Atmos. Meas. Tech. Discuss., 7, 4529–4550, 2014
www.atmos-meas-tech-discuss.net/7/4529/2014/
doi:10.5194/amtd-7-4529-2014

Atmospheric Measurement Techniques Discussions
Open Access

This discussion paper is/has been under review for the journal Atmospheric Measurement Techniques (AMT). Please refer to the corresponding final paper in AMT if available.

Potential radio frequency interference with the GPS L5 band for radio occultation measurements

A. M. Wolff[1], D. M. Akos[2], and S. Lo[3]

[1]Auburn University, Auburn, Alabama, USA
[2]Department of Aerospace Engineering, University of Colorado, Boulder, Colorado, USA
[3]Department of Aeronautics and Astronautics, Stanford University, Stanford, California, USA

Received: 19 February 2014 – Accepted: 20 March 2014 – Published: 7 May 2014

Correspondence to: A. M. Wolff (amw0031@auburn.edu)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

New Radio Occultation (RO) receivers are planned to utilize the newly implemented Global Positioning System (GPS) L5 signal centered at 1176.45 MHz. Since there are currently no operational GPS L5 receivers used for space-based RO applications, the interference environment is unclear. Distance Measuring Equipment (DME) and Tactical Air Navigation (TACAN) stations share the same frequency band as the GPS L5 signal. DME/TACAN signals have been identified to be a means of interference for any GPS L5 receiver. This study focuses on implementing a Systems Tools Kit (STK) simulation to gain insight into the power received by a RO satellite in Low Earth Orbit (LEO) from a DME/TACAN transmission. In order to confirm the validity of utilizing STK for communication purposes, a theoretical scenario was recreated as a simulation and the results were confirmed. Once the method was validated, STK was used to output a received power level aboard a RO satellite from a DME/TACAN station as well as a tool to predict the number of interfering DME/TACAN stations at any point in time. Taking a conservative approach, the signal power received was much greater than the typical power level received by a RO satellite from a GPS satellite transmission. This relatively high received power along with a high number of interfering DME/TACAN stations as an RO satellite passes over North America or Western Europe indicate that DME/TACAN interference may conflict with RO receivers.

1 Introduction

The Global Positioning System (GPS) L5 signal centered at 1176.45 MHz is now being transmitted with the latest IIF satellite design (Van Dierendonck et al., 2000). This signal is part of the GPS modernization effort and offers civil users additional power, a higher chipping rate, and an updated signal modulation structure. As such, it is a promising signal transmission for scientific applications of GPS.

AMTD
7, 4529–4550, 2014

However, certain aeronautical navigation systems already occupy this frequency range. Distance Measuring Equipment (DME) and Tactical Air Navigation (TACAN) systems offer potential sources of interference due to coexistence within the L5 band (Kim and Grabowski, 2003). These systems are comprised of an airborne interrogator and a ground-based transponder. A TACAN system is essentially a higher powered DME station used for military purposes. Due to the limited placements available within the Aeronautical Radio Navigation Services (ARNA) radio band for aviation use, the GPS L5 signal was placed within the already existing DME/TACAN band. The premise was that an aircraft using the system would only encounter a limited number of pulsed interfering signals thereby allowing the interoperability between a GPS L5 receiver and a DME/TACAN signal. However, due to the higher number of interfering stations seen by a GPS Radio Occultation (RO) satellite in Low Earth Orbit (LEO), the possibility for signal degradation for RO applications exists (Kim and Grabowski, 2003).

Interference incurred due to the coexistence of these systems degrades the Carrier-to-Noise ratio (C/No) of a GPS L5 receiver. However, the compatibility of these systems is sufficient for most applications. This resulting post correlation C/No is a popular metric to assess the quality of the received GPS signal. As interfering signals interact with the receiver, a corresponding degradation in the C/No can be witnessed. The low power of a received GPS L5 signal for terrestrial users on earth from the GPS satellites has little if any impact for DME/TACAN operators. Furthermore, the pulsed localized nature of the DME/TACAN signals has minimal impact on terrestrial GPS L5 users as there are limited DME/TACAN sources in close proximity to any terrestrial user and Code Division Multiple Access (CDMA) modulation of GPS is robust against pulsed interference.

While most users of GPS L5 will experience minimal degradation from DME/TACAN interference, GPS RO is one such application in which even a slight degraded C/No would have a significant impact on results. GPS RO is implemented today for use in weather forecasting and has been proven to be a very powerful and reliable tool. The architecture of a GPS RO system consists of a satellite in LEO receiving a signal

AMTD
7, 4529–4550, 2014

from a GPS satellite. The LEO satellite houses a set of antennas pointed towards the limb of the Earth in order to detect and measure refraction as the signal propagates through the earth's atmosphere. As a result of this directive orientation of the receiving antenna, these satellites may incur DME/TACAN interference that could obstruct RO data collection.

