Proposal to the National Radio Astronomy Observatory

Upgrade of the
Green Bank Solar Radio Burst Spectrometer

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1 Project Summary

The Green Bank Solar Radio Burst Spectrometer (SRBS) is a broadband swept-frequency spectrometer currently operating from 17 MHz to 1050 MHz. It utilizes a standalone Erickson dipole (17-70 MHz), and two log-periodic systems (80-300 and 250-1050 MHz) mounted on the 45 ft telescope. The data are acquired and archived daily and are available for inspection and download by the wider community through a convenient web interface (http://gbsrbs.nrao.edu). The instrument development was carried out by the NRAO in collaboration with the NRL, UMd, and ETH/Zürich. The project was funded by the NSF MRI program, funding that has now ended. To ensure continuing operations, a proposal is in preparation for submission to the NSF/ATM solar-terrestrial program requesting 3 yrs funding. It will be submitted in May 2007. Enhanced users support will become available through continuing development of the data archive and web-based tools, work that is being supported by an SR&T grant from NASA’s Living With a Star (LWS) program to UMd.

While the SRBS system is complete and functioning well, it is desirable to enhance its scientific capabilities with several upgrades. These are:

1. Replace the Erickson dipole and extend frequency coverage down to 10 MHz
2. Replace the high frequency log-periodic feed with a sinuous feed extending to 3 GHz
3. Implement dual-circular polarization observing
4. Implement a frequency agile digital receiver

The scientific returns of these upgrades include:

1. Improved low frequency sky coverage and sensitivity, and overlap with the STEREO WAVES experiment, a pair of satellites observing from a few kHz to 16 MHz
2. Improved coverage of decimetric radio bursts, key to impulsive energy release
3. Polarization measurements to constrain the coronal magnetic field.
4. The availability of high time- and high spectral-resolution measurements in parallel with daily patrol measurements.

The cost of these upgrades is $68k. In the event that only part of the proposal can be funded, we prioritize the upgrades in Section 5.

2 Science Background

Solar activity and the drivers of space weather, including flares and coronal mass ejections (CMEs), originate in the solar corona. Electrons accelerated by, or associated with, these phenomena radiate effectively at the local electron plasma frequency (plasma radiation), or its harmonic. The coronal plasma density at the sites of these phenomena correspond to plasma frequencies of ~10 MHz to ~2 GHz. Radio spectroscopic observations of these emissions therefore provide a convenient diagnostic of physical processes at various heights in the corona.
A particularly effective technique is *dynamic spectroscopy*, where a time series of spectra are obtained over a large bandwidth.

As disturbances such as CMEs propagate from the Sun’s corona into the interplanetary medium, the wavelength of associated radio emissions increases to hectometer and kilometer wavelengths, corresponding to frequencies <10 MHz. These frequencies lie below the cutoff frequency imposed by the Earth’s ionosphere and are consequently inaccessible to ground-based instrumentation. Instead, spectrometers on space-based platforms – e.g., the WIND/WAVES instrument (Bougeret et al. 1995) and, more recently, the STEREO/WAVES experiment (Kaiser 2005) – are required to observe radio emission from disturbances in the outer corona and the interplanetary medium. Ideally, the solar and space weather communities have access to a combination of ground- and space-based spectrometers that provide a comprehensive record of radio emission from the low corona to 1 AU. SRBS meets an important part of this requirement.

### 2.1 Types of Radio Bursts

The identification and classification of radio bursts dates back to the founding of radio astronomy as a distinct observational discipline in the late-1940s and 1950s. These are radio bursts of types I through V (e.g., McLean & Labrum 1985), first identified with instrumentation operating at meter and decameter wavelengths. While radio bursts of type I are of interest in their own right, most attention has been directed toward radio bursts of types II/IV (associated with gradual flares and CMEs) and types III/V (associated with impulsive flares). A composite dynamic spectrum is shown in Figure 1 illustrating radio bursts of type II, III, and IV observed from the ground and in space.

Type II and type III radio bursts emit via the plasma emission mechanism. Plasma waves are excited by non-equilibrium distributions of electrons, such as beam or loss-cone distributions of nonthermal electrons. The plasma waves then scatter from low-frequency waves or coalesce to produce radio waves at the fundamental and/or harmonic of the local electron plasma frequency. Type II and type III radio bursts occur in both the solar corona and the interplanetary medium, while type IV radio bursts are a coronal phenomenon involving synchrotron radiation from trapped electrons.

