The Bruny Island Radio Spectrometer

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Abstract

A radio spectrometer has been built on Bruny Island, south of Hobart, for the study of solar bursts in the rarely observed frequency range from 3 to 20 MHz. This spectrometer is an adaptive device that employs digital techniques to avoid most of the strong terrestrial interference prevalent in this frequency range. The residual interference that cannot be avoided is excised during off-line processing. As a result, successful observations are made down to the minimum frequency that can propagate through the ionosphere to the antenna. This minimum frequency depends upon the zenith distance of the Sun and it is usually between 4 and 8 MHz.

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1 Introduction

There exist a number of scientific questions to be addressed by solar observations in the 2 to 20 MHz frequency range. Energy releases, low in the solar atmosphere, produce coronal shock waves that generate coronal type II radio bursts. Ground-based observations have shown that these bursts usually die away in the 15 to 30 MHz range. Similar bursts are observed from spacecraft at frequencies below 2 MHz as interplanetary (IP) type II events and IP type II bursts are known to be generated by the IP shock waves associated with coronal mass ejections (CMEs). CMEs can have profound geophysical effects and it is of great importance to understand the physics of their origin and propagation. One key question is whether or not the IP shock waves are extensions of the coronal shock waves (Cane 1997). The most direct way to answer this question would be to observe a coronal type II burst that continued through the 20 to 2 MHz range to become an IP type II event, or to show that this does not occur. However, for reasons discussed below, this frequency range is virtually unobserved. Other questions to be addressed through observations in the 2 to 20 MHz range include the connection between shock associated (SA) events (Cane et al 1981) observed in the IP medium and the herringbone structures that are observed in coronal type II bursts above 20 MHz. There appears to be a time correlation between these phenomena, but no direct connection has been made because of the frequency gap in the observations. SA events are of particular interest because they are well correlated with major proton events in the Earth's environment (Cane and Stone 1984), (Kahler et al 1986).

Radio observations from the surface of the Earth at frequencies below 20 MHz are very difficult in the daytime because of high levels of terrestrial interference. Above 20 MHz the interfering signals are normally far enough apart in frequency that solar bursts can be observed between them but below this frequency interfering signals virtually fill the entire spectrum. This is because interfering signals in this frequency range propagate world-wide. Wide-band, impulsive emissions from lightening strokes also propagate over long distances at frequencies below 20 MHz and are another troublesome source of interference. Because of these problems, very few ground-based observations are attempted.

Observations with space-borne systems are also uncommon in the 2 to 20 MHz frequency range. Below the ionospheric critical frequency for vertical propagation (f_oF_2) the ionosphere will normally shield spacecraft from Earth-generated interference. Daytime values of f_oF_2 are 3 MHz or so, and above this frequency interference can break through the ionosphere to greatly disturb observations made from spacecraft located near the Earth. The problem is diminished by locating the spacecraft at a large distance from Earth, such as at the inner Lagrangian point, L1, but telemetry restrictions then limit the amount of spectral information that can be conveniently returned to Earth. For example, the WAVES experiment (Bougeret et al 1995) on the WIND spacecraft, that is located at L1, observes up to 14 MHz with limited spectral and temporal resolution.

Tasmania is known to have unusually low daytime ionospheric densities, which mitigates the problem of over-the-horizon interference from distant sources and allows solar bursts to propagate to the Earth's surface at quite low frequencies. On Bruny Island, an island off the southeast coast of Tasmania, locally generated interference is uncommon. Employing this good location from which to explore the possibilities for decametric solar observations, the Bruny Island Radio Spectrometer (BIRS) has been built. BIRS is an adaptive spectrometer designed to make use of modern digital techniques for the mitigation of terrestrial interference. The system is designed primarily for solar observations but it is also usable for Jupiter observing and for monitoring any other transient decametric radio sources. At the present time, it is adjusted for swept-frequency observations in the 3 to 37 MHz band. The upper portion of this band overlaps that covered by the Culgoora Radiospectrograph (Presage et al 1994), which is at nearly the same longitude, making data comparison convenient. [1] It has also been found useful to make detailed comparisons between BIRS and WAVES observations of the same bursts to delineate structure requiring high temporal and spectral resolution and to compare the flux density calibrations of the two instruments.

