Two-Way Development Update

Presented by

Microcom Design, Inc.

April 2020

Two-Way Update – Summary

- Two-Way Over-the-Air Demonstration Mostly Completed in Spring of 2020.
- Over-the-Air Demonstration primarily consisted of thee major tasks:
  - Develop and install Two-Way Modulator at WCDA.
  - Develop Two-Way Receiver/Demodulator to demonstrate ability to synchronize, and advantages of synchronizing, transmitted Two-Way signal to UTC at the satellite
  - Measure and confirm expected BER of the Over-the-Air Two-Way signal at the allowed PSD.
- Modulator completed and installed at WCDA on November 22ND 2019.
- Initial confirmation of reception and synchronization performed in February of 2020.
  - Reliably receiving data at expected SNR at the correct PSD.
  - Received signal level is in agreement with the calculated link margin analysis.
- Expected to complete Two-Way Over-the-Air BER testing by April 2020.
  - Task had to be put on hold in March 2020 due to COVID-19.
- Discovered issue with time variability due to GOES satellite motion in space.
  - With BER testing on hold Microcom proposed a separate task to address time variation.

Two-Way Update – BER Measurements

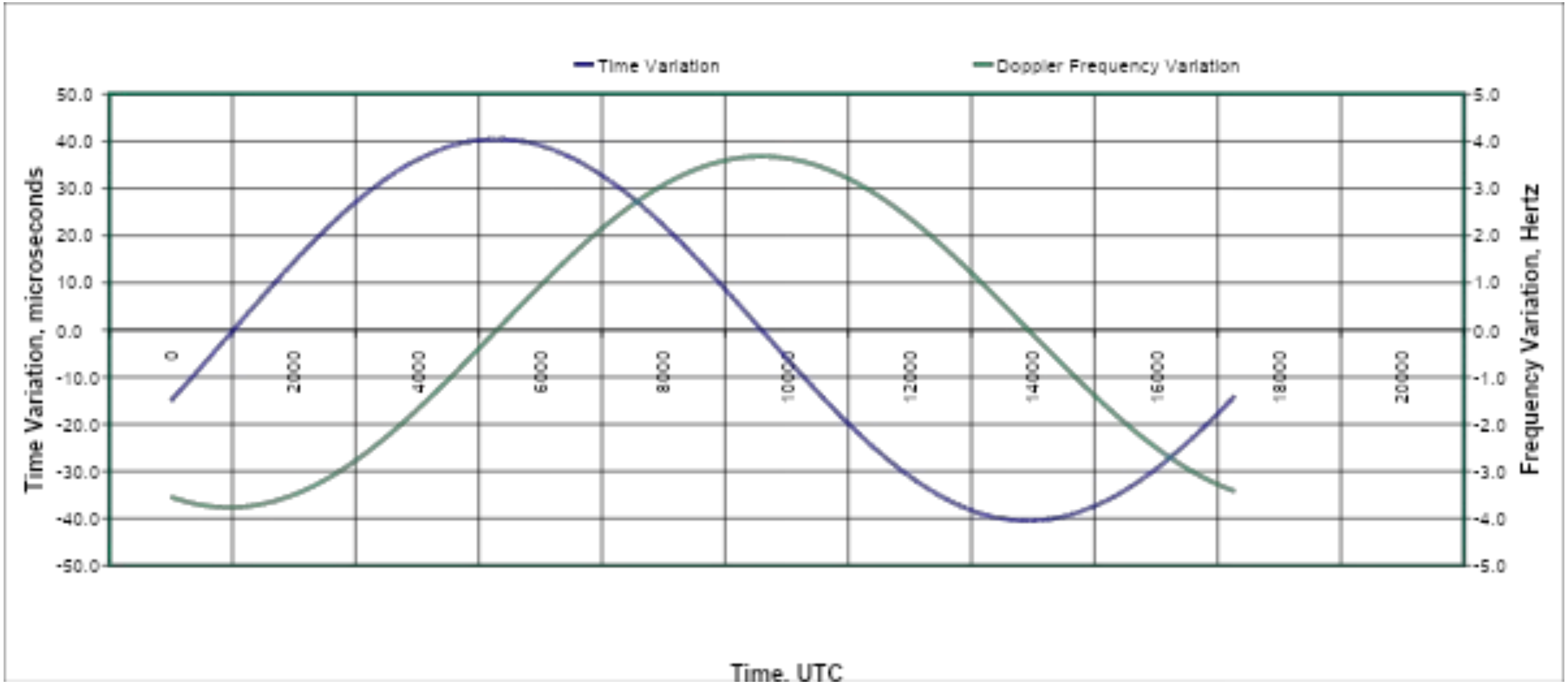
- BER measurement task was delayed due to unforeseen complications:
  - Strong interfering emitter - RF front end was damaged by an LMR transmitter.
  - February 19^{th} to March 4^{th} GOES operations were moved from WCDA to CBU.
- BER measurement task was put on hold due to COVID-19:
  - To perform BER measurements, need to be able to adjust Two-Way signal level coming from down from GOES satellite.
  - Modulator output power is adjustable, but transponder on satellite performs AGC to maintain downlink power constant regardless of uplink power.
    - The AGC feature prevented moving forward with BER measurements.
    - AGC can be turned off or the uplink could be modified to include two separate signals to "fool" AGC.
    - Either approach required onsite changes by NOAA personnel, and was not permitted due to COVID-19 since task is not critical work.
  - BER testing remained on hold through out summer, and continues to be on hold.

Two-Way Update – Satellite Movement Task

- Variability of signal travel time found to be significant and problematic:
  - For optimum performance Two-Way hopping requires timing accuracy better then 0.5 microseconds (1 µS worst case).
  - Time variability found to be on order of several tens of microseconds (see next slide).
  - Untracked movement will significantly increase phase noise due to hop misalignment.
  - Large hop timing misalignments will cause the demodulator to break lock.
- With BER Testing on hold, Microcom proposed alternate task to investigate and develop automated tracking algorithm to account for time variation.
- Three possible tracking solutions postulated:
  - Energy drop in received signal due to hop misalignment.
  - Phase transient that is known to occur when hops misaligned.
  - Alignment of symbol transitions in modulated data; Two-Way symbol rate is precise.
- Phase transient approach showed best results, but all three investigated.
  - Task is very close to completion.
  - Have demonstrated ability to track time variation on bench and over-the-air.

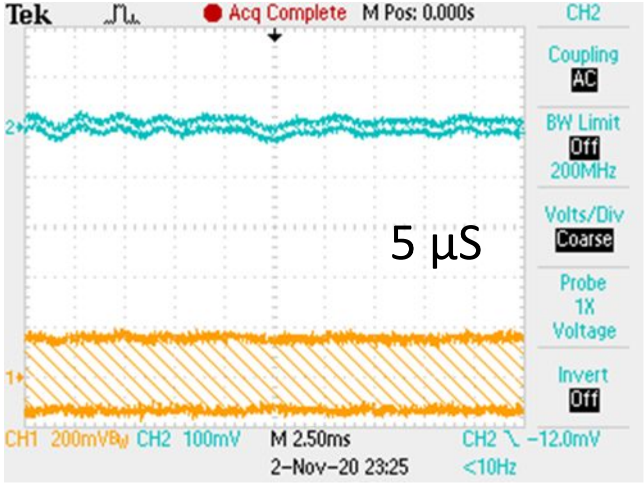
Two-Way Update – Satellite Movement

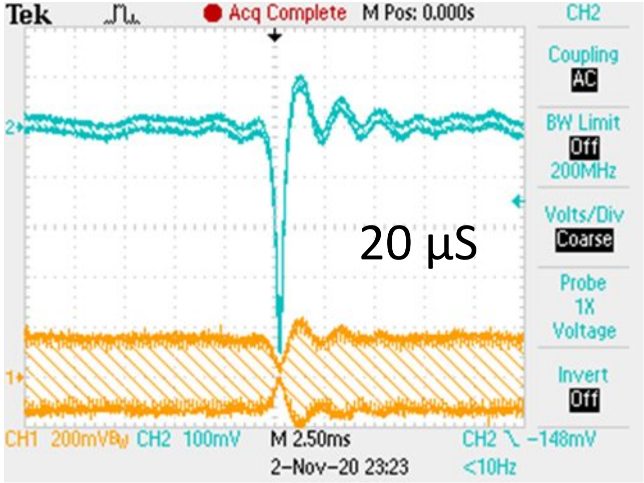
- ±40 µs travel time variation and 7 Hz frequency variation over 1 day due to motion.