Type II radio are tracers of MHD shocks in the corona and the interplanetary medium. They appear as relatively narrowband lanes or patches of emission at the fundamental and/or harmonic of the electron plasma frequency. Coronal type II radio bursts have a typical duration of 5-15 min and drift slowly to lower frequencies with time at a rate that is usually <1 MHz s⁻¹. For typical density gradients in the corona these frequency drift rates correspond to speeds of order 1000 km s⁻¹ that are several times the Alfvén speed in the corona, i.e., super-Alfvénic shock speeds. Type IV radio bursts are broadband continuum bursts that usually occur in association with type II radio bursts, following the type II and persisting for tens of minutes. They typically start at frequencies <150 MHz but can appear as high as 500 MHz.

Type III radio bursts are fast-drift bursts that are the result of electron beams propagating in the corona or interplanetary medium at speeds of ~0.15-0.3c. As they propagate outwards (inwards) in the solar corona they, too, drift to lower (higher) frequencies as a result of the changing
density. Start frequencies of type III bursts occur in the decimeter to decameter wavelength range and show a typical drift rate of $-0.01v_{\text{MHz}}^{1.84}$ MHz s$^{-1}$. Meter and decameter wavelength type IIIIs can show harmonic structure.

![Composite Spectrum](image)

**Figure 1** An example of a composite spectrum using data from the Culgoora spectrometer (18-1800 MHz) and the space-based WIND/WAVES instrument (<14 MHz), originating from the low corona to more than 70 solar radii. Type III radio bursts commence in association with a flare at 5:55 UT; a type II radio burst is clearly visible between roughly 10-50 MHz from approximately 6:00-6:18 UT. Type III radio bursts that appear to emanate from the type II radio burst, notably from 6:05-6:18 UT, are referred to as SA type III bursts. Type IV emission is seen between ~50-200 MHz for times later than 6:07 UT (from Dulk et al. 2000).

### 2.2 Radio Signatures of Coronal Energy Release

Progress has been made in recent years on identifying tracers of energy release in the solar corona (see Bastian, Benz, & Gary 1998 for a review). Decimetric type III bursts (type IIIdm) occur most commonly in the 400-800 MHz range but have been known to occur at both lower and much higher frequencies. This frequency range corresponds to densities of $2-8 \times 10^9$ cm$^{-3}$,
i.e., the densities where energy release in flares is thought to take place. Multitudes of bursts are released during the course of the impulsive phase of a flare (Figure 2). Type IIIdm bursts are more numerous than metric type IIIIs and show positive or negative frequency drifts, indicating upward or downward motion in the corona. Some events show positive and negative drifts, indicating the presence of bi-directional electron beams. Outward propagating electron beams sometimes show a reversal in frequency drift (type U bursts), indicating that the beam is propagating along a closed magnetic loop. Type IIIdm bursts are believed to be intimately related to energy release via magnetic reconnection.

Figure 2 Example of type IIIdm bursts during the impulsive phase of a flare. Note that ~100 are visible and that they drift from low to high frequencies with time, indicating that they are the result of downward-directed electron beams (from Isliker & Benz 1994).

Metric type III bursts first appear between 200-1000 MHz and drift to lower frequencies implying electron beams propagating outward in the corona. Those which are confined to coronal magnetic loops may produce a type U burst. Those which escape the corona into the interplanetary medium continue to drift to lower frequencies – decimeter to hectometer to kilometer wavelengths where they can be detected by space-based spectrometers – as they propagate to 1 AU. Discrete metric type IIIIs often merge into a smaller number of interplanetary type IIIIs.

A second type of radio emission thought to be associated with coronal energy release is the narrowband spike burst (e.g., Benz 1986). These are short-lived (<0.1 s), narrowband (~1%) bursts that occur at meter and decimeter wavelengths. Metric spikes are associated with metric type III radio bursts about 30% of the time but in contrast to associated type III bursts, they are characterized by a high degree of circular polarization. They are believed to be associated with energy release but the details remain an active research area.
Finally, certain radio precursors may also signal energy release in association with the early stages of acceleration and launch of a CME (Klassen et al. 1999, Bastian et al. 2001). Radio spectroscopy at decimeter and meter wavelengths therefore offers unique insights into coronal energy release associated with impulsive flares and coronal mass ejections.

2.3 Radio Signatures of Coronal and Interplanetary Shocks

It is generally accepted that type II radio bursts are a tracer of fast MHD shocks. The shocks that produce coronal type II radio bursts may be driven by fast ejecta, by a blast wave, or by a CME. The relationship between these shocks, their radio-spectroscopic signature, and other phenomena of interest such as Moreton waves and “EIT waves” remains a matter of considerable controversy. Another issue of interest is radio precursors associated with type II radio bursts and CMEs. A study by Klassen et al. (1999) found a possible link between type II radio bursts and earlier activity in underlying coronal loops. This activity is manifested as narrowband fast-drift bursts or pulsations at frequencies corresponding to the extrapolated frequency of the subsequent type II radio burst. Also of interest are a variety of faint, drifting continua that may be CME precursors (e.g., Aurass et al. 1999) or are associated with the CME itself, as verified by direct imaging (Bastian et al. 2001).

