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Title: MEASUREMENTS OF IONOSPHERIC EFFECTS ON WIDEBAND SIGNALS AT VHF

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Measurements of Ionospheric Effects on Wideband Signals at VHF

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Abstract

Radars operating at very high frequency (VHF) have enhanced foliage and ground penetration compared to radars operated at higher frequencies. For example, VHF systems operated from airplanes have been used as synthetic aperture radars (SAR); a satellite-borne VHF SAR would have considerable utility. In order to operate with high resolution it would have to use both a large relative bandwidth and a large aperture. A satellite-borne radar would likely have to operate at altitudes above the maximum density of the ionosphere; the presence of the ionosphere in the propagation path of the radar will cause a deterioration of the performance because of dispersion over the bandwidth. We present measurements of the effects of the ionosphere on radar signals propagated from a source on the surface of the Earth and received by instruments on the FORTÉ satellite at altitudes of 800 km. We employ signals with a 90 MHz bandwidth centered at 240 MHz with a continuous digital recording period of 0.6 s.

I. Introduction

In general, as the frequency of a radar is reduced the transmissions undergo less scattering by vegetation and therefore the ability of the radar to detect targets in a forest is enhanced (foliage penetration). Also at lower frequency the transmissions suffer less absorption in the ground so that the ability to detect sub-surface targets is enhanced (ground penetration) [1], [2]. For example, synthetic aperture radar (SAR) systems with resolution of the order of meters have been deployed on both aircraft and satellites. Aircraft borne SAR's have operated at frequencies as low as 215 MHz while satellite-borne SAR's have been restricted to frequencies above 1 GHz to avoid ionospheric degradation [3]. The utility of a satellite-borne SAR operated at very high frequency (VHF) depends on compensation for the degrading effect of the ionosphere on imaging [4], [5]. There have been a number of previous papers on the effects of the ionosphere on SAR imaging which have examined the effects of dispersion on range resolution [6], [7] or degradation by electron density irregularities [8], [9].

The range resolution of a SAR is given by $\rho_r \approx c/2B$ where B is the bandwidth and c is the speed of light [10]. Therefore, as the center frequency, f_c, is reduced, a larger relative bandwidth, B/f_c, is necessary to attain the same resolution. The first effect of the ionosphere on a SAR pulse is to produce a group path change; that is, the target will appear to be displaced in range, Δr. This effect depends upon the operating frequency,

f_c, and the integrated electron column density (total electron content or TEC) along the ray path and is $\Delta r \approx 81\,\mathrm{TEC}/f_c^2$ meters if f_c is given in Hz and TEC in m^{-2}. Daytime values of TEC are approximately $10^{17}\,\mathrm{m}^{-2}$ so that for $f_c = 250\,\mathrm{MHz}$, $\Delta r \approx 130$ m. The displacement will also be affected by refraction as the radar pulse traverses the ionosphere. The second effect of the ionosphere on the radar pulse is that of dispersion; that is, higher frequencies will return sooner than lower frequencies from the same target. The amount of spreading, $\Delta\rho_r$, depends upon the bandwidth of the pulse and is given by

$$\Delta\rho_r \approx \Delta r \left[\frac{1}{(1 - B/2f_c)^2} - \frac{1}{(1 + B/2f_c)^2}\right]. \quad (1)$$

For a 100 MHz bandwidth pulse centered at 250 MHz, $\Delta\rho_r \approx 110$ m which is considerably larger than $\rho_r \approx 1.5$ m. In this paper we report on measurements of the ionospheric effects on wide-bandwidth VHF signals transmitted from the ground and recorded on a satellite in low earth orbit.

II. FORTÉ Satellite

FORTÉ, which stands for Fast On-Orbit Recording of Transient Events, was launched Aug 29, 1997. Los Alamos National Laboratory and Sandia National Laboratories developed FORTÉ, an advanced radio frequency impulse detection and characterization experiment. Emphasis is on the measurement of electromagnetic pulses, primarily due to lightning, within a noise environment dominated by narrow-bandwidth carriers, such as TV and FM stations.

The seven-foot-tall satellite, which weighs 210 kg, carries three decks with aluminum honeycomb cores and composite facing to support the onboard instruments. FORTÉ includes a radio frequency sensor system with three broad-bandwidth receivers covering the range of 30–300 MHz. It receives radio frequency signals via a novel, 10 m-long antenna that has two arrays set at right angles to each other. The antenna, which was coiled up inside the satellite, was unfurled after FORTÉ reached orbit. The antenna's two receiving arrays span about 10 m at the base of the boom nearest the satellite body and taper to about 1 m across at the antenna's tip. The received signals are recorded by high speed waveform digitizers. The satellite is nadir pointing and three axis stabilized. Body mounted solar cells provide a daily averaged 55 Watts of power. The orbit is 800 km altitude at 70° inclination. A minimum mission duration of one year is forecast with the capability to operate for up to three years.

III. Experiment

Our goal is essentially to construct a bistatic radar using a ground transmitter and a satellite-borne receiver. Our initial measurements have attempted only to detect the direct transmission to the satellite; with higher power transmitters we will attempt to observe reflections from illuminated objects at the satellite. Our limited collection time will allow us to construct a bistatic synthetic aperture radar with a dimension of approximately 4 km. This will allow imaging at a crude resolution of about 200 m at the frequencies we are using; this is likely not to allow a good test of the effects of phase variations induced by ionospheric structures on azimuth resolution.

We have transmitted a variety of signals to the FORTÉ satellite and recorded them using the 90 MHz bandwidth receiver and 300 MHz digitizer. The memory allows a continuous recording of up to 560 ms of data with the 8 bit digitizer. The receiver can be tuned with the choice of local oscillator to ranges of 0–90, 108–198, and 198–288 MHz. For the measurements reported here we have used the highest frequency range. The signals are filtered with a bandpass filter before being mixed with the local oscillator.

IV. Discussion

One challenge to obtaining useful performance from a satellite-borne VHF radar is the effect of dispersion. Our measurements indicate that, by modifying the radar waveform using the slant TEC, the pulse broadening introduced by the ionosphere may be compensated by optimizing the pulse compression using an adjustable TEC. For synthetic aperture radars another challenge is to compensate for any non-uniformities in the ionosphere such as those produced by acoustic-gravity waves (Traveling Ionospheric Disturbances) which cause phase variations over the aperture. For the limited aperture available using our measurement technique such phase variations do not limit the resolution.

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