Wideband Modelling and Measurement of Trans-Ionospheric Radar Waveform Propagation

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Introduction

QinetiQ have developed a model to simulate the corruption of wideband radio waveforms propagated through a non-homogeneous ionosphere. The model is capable of simulating measurements from the ALTAIR VHF/UHF wideband satellite tracking radar on Kwajalein Atoll. Performance aspects of space-based Synthetic Aperture Radar (SAR) have also been simulated.

The Wideband Model

A multiple phase screen, split-step Parabolic Equation technique is used to describe the propagation of the complex electromagnetic field in planes normal to the propagation vector.

Phase screens are produced as stationary random functions whose spatial power spectra average to an ideal profile. This may be a log-log-linear spectrum parameterised by spectral index and strength of turbulence, and defined between inner and outer irregularity scale sizes. Elongation and orientation of the irregularities relative to both the geomagnetic field and propagation vectors are included in the model.

Measurement of Ionospheric Irregularities from Ascension Island

To provide ionospheric irregularity (spatial) spectra in the highly structured equatorial anomaly region, Total Electron Content (TEC) and 50Hz scintillation measurements have been made from a dual-frequency GPS receiver deployed on Ascension Island in 2004.

Temporal power spectra of TEC have been analysed and, using a model estimate of the ionospheric drift velocity, the RMS phase variation within the beam of a proposed foliage-penetrating space-based SAR has been determined. This quantity determines the ability of such a radar to apply autofocus techniques in forming an image.

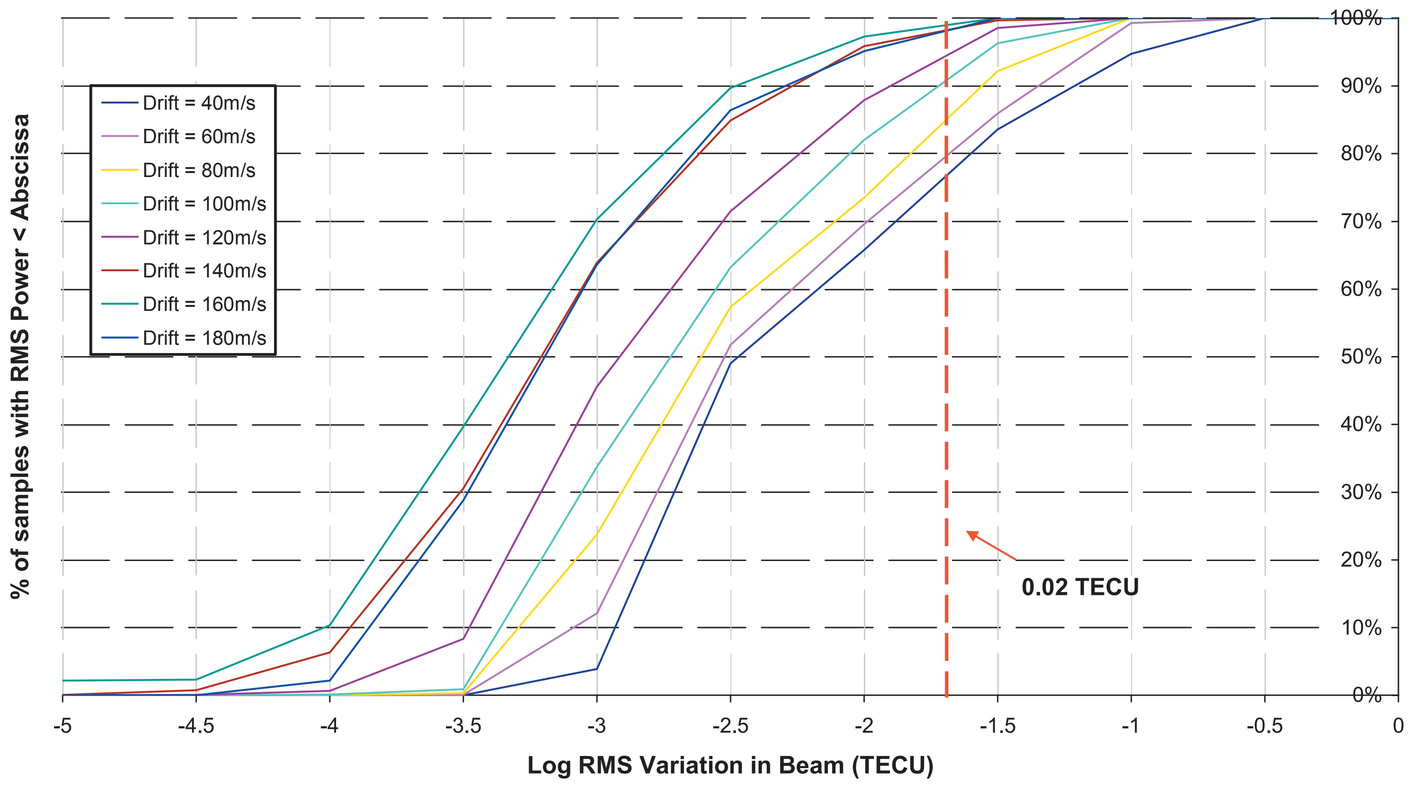


Figure 1: Cumulative distributions of RMS vertical TEC within a 5km ionospheric 'footprint', measured from Ascension I. (2100-0100 LT, 1-31 Oct. 2004) for various ionospheric eastward drift velocities. The 0.02TECu value indicated is a critical value for autofocus operation in a proposed 500MHz foliage penetrating SAR.