2 Background

2.1 Radio occultation

GPS has stimulated an evolution in weather forecasting technology. Utilizing the GPS satellite network, RO techniques leverage the stability and global coverage of the GPS network in order to provide higher accuracy temperature, pressure, and humidity data (Healy et al., 2005). RO involves a sounding technique where a satellite emits a radio wave whose path is then perturbed by an intervening planetary atmosphere before reaching the receiver (Kursinski et al., 1997). Earth-based RO specifically involves a GPS satellite transmitting a signal to a receiving satellite orbiting in LEO. After the transmitted radio wave is refracted, phase and amplitude variation at the receiver is observed over time in order to define the refractive properties of the surrounding atmosphere (Melbourne, 2004). The refraction of the signal causes a delay in the dual frequency carrier phase results as seen by the GPS receiver in LEO (Ware et al., 1996). By observing the degree of refraction, one can gain insight into desired values for atmospheric pressure, temperature, and humidity. The atmospheric depth of RO retrievals is currently limited by the available Signal to Noise ratio (SNR). Additional SNR, or reduced Signal to Interference plus Noise (SN($R+I$)) would allow for lower atmospheric data to be obtained.

Previous Earth-based occultation missions such as GPS/MET and CHAMP improved upon numerical weather prediction (NWP) models when compared against the industry standard (Healy et al., 2005). All previous missions have utilized the L1 and L2

AMTD
7, 4529–4550, 2014

GPS frequencies and have exceeded expectations with respect to weather forecasting (Melbourne, 2004). However, the planned implementation of the L5 frequency offers an opportunity to improve upon these results. The COSMIC 2 mission is a future mission that aims to utilize L5 receivers for reasons of increased power, overall improvement of signal structure, and the civil designation of the transmission (Mannucci et al., 2012).

2.2 Distance measuring equipment

DME offers a method to determine distance from an aircraft to a ground station (Fisher, 2004). The DME architecture is comprised of an airborne interrogator and a ground based transponder that operates in four codes (X, Y, W, Z). However, the X-code is the only possible interferer with respect to the L5 frequency. The aircraft interrogates within a frequency range of 1025–1150 MHz whereas the ground station transmits over frequencies between 1151–1213 MHz within X-mode (Bastide et al., 2004). Therefore, any airborne interrogation within this architecture does not directly impinge upon any signal transmitted over the L5 frequency. A number of DME/TACAN ground stations, however, transmit within this frequency range and could become a source of interference for L5 transmissions. For this reason, DME/TACAN ground stations will be the focus for determining interoperability within the L5 frequency for GPS RO applications.

A DME ground station transmits in pulse pairs with a pulse period of 12 µs and a pulse width of 7 µs (Ostermeier, 2010). This signal structure can be seen in Fig. 1. DME stations either operate at a high power of 1000 W or at a low power of 100 W. During peak activity, a DME station transmits up to 2700 pulse pairs per second. The effective width of each pulse is defined to be 8 µs taking into account a 1 µs desaturation time for the receiver. Using this effective pulse width and the pulse pair rate previously defined, a single DME pulse duty cycle is calculated to be 0.0432 s per second (Roturier, 2001). Therefore, a single DME transmitter at its peak is being seen 4.32 % of the time by an L5 receiver.

A TACAN station has many of the same characteristics as a DME station. However, unlike DME stations which transmit at a constant power of 100 W or 1000 W, a TACAN

AMTD
7, 4529–4550, 2014

station's transmission power ranges cyclically (sinusoidally at 135 and 15 Hz) up to 3500 W. These stations are consequently high powered military versions of their DME counterpart.

A standard ground based DME antenna pattern is maximum at 4° in elevation above the horizon and is omnidirectional in the azimuth. This orientation slightly above the horizon directly aligns with the directional gain pattern of a GPS RO satellite. As the orbiting satellite scans the limb of the earth gathering atmospheric data, it is in the main lobe of the directional beam of the DME station for a short period of time.

The United States and Western Europe have high concentrations of DME stations possibly inhibiting a GPS L5 RO receiver in LEO from properly functioning as the difference here is that the satellite will be illuminated by multiple DME stations. In the United States alone there are approximately 203 DME or TACAN ground stations that transmit within ±10 MHz of the L5 center frequency of 1176.45 MHz. In assessing the impact to GPS RO, this is likely a conservative approach due to the fact that some RO receivers have wider bandwidths than ±10 MHz. A receiver with a wider bandwidth will encounter a higher number of interfering DME stations. This is troubling for GPS RO scenarios because it offers up the possibility of receiver saturation, a situation in which no valid atmospheric data can be retrieved (ITU, 1998). Furthermore, the directive orientation of the receiver antenna pattern aboard a RO satellite with respect to a DME station increases the received power level from a DME station as well as increases the total number of DME stations effectively witnessed by the receiver.

3 Pikes Peak L5 data collection

In order to assess the degree to which a directive antenna amplifies DME interference, it is useful to extract and analyze a real world interference environment in which two separate antennas were compared. On 21 October 2011, data were collected on top of Pikes Peak mountain in Colorado at an elevation of approximately 4320 m by a team from the University of Colorado-Boulder with the intention to conduct a ground-based

AMTD
7, 4529–4550, 2014

RO measurement (Griggs, 2012). This test scenario was constructed in order to gain an understanding of the potential of the new GPS L5 signal for space-based RO. Collections of data from L1, L2, and L5 frequencies were gathered with two separate antennas. One antenna was a hemispherical survey grade antenna oriented vertically and the other was a helical antenna oriented horizontally and pointed 38° in the azimuth. Although this test cannot directly represent the results that a space-based receiver would yield, the data collected from this study has provided an insight into the number of DME stations seen when a more directive antenna pattern is utilized.

