CANCELLATION OF TV INTERFERENCE

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Abstract

Radio frequency interference (RFI) is increasingly affecting radio astronomy research. A few years ago, active research to investigate the possibility of observing in the presence of interference using RFI mitigation techniques was initiated. This paper presents techniques to suppress interference due to TV transmission. A combination of noise-free modeling of the TV signals and adaptive filtering is used for suppressing the interference. The measured lower limit on RFI rejection using this technique on TV synchronization signal is about 12 dB. We also present a simple, but interesting, technique to suppress double sideband amplitude modulated interference.

Introduction

The need to find ways to deal with radio frequency interference (RFI) is becoming more urgent because: (1) increase in research interests outside the allocated frequency bands for radio astronomy and (2) growing technological resources which are becoming potential sources of radio frequency interference. Spectrum regulations alone cannot help future astronomy research. Active research was started a few years ago to investigate the possibility of doing radio astronomy observations in the presence of interference using RFI mitigation techniques. Several new mitigation techniques were developed[1 and references therein]. However, RFI rejection achieved in these techniques are not sufficient for sensitive radio astronomy observations. We feel that better rejection of RFI can be achieved by making use of the characteristics of the interfering signal. With this aim, we studied the characteristics of television (TV) signals and developed techniques to suppress interference due to these signals. The motivation to suppress television signals is that a considerable fraction of the radio frequency spectrum in the VHF (54 – 88 and 174 – 216 MHz) and the UHF (470 – 890 MHz) bands are allocated for TV transmission. These frequency ranges can be of potential importance for astronomy for a variety of observations. For example, the signature of reionization of the Universe is expected as a sharp step in the spectrum of the sky due to red-shifted HI 21-cm line emission anywhere in the frequency range $\sim$ 70 to 240 MHz[2]. Developing techniques to suppress TV signals are thus important for doing such observations in the presence of the interfering signals. This paper presents techniques to suppress synchronization signals in TV interference. The suppression of the picture part of TV interference will be discussed elsewhere.

Characteristics of TV signal and the data used for the work

The TV signal consists of picture and frame synchronization signals – referred to as composite video signal. The synchronization signals consist of horizontal and vertical synchronization and blanking pulses and 8 to 10 cycles of the 3.58 MHz color sub-carrier (‘color burst’). The picture part of the composite video signal consists of luminance and chrominance components. The chrominance components are quadrature modulated on a sub-carrier of frequency 3.58 MHz. The total bandwidth of the composite signal is 4.5 MHz. The composite video signal is then vestigial sideband (VSB) modulated on a carrier for transmission. The picture frame rate and other details of the composite video signal depend on the standard used for TV transmission. Here we use a data with NTSC standard.

The data for the present work were obtained from the output of a video player. The RF output of the video player was digitized and acquired using a commercial data acquisition system. The carrier frequency of the video player output was near 61.2 MHz and the data were sampled at 50 MHz rate with an 8 bit analog-to-digital converter. A contiguous set of 50 Mbytes of samples was stored in the computer hard disk. Interestingly, the video player output was double sideband (DSB) amplitude modulated. A VSB modulated signal was obtained by appropriately bandpass filtering the recorded data.

‘DSB suppressor’

Since the TV signal in the recorded data is DSB modulated, a technique to suppress DSB modulated signal is tried first. Consider an astronomically interested spectral feature (for example, a red-shifted HI feature) at the upper sideband

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[2] The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

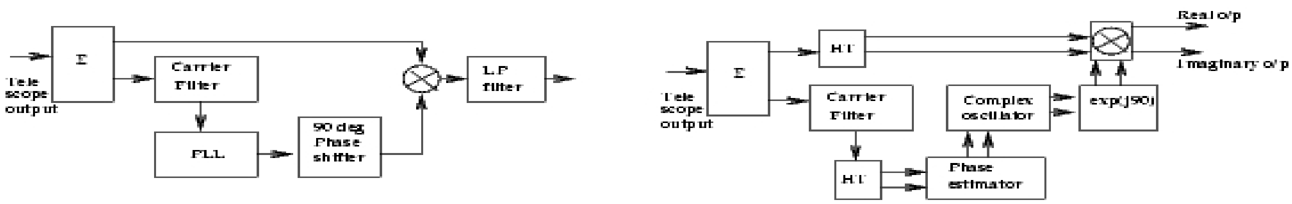

Figure 1: Simplified block diagrams of a ‘DSB suppressor’ (left) and its MATLAB implementation (right).