While progress has been made in understanding the sources and nature of coronal and interplanetary shocks, many questions remain unresolved: what are the necessary and sufficient conditions for production of a coronal type II radio burst? How are CMEs related to Moreton waves and “EIT waves”? Do certain coronal type II radio bursts represent nascent IP shocks? To what extent can type II radio bursts be used to infer or constrain the trajectory of a CME? Much work remains before the conditions for, and properties of, flare-driven and CME-driven shocks can be reliably deduced from the data available and used to robustly predict the nature of disturbances propagating out into the interplanetary medium. However, it is clear that these studies require radio dynamic spectra from 15 MHz up to at least 500 MHz.

2.4 Radio Signatures of Particle Acceleration

Particle acceleration in flares and shocks has been of fundamental interest for many years. Of particular relevance to space weather studies are solar energetic particle (SEP) events. During the past ~15 years, SEP events have been classified as impulsive or gradual events (e.g., Reames 1988) based on the properties of the associated soft X-ray flare, correlations with radio bursts of type III/V (impulsive) or types II/IV (gradual), abundances and charge states of the energetic particles, and the presence or absence of a CME. Impulsive SEP events were believed to originate in solar flares while the energetic particles in gradual SEP events were thought to be accelerated in CME-driven coronal and/or interplanetary shocks. Since the largest SEP events are gradual events in this scheme, interest in particle acceleration by CME-driven shocks has remained high.

Several analyses of radio spectroscopic and energetic particle data have called this simple picture into question (e.g., Klein & Trottet 2001), arguing that sustained particle acceleration can, and does, occur in the mid-corona. At the very least, the impulsive/gradual paradigm requires modification in recognition of complicating realities. Detailed observations of abundances and
charge states by the Advanced Composition Explore suggest that SEP events show a far richer variation in charge states of iron than the simple impulsive/gradual picture would imply (Möbius et al. 2002).

Many questions remain open: what are the relative roles of flares and CMEs in the production of SEPs? To what degree do coronal shocks accelerate particles? Do flares and/or coronal shocks provide a seed population for CME-driven shocks? Do CME-driven shocks pick up and accelerate residual flare-heated particles from previous events? Addressing these questions requires that we be able to investigate the radio bursts associated with CMEs and SEP events, those of type II/IV and type III/V, requiring both ground- and space-based spectrometers.

3 SRBS in Context

With the deployment of GB/SRBS an important gap in radio spectroscopic coverage has been filled. Figure 3 summarizes the present state of ground based solar-dedicated spectroscopic instrumentation around the world. Asterisks mark the locations of spectrometers. Vertical lines indicate the frequency range supported by a given observatory using the scale on the frequency axis to the left. Solid blue lines indicate those observatories whose data is easily accessible through the web. The dashed red lines indicate those locations for which this is not the case (the USAF/RSTN network). The heavy solid green line indicates the location and range of SRBS, showing that it is the sole source of broadband coverage in the Americas.

Figure 3 A map showing the locations of observatories with solar radio spectrometers (asterisks). The vertical lines refer to axis to the left, which indicates the frequency range observed by each instrument. Those where the data are easily accessible through the web are indicated in blue. Those where this is not the case are indicated in red. SRBS is indicated in green.
SRBS is a complete, functioning, and successful system. The data are being routinely used in multi-band coronal and space weather studies, as evidenced by several papers presented at the June 2006 AAS/SPD Meeting in Durham, NH. It is also producing new science. An example is shown in Figure 4, which shows one of the highest frequency type II (shock driven) radio bursts ever recorded and one of the few with joint imaging (from the Nançay Radioheliograph in France). It is challenging a number of ideas related to the shock drivers responsible for coronal type II burst (White et al. 2007).

![Figure 4](image)

**Figure 4** A dynamic spectrum from the SRBS showing one of the highest frequency shock-driven type II radio bursts ever observed. Two harmonic lanes are clearly visible, as are “split bands”. It is discussed in detail by White et al (2007).

A proposal to the Air Force Office of Space Research (PI, E. Cliver, USAF/Hanscom) has been prepared that will perform a statistical study of type II radio bursts observed by SRBS and chromospheric Moreton waves observed by the ISOON network in Hα.