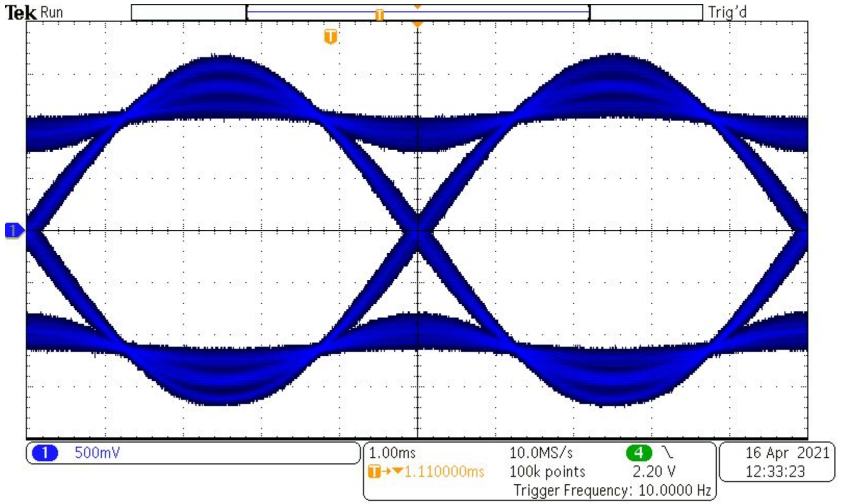
Two-Way Update – Energy Drop Misalignment Investigation

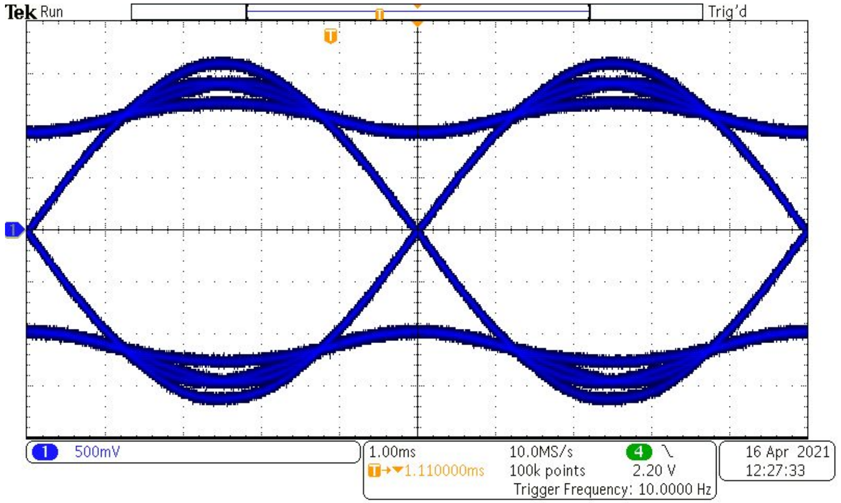
- Microcom developed separate energy detection circuit that was connected 455 kHz de-hopped IF.
- Testing showed that no significant drop in energy detection feedback was observable until misalignment exceeded 5 microseconds.
  - Top trace in oscilloscope images is output of energy detector.
  - Bottom trace in oscilloscope images is 455 kHz de-hopped IF.
- Lack of significant drop due to low frequency IF signal; at 455 kHz, 1 cycle has a period of just over 2 microseconds.
- Conclusions:
  - ***Approach not useful for required alignment precision.***
  - ***May be useful in field receivers that will not have as precise timing system to provide course alignment before engaging fine-tune control.***





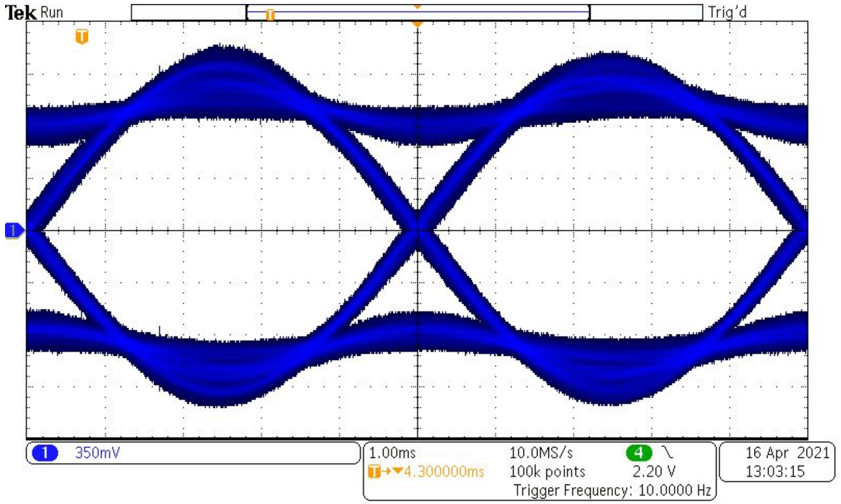
Two-Way Update – Symbol Transition Initial Investigation

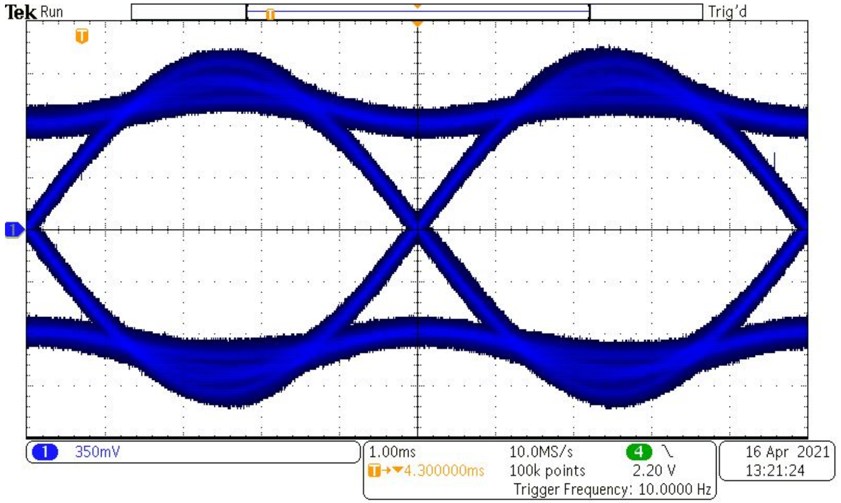




- Symbol transition occurs when transmission goes from a 0 to a 1 and vice versa.
  - 20 Symbols per hop implies expect 10 symbols transitions per hop; 100 transitions a second on average.
  - Using symbol transitions is common method for tracking symbol rate variations.
- Initial determination was that this approach would be difficult with standard RRC filter since cross over point has approximately 400 microsecond variation.
- Needed a different digital filter that preserves symbol crossing ***point***, and has similar spectral characteristics.
  - Settled on a modified or ***Truncated*** version of the standard RRC.
  - Symbol crossing occurs at a distinct point.
  - Spectral response very similar to standard RRC.