2 The Antenna

The geographic coordinates of the antenna are: Latitude 42.370° S, Longitude 147.218° E. As shown in Figure 1, the antenna is a 23 element log-periodic structure fixed in position and pointed to the celestial equator near the meridian. Its response pattern is broad enough to cover the whole ecliptic and to have reasonable hour angle coverage. The antenna's directivity is low, about 6 db/isotropic; its horizontal, E-plane pattern is about 90° wide and its vertical, H-plane pattern is more than 100° wide. The antenna has an opening angle of 90° at its apex, and a scale factor of 0.89. The longest dipole is 50.0m and the largest spacing between dipoles is 2.75m. These values decrease geometrically by the scale factor to the shortest, 3.05m, dipole. The height of the tower which supports the apex of the antenna is 21.4m. The geometrical bandwidth of the structure is 3 to 45 MHz but, since the radiating region spans an appreciable length of the structure at any single frequency, the RF bandwidth of the system is 3.3 to 40.9 MHz. Interference effects between

[1] The original Culgoora spectrograph operated down to 8 MHz but did not produce very much useful data in the lower part of its frequency range. When the spectrograph was rebuilt in 1992 the lower limit of its operating range was changed to 18 MHz.

the direct ray and the ray reflected from the ground, i.e. Lloyd's mirror effects, are observed, but the reception of the reflected ray is diminished by 5 to 20 db because of the antenna's directivity. These effects are calculated and partially removed in the data processing. The instrument is normally operated from $22^h\,00^m$ UT to $06^h\,30^m$ UT each day although the directivity of the fixed antenna limits the observing period to about six hours with good sensitivity.

3 Preamplification

A preamplifier, located at the base of the tower, employs a small, high dynamic range, monolithic amplifier with a noise figure of 3.6 db. This wide-band (1-1000 MHz) device is protected with filters to restrict its bandwidth to 3 to 45 MHz. Its gain is kept low (13 db) to avoid any possibility of overloading on strong interference. However, the gain is sufficient to overcome line losses between the antenna and the laboratory.

Before preamplification the antenna signals pass through a 10 db directional coupler for injection of calibrations. After preamplification the signals are transmitted to the laboratory through 125m of buried coaxial cable. In the laboratory a slope filter attenuates the signals below 18 MHz by 20 db. This avoids any possibility of overloading by strong, low frequency interference while the noise generated by the galactic background radiation still dominates the system noise. After 25 db of amplification in a high power amplifier, the signals are presented to a spectrum analyzer.

4 Spectrum Analysis

The signal spectrum is analyzed with a commercial spectrum analyzer that is controlled by a 386 PC. The analyzer operates from 3 to 37 MHz with an instantaneous bandwidth of 10 kHz. The spectrum is sampled at 128 points every three seconds. The detected output signal from the analyzer is linearly integrated at each frequency step for about 20 ms, then A/D converted and sent to the PC that controls the system and acquires the data. Every 30 minutes the system makes a full scan of the spectrum, from 3 to 37 MHz, with 10 kHz resolution. It then finds any 'holes' between interference transmissions in each 265.6 kHz-wide section of the spectrum and, for the next 30 minutes, it observes only in these 128 'holes'. After 30 minutes the system re-adapts itself to the constantly changing interference environment. The data are displayed in frequency-time coordinates on a monitor with signal intensity on the colour axis. The data are also written to disk every 30 minutes and, at the end of each day, they are compressed and automatically transferred to tape for off-line processing and long-term storage.

Without these adaptive procedures to avoid most of the interference, observations below 20 MHz would be practically impossible and, in spite of these procedures, high interference levels from over-the-horizon sources remain. In addition to man- made interference, wide-band spikes caused by lightening, both local and distant, are common. An off-line filtering program has been developed which reduces the response of the system to steady narrow-band signals and to instantaneous wide-band spikes. As illustrated in Figure 2, the output of this filtering program produces records of solar emissions that are virtually interference-free.

5 Data Description and Calibration

The system began operation in mid-1994. Since the level of solar activity has been low, only about a dozen type II bursts have been observed thus far. All of them have stopped within the observed frequency range. Hundreds of type III bursts have been observed from 37 MHz down to the ionospheric cut-off. This cut-off is usually 4 to 8 MHz but the cut-off frequency depends strongly upon the zenith distance of the Sun. The 3 MHz limit to the observed frequency range ensures that any emission that can possibly get through the ionosphere in daytime will be observed. When the cut-off has been below 3 MHz late at night, some bursts, believed to be from Jupiter, have been observed down to the 3 MHz limit of observing range.