While the strength of the interference will undoubtedly be weaker in space, there will, however, be a sharp rise in the number of DME stations affecting the GPS RO receiver. Within the L5 component of this collection, DME pulses can be seen within the data set. Figure 2 offers a depiction of the frequency domain as seen by the helical antenna pointed in approximately the Northeast direction of Pikes Peak. Noting that the center frequency is 1176 MHz, DME stations transmitting at frequencies of 1176 MHz, 1178 MHz, and 1181 MHz can be seen within the collection. These frequencies correspond to DME stations in Gill, Colorado Plains, and Denver as shown in Fig. 3. On the other hand, DME interference is not directly observed in the data set collected by a survey grade antenna. The reason for this contrast is the differing orientations of the two antennas. The side by side comparison shown in Figs. 4 and 5 illuminates this stark contrast of interference between the data gathered by both antennas.

The interference experienced by the helical antenna registered considerably higher, greater than the thermal noise floor. The helical antenna is focused on the area of interest and therefore gathers visible DME interference. Similarly, a GPS L5 receiver used for RO applications utilizes a high gain directive antenna that's energy is focused on the limb of the earth (Wu et al., 2005). Therefore, it is consistent that GPS RO receiver will witness interference comparable to that seen by the helical test. Further analysis was conducted in order to further detail the interference that a GPS RO satellite may encounter due to DME pulses.

4 Systems Tool Kit validation

Systems Tool Kit (STK) was utilized to attain a link budget for the received power of a DME station by a satellite in LEO. In order to establish the credibility of a space-based STK simulation, a scenario of a theoretical calculation was reconstructed within STK and the results were compared to the theoretical solution. The author of Roturier (2001) calculates the minimum pulse peak power at an aircraft's GPS receiving antenna under certain conditions. He defines the scenario as a receiving aircraft flying at an altitude of 12 192 m and a transmitting DME station located on the radio horizon from the aircraft's perspective. Both antennas were modeled as isotropic and the DME radiated peak power was set at 40 dBW. Inputting these specifications in Eq. (1) below yields an approximate minimum pulse peak power received, P_1, of -107 dBW where P_e is the effective radiated peak power, G is the gain of the airborne GPS antenna, λ represents the signal's wavelength, and d is the distance between transmitter and receiver.

$$P_1 = P_e G \left(\frac{\lambda}{4\pi d} \right) \tag{1}$$

Although Roturier simplifies this scenario by using isotropic antennas for both the DME stations and the GPS receiver, these identical parameters were recreated within STK and the results were compiled. The STK simulation outputted a value of -106.91 dBW for the minimum pulse peak power received. The accuracy of this result when compared to the theoretical value supplies a level of integrity for using STK to compute a communication link budget.

5 STK simulation and link budget results

In order to estimate the received power levels and range of a DME ground station as seen by a satellite in LEO, a simulation modeling these conditions was constructed

AMTD
7, 4529–4550, 2014

within STK. STK has a satellite database that was used to insert the Formosat-3/COSMIC satellite into the simulation. This satellite is currently commissioned under the COSMIC 1 mission and therefore lends an accurate portrayal of a satellite that would house an L5 receiver for future RO missions. A single DME station was placed in Boulder, Colorado for testing purposes and a custom antenna pattern was modeled after the dB Systems Inc. 5100A High Performance DME antenna available at their website (dB Systems Inc., 2013). It should be noted that this model was chosen only as a representative pattern. Figure 6 is an image of the modeled gain pattern within STK.

The transmission power of the DME station was set at 1000 W. This value was chosen based upon the fact that DME stations most commonly transmit at this high power setting. It should be recalled that this model is not accounting for the low DME power setting of 100 W and the dynamic power ranges of a TACAN that can reach 3500 W. With the standard DME model in place, the simulation was progressed over a period of six months within STK and a plot of the results is illustrated in Fig. 7.

The plot demonstrates a color coded map of the received power with respect to the COSMIC satellite's position over the United States. This simulation indicates that, under ideal conditions, a DME transmission is received by the satellite at a maximum power level of −123 dBW. This power level reaches a maximum when the satellite is within the main beam of the DME antenna. The received power then lessens until it abruptly ends as the satellite loses line of sight with the DME station.

In order to evaluate if receiver saturation will be a potential problem for GPS RO satellites, an estimation of the time a single DME station interferes with a GPS L5 receiver as well as the total number of DME stations inferring at a given point in time are required. Due to the pulsed nature of a DME station, a GPS L5 receiver technically will not experience the DME transmission at all times. Recalling the calculated duty cycle of 4.3 % for a single DME station offers an estimate for the maximum time a DME station may transmit every second. In order to estimate how many DME stations would

AMTD
7, 4529–4550, 2014

be interfering with a receiver in LEO at any given time, STK was utilized to provide a plot of the stations whose received power was greater than −125 dBW.