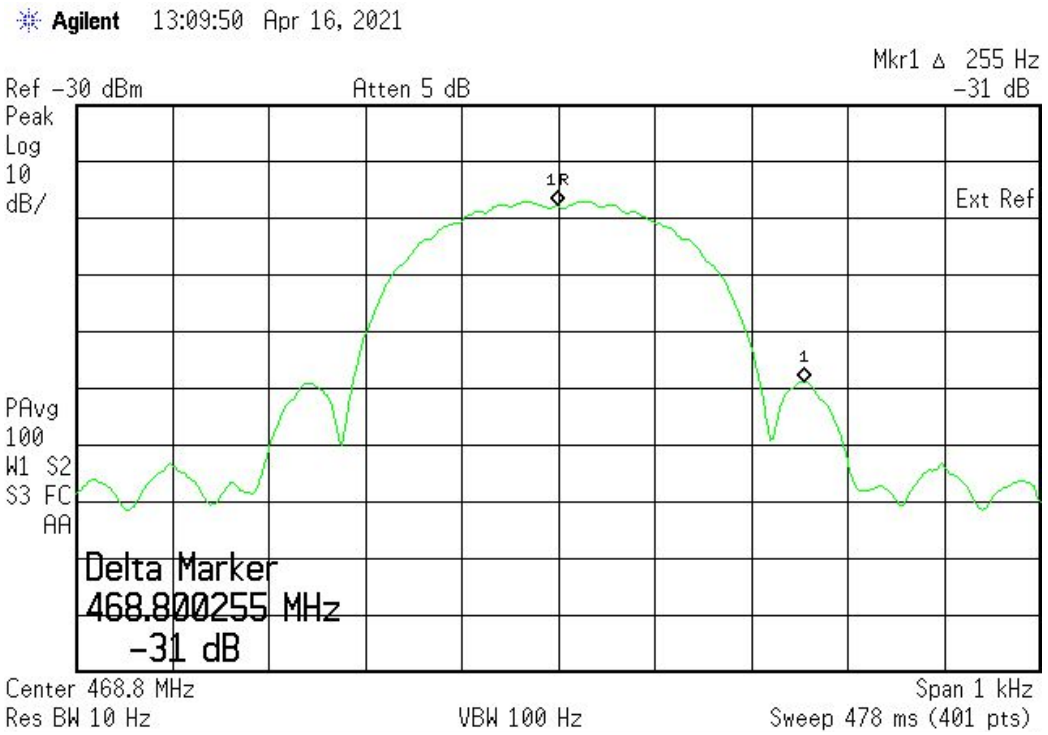
Two-Way Update – Symbol Transition Results

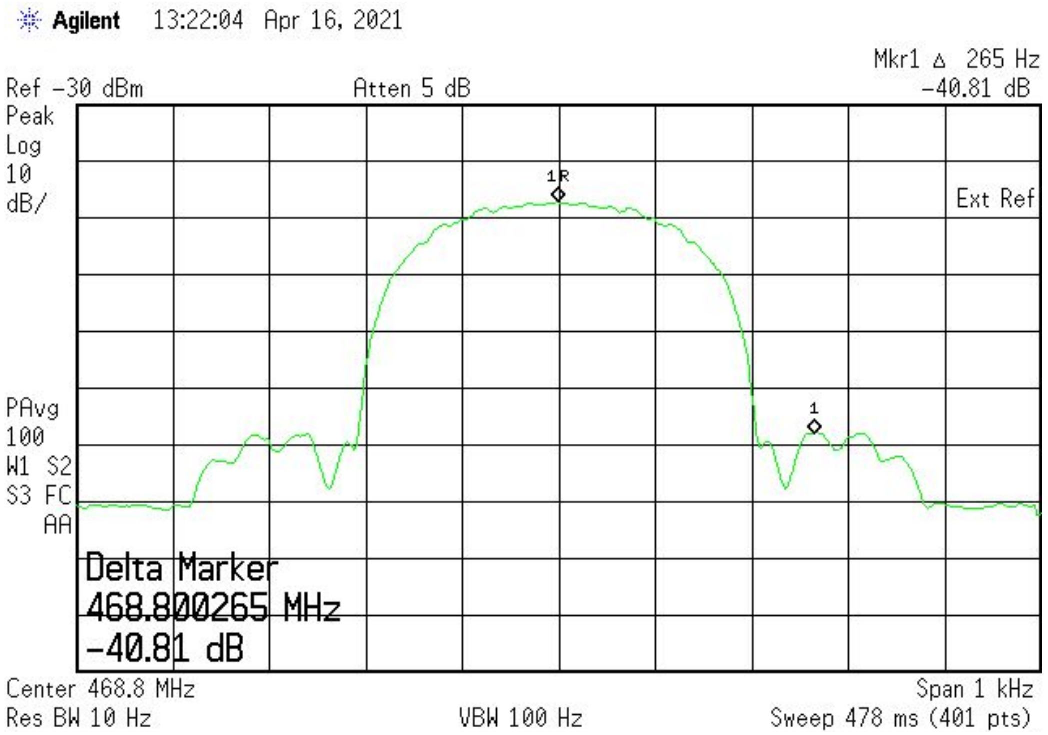




- Improvement in Symbol crossing did translate to demodulation.
  - Convergence is not quite as distinct at Demodulator as it is at the Modulator due to system noise.
  - Convergence did NOT appear to be significantly impacted by using Standard RRC at demod versus Truncated RRC.
- Microcom was not able to come up with a sufficiently accurate tracking algorithm for Symbol crossing approach.
  - Alignment accuracy on the order of 25 microseconds was achieved, but need microsecond resolution.
  - Believe the issue is related to current implementation of digital sampling and DSP decimation processing.
- Conclusions:
  - ***It should be possible to improve accuracy, but would require significant changes beyond scope of the task.***
  - ***Suggest preserving use of Truncated RRC at Modulator to allow for alternate implementations in future.***

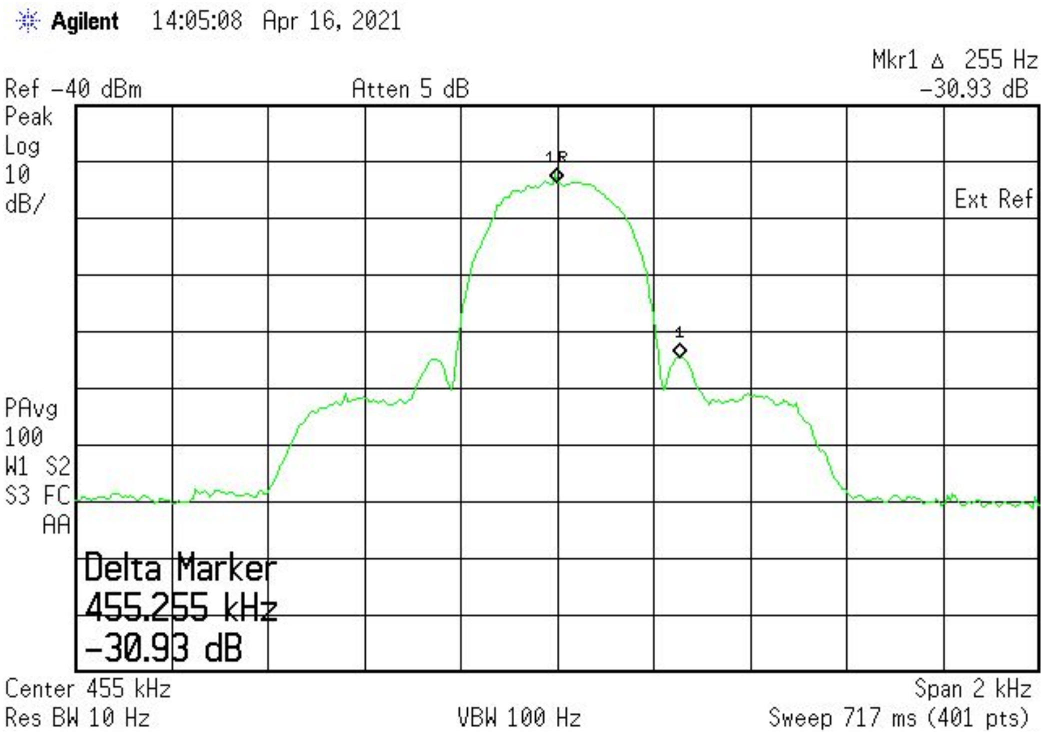
Two-Way Update – Symbol Transition – RRC Comparison Mod

