Automatic 0^+ Whistler Detector Deployed on board the TARANIS Satellite

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When it is launched in 2016, the TARANIS satellite, having a mission to study transient luminous events (TLEs), terrestrial gamma-ray flashes (TGFs), and other lightning-related phenomena, will carry an instrument developed by the Stanford VLF Group to automatically detect and classify 0^+ whistlers. The instrument operates by decimating the electric or magnetic field data input from 2 MHz down to a sampling frequency of 31.25 kHz, constructing spectrograms, and looking for the distinctive dispersive shape that a 0^+ whistler has. Data from the instrument, which is limited to approximately 6 kbits/second, will be useful specifically in drawing comparisons between lightning that do and do not cause TLEs and TGFs and more generally as a supplement to any other study on the occurrence of global lightning.

1 Introduction

Lightning discharges radiate broadband electromagnetic pulses known as sferics. The surface of the Earth and the ionosphere form a waveguide through which sferics efficiently propagate over long distances. A small fraction of the sferic energy escapes the waveguide and travels upward in the whistler mode enabled by Earth's magnetic field through the ionosphere [1], and the resulting waves, known as whistlers (specifically, 0^+ or fractional hop whistlers in this case), have been observed in low Earth orbit at lateral distances of up to 1500 km from their parent lightning stroke [2]. In addition to the electromagnetic radiation emitted, lightning has been shown to cause a number of optical phenomena directly above lightning known generally as transient luminous events (TLEs), with sprites, elves, and jets being specific examples. Moreover, bursts of gamma rays from the Earth known as terrestrial gamma-ray flashes (TGFs) have been observed to coincide with lightning and are possibly related to TLEs.

The TARANIS satellite, expected to be launched at the end of 2016, has been commissioned by CNES to provide a single platform for the study of a number of lightning related phenomena, including TLEs and TGFs in particular, over a mission lifetime of two to three years. It is important to note that not all lightning generates TLEs or TGFs, and TLEs and TGFs often have widely different measurable properties (see, for example, [3] for the case of sprites). Lightning itself is also highly variable, and measurement of a lightning stroke's electromagnetic radiation can reveal important information about the lightning's properties. While TARANIS will collect high resolution data upon detecting a TLE or TGF, it is also desirable to have data on the electromagnetic emissions from lightning that do not cause TLEs or TGFs.

Therefore, TARANIS will carry an automatic 0^+ whistler detector, also called the sferic detector (SD), that will operate continuously and characterize the 0^+ whistlers measured on the satellite. In particular, the Stanford VLF Group has devised an algorithm to identify 0^+ whistlers in electromagnetic field measurements on a low earth orbiting satellite, and implemented the design on an FPGA to be integrated into the TARANIS hardware. Because the bandwidth allotted to the sferic detector is about 6 kbits/second, the instrument will toggle between four different output modes that will provide less and less information for each 0^+ whistler as the occurrence rate increases. Not only will data from the sferic detector be useful in providing context to TARANIS's primary mission of studying TLEs and TGFs as previously described, it will likely find application as well in comparisons with global lightning detection networks. Furthermore, data from the instrument could be used to measure the amount of lightning energy input into the magnetosphere.

2 Algorithm Details

It can be shown from the Appleton-Hartree equation that the instantaneous frequency of a whistler is inversely proportional to the square of the time after the whistler is first recorded [4, ch. 2]. That is, when plotted as a spectrogram, the whistler should follow a shape given by

$$t = \frac{D}{\sqrt{f}} \tag{1}$$

where D, known as the dispersion constant of the whistler, represents the degree to which the whistler