All 203 relevant DME stations were inserted into STK and the number of interferers with respect to time was computed as the COSMIC satellite traveled over the United States from North Dakota down towards Louisiana until all connections were lost. The resulting plot is shown in Fig. 8. This figure indicates a maximum number of 76 stations transmitting with received powers of above −125 dBW. The typical received power on earth from a GPS satellite is −157.5 dBW and in space is only about 1 dBW less (GPS, 1995). The large amount of DME stations appear much more powerful than a GPS satellite from the perspective of a receiver. Not only is the power level a cause for concern, but the sheer number of DME stations all operating with a maximum of 4.3 % duty cycle may indeed saturate a GPS receiver. An amount of overlap between signals from each station will undoubtedly occur; however, receiver saturation remains as a possibility. The curves depicted in Fig. 9 illustrate the respective receiver interference caused by DME and TACAN stations as the number of interfering stations approaches close to 80.

6 Conclusions

A real world validation of any simulation within STK is currently impossible due to the lack of space-based L5 GPS receivers with a representative RO pattern. With the future implementation of L5 receivers in space, the opportunity for experimental testing will be realized. However, without full knowledge of the parameters and conditions that a specific DME/TACAN station was operating under at the exact time of the data collection, any simulation will inherently be flawed. Specific antenna patterns, antenna efficiencies, transmitter noise figure and other unknown variables obscure any reasonable result. Although a space-based test cannot currently be conducted, other tests were undertaken in order to add to the credibility of the space-based STK simulation.

The single transmitting DME station and orbiting RO satellite simulation yielded a maximum received power level of −123 dBW which when compared to the standard received power from a GPS satellite of −157 dBW is relatively high. The STK simulation included all of the relevant DME stations and was performed across the United States indicated that, at any given point in time, more than seventy stations with received power levels above −125 dBW would interfere with a GPS L5 receiver in LEO. This substantial number of relatively high powered transmissions may cause substantial interference and possible saturation for a space-based GPS L5 receiver.

The resultant maximum received power should be noted as a conservative estimate due to restricting the study of the RO receiver bandwidth to within ±10 MHz of the center frequency of 1176.45 MHz. Many RO receivers utilize a wide bandwidth with limited filtering in order to optimize data collection. However, this study implicates that this approach may prove to have an adverse effect on the receivers ability to gather data due to a greater number of interfering DME stations within the collected frequencies.

The resultant values may still not portray an entirely accurate estimate due to the inability to calculate an accurate free space path loss and possible inaccuracies embedded in custom antenna patterns. A detailed analysis specifying correct transmission powers for each station could yield different results; however, using a 1000 W transmission power appears to be a suitable approach.

With these considerations in mind, the results gathered from the STK simulations indicate that L5 GPS receivers in LEO may experience interference caused by DME and TACAN stations resulting in the possible saturation of the receivers. For the application of Radio Occultation, this interference could result in a loss of collected data as the satellite orbits over regions highly populated with DME stations namely the United States and Western Europe.

Supplementary material related to this article is available online at http://www.atmos-meas-tech-discuss.net/7/4529/2014/amtd-7-4529-2014-supplement.zip.

AMTD
7, 4529–4550, 2014

References

Bastide, F., Chatre, E., Macabiau, C., and Roturier, B.: Gps L5 and Galileo e5a/e5b signal-to-noise density ratio degradations due to DME/TACAN signals: simulations and theoretical derivation, J. Inst. Navig., 26, 1049–1062, 2004. 4533

dB Systems Inc.: available at: http://www.dbsant.com/5100A.php (last access: 20 June 2013), 2013. 4537

Fisher, J. R.: Signal analysis and blanking experiments on DME interference, National Radio Astronomy Observatory, Electronics Division, Report 313, 2004. 4533, 4542

GPS: Global positioning system standard positioning service signal specification, p. 18, available at: http://www.gps.gov/technical/ps/1995-SPS-signal-specification.pdf (last access: 19 July 2013), 1995. 4538

Griggs, E.: Ground-based GPS occultation utilizing modernized signals, in: Proceedings of IROWG-2m, Estes Park, Colorado, 28 March 2012, 2012. 4535

Healy, S. B., Jupp, A. M., and Marquardt, C.: Forecast impact experiment with GPS radio occultation measurements, Geophys. Res. Lett., 32, L03804, doi:10.1029/2004GL020806, 2005. 4532

International Telecommunication Union: Feasibility of sharing between radionavigation-satellite service and the earth exploration satellite (active) and space research (active) services in the 1 215-1 260 MHz BAND, Recommendation RS.1347-0, 1998. 4534

Kim, T. and Grabowski, J.: Validation of GPS L5 coexistence with DME/TACAN and link-16 systems, J. Inst. Navig., 9, 1455–11469, 2003. 4531

Kursinski, E. R., Hajj, G. A., Schofield, J. T., Linfield, R. P., and Hardy, K. R.: Observing Earth's atmosphere with radio occultation measurements using the global positioning system, J. Geophys. Res., 102, 23429–23465, 1997. 4532