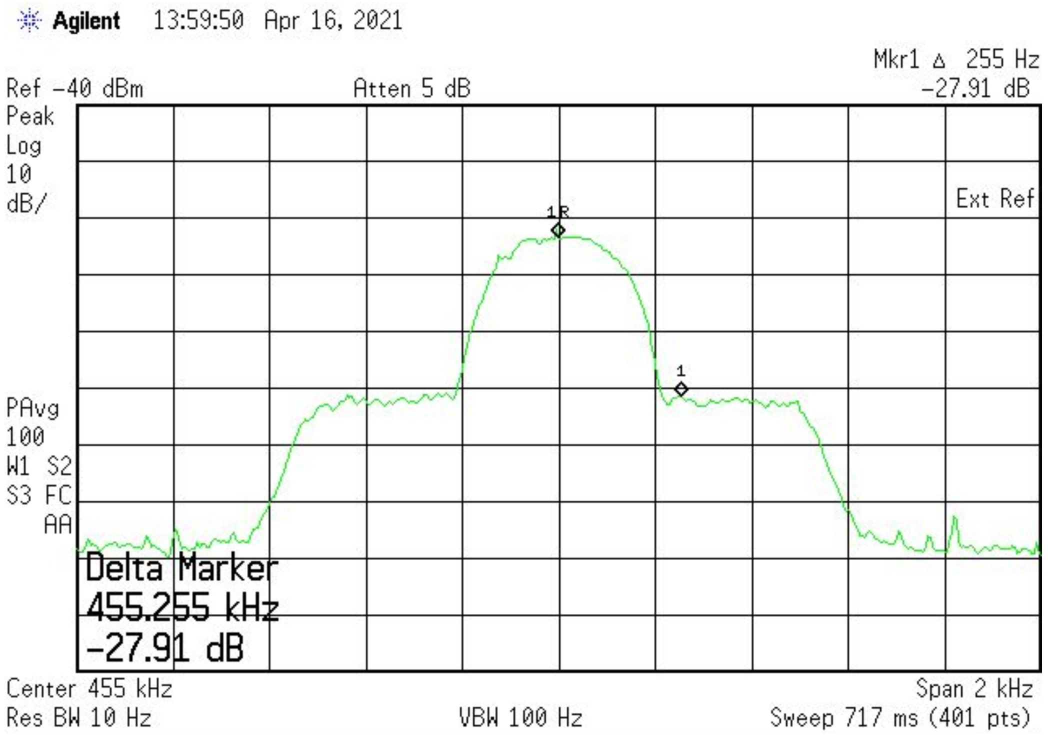




- Truncated RRC (left) only shows minimal spectral differences from Standard RRC (right) so it is not expected to have significant, if any, impact on BER performance.
- Even slight BER degradation may be acceptable tradeoff for convergent crossing.

Two-Way Update – Symbol Transition – RRC Comparison Demod

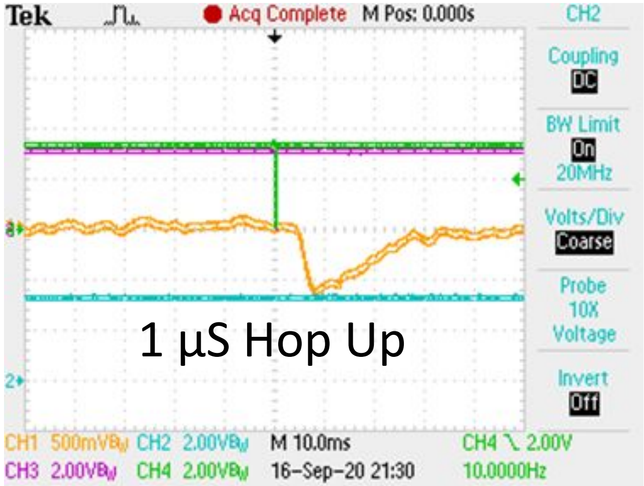


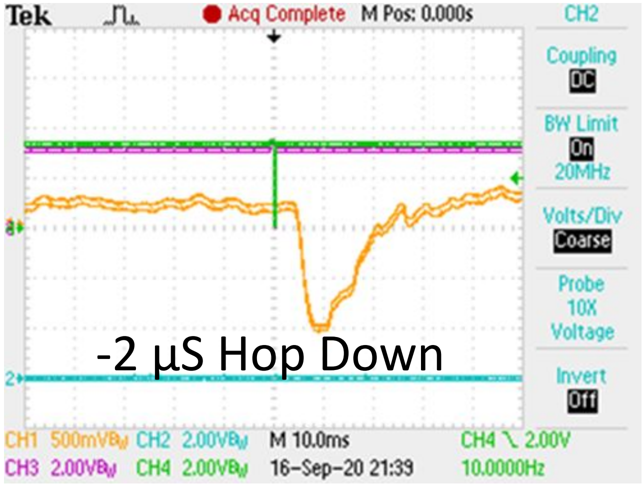


- Sidelobe regrowth can be seen at receiver with sufficient Signal-to-Noise Ratio (SNR).
- However, at highest expected receive levels, sidelobes fall below noise floor in 455 kHz Crystal Filter bandwidth.

Two-Way Update – Phase Transient Tracking Algorithm

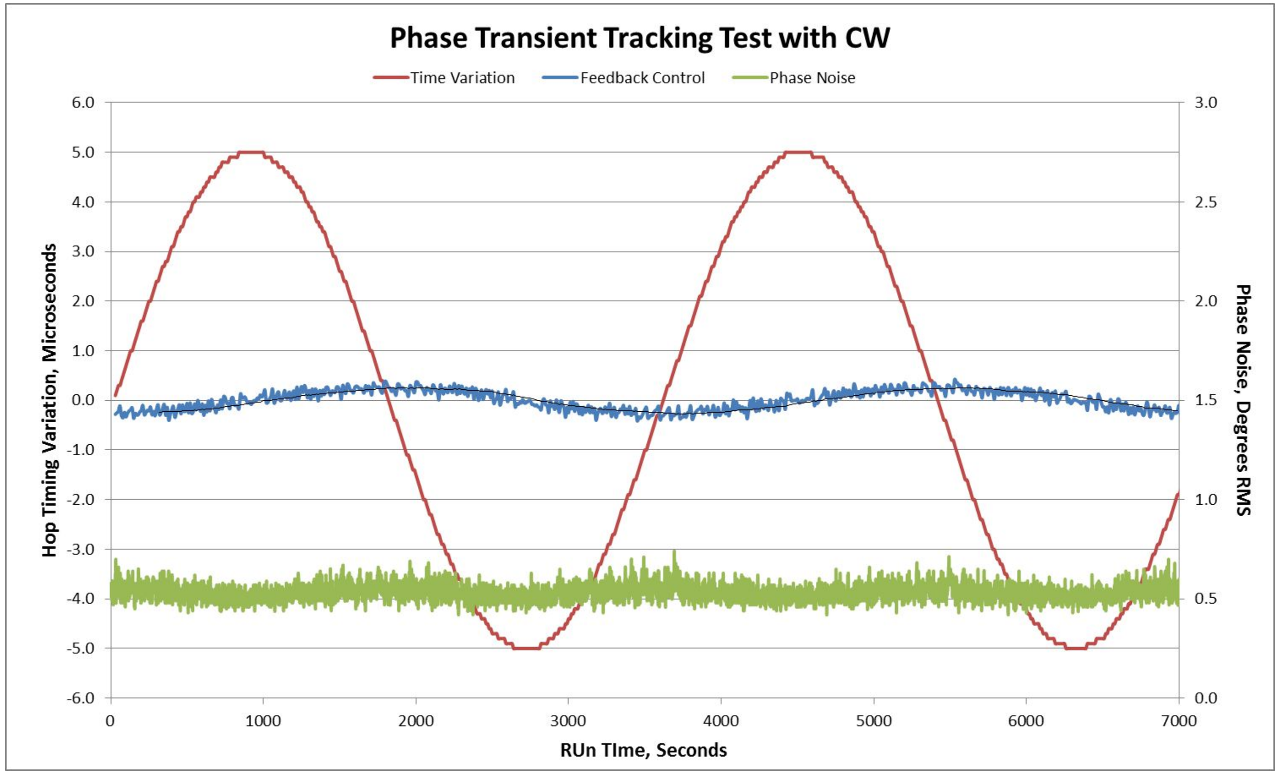
- Microcom performed series of tests to quantify and determine nature of phase transient.
- Testing showed height of phase transient directly correlated to level of misalignment, even below 1 microsecond, and provided direction of misalignment, but must account for direction of hop and phase of symbol.
- Modulator code enhanced to perform drift simulation.
  - Implemented sinusoidal hop drift alignment function with ...
    - Variable period in seconds (100 to 100,000)
    - Variable amplitude in microseconds (±1 to ±50)
- Demodulator code enhancement to …
  - Locate and compute height of peak in transient
  - Determine direction of timing offset (i.e. sign of peak) factoring in hop direction and phase of symbol.
  - Average individual readings over 10 seconds.

