Suppression of GLONASS signals using Parametric Signal Modelling

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Abstract

Astronomers use the 1612 MHz OH spectral line emission as a unique window on properties of evolved stars, galactic dynamics, and putative proto-planetary disk systems around young stars. In recent years, experiments using this OH line have become more difficult because radio telescopes are very sensitive to transmissions from the GLONASS satellite system. The weak astronomical signals are often undetectable in the presence of these unwanted human generated signals. In this paper we demonstrate that GLONASS narrow band signals may be removed using digital signal processing in a manner that is robust and non-toxic to the weak astronomy signals, without using a reference antenna. We present results using real data and outline the steps required to implement useful systems on radio telescopes.

1 Introduction

Many papers in the astronomical literature cite problems with interference from the Russian *Global'naya Navigatsionnaya Sputnikovaya Sistema* (GLONASS) system of navigational satellites when trying to observe 1612 MHz OH spectral line emission [3]. Some reports have stated that up to 50% of all observations have had to be discarded [4]. The scientific merits of OH spectral line observations are discussed in detail elsewhere[2]; however, there is no question that this is extremely valuable spectrum whose continued use is essential to radio astronomy.

One possible solution to the problem is regulation; this is being addressed within international organisations such as the ITU and URSI. However, regulation cannot be expected to recover the spectrum into which the GLONASS system already transmits. The solution most often employed by radio astronomers in dealing with unwanted signals is to put their telescopes in remote locations. However, when dealing with signals that emanate from Earth-orbiting satellites, that method obviously fails. The next most obvious solution is not to observe when interfering signals are present and some ``GLONASS aware" tools for dynamic scheduling of observations are available [4].

Here we present a direct, technical solution to the problem. We have developed and demonstrated a parametric signal processing algorithm which identifies GLONASS signals present in the pre-detection, complex base band data, and removes them. This algorithm results in a high degree of suppression with negligible distortion of radio astronomical signals. We believe this approach can be applied to interference from the U.S. Global Positioning System (GPS) and possibly other sources as well. This technique is presented in Section 3 of this paper. First (Section 2), we describe the properties of GLONASS that are relevant to the operation of the canceller. In Section 4, we present experimental results demonstrating the effectiveness of this approach. In section 6, we consider how this approach may be implemented as a real-time system.

2 Properties of GLONASS signals

GLONASS satellites transmit at frequencies between 1602 – 1616 MHz and have shared primary user status with radio astronomy for the 1610.6 - 1613.8 MHz band [3]. There are 24 carriers spread over the 14 MHz band at intervals of 0.5625 MHz. The carrier is modulated by a pair of noise like, equal power, pseudo noise (PN) codes of 0.511 and 5.11 MHz. Figure 1 of [3] shows time averaged spectra of these signals. The unfiltered sinc^2 side lobes of these signals have relative power levels as high as –25 dB extending out to 20 MHz either side of the main carrier in some cases [4]. GLONASS satellites launched more recently do have some band-limiting filters.

GLONASS, despite its wide band spectrum, actually has a very simple structure [5]. Consider the narrow band (0.511 MHz) GLONASS modulation. This signal is simply a sinusoidal carrier which experiences a phase shift of 0^0 or 180^0 every 0.511 MHz^{-1}. Each phase shift represents a modulation symbol, or *chip*. Each group of 511 chips represents a PN code, which is public knowledge, never changes, and is the same for every GLONASS satellite. GLONASS data bits are represented by changing the sign of a block of 10 PN codes, with 10 ms period. Parameters of the signal which are unknown when received are: (1) the Doppler shift due to satellite motion, (2) the *code phase*, that is, the relative position within the 1 ms PN code period, and (3) the carrier phase, which rotates because the satellite is moving and the transmitter's LO is not perfectly stable. However the carrier phase, the current value of the data bit, and the complex gain due to the antenna pattern can all be combined into a single unknown complex parameter. Thus three parameters are sufficient to describe the GLONASS signal with high accuracy.

Finally, we note that the modulation used by the course/acquisition (C/A) mode of the U.S. Global Positioning System (GPS) is very similar to modulation used in the GLONASS 0.511 MHz transmission. The main differences are longer code (1023 chips) and higher chip rate (1.023 MHz); also, all GPS satellites transmit on the same centre frequency, but with different (but known) PN codes. Thus, techniques which are effective against 0.511 MHz GLONASS signal may be effective against GPS C/A signal.