SRBS is therefore fulfilling its role as an important radio asset in support of solar and space weather physics and their associated scientific communities. However, there are several upgrades that would make SRBS and even more powerful instrument.
4 SRBS Upgrades and Justification

In this section SRBS upgrades are outlined and the science justification is briefly summarized.

Replace the Low Frequency Antenna and high frequency feed

The Erickson dipole antenna currently supports a frequency range of approximately 17-70 MHz. The beam performance is less than optimum for this broad frequency range: it supports only one polarization and has a highly non-uniform beam on the sky, actually evolving from a single lobe to a double lobe from low to high frequencies. We wish to replace the Erickson dipole with a dual-polarization fat dipole operating from 10-25 MHz, and three sleeve dipole antennas to cover 25-85 MHz. The sleeve dipole design provides dual-polarization performance and a uniform beam. They were originally developed for the PAPER array and are well understood. The desire to push to as low a frequency as possible is to overlap with the recently launched STEREO/WAVES experiment, which provides frequency coverage on two spacecraft from 16 MHz down to a few kHz.

A wide bandwidth feed amplifier combination to meet FASR-B requirements is currently under development at the CDL (left). A prototype covering the 0.5 - 3.0 GHz band was fabricated and has demonstrated excellent performance in terms of controlled beam pattern, terminal impedance, and confirmation of proper noise modeling over the band. A more suitable low noise active balun that will be integrated directly with the feed is also under development. We propose here to fabricate a rugged version of this feed / amplifier system for use directly with GB/SRBS.

Support Dual-Circular Polarization Measurements

Radio bursts in the solar corona can be moderately circularly polarized. They are not linearly polarized due to the extreme Faraday depth of the Sun’s corona at these frequencies. The degree of circular polarization as a function of frequency embodies important information on the coronal magnetic field. Daily observations of radio bursts during active phases will allow us to build up a statistical model of the Sun’s coronal magnetic field. SRBS antennas (low and medium frequencies) and feeds (high frequency system) are native linear. We wish to convert the two polarization channels to RCP and LCP using 90° hybrids. We expect to achieve better than 20 dB isolation between the two circularly polarized channels using COTS hybrids, sufficient for most purposes.
Add Support of a Frequency Agile Digital Receiver

The digital receiver was designed to enhance frequency agility and stability at an affordable cost. The basic system concept was developed under the NSF MRI grant and has involved both graduate students and REU interns. It is a dual-conversion heterodyne system that translates any 20 MHz wide segment of the RF band to baseband where it is digitized by a relatively inexpensive data acquisition board, such as the Adlink 9820, installed in a PC. The PC acquires a burst of data from the card, integrates, and performs an FFT. The segment of RF band is under full control of the processor by setting the first local oscillator frequency. For example, it can be stepped across the full RF band in a sweep-like mode, jump quickly to set frequencies throughout the band, or dwell on any segment for a period of time. The time required to sweep the entire band depends on the amount of time spent on each band segment. A prototype was constructed in the laboratory and it has demonstrated satisfactory performance over the 30 – 300 MHz band.

We propose here to convert the laboratory version into a field unit that can be run in parallel with the existing analog system for a comparison study. If found suitable, we would replace all of the existing back-ends with the digital counterparts. Three unique receiver / data acquisition systems would be required to cover the entire 10 – 2500 MHz band. In addition, a second complete system, running in parallel with the first, would enhance the frequency agility, decrease the time required to sweep the RF band, and provide a built-in backup system.

5 Proposal Budget

The budget detail is attached. The total is $68k, with $41k for M&S and $27k for labor. In the event that the complete upgrade package cannot be funded, we prioritize the upgrades according to science return and cost effectiveness and break out their individual budgets:

1. Implement dual-circular polarization observing ($5.8k)
2. Replace high frequency log-periodic feed with a sinuous feed extending to 3 GHz ($6k)
3. Implement a frequency agile digital receiver ($18.5k)
4. Replace the Erickson dipole and extend frequency coverage down to 10 MHz ($37.7k)

Alternatively, the upgrades could be funded over 2 yrs.

6 Work Plan

The upgrades will be implemented through Bradley’s Dynamic Spectroscopy Lab at the NTC, with technician support from Dan Boyd, student assistance from Rohit Gawand and Chataili Parashare, and machine shop and ground work provided through Green Bank. Langston will assist with implementation and testing. Bastian will coordinate the necessary activities, including modifications to the data archive and access, and will have overall responsibility for the project.
As mentioned, the upgrades could be implemented in part or in full during the course of FY 2008 and/or 2009.

References

## GB/SRBS Upgrade Budget Estimate

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Labor cost estimated at $400 / day.