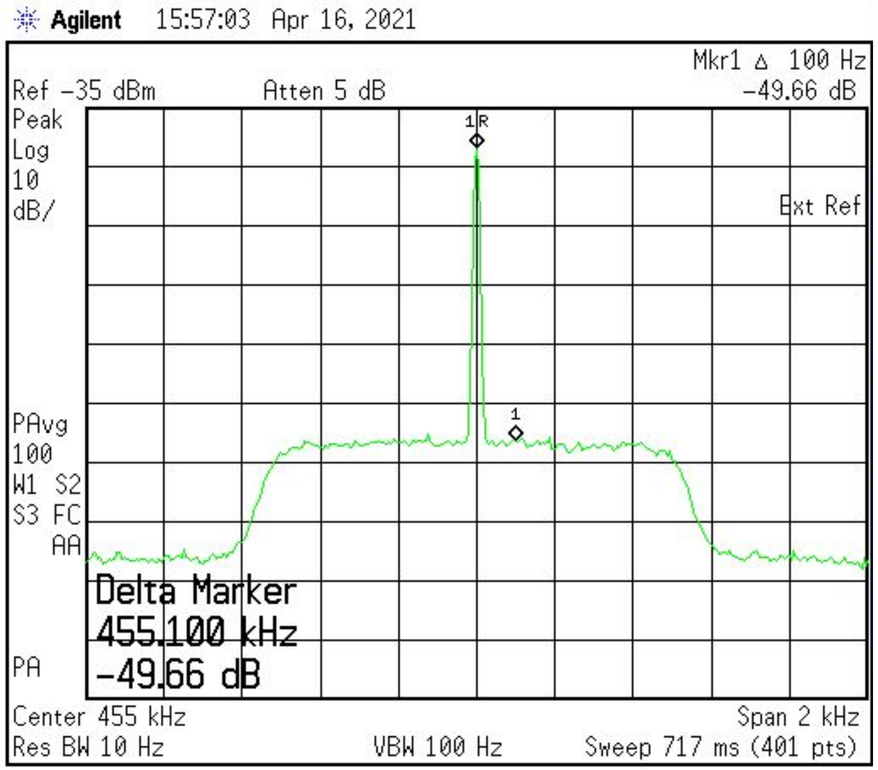




Two-Way Update – Phase Transient Control Algorithm Test

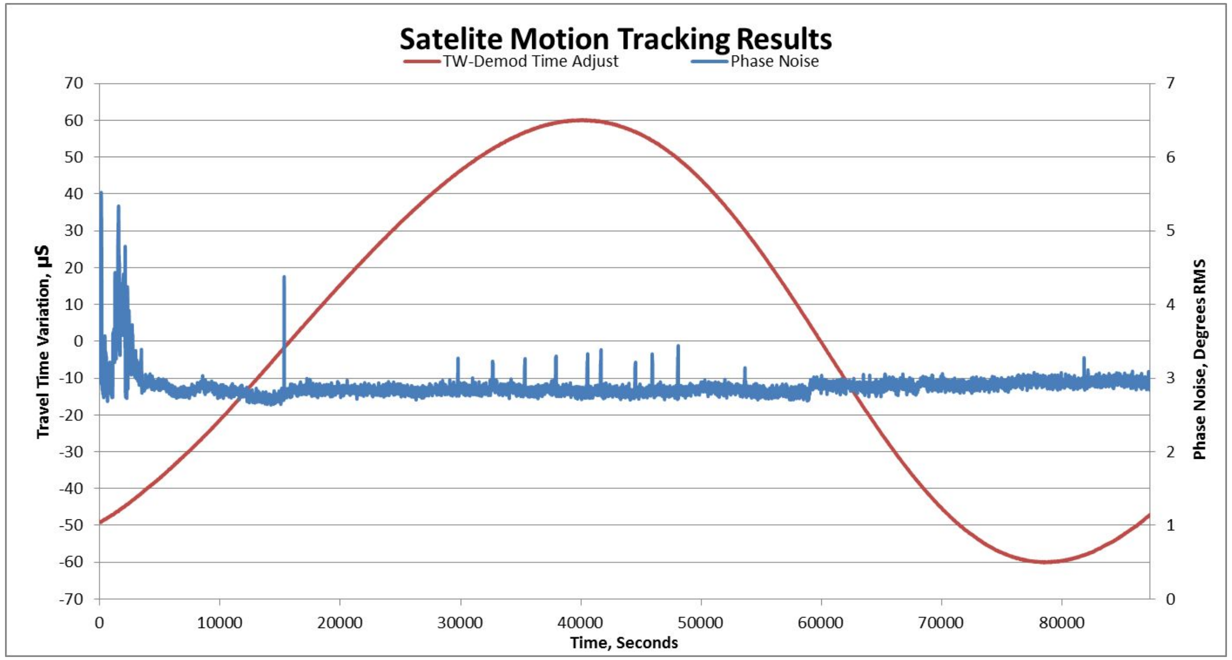
- Initial control algorithm bench tested with hopped CW or carrier signal - results were very promising, but SNR was very high (C/N = 50 dB) => needed to continue testing.
  - Test run used ±5μS variation over 1 hour matching expected maximum rate of change.
  - Phase noise remained consistent and error feedback showed low level sine shape.