The response of the receiving system has been carefully calibrated with a thermionic diode and the antenna gain has been estimated theoretically. The polar galactic background spectrum has been observed late at night and this observed galactic spectrum agrees well with calibrated, fixed-frequency measurements made by other observers. Appreciable ionospheric absorption occurs below 15 MHz in daytime. In order to estimate and correct for this effect, during data analysis an apparent galactic background spectrum is determined for a time adjacent to the solar burst. This apparent spectrum is then compared with an archived, absorption- free spectrum that was previously observed at the same Right Ascension late at night, and the amount of daytime absorption is then estimated.

6 Summary

A radio spectrometer has been designed and constructed for ground-based solar observations in the poorly covered frequency range below 20 MHz. Techniques have been developed to avoid and excise the abundant interfering signals prevalent in this frequency range. The system scans the radio spectrum from 3 to 37 MHz and provides nearly interference-free records of solar radio bursts with three second time resolution, 268 kHz frequency resolution, and a well-calibrated flux density scale. The instrument is normally operated from $22^h\,00^m$ UT to $06^h\,30^m$ UT each day.

Figure Captions

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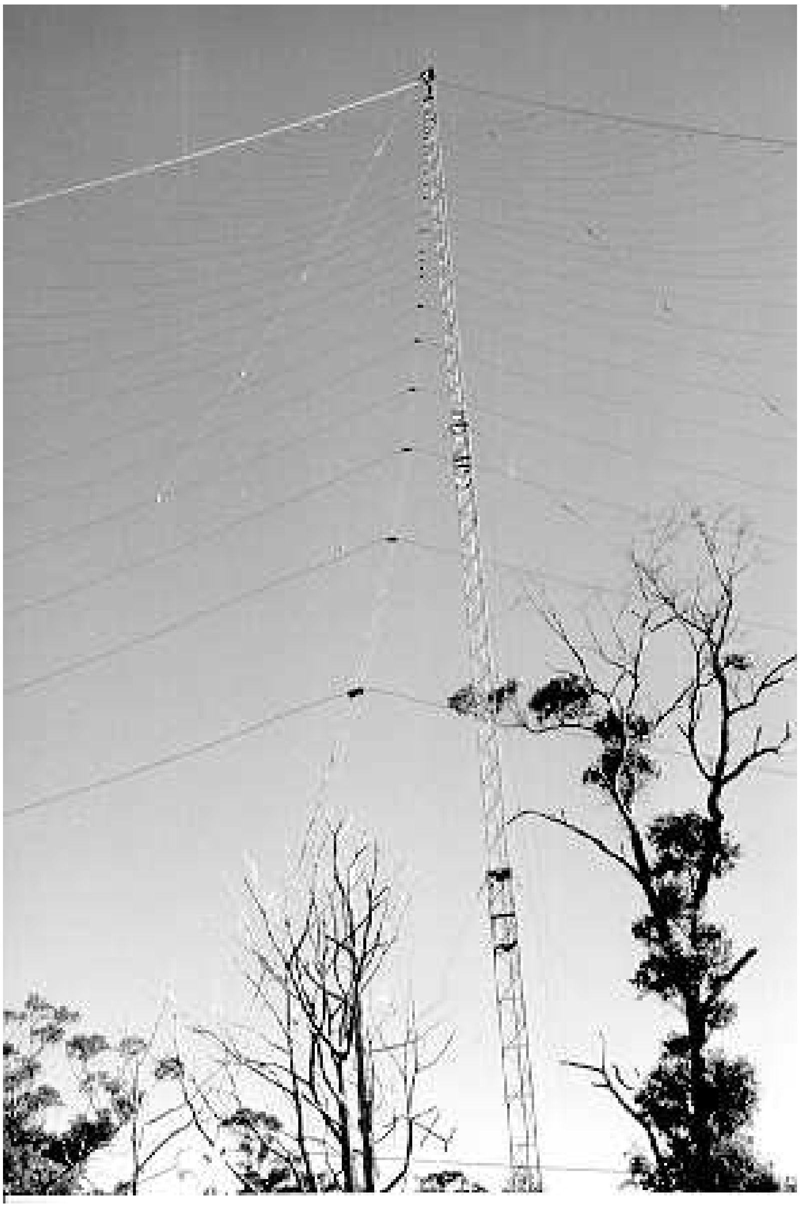

Figure 1: A photograph of the antenna.

