PN DOR Modulation

A proposed revision to CCSDS Standard for DOR modulation

Delta-DOR Working Group

Presentation to RF&Mod Working Group

Spring 2019 CCSDS Meeting

Background

- Delta-DOR uses common mode error cancellation to obtain high accuracy spacecraft angular position in the radio reference frame defined by the quasar catalog
- Temporal errors are cancelled by observing quasars before and after spacecraft
- Spatial errors are cancelled by observing a quasar that is angularly close to spacecraft or by observing two quasars on either side of spacecraft
- Spectrum mis-match prevents full cancellation of instrumental effects
  - Quasar spectrum is white noise filling a ≈ 8 MHz channel bandwidth for X-band
  - Current CCSDS Standard specifies a sinusoidal spacecraft signal
  - Linear instrumental group delay effects are cancelled by spacecraft-quasar differencing
  - Non-linear (dispersive) phase shifts do not cancel to the extent that the phase shift at the spacecraft frequency differs from the average phase shift across the quasar channel

Objective

- This proposal would spread the DOR signal with a PN code to more closely resemble the quasar signal
- Improved Delta-DOR performance is needed for future missions with tight targeting requirements, such as a Mars sample return mission

Dispersive Phase Measured by Binning Quasar Signal

https://ipnpr.jpl.nasa.gov/progress_report/42-184/184B.pdf

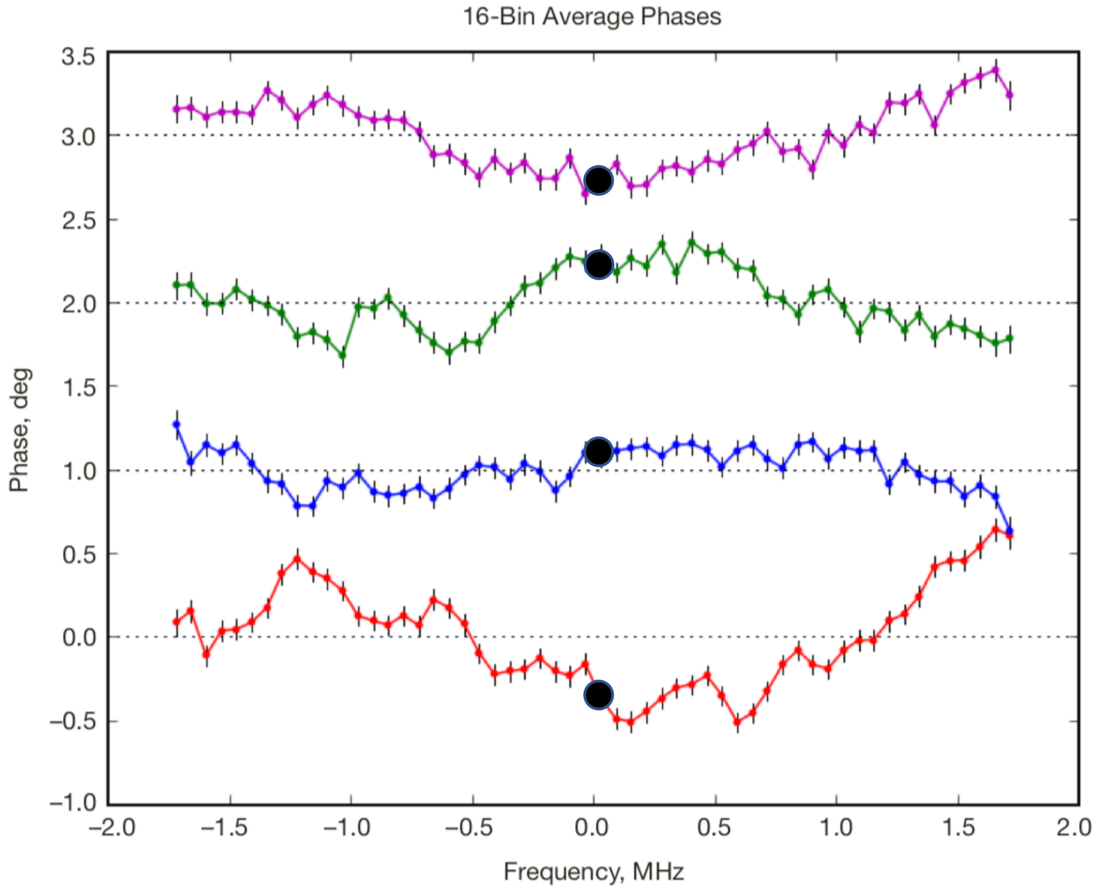
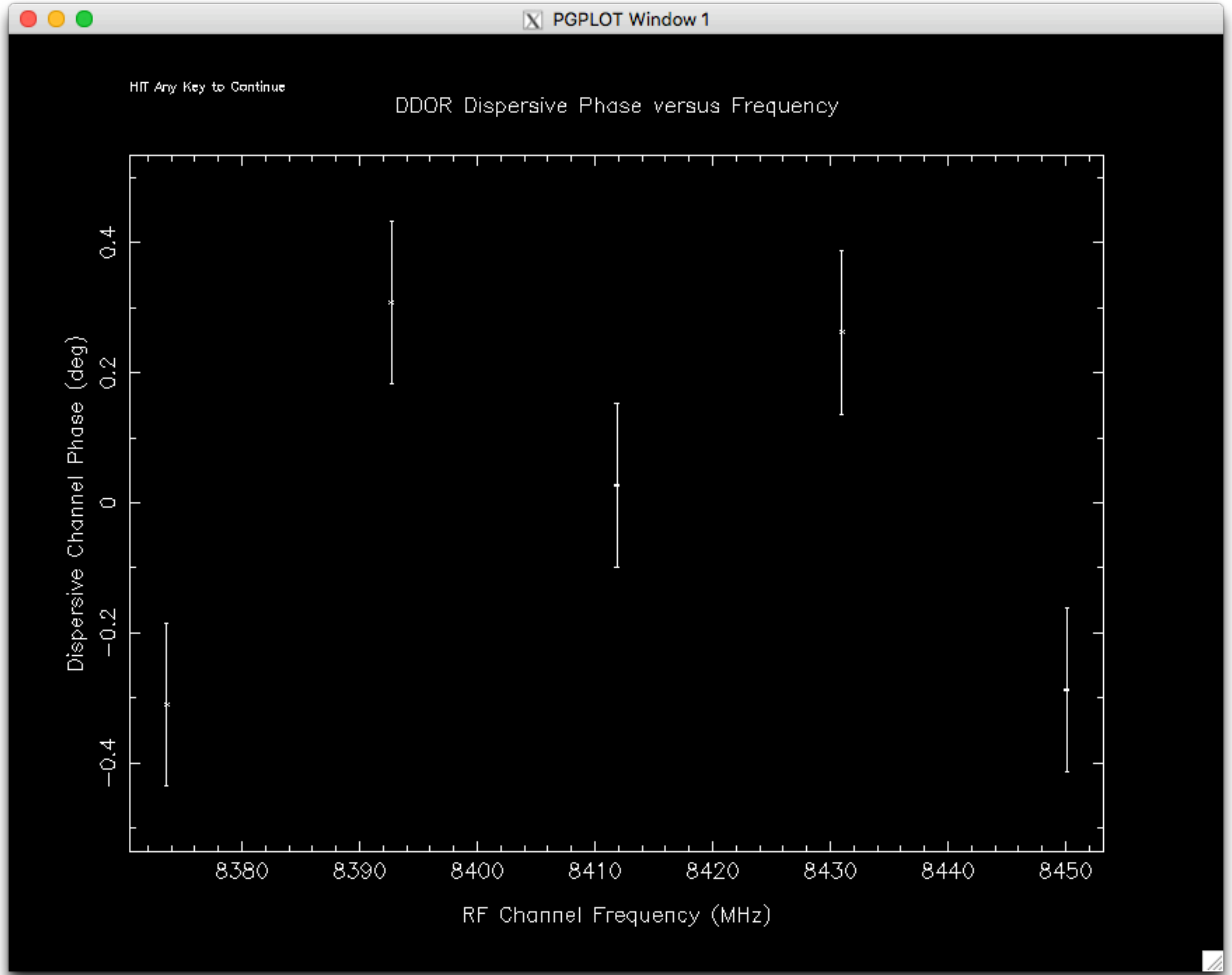


