbNo = 14.3dB, than the LDPC encoded signal, but it has a lower DQE = 46k, the LDPC encoded signal has a lower EbNo = 6.7, but a better DQE = 65k.

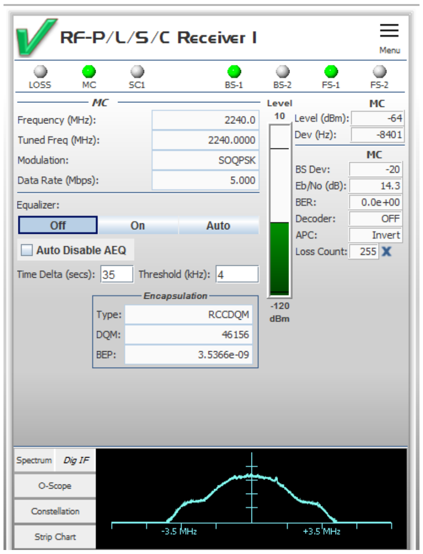


Figure 23 – Uncoded Signal

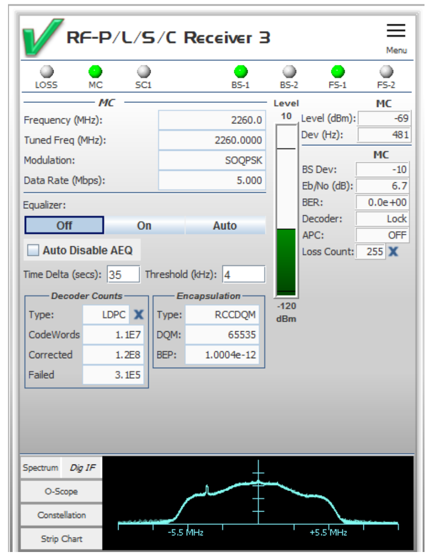


Figure 24 – LDPC encoded Signal

As seen in figure 25, if DQE is used as the tracking decision metric, the lower quality LDPC encoded signal is selected for tracking.

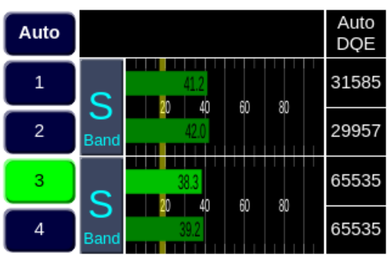


Figure 25 – Auto DQE

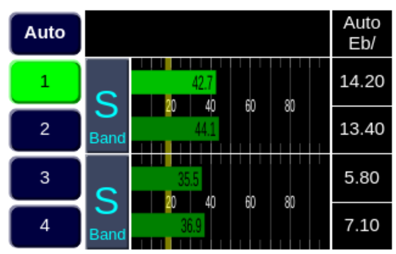


Figure 26 – Auto EbNo

However, if EbNo is used for the decision metric, the better-quality signal is selected and the signal with the higher fade margin and better SNR is used for tracking.

CONCLUSION

Antenna testing has verified that a modern ACU can provide significantly better, more reliable, tracking performance by using a DQ metric instead of the classic AGC. By using DQ an antenna can protect against tracking the wrong signal, a signal with a lower data quality such as a multipath corrupted signal, or an interfering signal. For antenna tracking, using a DQ metric provides superior performance over AGC but for maximum benefit the DQ metric should be based directly on signal quality, such as an EbNo, and not solely on BEP as the RCC/IRIG DQE.

ACKNOWLEDGEMENTS

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[1] S. Nicolo, "History and Advantages of Best Source Selection", in *Proceedings ettc2018*, pp. 48 – 54, June 2018