3 Cancellation Algorithm

3.1 Theory

Our technique for suppressing GLONASS signals in radio astronomy data is based on *parametric signal modelling*. Recall that the GLONASS signal can be described using a model consisting of just three parameters: Doppler, code phase, and complex magnitude. Given a block of data containing a GLONASS signal, one can then estimate the parameters. Given the parameters, it is possible to synthesise a noise-free copy of the GLONASS signal. This copy is then subtracted from the telescope output to achieve the suppression. This procedure is illustrated in Figure 1.

The parametric solution proceeds on two time scales. Doppler frequency and code phase are difficult to estimate, but change slowly. Complex magnitude, on the other hand, is simple to estimate, and changes quickly. Our approach is to first acquire the GLONASS signal. This involves a joint search over the possible Doppler frequencies and the code phases. For each Doppler/code phase pair, a complex base band (zero-IF) version of the signal is cross-correlated with the PN sequence. The correct Doppler/code phase pair is the one which maximises the magnitude of the cross-correlation. Although tedious, this is a simple procedure, and is essentially the same acquisition procedure used by hand held GPS receivers. Once acquired, the Doppler and code phase can be tracked simply by sensing the drift in the correlation peak and adjusting the Doppler and code phase parameters accordingly. It appears that the Doppler and code phase estimates can be frozen for at least 0.1s between updates without any significant effect on the results.

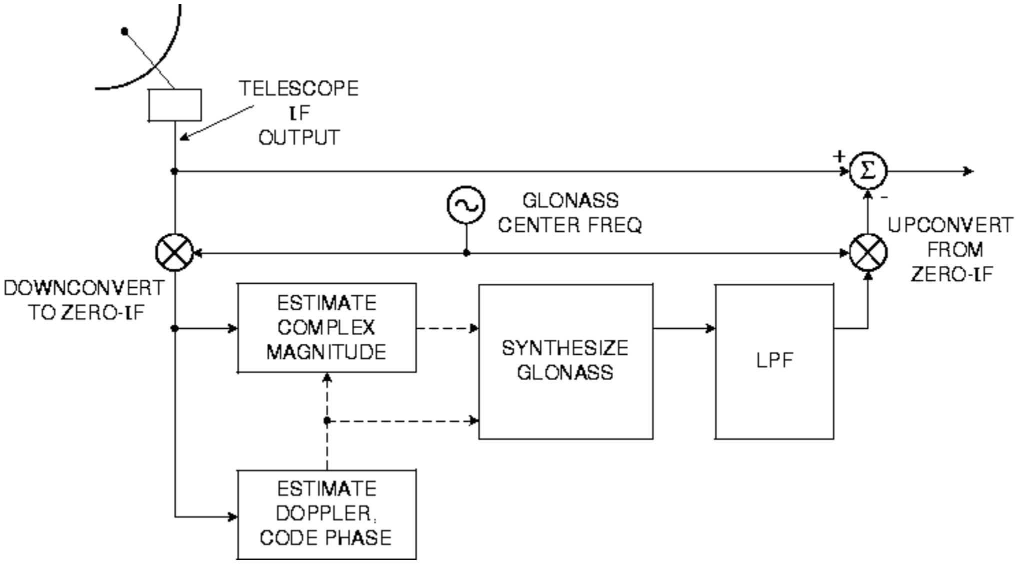

Figure 1: Parametric cancelling technique. The *ESTIMATE DOPPLER, CODE PHASE* block uses the down converted telescope signal to generates an estimate of the time aligned PN code and the offset in frequency between the *GLONASS CENTER FREQ* oscillator an the down converted GLONASS signal. These two estimates and the down converted signals are used by *the ESTIMATE COMPLEX MAGNITUDE* block to calculate a magnitude and phase correction. These estimates of time aligned PN code, frequency, magnitude and phase are then used to synthesise a zero-IF GLONASS signal.

Once the signal is acquired, we estimate the complex magnitude by cross-correlating the time- and frequency-aligned PN code with the complex zero-IF representation of the GLONASS signal. The magnitude and phase of the cross-correlation then represents the desired complex gain. The complex gain is expected to change quickly, so this procedure must be updated often. In the example presented below, the complex gain update rate is 128 μs, using 1024 samples at 8 Msamples per second (conversion to a complex base band signal has halved the sample rate).

Given the Doppler frequency, code phase, and complex magnitude, one can then synthesise a noise-free estimate of the GLONASS signal. However, it has been found by experience that better cancellation is achieved by low-pass filtering the zero-IF version of the synthesised GLONASS signal before subtraction from the telescope output. This models the real-world low-pass effect which smoothes discontinuities in band limited signals. This also has the desirable effect of suppressing the high-order side lobes of the synthesised signal, which may not be accurately represented by the proposed signal model. A suitable filter was found to be a 32-tap finite impulse response (FIR) filter based on the Hamming window, with cutoff frequency equal to $0.05F_S$ at F_S=8 MSPS. Such a filter can be obtained using the MATLAB command fir1(32,0.1).