Mannucci, A. J., Lowe, S. T., Franklin, G., Meehan, T. K., and Xie, F.: New science opportunities on COSMIC-2/FORMOSAT-7, Sixth FORMOSAT-3/COSMIC Data Users' Workshop, 30 October 2012, Boulder, Colorado, 2012. 4533

Melbourne, W. G.: Radio occultations using earth satellites: A wave theory treatment, Deep Space Communications and Navigation Series, Jet Propulsion Lab, California Institute of Technology, Monograph 6, 2004. 4532, 4533

Ostermeier, J.: Test of DME/TACAN transponders application note – 1GP74, Rohde and Schwarz Co., Munich, Germany, 5–9, 2010. 4533

AMTD

7, 4529–4550, 2014

Roturier, B.: Report on DME interference on GPS/L5, Direction Generale de l'Aviation Civile, Report (Third Version), 9 March 2001. 4533, 4536

Systems Tool Kit: available at: https://www.agi.com/products/ (last access: 2 April 2014), 2014. 4547

Van Dierendonck, A. J., Hegarty, C., Scales, W., and Ericson, S.: Signal specification for the future GPS civil signal at L5, Proceedings of the IAIN World Congress and the 56th annual meeting of The Institute of Navigation, San Diego, California, 232–241, 2000. 4530

Ware, R., Rocken, C., Solheim, F., Exner, M., Schreiner, W., Anthes, R., Feng, D., Herman, B., Gorbunov, M., Sokolovskiy, S., Hardy, K., Kuo, Y., Zou, X., Trenberth, K., Meehan, T., Melbourne, W., and Businger, S.: Gps sounding of the atmosphere from low earth orbit: preliminary results, B. Am. Meteorol. Soc., 77, 19–40, doi:10.1175/1520-0477(1996)077<0019:GSOTAF>2.0.CO;2, 1996. 4532

Wu, B., Chu, V., Chen, P., and Ting, T.: FORMOSAT-3/COSMIC science mission update, GPS Solut., 9, 111–121, doi:10.1007/s10291-005-0140-z, 2005. 4535

AMTD

7, 4529–4550, 2014

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

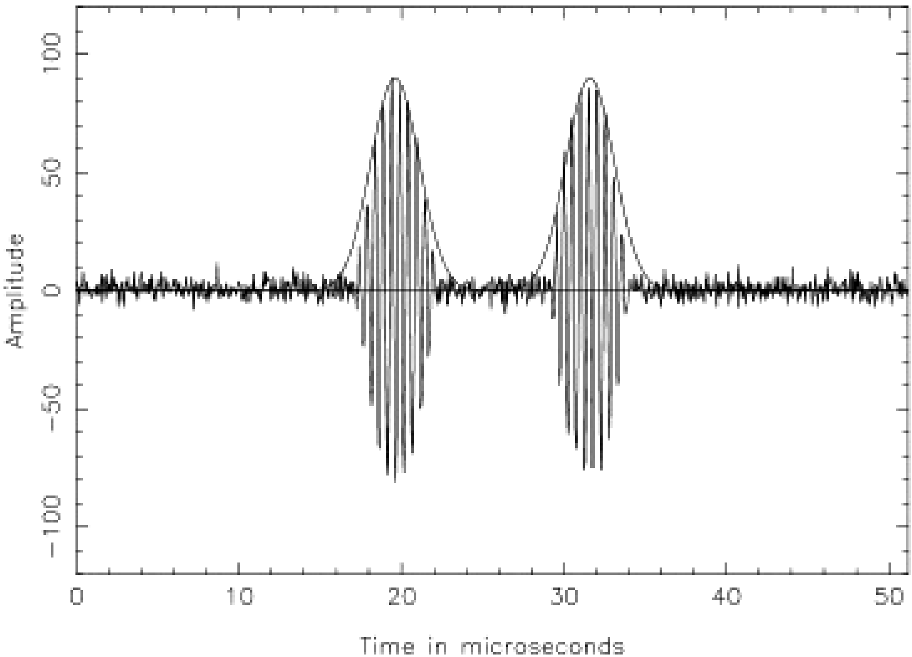

Fig. 1. DME pulse pair (Fisher, 2004).