side of a DSB modulated interference. The output of the radio telescope can be written as

$$y(t) = I_c \cos(\omega_c t)\,[1 + I_m \cos(\omega_m t)] + n(t) \tag{1}$$

where, I_c & ω_c are the amplitude and angular frequency of the carrier signal, I_m & ω_m are the amplitude and angular frequency of the modulating signal and $n(t)$ is the astronomical signal. For simplicity, we consider only one Fourier component of the modulating signal. Multiplying $y(t)$ with $\sin(\omega_c t)$ gives

$$y'(t) = \frac{I_c}{2}\sin(2\omega_c t)\,[1 + I_m \cos(\omega_m t)] + n(t)\sin(\omega_c t) \tag{2}$$

Equation (2) shows that interfering signal will be present only at $2\omega_c$ and not at the baseband after multiplication. The astronomical signal $n(t)$ is essentially a Gaussian random noise. Multiplying $n(t)$ with $\sin(\omega_c t)$ therefore produces noise signals at $(\omega + \omega_c)$ and $(\omega - \omega_c)$ frequencies. The noise at $(\omega + \omega_c)$ will be contaminated by the interference. The noise at $(\omega - \omega_c)$ frequency is at the baseband free of any interference. However, at the baseband, the noise below ω_c folds back resulting in a degradation of the signal-to-noise ratio by 2 compared to the detection of the astronomical signal in single sideband mode in the absence of the interfering signal.

In reality, the phase of the carrier frequency changes with time due to a variety of reasons; for example propagation effects. This change has to be taken into account by the suppressor for effective RFI rejection. This is done by filtering the carrier signal from the output of the telescope and phase locking with an oscillator (see Fig. 1). The oscillator is then phase shifted by 90^o and mixed with the telescope output. The mixer output is low-pass filtered to get the desired astronomy signal. We implemented a variation of this technique in MATLAB, where a Hilbert transform of the telescope output is taken first to convert it into an analytic signal. This signal is then multiplied with a complex oscillator, which is phase locked to the carrier. The output of the multiplier is now a complex signal. The real part of the complex output (‘real’ output) is equivalent to that described above. The imaginary part of the complex output (‘imaginary’ output) is equivalent to the telescope output being multiplied by the oscillator signal with 0^o phase shift with respect to the carrier – essentially a coherent detector.

The performance of the ‘DSB suppressor’ is measured using the recorded data (see Fig. 2). The measured lower limit on the interference rejection is ~ 12 dB. The limitations of the ‘DSB suppressor’ are: (1) good suppression can be achieved only if both sidebands are of equal amplitude and their relative phase is as expected theoretically and (2) any non-DSB noise from the interfering source will degrade the system temperature of the radio telescope. From an observational point of view, the DSB suppressor is good for continuum observations. For spectroscopic observations, the spectral feature should be positioned either on the upper or lower side of the carrier frequency. Otherwise the spectral feature gets folded in frequency.

TV synchronization signal suppressor

As mentioned earlier, the NTSC TV transmission retains only about 1.25 MHz of the lower sideband. Since the spectral power of the synch and blanking pulses increase by more than 10 dB in the frequency range 0 to 1 MHz, the lower sideband in TV transmissions can be used to suppress this power using a ‘DSB suppressor’. Thus, after passing the VSB modulated TV signal through the ‘DSB suppressor’ the ‘real’ output consists of frequency components all above 1 MHz (see Fig. 2). These components include the color burst and the higher frequency components of the synch and blanking pulses in addition to the picture signal.

We first try to suppress the color burst in the ‘real’ output by subtracting a noise-free model of this signal. The color burst signal in the ‘imaginary’ output, which is now considered as a reference signal, is used to make the noise free model. The color burst is filtered out from the ‘imaginary’ output and used to synchronize the phase of an oscillator (see Fig. 3). This is done every horizontal synch period where a color burst is present. The oscillator output is then multiplied by a