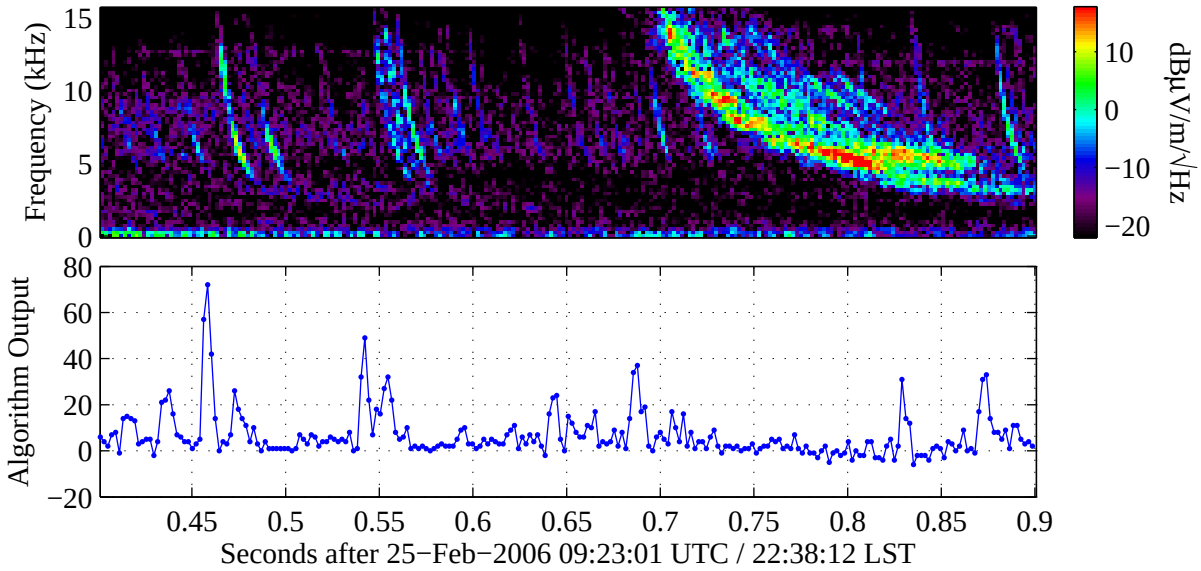

Figure 1: (top) Spectrogram of electric field data from DEMETER resampled to the the sampling frequency used by the automatic 0^+ whistler detector on board TARANIS. (bottom) Algorithm output when applied to the spectrogram above.

is dispersed. The SD detects 0^+ whistlers by making spectrograms of either the electric or magnetic fields as measured by the satellite and looking for shapes in those spectrograms given by (1). First, the analog wave field data are digitzed and input to the FPGA. Next, the data are decimated by a factor of 64, resulting in a sampling frequency of 31.25 kHz, and then spectrograms are computed. Finally, the spectrograms are input into the detection algorithm, and when the algorithm detects a 0^+ whistler, information on the event is output to the an external FIFO memory that is uploaded to the ground.

The algorithm decides whether or not a particular spectrogram is a 0^+ whistler by first normalizing the spectrograms by the background noise, which is done by taking the mean and standard deviation of the previous 16 spectrogram bins for each frequency and checking whether or not the bins in the current spectrogram exceed the computed mean by at least N_σ standard deviations, where N_σ is adjustable with the input command provided at the beginning of each half-orbit. Then, the SD computes the cross-correlation of the spectrogram with a matrix with 1 in pixels that follow a curve given by (1), -1 immediately surrounding that curve, and 0 elsewhere. Because the dispersion of the 0^+ whistlers is known *a priori*, a total of 8 different matrices are compared against each spectrogram, and the maximum across those 8 computations is used. Finally, a spectrogram is considered to be a 0^+ whistler if the result is a local maximum and exceeds an adjustable threshold.

Figure 1 shows the algorithm applied to an electric field measurement from the DEMETER satellite, which had a similar orbit to TARANIS's. Note the peaks in the algorithm output on the bottom plot coincide with the 0^+ whistlers in the spectrogram above. We have found that peaks in the algorithm output greater than or equal to about 20 are sufficient to indicate the presence of a 0^+ whistler in the corresponding spectrogram. There is also a whistler with dispersion larger than a 0^+ whistler, and the algorithm correctly does not show a peak for it; however, the whistler's presence does not prevent the 0^+ whistler at about 0.84 seconds from being identified.

3 References

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