AMTD

7, 4529–4550, 2014

Radio occultation interference analysis

A. M. Wolff et al.

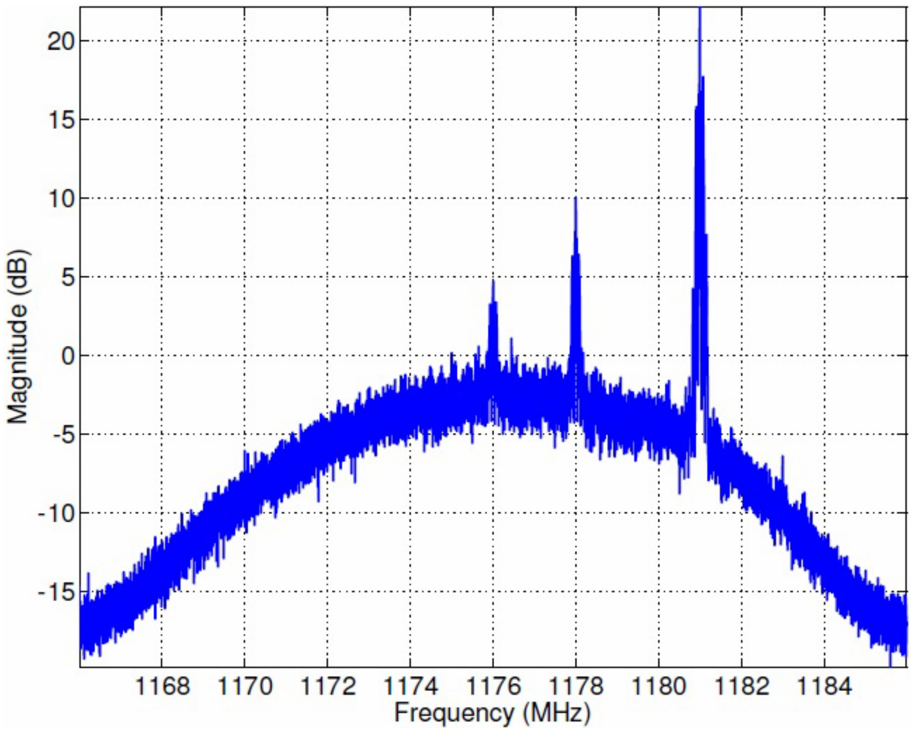

Fig. 2. Frequency domain as seen by helical antenna atop Pikes Peak.

AMTD

7, 4529–4550, 2014

Radio occultation interference analysis

A. M. Wolff et al.

Fig. 3. DME/TACAN stations seen within Pikes Peak data.

AMTD
7, 4529–4550, 2014

Radio occultation interference analysis

A. M. Wolff et al.

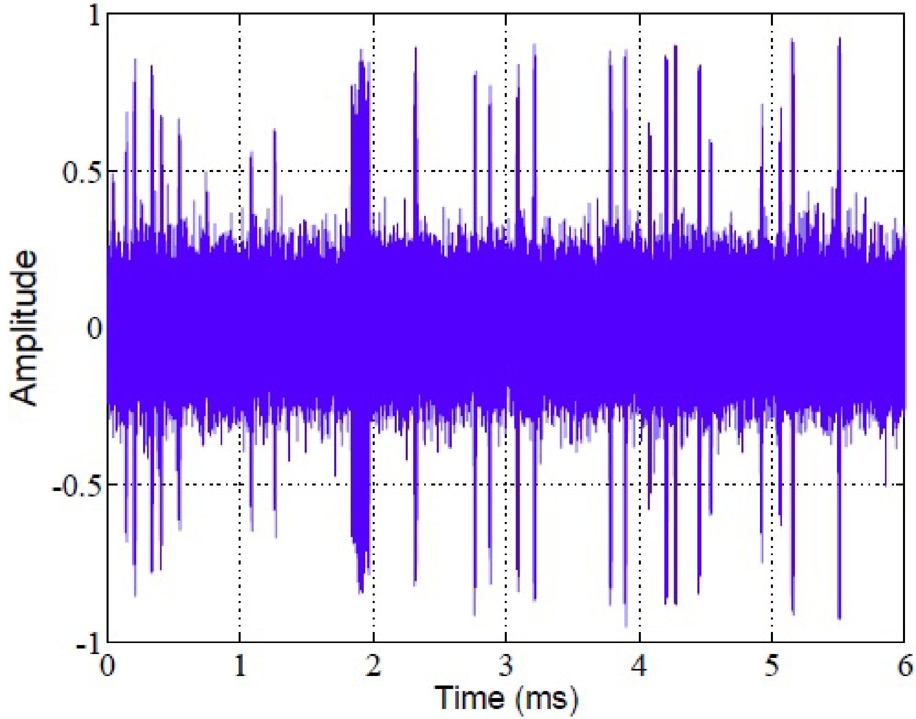

Fig. 4. Time domain as seen by helical antenna atop Pikes Peak.