Measurement and Simulation of Linear FM Chirp Propagation from the ALTAIR V/UHF Radar on Kwajalein

An experimental campaign has been conducted at the ALTAIR radar facility on Kwajalein Atoll (9.4˚N, 166.8˚E). Linear FM chirp waveforms were transmitted with 6MW power into a 42m dish (Figure 4) which tracked satellite calibration spheres of uniform radar cross section. The chirp bandwidth was either 7MHz on a 158MHz carrier or 18MHz on a 422MHz carrier. Sample results of the power distribution of returned 158MHz chirps are presented in Figure 2 as a function of Doppler and Delay.

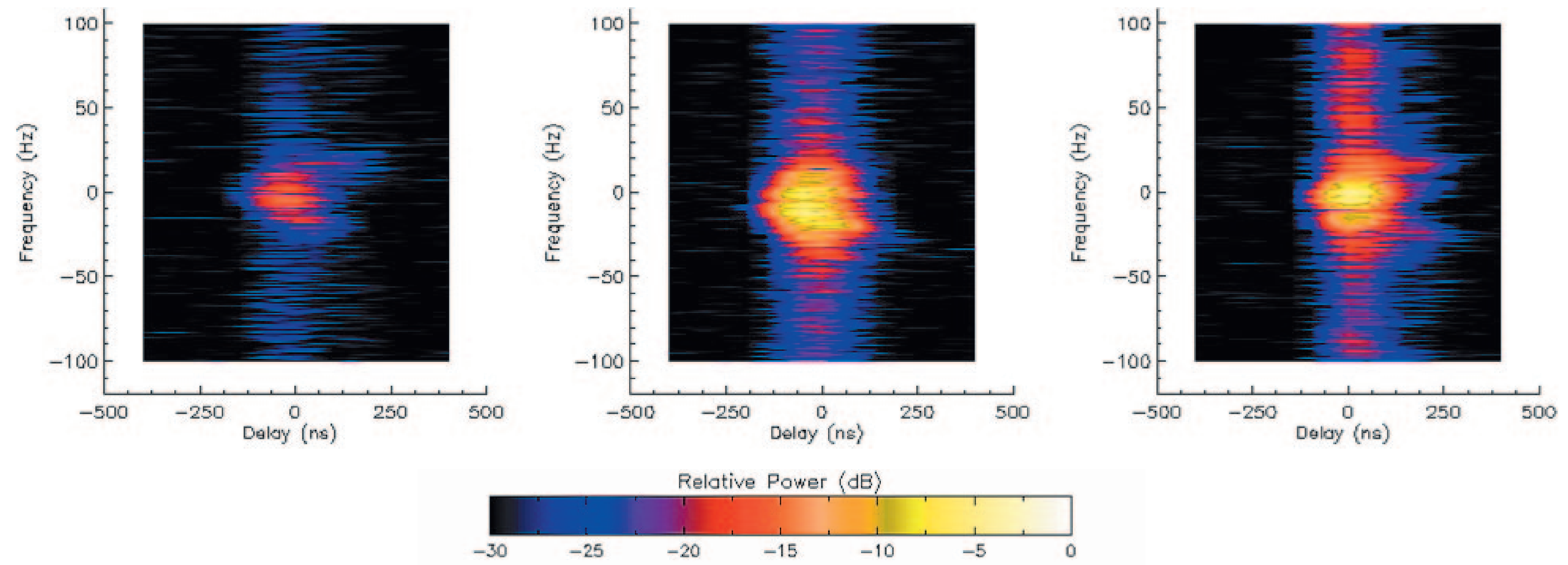


Figure 2: Delay and Doppler profiles of 158MHz ALTAIR chirp radar returns from the LCS-4 satellite (a calibration sphere) for three consecutive 3.3s periods on 21 January 2005.