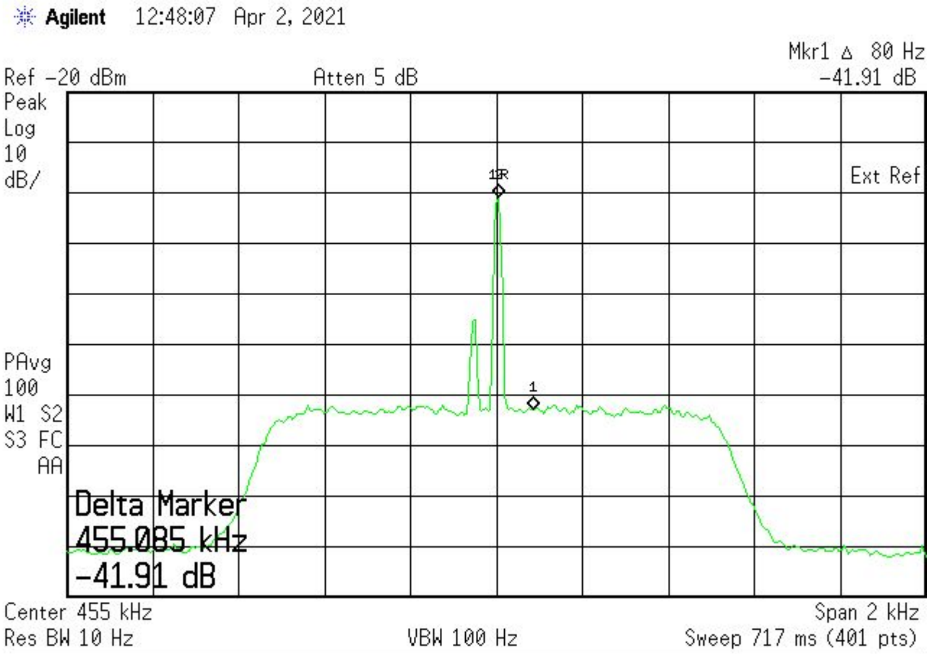




Two-Way Update – Phase Transient Over-the-Air Test

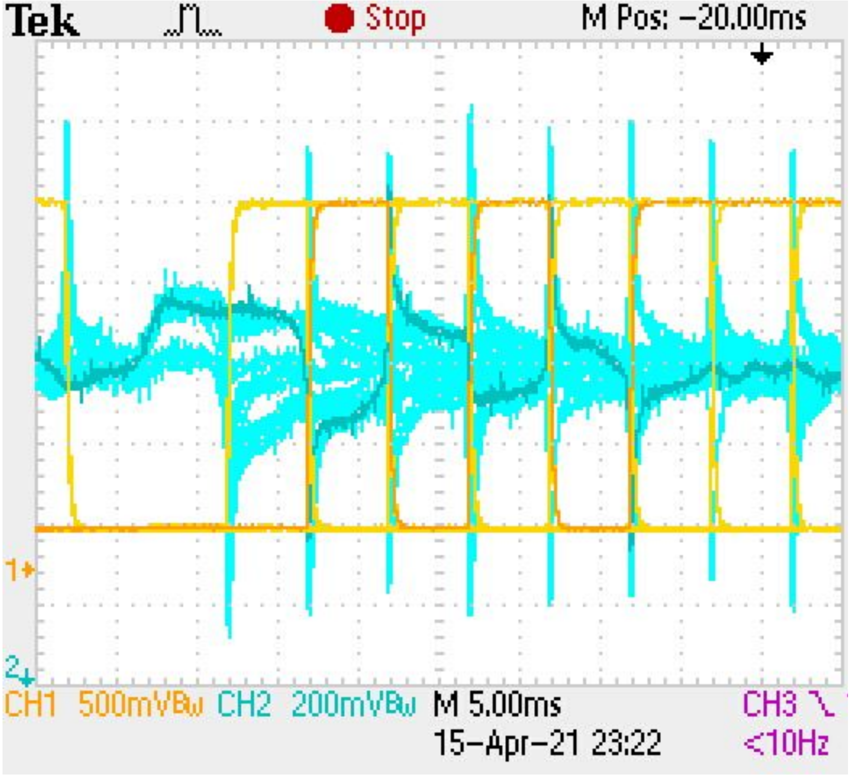
- Performed Over-the-Air hopped CW test – again results were very promising.
  - Test run showed ±60µS variation over 24-hour period.
  - Phase noise level of ~3º RMS consistent with reduced satellite SNR (C/N = 42 dB).
- Next steps were to extend algorithm to handle modulation and even lower SNR.

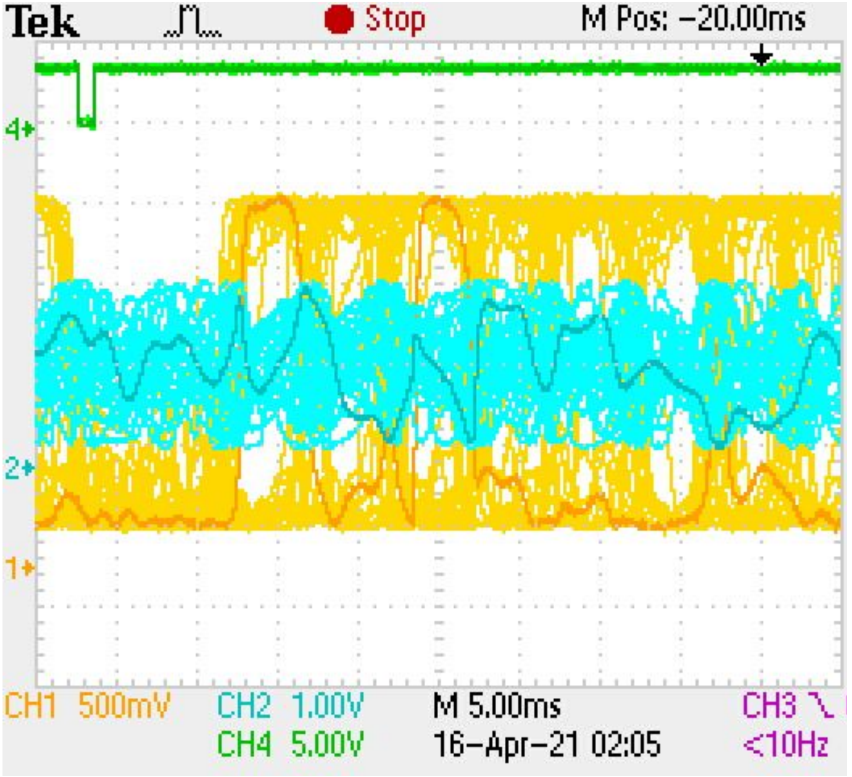




Two-Way Update – Phase Transient with Modulation & Noise

- Addressing Modulation required some tweaks to the algorithm since the transient reverses polarity with bit changes.