AMTD
7, 4529–4550, 2014

Radio occultation interference analysis

A. M. Wolff et al.

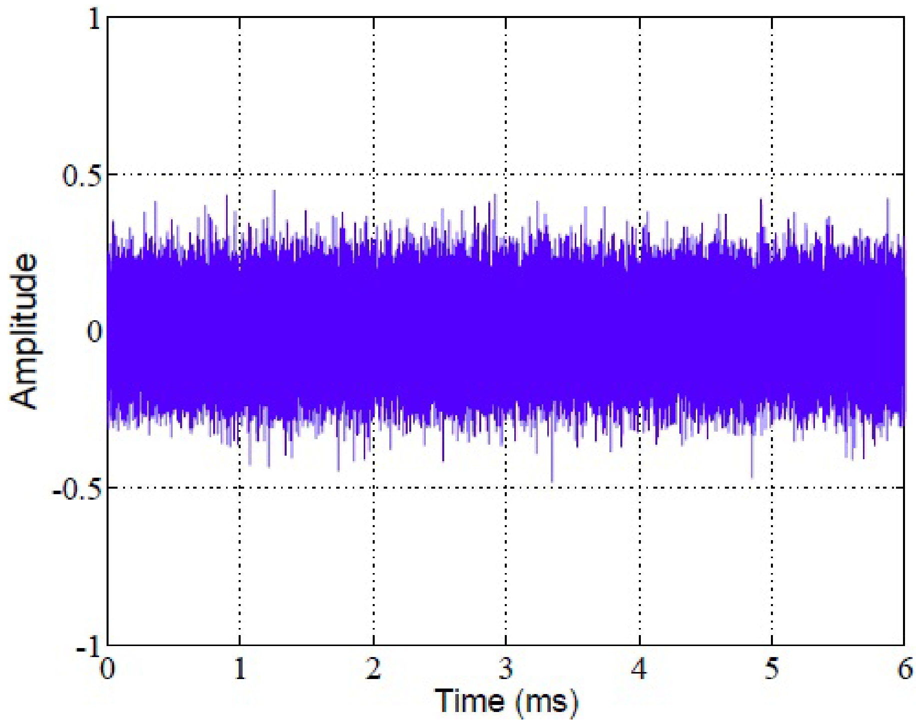

Fig. 5. Time domain as seen by a standard survey grade antenna atop Pikes Peak.

AMTD
7, 4529–4550, 2014

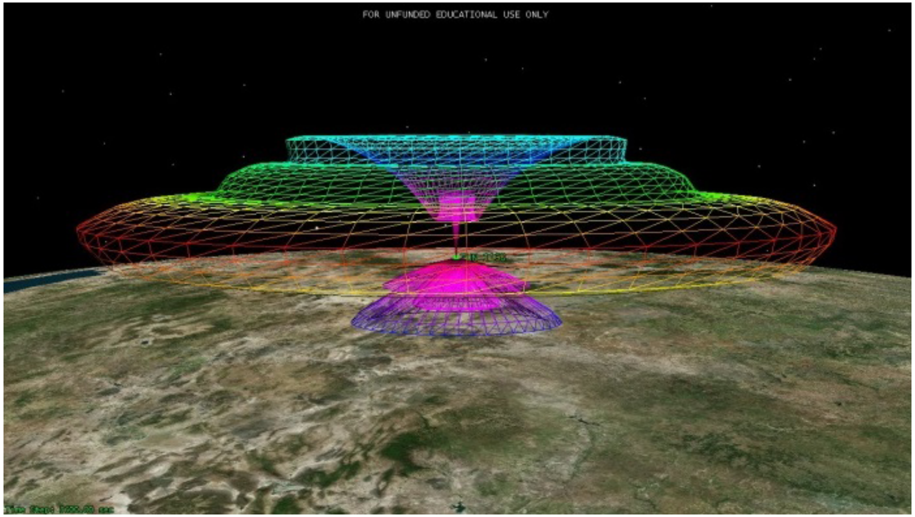

Fig. 6. Systems Tool Kit model of dB Systems 5100A DME antenna pattern (Systems Tool Kit, 2014).

AMTD
7, 4529–4550, 2014

Radio occultation interference analysis

A. M. Wolff et al.

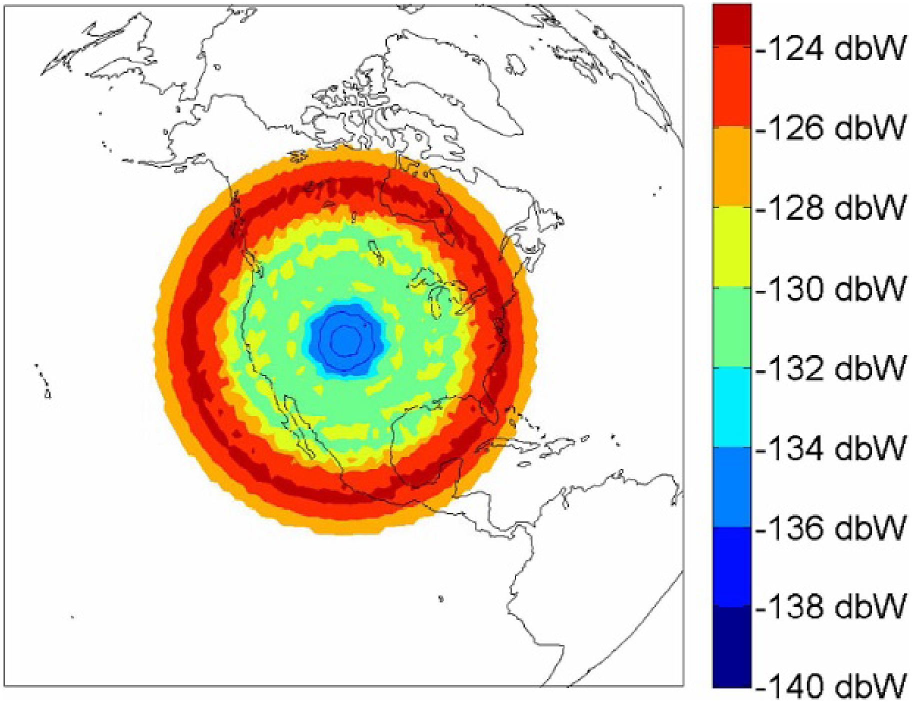

Fig. 7. RO satellite received power from single DME station.