3.2 Implementation

The results presented below were obtained using non-real-time post-processing software, written in MATLAB. On a 400 MHz pentium the processing presently runs at 1000 times real time. The MATLAB source code is freely available from the authors. Any practical system would, of course, require real time implementation. The maturity of GPS technology means that the techniques and hardware for the acquisition of GLONASS and GPS signal parameters are well developed. The design of the signal modulators in the satellites is also known. With the knowledge of these two areas a practical real time implementation is within reach and is discussed in Section 5. The data used in testing these algorithms is a single linear polarisation, 4-bit data stream from an antenna of the 6x22m antenna, CSIRO Australia Telescope Compact Array at Narrabri in Australia. The data was 4-bit sampled at 16 MHz and recorded on video tape. The resulting 8 MHz band pass centred on 1610 MHz was wide enough to include signals from GLONASS-69 at 1609 MHz, an OH maser source (IRAS 1731-33) at 1612 MHz and flat spectrum. This data set and others that are freely available for conducting these kind of experiments [1].

4 Results

The results so far are encouraging, with GLONASS narrow band signals being effectively removed in a way that is non toxic to astronomy signals. Figure 1 (left plot, top curve) shows a spectrum of the raw data, with test tones added in software. The middle curve shows the same 0.1s (1.6 Msamples) of data after the cancellation technique was applied. The GLONASS signals left is a small amount of carrier breakthrough probably due to imbalance in the GLONASS phase modulator. It should be possible to model and remove this as well, but we have not addressed that yet.

In order to examine the toxicity of this algorithm in the same frequency range as the GLONASS signal, the test tones were subtracted after the cancellation was applied (see Figure 2, left plot, bottom curve). Since the test tones were inserted in software, they could be subtracted in the same way, showing that the corruption caused by the cancelling algorithm was about 1 part in 1000. There is an OH maser source at 1612.3 MHz. The top two curves in the right plot of Figure 2 show a blow up of this region. The bottom curve in the same plot shows the difference of the top two curves multiplied by a factor of 1000, indicating that no damage has been done in the spectral region of the OH source.

To assess the effect on an OH maser lying underneath the GLONASS signal, we inserted synthetic band limited noise at the same frequency as the GLONASS signal before cancellation and then subtracted it again afterwards. We also ran the canceller over the same data with no signals added. As shown in Figure 3, the small difference (only discernible at 1-2 parts in 1000) between the results of this processing, suggesting that the algorithm does not harm other signals which are coincident in frequency with unwanted signals.

6 Limitations and Future Improvements

The carrier break through described earlier needs to be modelled and cancelled. While we have not investigated this carefully yet, we believe this should be possible. At present we have modelled the band limiting filters of the GLONASS transmission system by a low-pass filter when the signal is centred on zero-IF. This may be limiting the accuracy with which we estimate the GLONASS spectrum and therefore possibly limiting the cancellation. We aim to either obtain details of the band limiting filters used on the GLONASS transmission system, or use the existing data to estimate them.

