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A Wide Bandwidth Channel Probe for Space Situational Awareness

Dennis L. Knepp, Chad M. Spooner, Mark A. Hausman

NorthWest Research Associates
301 Webster Street
Monterey, CA 93940, USA
e-mail: dennis.knepp@nwra.com, web page: http://www.nwra.com

ABSTRACT

There is a recognized need for wide bandwidth communications and radar systems in space, both for military and civilian applications. Space-based SAR offers the potential of wide-area surveillance and biomass characterization, including terrain topography under dense vegetation [1]. To obtain foliage penetration (FOPEN) the transmission frequency should be as low as possible. Good range resolution demands high bandwidth. However, ionospheric effects on the propagating signal are an inverse function of frequency and are known to be severe at certain locations and times for frequencies of L-band (1-2 GHz) and lower [2]. For a successful SAR/FOPEN system, design tradeoffs involving ionospheric effects must be investigated and resolved early in the system development.

A space-based wide bandwidth channel probe is an excellent choice to investigate ionospheric propagation effects for planned SATCOM and radar systems that operate at L-band and below. This talk discusses the use of such an instrument to support such wide bandwidth UHF systems. The primary goals of this work are to specify the transmitted waveform and to provide proof-of-concept estimators for the ionospheric impulse response function as well as the parameters that describe the propagation channel in a statistical sense. We describe signal processing algorithms that allow good estimation of the transfer function and impulse response function of the ionosphere at 383 MHz over a bandwidth of 5 MHz with as little as 1 watt of transmitted power.

Channel probes fully characterize time-varying propagation channels for communications and radar systems. A channel probe measures the channel transfer function and its Fourier transform, the impulse-response function. The channel transfer function provides the amplitude and phase of each spectral component over the system bandwidth as a function of time, while the impulse-response function is the temporal response to a transmitted impulse function. Either of these functions is sufficient to calculate the propagating signal for any transmitted signal whose spectral components are within the bandwidth of the probe.

This paper discusses the key issues associated with development of a space-based wideband channel probe designed to operate at a transmission frequency of 383 MHz. Important considerations are the transmitted power and bandwidth, the details of the transmitted waveform, the severity of the propagation environment, and the processing of the received signal at a ground station after propagation through the ionosphere.

The utility of a wide bandwidth channel probe ultimately depends upon the severity of ionospheric propagation disturbances at the planned system transmission frequency and over the desired bandwidth of the communications, navigation, or radar system under consideration. If

the transmission frequency is high and the bandwidth is small, a channel probe is unnecessary because the channel is flat (not a function of frequency). . In advance of deploying a channel probe, it is important to estimate its utility. Questions of interest include: (1) Is the ionospheric propagation channel frequency-selective over the bandwidth of the system; (2) What is the range of channel decorrelation time likely to be experienced? The first question addresses the necessity of a wide bandwidth channel probe. The second question is important for channel probe design, since the probe must have sufficient SNR to be able to accurately measure the ionospheric transfer function over a time interval during which the channel is relatively constant. This is simply the statement that changes with wall-clock time of the propagation channel act to limit the coherent integration time available. In general, any coherent measurement must be accomplished over a time period in which the time-varying channel is approximately constant.

We illustrate these important points through the analysis of several hours of equatorial scintillation data from a wideband receiver at Kwajalein that recorded the 20-MHz bandwidth signal transmitted on a carrier frequency of 370 MHz by the Pacific MUOS satellite.

We apply the NWRA PROPMOD code [3, 4] to determine the likely minimum values of the decorrelation time and coherence bandwidth. These minimum values will drive the design of the channel probe here. This study considers the transmission frequency (lower frequencies exhibit stronger scintillation), the satellite-receiver geometry (lines of sight from LEO satellites to ground cut through ionospheric irregularities at a higher rate than those from HEO satellites), and the ambient ionospheric propagation environment.

In order to test our signal processing software, we need realistic sample functions of the time-varying transfer function of the ionosphere. To obtain these realizations, we utilize the NWRA multiple phase screen (MPS) propagation simulation [5]. The MPS code solves the parabolic wave equation and allows for direct computation of realizations of the ionospheric transfer function. The ionization is represented by a series of random phase screens that characterize the severity and spectrum of the electron density fluctuations. For wide bandwidth signals, the MPS code is exercised for many frequencies over the bandwidth of the propagating signal; Fourier transform techniques are used to obtain the propagating signal in the time domain.

We develop signal processing strategies and methods that are intended for analysis of the signal received after ionospheric propagation. Time synchronization and measurement of mean Doppler are requirements for our signal processing. We also consider the performance of signal processing software developed to estimate the time-varying transfer function and the impulse response function. Other algorithms also estimate the important parameters that describe the ionospheric propagation channel in a statistical sense, including the scintillation index, the decorrelation time, and the coherence bandwidth.

