ANALYSIS OF THE CORRELATION PROPERTIES OF DIGITAL SATELLITE SIGNALS AND THEIR APPLICABILITY IN BISTATIC REMOTE SENSING

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1. INTRODUCTION

A study of relevant correlation properties of signals transmitted from commercial XM satellite digital radio is presented with the purpose of evaluating their potential use as "signal of opportunity" for bistatic remote sensing. The ambiguity function for XM radio satellites is computed analytically from published information on the modulation schemes and bandwidth, under the assumption that the data modulation is random. The model is then experimentally tested by recording the received signals from these satellites. Finally, this ambiguity function model will be used within a simulation of rough-surface scattering of digital signals, originally developed for Global Navigation Satellite system (GNSS) signals.

2. PROBLEM

This study is related to the use of navigation (GNSS) signals as illuminators in a bistatic radar system for remote sensing [1], [2], [3], [4]. Those signals, however, have a relatively low power and time-varying geometry. Communications satellites, in contrast, are typically in geostationary orbit, and have a much higher transmitted power. In addition to that, unlike navigation signals, which are designed for range measurements, communication signals are designed for the transmission of data bits at a low error rate. The drawback, therefore, is that there is no a priori knowledge of the data bits.

The potential use of these signals thus requires an evaluation both of the practical aspects of generating a cross-correlation waveform when the data cannot be synthesized inside the receiver, as well as the theoretical dependence of the shape of that waveform on the relevant features of the scattering surface. In addition, the different frequency regime allocated for satellite communication (2332.5 to 2345.0 MHz of S-band for XM vs. 1545 MHz of L-band for GNSS) may offer a different sensitivity to both surface reflectivity (for the retrieval of soil moisture) and roughness at higher frequencies (for retrieval of wind speed).

There has also been significant work conducted on the use of both terrestrial and satellite communication transmitters as sources of opportunity for the purpose of detecting point targets or stationary observation of slow–moving processes on the solid Earth surface [5], [6], [7]. The waveform properties of several common signals of

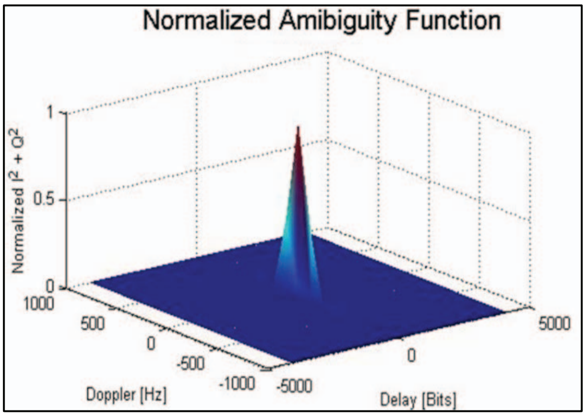

Figure 1: Ambiguity function for XM Radio signal

opportunity (analog FM radio, UHF television, and Digital Audio Broadcast) were studied experimentally to determine their performance in passive coherent location (PCL) for the detection and tracking of point targets [8]. In that study, the "self-ambiguity function"

$$|R(\tau, f_D)|^2 = \left|\int_{-\infty}^{\infty} s(t)s^*(t+\tau)e^{2\pi f_D t j} dt\right|^2 \tag{1}$$

was computed from signals s(t) recorded from the aforementioned sources. It was found, particularly in the case of analog sources, to vary with time, leading to the conclusion that the performance (range and Doppler resolution) of such a passive locating system would be time-dependent.

The basic model for the cross-correlation waveform of a digital signal bistatically scattered from a random surface random surface is given by the following surface integral [3].

$$\langle Y^2(\tau, f_c)\rangle = \iint \frac{|R|^2 D(\vec{\rho})|R(\Delta\tau, \Delta f_c)|^2}{4R_0 R} \frac{q^4}{q_z^4} P_{\vec{v}}\left(-\frac{\vec{q}_\perp}{q_z}\right) d^2\vec{\rho} \tag{2}$$

The function, $\langle Y^2(\tau, f_c)\rangle$, is a description of scattered power in delay, τ, and Doppler, f_c. $|R(\Delta\tau, \Delta f_c)|^2$ is the ambiguity function, $|R|^2$ is the reflectivity and $D(\vec{\rho})$ is the antenna gain pattern. Sensing of the ocean surface enters through the PDF of the surface slopes, $P_{\vec{v}}$, which can be parameterized with a few slope moments. These slope moments have been empirically related to the surface wind speed and the frequency of illumination [3]. Sensing of soil moisture enters through the reflectivity $|R|^2$, which can be measured by the total power in the waveform (integrated over delay and Doppler).