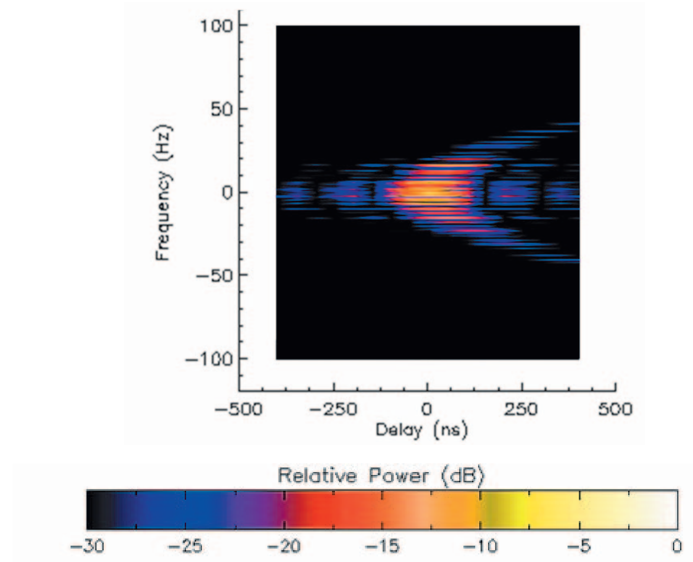


Figure 3: Ray-traced simulation of the 158MHz two-way channel impulse response power spectrogram for the ALTAIR 7MHz linear FM chirp following two-way propagation through a strongly disturbed ionosphere phase screen model ($C_kL = 10^{34}$, spectral index =2.7). The two 'horn' features at positive delays resemble those observed in the measurements (Figure 2).

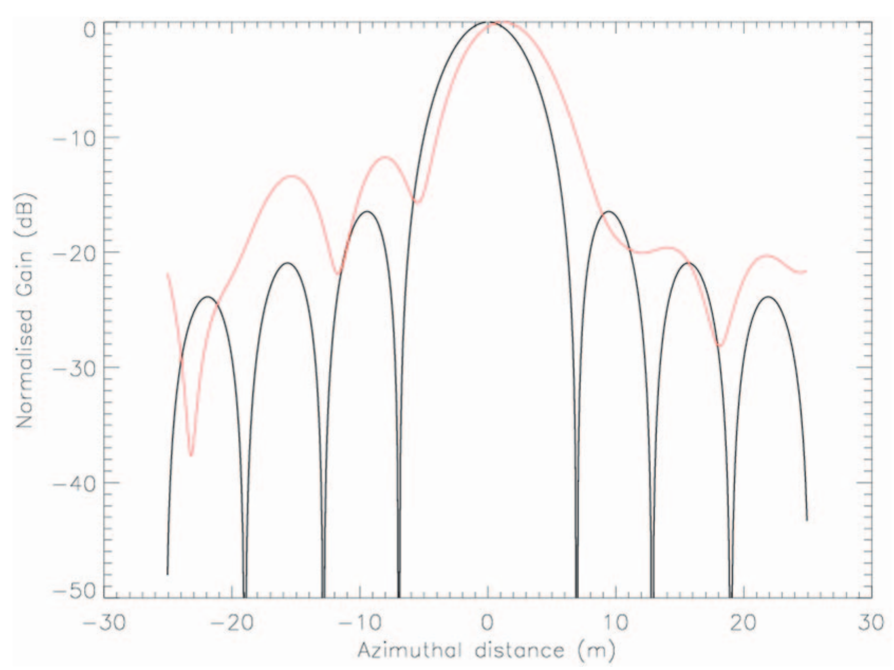
The wideband characteristics of the channel have been modelled by propagating spectral components of the chirp waveform through the phase screens and then reconstituting the signal at the ground via a Fourier transformation into the time (delay) domain. By estimating the ionospheric drift velocity, the delay and Doppler power distribution is calculated using knowledge of the satellite orbit and pulse repetition interval. The ionosphere is assumed stationary between up-going and down-going ionospheric transitions of the pulse.

A sample of model results is presented in Figure 3 which shows delay, Doppler spreads and some shape features that bear a close resemblance to the measurements.

Figure 4: The 42m ALTAIR 6MW radar at Roi, Kwajalein Atoll.

Simulation of SAR Point Spread Functions

The point spread function (PSF) has been simulated for existing and proposed satellite SAR operating between 500MHz and 5.3GHz for a range of ionospheric turbulence conditions (see example in Figure 5). The model records parameters such as beamwidth (azimuthal resolution), RMS and mean shift of peak (SAR image shift) and sidelobe levels which determine contrast in the SAR image.



	No ionosphere	Ionosphere (S_4=0.2)
Peak shift (m)	–	1.1
3dB width (m)	5.9	6.2
Sidelobe level (dB)	16.4	11.7
Energy in main lobe (%)	78.8	76.0
Equivalent Rectangle of resolution (m)	6.3	7.1

Figure 5: An example of the modelled degradation of the SEASAT (1.3GHz) azimuthal PSF under moderate ionospheric scintillation conditions (S_4=0.2). Calculated parameters of the PSF are shown in the table (right).

Conclusions

The QinetiQ wideband propagation model provides a method of predicting and analysing trans-ionospheric radar performance. Low latitude TEC measurements in Ascension I. and wideband VHF and UHF radar measurements in Kwajalein are helping to parameterise and improve this model.

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