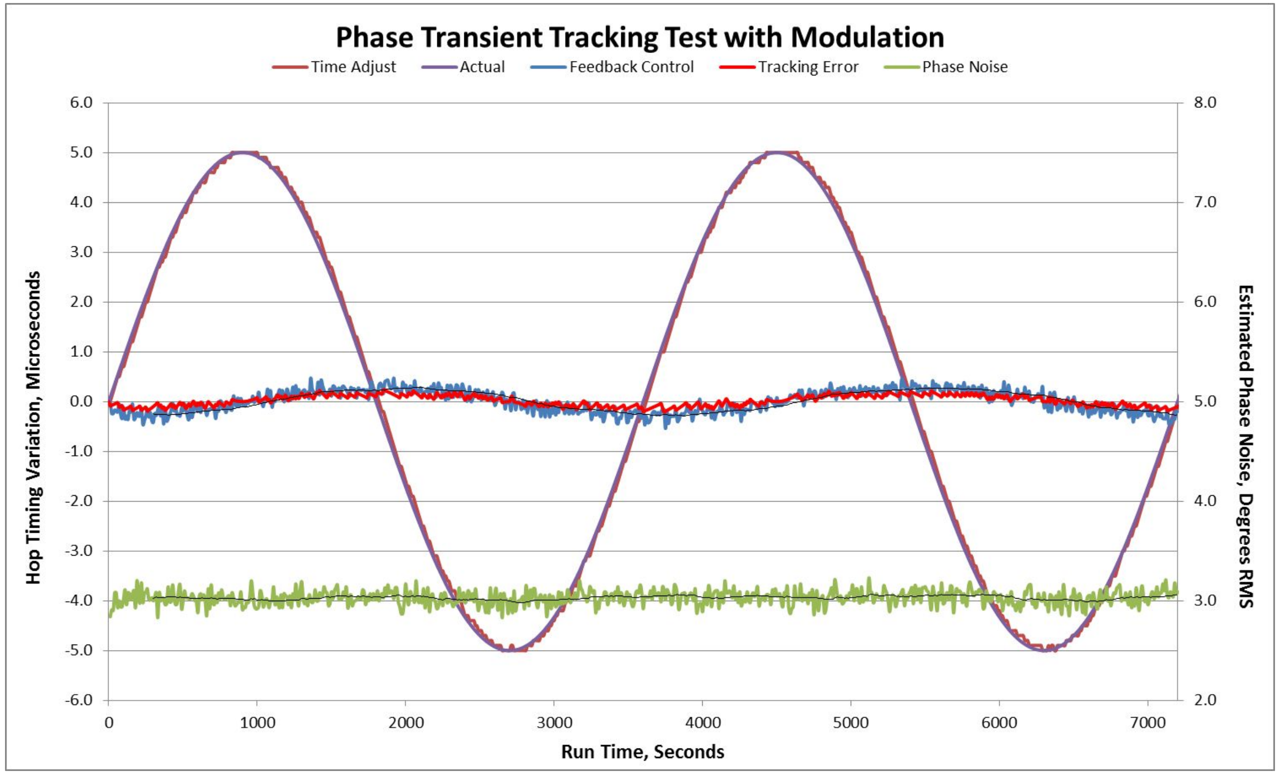


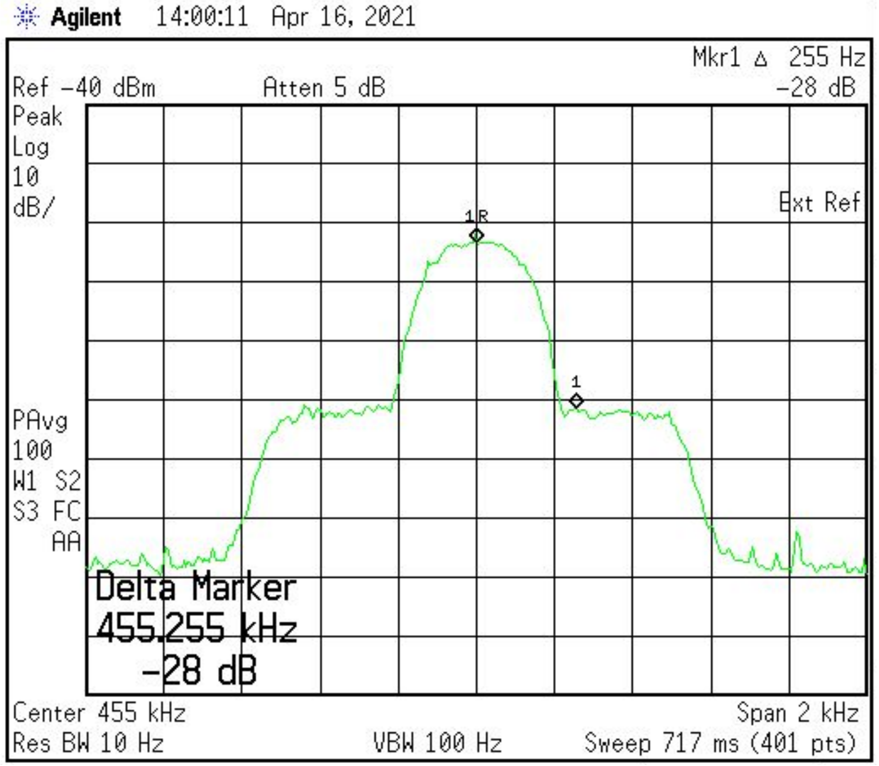


- Goal for low SNR performance was to support Over-the-Air BER testing at 10^{-4} to 10^{-6}, but noise obscures transient.

Two-Way Update – Phase Transient Performance Typical SNR

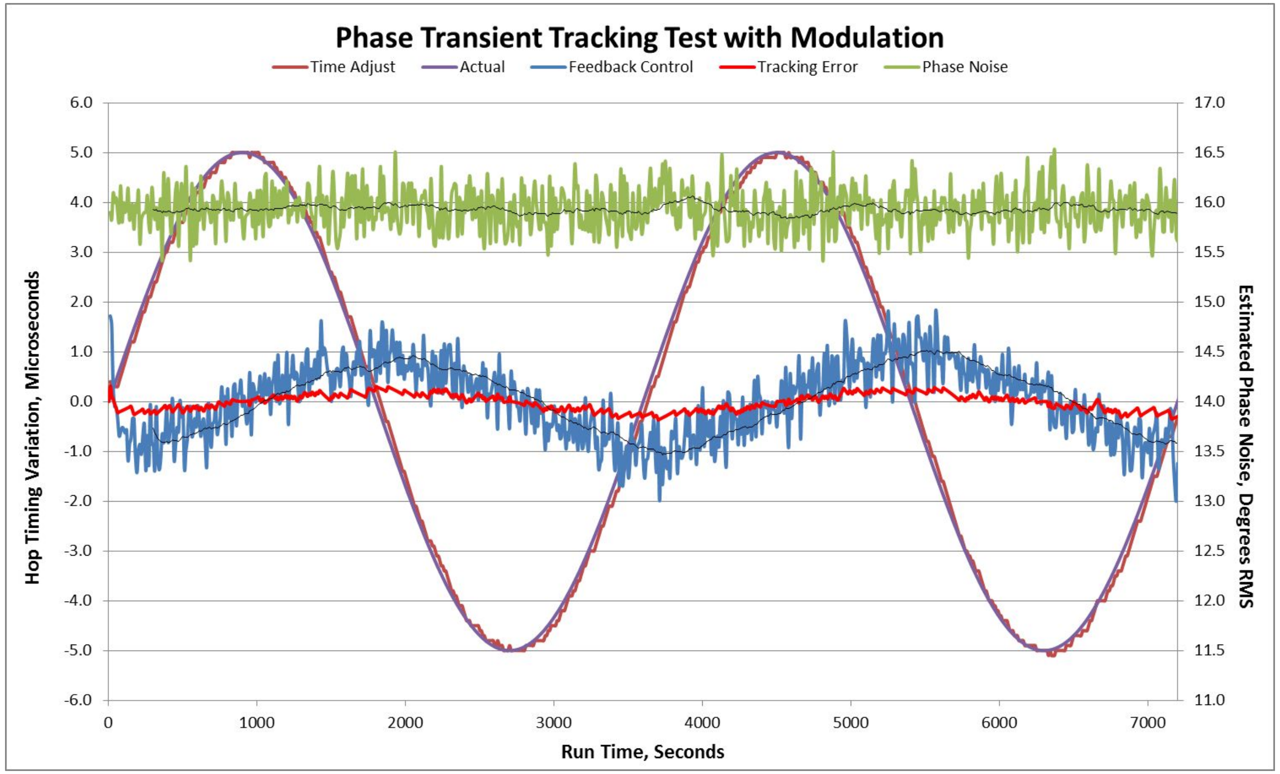
- Initial modulation bench tracking test performance at SNR (28 dB) equivalent to received SNR.
- Modulation tweaked algorithm worked extremely well.
- Similar performance to CW test; increase in Phase Noise due to modulation transients in Q signal used to estimate statistic.