3. METHODOLOGY AND RESULT

Experiments were conducted to collect sampled data from the XM radio satellite, generate the self-ambiguity function from these data streams (with no a priori knowledge of the bits) and derive a corresponding model for this ambiguity function under the assumption of infinitely-long random data. The satellite component of XM-radio occupies a spectrum allocation between 2332.5 to 2345.0 MHz (S-band), separated into individual

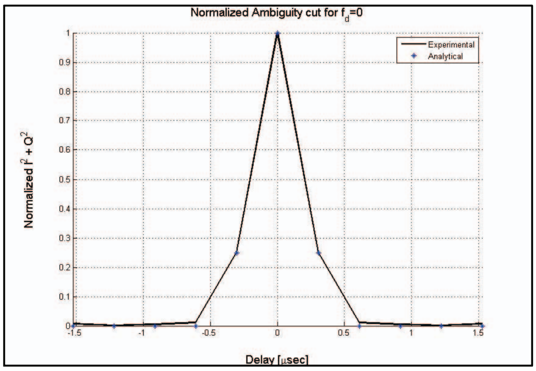

Figure 2a: Single-Channel Delay Resolution

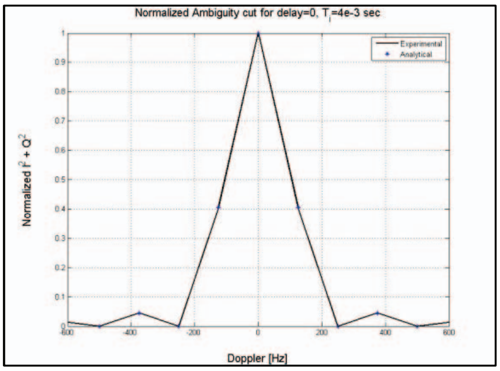

Figure 2b: Single-Channel Doppler Resolution

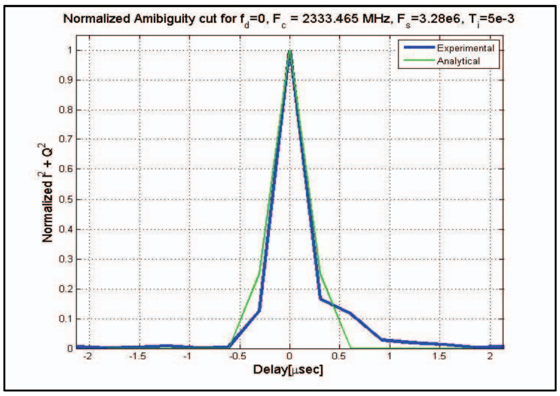

Figure 3a: Dual Channel Delay Resolution

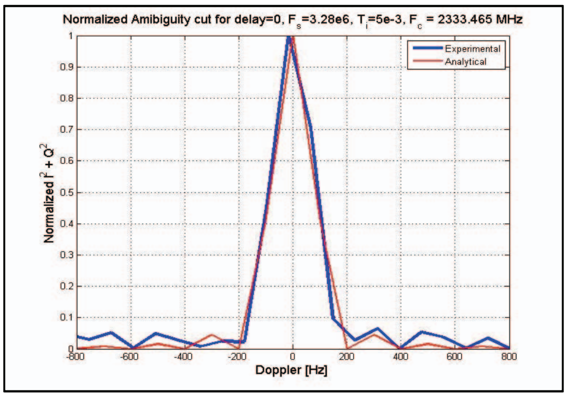

Figure 3b: Dual Channel Doppler Resolution

multiple slots, each with a QPSK modulated signal using data and symbol rates of 3.28 Mbps and 1.64 Msps, respectively. Each channel has a bandwidth of 1.886 MHz. [9]. The signal model assumes that the data modulation is comprised of uniformly distributed random binary digits. Given that the signal is QPSK modulated, the analytical models for the Doppler axis and delay axis are represented in (3) and (4) respectively.

$$|R(\tau,0)|^2 = \left|2P * tri\left(\frac{t}{T_s}\right)\right|^2 \tag{3}$$

$$|R(0,f_D)|^2 = |T_i * sinc(f_D T_i)|^2 \tag{4}$$

Here tri(*) is the triangular function, T_s is the symbol rate, P is the power and T_i is some finite integration time.

The digitized data from the direct signal of XM radio signal is recorded using a Universal Software Radio Peripheral (USRP) and a commercial XM radio antenna i.e. Terk XM6 at 4 MHZ and the “self ambiguity function” (1) is computed numerically using integration time of 4ms [10]. Data collections were conducted at various times of the day to verify that the statistical properties of the signal remained constant. The corresponding model ambiguity function was derived analytically and computed for comparison. Figure 1 shows the 3D plot of the “self-ambiguity function.” Figures 2a and 2b show the analytical model compared to the ambiguity function computed using (1) from the experimental data for the delay and Doppler cut, respectively. In order to estimate the SNR more realistically, the same transmission is recorded using two different receive paths. The two recorded signals, with their independent noise sources, are then cross-correlated. This results in a SNR after correlation of 30dB. However, the time delay between the two channels adds a bias to the delay when cross-correlated. This effect is shown in Figures 3a and 3b.

4. CONCLUSION AND FUTURE WORK

The analytical model, overlaid onto both Figures 2a and 2b, shows good agreement with that computed from the recorded signal. The post-correlation SNR is also high. The next step is to incorporate the ambiguity function into the model for the scattered waveform (2) and its second-order statistics which were derived in [10], [11]. The model could then be used to predict the sensitivity of the cross-correlation waveform to surface roughness and reflectivity from airborne or orbiting receivers. Bistatic sensing methods, previously demonstrated with satellite navigation signals, could be applied to satellite communications signals, taking advantage of the substantially higher transmitted power. A system for remote sensing of ocean winds or soil moisture, based upon these techniques, could fit within a smaller footprint and substantially lower power requirements than active radars (due to the absence of a transmitter). UAVs and small satellites are potential platforms for this sensor.

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