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Radio Science

COMMENTARY

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Key Points:

- First results from new space-based high-frequency receiver examine artificially generated pulses
- RRI e-POP successfully used multipath propagation to identify an ionospheric irregularity
- Future opportunities for investigation include HF propagation and ground-instrument characterization

Correspondence to:
A. G. Burrell,
agb073000@utdallas.edu

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e-POP RRI provides new opportunities for space-based, high-frequency radio science experiments

Angeline G. Burrell[1,2]

[1]Department of Physics and Astronomy, University of Leicester, Leicester, UK, [2]Center for Space Science, University of Texas at Dallas, Richardson, Texas, USA

Abstract Perry et al. (2016) present the first results of the Radio Receiver Instrument (RRI), a part of the enhanced Polar Outflow Probe (e-POP) that flies on board the CAScade, Smallsat and IOnospheric Polar Explorer satellite. Using a matched filter technique, e-POP RRI was able to observe individual radio pulses transmitted by a ground-based radar. These results were used to examine the temporal variations in the dispersion, polarization, and power of the pulses, demonstrating the capacity for e-POP RRI to contribute to studies of radio propagation at high-frequency (HF) ranges. Understanding radio propagation in the presence and absence of ionospheric irregularities is crucial for ionospheric physics, as well as commercial and military radio applications. Conjunctions between e-POP RRI and ground- or space-based HF transmitters offer a new opportunity for coherent scatter experiments.

1. Introduction

High-frequency (HF) radio propagation has long been an instrumental part of ionospheric research [e.g., *Appleton*, 1946; *Belrose*, 1995]. HF signals are refracted by the ionosphere, making them capable of traveling over the horizon (OTH). Extremely long distances may be reached by either ducting within the ionosphere or hopping off of appropriately sized irregularities on the ground or sea. HF signals will also reflect off irregularities aligned with the geomagnetic field in the ionosphere, allowing ground-based radars to observe ionospheric irregularities with a single antenna array acting as both a transmitter and a receiver.

Historically, advances in HF radio science have been made in response to the military need for OTH target detection [*Headrick and Thomason*, 1998]. The HF band (3–30 MHz) is attractive for detection and point-to-point communications because it is refracted by the ionosphere, but it also provides challenges. Initially, clutter in the signal and the formation of rear and side lobes made the HF band impractical to use. Advances in radar design [e.g., *Sweeney*, 1970] and signal processing made HF radar operations a possibility, while the continued development of integrated and external mitigation techniques has improved the understanding and application of HF radio science [*Cannon*, 2009].

Due to the need for a very wide aperture to form a directed HF beam, most HF radars have been ground based. Canada has bucked this trend from the inception of its space program. The first Canadian satellite, the Alouette 1, was a joint undertaking with the United States of America that carried a suite of scientific instruments that included the Sweep-Frequency Sounder, which measured topside electron density profiles by transmitting and receiving signals between 1 and 12 MHz [*Warren*, 1962] and a very low frequency (VLF) receiver that measured spontaneous and artificial signals [*Barrington et al.*, 1963]. The success of Alouette 1 led to improvements in the design of spaceborne sounders [*Franklin and Maclean*, 1969]. The Alouette program was extended and eventually succeeded by ISIS, the International Satellite for Ionospheric Studies. Alouette 2, ISIS 1, and ISIS 2 all carried sweep-frequency sounders and VLF receivers with increasingly improved performance that monitored the topside ionospheric electron density until 1990 [*Jackson*, 1986; *Boyko*, 1996]. The inclusion of the Radio Receiver Instrument (RRI) in the enhanced Polar Outflow Probe (e-POP), continues this Canadian legacy. e-POP RRI is a four-channel digital receiver that is capable of measuring natural and artificial signals between 10 Hz and 18 MHz [*James et al.*, 2015]. The CAScade, Smallsat and IOnospheric Polar Explorer (CASSIOPE) satellite that carries e-POP orbits with an inclination of 80°, a perigee of 325 km, and a declining apogee that was 1500 km at launch [*Yau and James*, 2015].

2. First Results

Since launch, e-POP RRI has been used in international collaborations to detect artificially generated radio transmissions[*James et al.*, 2015; *Burrell et al.*, 2015; *Frissell et al.*, 2015]. However, *Perry et al.* [2016] performed the first in-depth e-POP RRI study, presenting conjunctions with the HF Super Dual Auroral Radar Network (SuperDARN) [*Chisham et al.*, 2007]. Their study used observations of individual pulses to show evidence of mode splitting, multipath propagation, and fading.

Mode splitting is the term used to describe the decomposition of a propagating radio wave into its ordinary (O) and extraordinary (X) components. This is expected when the wave frequency is close enough to the plasma frequency that the delay to the group speed caused by refraction can no longer be ignored [*James*, 2006]. Thus, the presence and severity of mode splitting in observations made by e-POP RRI can be used to study the plasma density between the transmitting radar and the receivers onboard CASSIOPE.

Multipath propagation is a common problem for transmitted signals of many wavelengths. When multiple propagation paths to the same target are available, as may occur when there are density gradients or irregularities present in the ionosphere, the signal will take all of the possible paths. This causes the receiver to observe the same pulse multiple times, as well as causing interference between different pulses. e-POP RRI deduced the occurrence of multipath propagation through the observation of pulses separated by temporal periods shorter than the shortest time between radar transmissions. *Perry et al.* [2016] hypothesized the existence of an ionospheric irregularity between the transmitting SuperDARN radar at Saskatoon and CASSIOPE and examined the temporal variations in the time between the observations of the same radar transmission to determine where such an irregularity would be located. They were able to determine the location of the hypothesized irregularity and confirm its existence using backscatter observed by the SuperDARN Saskatoon radar.

As predicted by *James et al.* [2006], *Perry et al.* [2016] also observed fluctuations in the power signatures, or fades, in received pulses. There are a variety of explanations for these fades, including Faraday rotation (which causes the signal to rotate and the receiver to pick up different phases of the signal) and single-mode fades (which are caused by the destructive interference of wave fronts affected by multipath for either the *O*-mode or the *X*-mode). Distinguishing the types of fades and examining their variation along the satellite track could also assist in the detection or characterization of ionospheric irregularities.

3. Conclusions

e-POP RRI has been shown to be an effective tool for detecting HF signals and studying HF radio wave propagation in the ionosphere. It is possible to examine the strength, polarization, and coherence of the received signals. When the source is known, these parameters can be used to examine the ionosphere through which the signal propagated.

Multipath propagation, a common phenomenon in an inhomogeneous medium, is usually studied with the aim of reducing or masking its effects. *Perry et al.* [2016] showed how changes in the time delay resulting from multipath propagation from a single transmitted pulse could be used to identify and locate inhomogeneities. In the ionosphere, localized inhomogeneities are often regions of disturbed plasma that can be used to study basic plasma physics and magnetosphere-ionosphere coupling, both areas of great interest to the scientific community [*National Research Council*, 2013]. Using multipath from e-POP RRI and other spaceborne receivers to study ionospheric irregularities will open up new possibilities for studying the disturbed ionosphere.

Another important avenue of study for ground instruments and e-POP lies in using RRI to characterize the performance of the ground-based transmitter. e-POP RRI proved capable of detecting individual pulses with enough accuracy to determine the signal dispersion, presence of multipath, and existence of fading. This means that it is capable of identifying the presence of rear and side lobes from HF radars, measuring changes in dispersion with increasing hop, and much more. Such characterizations would prove invaluable to instruments located in hard-to-reach areas such as Antarctica.

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