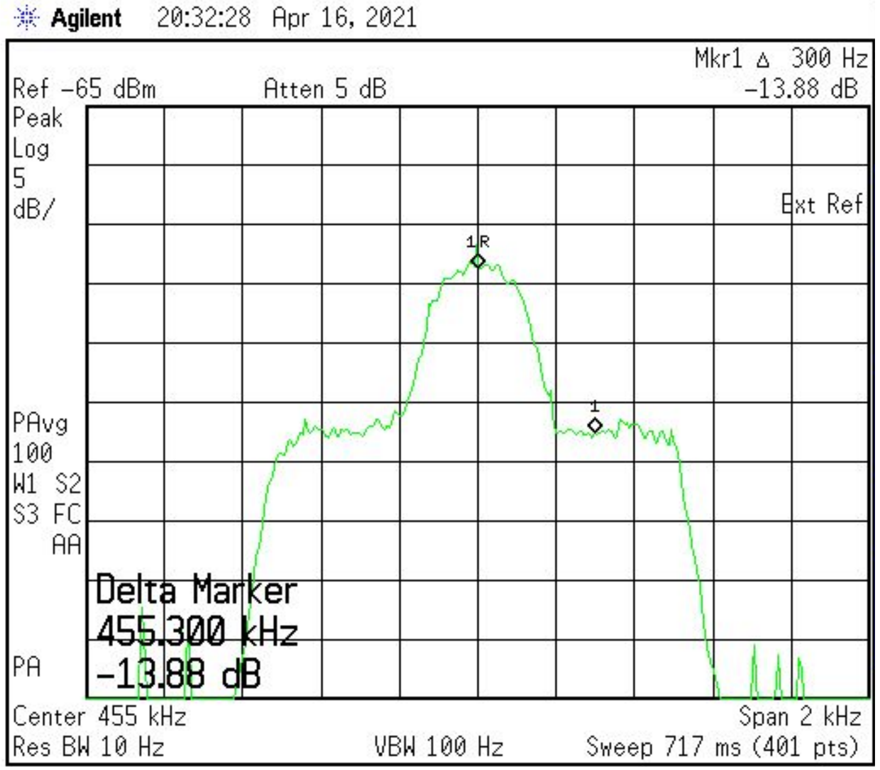




Two-Way Update – Phase Transient Performance Low SNR

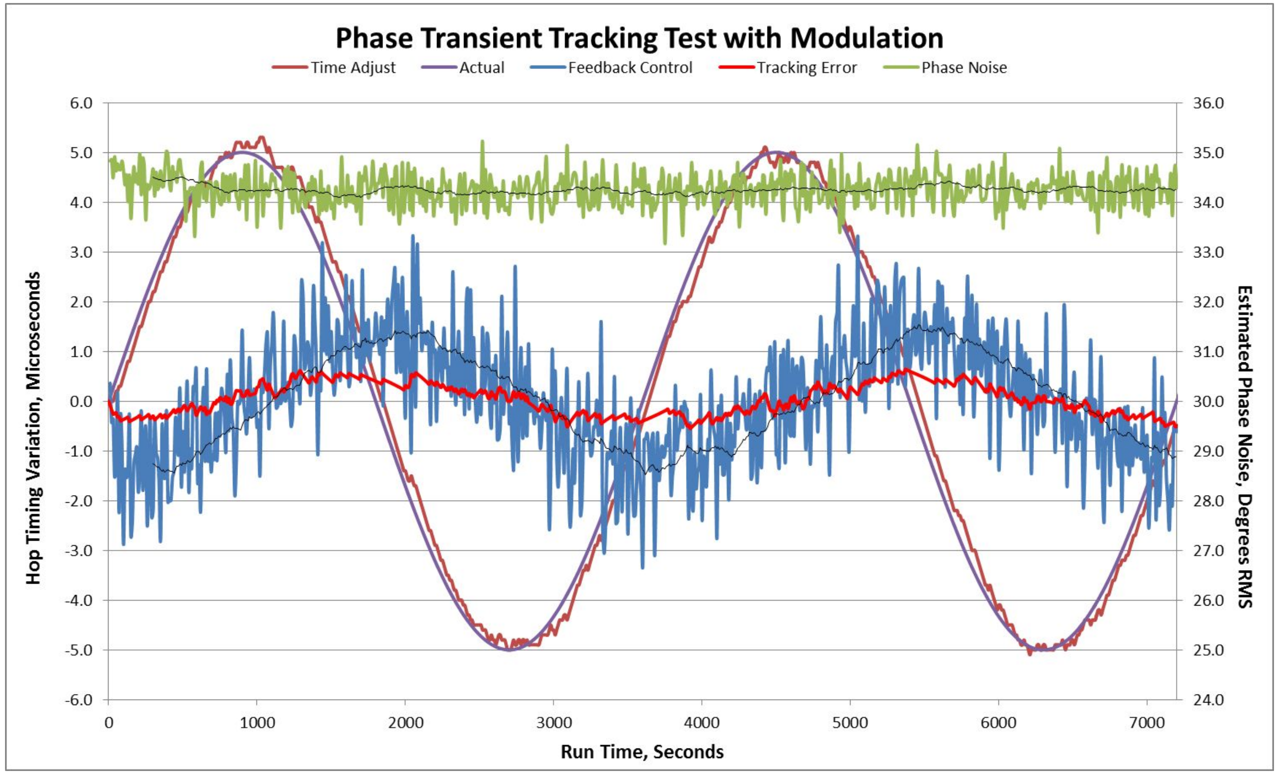
- Modulation Tracking test repeated at 15 dB lower SNR (~13 dB).
- Even at ~16 degrees RMS Phase Noise, results quite good; tracking error still well under 0.5 µS.
- This performance will allow use of lower gain antennas than 11 dB Yagi currently being used for testing.

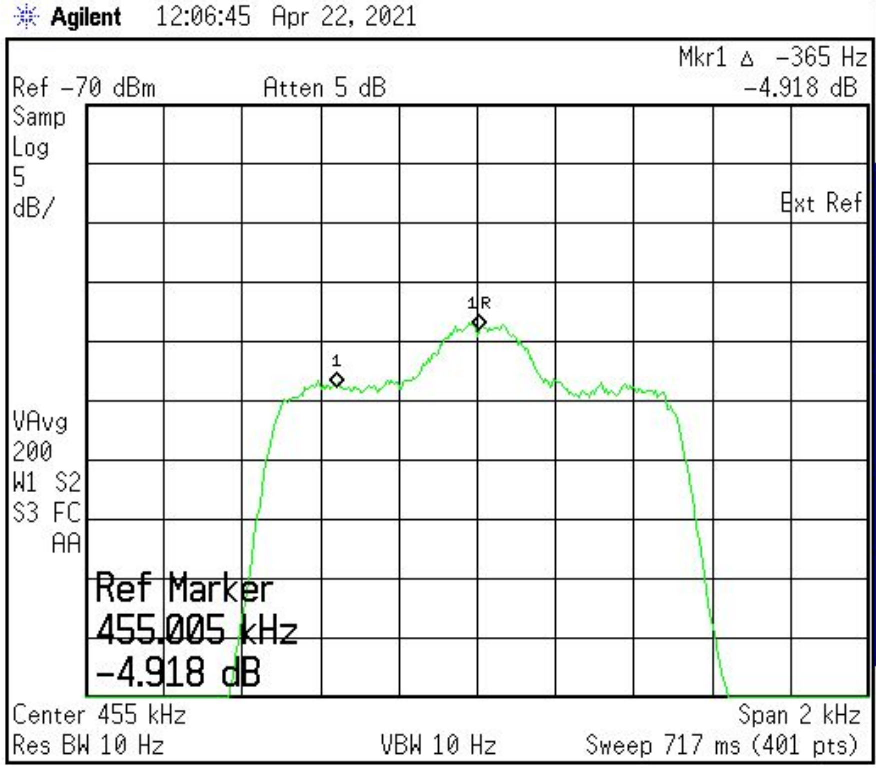




Two-Way Update – Phase Transient Performance at 10^{-4} SNR

- Modulation Tracking test run at ~5 dB SNR where previous bench testing indicated 10^{-4} BER.
- Phase Noise increases significantly as expected (>34º Degrees RMS).
- Tracking Error never above 1 µS, and under 0.5 µS >99% of the time => satellite motion should have negligible impact on BER measurements.





Two-Way Update – Summary, Conclusion & Next Steps

- Summary
  - All 3 approaches (energy drop, symbol crossing, and phase transient) investigated may ultimately prove useful.
  - Satellite motion confirmed and tracked on bench and over-the-air with phase transient implementation.
- Conclusion
  - ***Phase Transient Tracking Algorithm meets Objective of 1µS Alignment.***
  - Tracking Algorithm will support final BER Testing.
- Next Steps: Finish Over-the-Air Testing once power control is addressed.
  - First confirm modulation tracking over-the-air at various SNRs.
  - Perform BER measurements with Standard and Truncated RRC at Modulator.
  - Prepare and submit final Over-the-Air Testing report.