Figure 7. The 16-bin averaged phase as a function of baseband frequency for all four channels (each channel is offset 1 deg above the previous channel).

- Quasar signal is recorded in four separated frequency channels
- Strong quasar signal is cross-correlated separately in each frequency bin
- Phase Dispersion of tenths of a degree are seen across each channel
- Spacecraft phase shift at 0.0 MHz baseband (shown as dot) does not match quasar phase shift averaged across channel (shown as line)

Dispersive Effects Seen in a Delta-DOR Measurement



- Spacecraft signal is sinusoidal in each of five channels: carrier and four DOR harmonics
- Residual spacecraft minus quasar cross-correlation phase plotted at carrier and each DOR tone frequency (straight line removed)
- Points would fall on a line with slope equal to group delay if instrumental effects were not dispersive
- Phase Dispersion of tenths of a degree is seen between channels

Proposed Technical Solution

- Spread spacecraft signal with a shaped PN sequence to obtain flat spectrum over at least 90% of channel bandwidth
- Ground station instrumentation affects signals with the same flat spectrum in the same way
  - No error of phase dispersion type is seen in astrometric or geodetic quasar VLBI measurements
- Delta-DOR accuracy improved by 90% cancellation of dominant error source

References

- Delta-VLBI with quasars is not affected by phase dispersion: Treuhaft, R. N., and S. T. Lowe, "A Nanoradian Differential VLBI Tracking Demonstration," TDA PR 42-109, January-March 1992, pp. 40-55, May 15, 1992. https://ipnpr.jpl.nasa.gov/progress_report/42-109/109C.PDF
- Spread spectrum DOR proposed in first document of DDOR WG: Delta-Differential One Way Ranging (Delta-DOR) Operations, CCSDS 506.0-W-2a, White Book, June 2007. (available in CWE)
- Study of phase dispersion, candidate modulation schemes, and resulting error cancellation: Mercolino, M., et al., "A 1 nrad Delta-DOR System," in Proceedings of TTC 2016, 7th ESA International Workshop on Tracking, Telemetry and Command Systems for Space Applications, ESTEC, Noordwijk, The Netherlands, 13-16 September 2016. http://old.esaconferencebureau.com/2016-events/16a05/proceedings
- Lorenzo Simone, Thales-Alenia Space, Italy, 2016 (private communication to Mattia Mercolino).
- Performance advantage documented in: DDOR GB v2 (draft 2019), CCSDS 501.1-G-2.
- Prototype implementation on JPL software defined radio (2019): https://ipnpr.jpl.nasa.gov/progress_report/42-216/42-216A.pdf