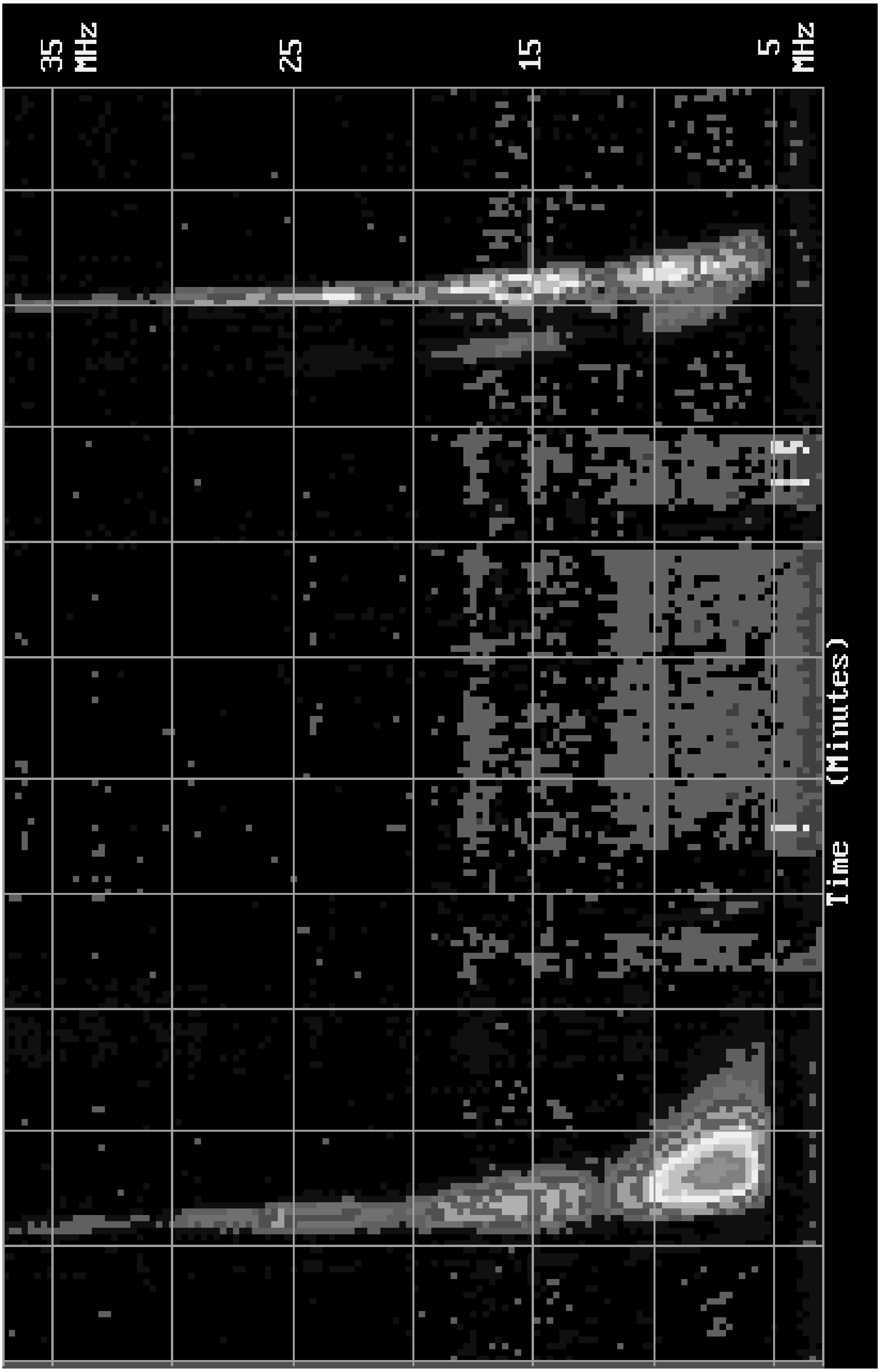

Figure 2: A display of two solar Type III bursts that extend (with differing spectra) down to 5 MHz where they are cut off sharply by the ionosphere. Each square represents 1 minute in time and 5 MHz in frequency. Destructive interference effects between the direct and ground-reflected ray are observed at 12.5 MHz and at 31 Mhz. The original display is in colour; this is a black and white adaptation.