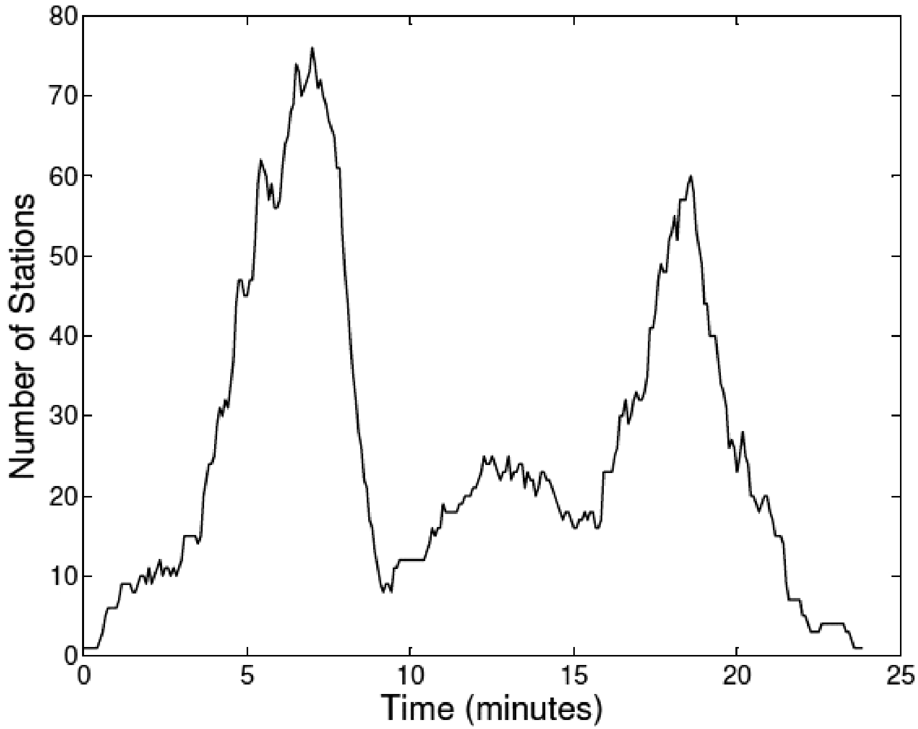

Fig. 8. Number of interfering DME stations with respect to time.

AMTD
7, 4529–4550, 2014

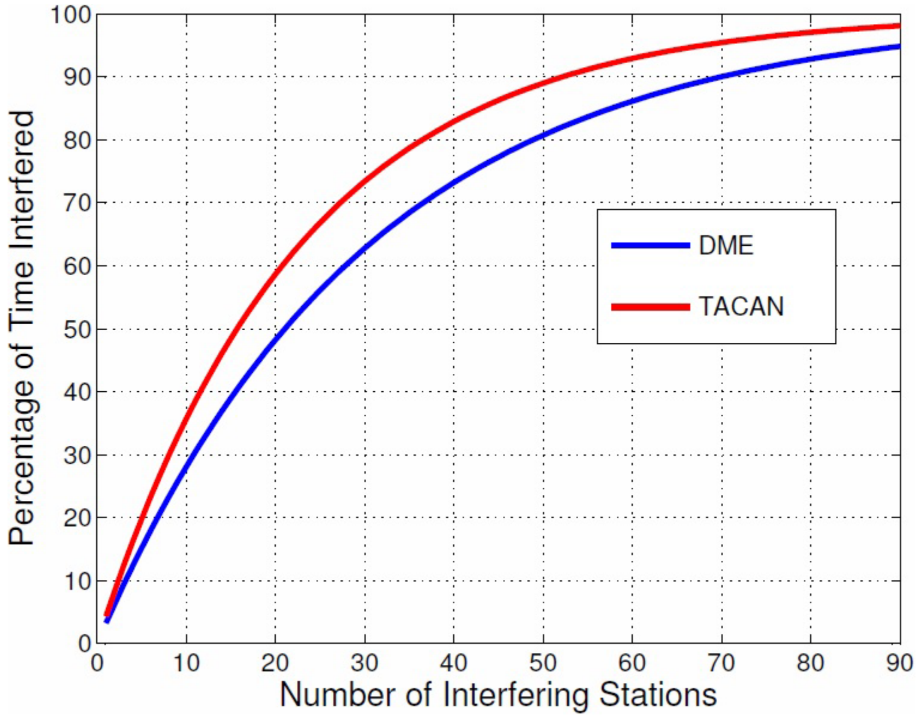

Fig. 9. Percentage of time interfered as a function of the number of stations.

AMTD

7, 4529–4550, 2014

Radio occultation interference analysis

A. M. Wolff et al.