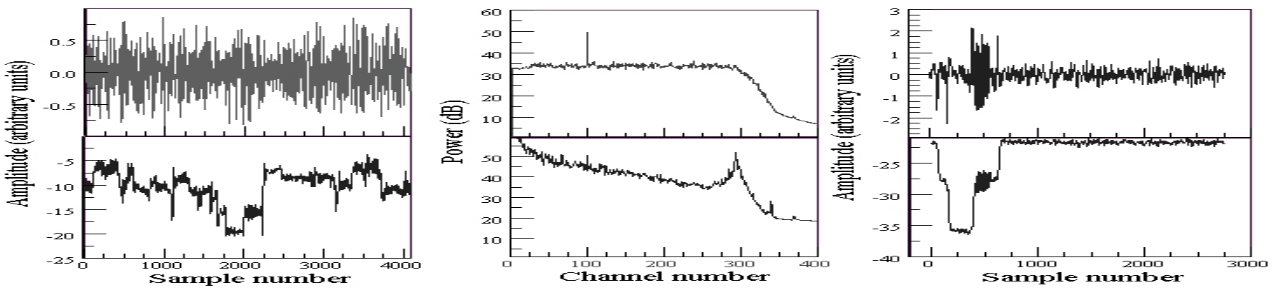

Figure 2: Time series of the 'real' (top-left) and 'imaginary' (bottom-left) outputs when the recorded signal is passed through the 'DSB suppressor'. The average spectra (average over 1.6 x 10^5 samples; spectral resolution 12 KHz) of the two outputs are shown in the top-middle and bottom-middle panels respectively. A narrow band signal near channel 100 (top-middle plot), which is a spurious pickup in the ADC and not related with the TV signal, is clearly detected. This pickup is also present in the bottom-middle plot but barely detected due to the interference. The 'real' (top-right) and 'imaginary' (bottom-right) output when a VSB modulated signal is passed through the DSB suppressor is shown on the right. No picture signal is added to the input signal for this plot.

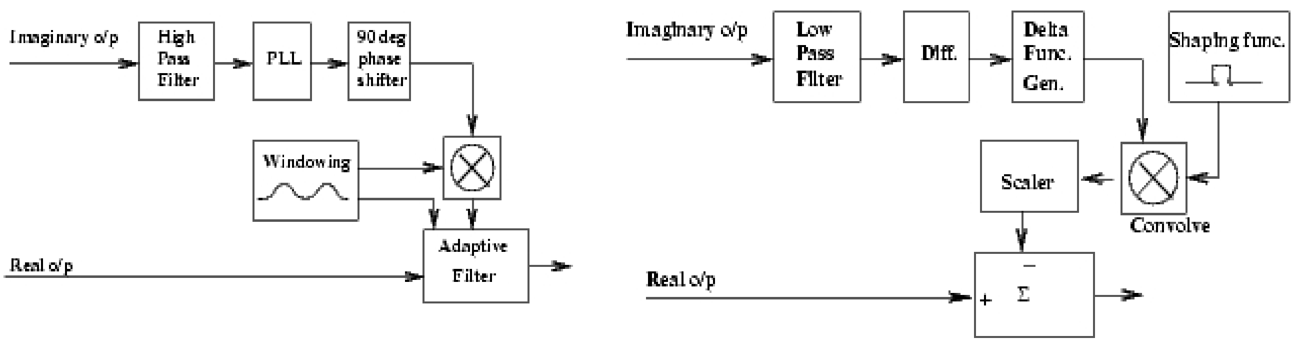

Figure 3: Block diagram of the color burst (left) and synch signal (right) suppressors.

'window' function to generate the model. The position of the window function in time relative to the horizontal synch signal is estimated in sample numbers and used for synchronizing. The shape of the window function is initially estimated from the reference signal itself and held constant. Subtracting a scaled version of the noise-free model, however, did not give good RFI rejection. Therefore the noise-free model is used as the reference signal for a three tap adaptive filter and the 'real' output is used as the second (main) signal for the filter. New filter weights are computed only during the time interval when the color burst amplitude is not changing rapidly. The need for the adaptive filter is because the shape of the weighting function is changing with time.

After passing the 'real' output through the 'color burst suppressor', what remains are the residuals of synch and blanking pulses. To get a noise-free model for the residual, the synch and blanking pulses from the 'imaginary' output are filtered out first for each horizontal synch period (see Fig. 3). Passing the derivatives of these pulses through a threshold detector gives the time of occurrence of these pulses. A 'delta' function model of the residuals is generated using this information. This model is then convolved with a shaping function, which is determined initially from the 'imaginary' output. The noise-free model is then scaled and subtracted from the 'real' output. The scaling factor is adjusted manually to get the best suppression. A typical output after passing the signal through the color burst and synch and blanking pulse suppressors is shown in Fig. 4.