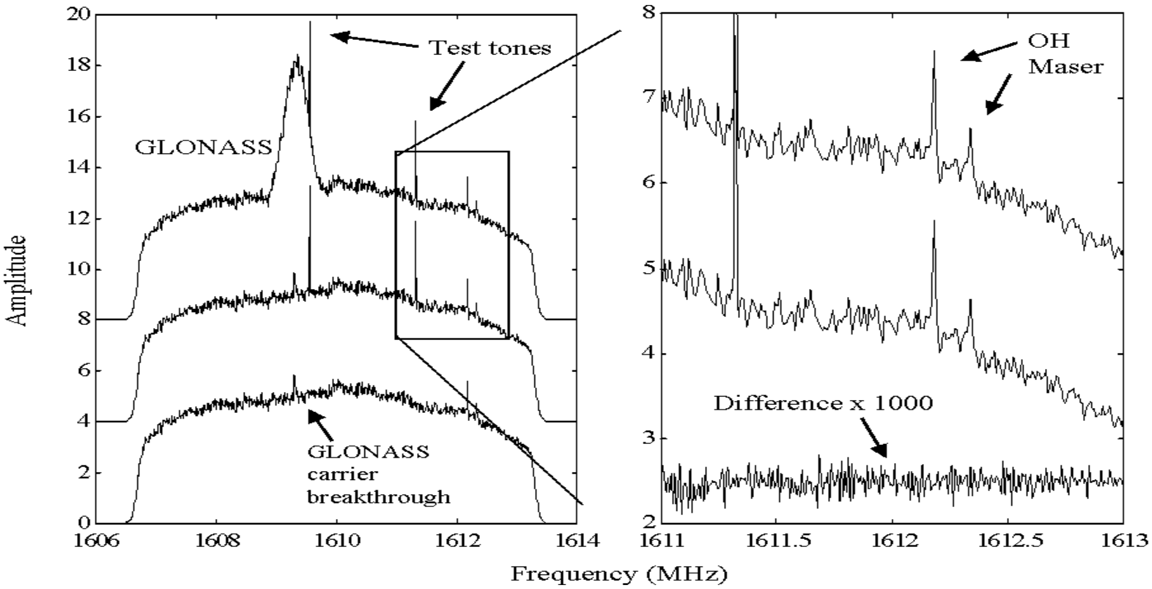

Figure 2: Left plot: top curve: raw data, OH maser source at 1612.3 MHz, test tones inserted (in software) at 1609.3 and 1611.3 MHz. Left plot: middle curve: data with GLONASS removed. Left plot: bottom curve: Test tone subtracted after cancellation. Right plot: blow up of region around OH source. The bottom curve shows the difference of the pre and post cancellation spectra multiplied by 1000. This indicates that this region of the spectrum is not changed by more than a few parts in 1000. (curves offset for clarity).

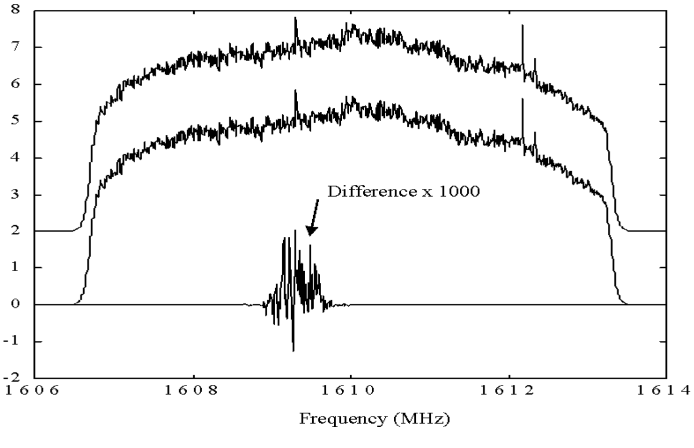

Figure 3: Effect of cancellation on signals coincident in frequency with GLONASS. Top curve: result of cancellation with band limited noise added before cancellation and subtracted again after cancellation. Middle curve: result of cancellation with no addition signals. Bottom curve: Difference of top and middle curves, multiplied by 1000. (Curves offset for clarity).

Note that both GPS and GLONASS have in-band secondary channels that are spread 10 times wider, and therefore have power spectral density about 10 times weaker. This secondary channel for GPS and GLONASS is much harder to deal with, because the PN codes are more complex and may not be completely known. We do need to find a way to mitigate against these signals, because they do still cause substantial problems for radio astronomy. An ideal approach may to be use a reference antenna, to obtain a clean copy of the wide band GLONASS signal without any astronomy signals present.

In addition to GLONASS and GPS, many other satellite and terrestrial communications systems have well-specified modulation and coding schemes. This opens up the possibility of removing these other classes of signals using digital signal processing. The techniques described here will be useful for some others, but not all.

The usefulness of the method presented here must ultimately be tested by conducting astronomy in the presence of GLONASS or GPS signals. Ideally the astronomy results with and without interference present would be indistinguishable. The use of recorded data and post processing is useful for demonstrating the method. But with processing currently running at 1/1000 real time the amount of astronomy that can be demonstrated is very limited. It is therefore desirable to explore the use of dedicated hardware to achieve real time processing of the signal. The hardware used to synthesise the base band GLONASS or GPS is comparatively simple and easy to emulate in an FPGA based systems. The main difficulty is the estimation of and tracking of signal phase and amplitude. This task is best left to software. Data needed to perform this task are correlations between the input and the current estimate of the interferer. If a reasonable initial estimate of the interferer has been found then very few correlations are needed to maintain tracking of carrier phase, carrier Doppler and code phase. The same hardware could also be used to generate these correlations. It should be possible to implement such a system for a few thousand dollars.

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