The transmitted signal consists of the filtered (using a square-root raised cosine filter) repeated set of binary symbols based on a maximal length shift-register (MLSR) sequence. The Fourier transform of this repeated sequence has spectral components (equally spaced tones) that are approximately flat across the bandwidth of the transmitted signal. The signal processing algorithms that are applied to obtain the channel transfer function include time and frequency synchronization, and the FFT of the received signal, including the effects of the propagation channel. The ionospheric transfer function is obtained by dividing the FFT of the received signal by the known FFT of the transmitted signal. Since the power in the transmitted FFT is spectrally flat, the result is an estimate of the ionospheric transfer function with approximately the same average SNR across the transmitter bandwidth.

Fig. 1 shows an example of the simulated (ideal) impulse response function and transfer function and the estimated results from our signal processing.

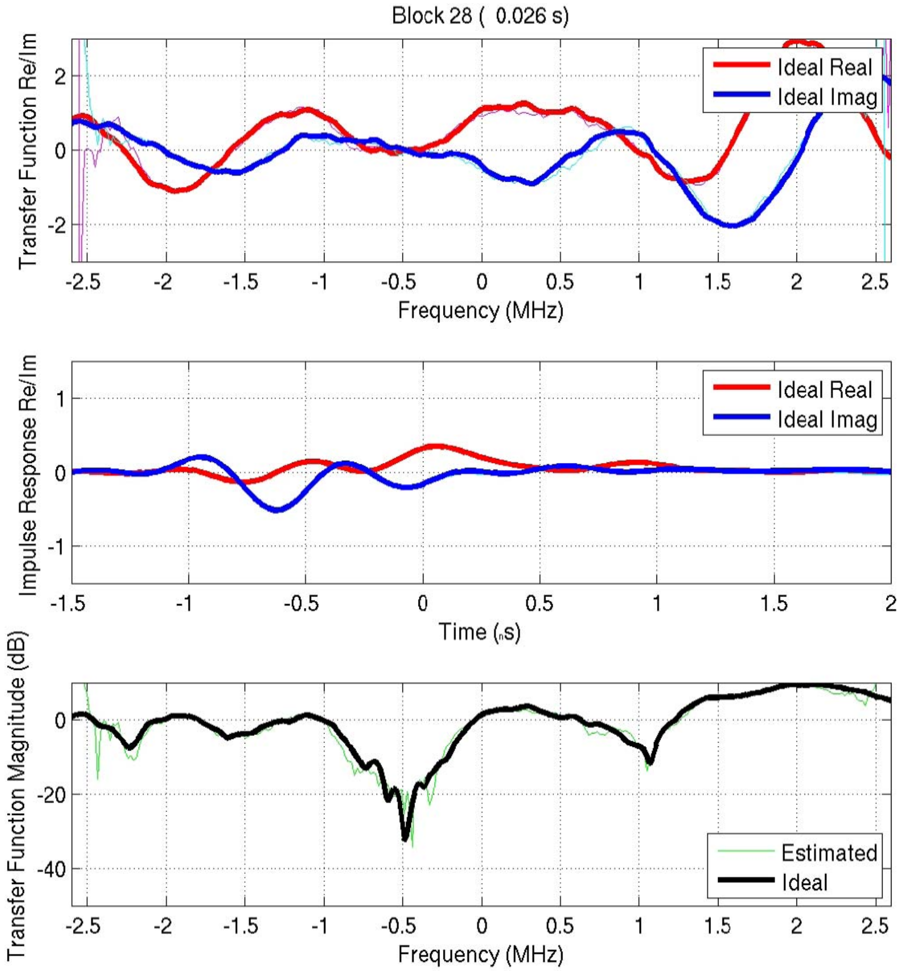

Figure 1. Example of the time-varying transfer function and the impulse response function.

We have tested our processing algorithms for values of decorrelation time ranging from 10 to 50 msec and values of the ionospheric coherence bandwidth of 320 and 390 kHz. From our PROPMOD calculations, we expect that ionospheric disturbances will be more severe less than 5% of the time at the peak of the solar cycle. We considered LEO satellites in equatorial orbits with a transmitted power of 1 watt, altitudes from 500-800 km, and transmit and receive antennas with gains of 5 dBi. In all cases we are able to accurately measure the ionospheric impulse response function, the transfer function, and the coherence bandwidth.

This paper conclusively demonstrates that the MLS signal and the signal processing algorithms have the capability to measure the channel impulse response function and coherence bandwidth and fully characterize a wide bandwidth channel. The algorithm testing to date is designed to test against the most difficult propagation environment likely to be encountered. Additional work is needed to fully characterize algorithm performance in the varied and dynamic environment that will be experienced from a low-altitude satellite.

Key words: Beacon satellite, Wide Bandwidth Channel Probe, UHF Scintillation.

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