The performance of the synchronization signal suppressors is tested using a data set with no picture information. An average spectrum of the interference is obtained from the samples where the synchronization signals are present in the 'real' output. To measure the achieved RFI rejection, an average spectrum after suppressing the interference is obtained from the same set of samples. These spectra are shown in Fig. 4. The averaging is done over 8.6 x 10^6 samples, which corresponds to about 160 msec. No residual of the color burst is present in the second average spectrum, which gives a lower limit on the interference rejection of 12 dB. The average spectrum of the output of the suppressors is compared with a reference spectrum, which is obtained from the samples with no picture and synchronization signals. The comparison shows good agreement between the reference and average spectrum. The total power in the average spectrum of the output

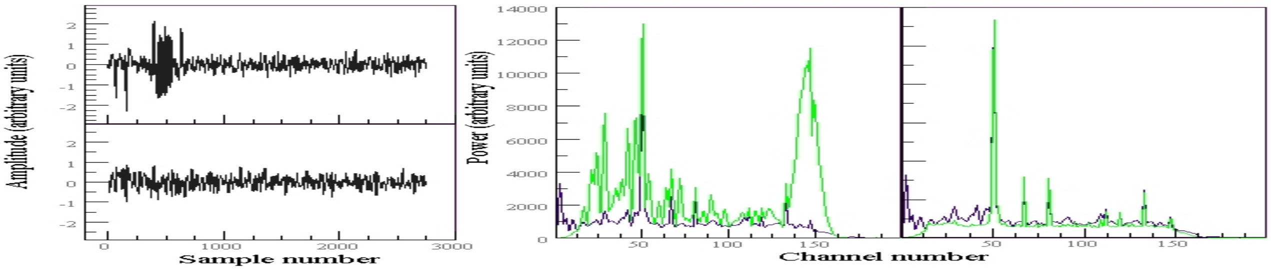

Figure 4: A typical time series of the 'real' output before (top-left) and after (bottom-left) passing through the color burst and synch and blanking pulse suppressors. The middle panel show the average spectra (spectral resolution 24 KHz) obtained from the samples where interference is present in the 'real' output (green) and that obtained from the same set of samples after passing the data through the color burst and synch and blanking pulse suppressors (black). The right panel shows the reference spectrum (green), which is obtained from the samples of the 'real' output that do not have picture or synch information. The spectrum shown in black in the right panel is same as that shown in the middle panel.

of the suppressors is, however, about 0.6 dB more than that of the reference spectrum. The excess power is mostly due to the inadequate suppression of the synch and blanking pulse residuals.

Discussion and Conclusion

In this paper, we present techniques to suppress interference due to TV synchronization signals. A combination of noise-free modeling of interfering signal and adaptive signal processing is used for canceling the interference. The measured lower limit on interference rejection obtained using this technique is $\sim$ 12 dB. The suppression technique uses a reference signal to generate the noise free model. Since the timing and shape of synchronization signals are well specified, a state model could be used to generate the signals. However, information from reference signal needs to be incorporated in the state model generation for better RFI rejection. This could be implemented as a Kalman type filter. The state model could give a first approximation to the timing of the synch signal, but the signal shape (eg. shape function) and a better timing (eg. for delta function generation) need to be derived from the reference signal. The scaling factor in the synch signal suppressor, which is currently held constant, should be changed adaptively using the reference data. Note that for short pulses, like the residual of the synch signal in the 'real' output, conventional adaptive algorithms cannot be used. We think a stochastic model for the picture component of the TV interference can be generated using the reference signal. This model could be then subtracted from the RFI contaminated data. This will be attempted in future. The effectiveness of suppression for different interference-to-noise-ratio of the reference signal also needs to be tested.

The TV synch signal suppressor also has the same limitations as the DSB suppressor (see Section 'DSB suppressor') as far as spectral line observations are concerned. Since a satisfactory noise free model of TV interference could be generated with the help of a reference signal, this model can be modulated on a carrier and subtracted from the data. Thus no mixing of the signal with a carrier is needed. The carrier phase and amplitude in the telescope output should be matched before subtraction.

Our experience with TV interference cancellation indicates that a single cancellation technique may not give adequate suppression of interference for radio astronomy purposes. This is suggested by the fact that a combination of adaptive cancellation and noise-free modeling were needed to get better suppression of TV signals. Also, cancellation techniques have to be 'tuned' based on the characteristics of the interfering signal to get better suppression. This is again evident, for example, in the case of TV synch signal suppression, where we restricted updating the weights of the adaptive filter.

Acknowledgment

I thank Rick Fisher and Rich Bradley for the many fruitful discussions I had with them while I worked on this project.

Reference

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