MILLISECOND STRUCTURES IN NOISE STORMS AND OTHER SOLAR RADIO EMISSION

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Abstract
Preliminary results of a high time-resolution fine structure study are reported. In 1978 and 1979, observations were made on analog magnetic tape with a fixed frequency receiving system having a bandwidth of 2 MHz centred on 264 MHz; by playing the tape back at a much slower speed, a time resolution of about 5 msec could be obtained. At that time, the ETH Zürich-Bleien IKARUS system operated with a sweep-rate of 80 Hz, in 1 MHz steps over the range 250 to 273 MHz, giving an effective single frequency time-resolution of about 50 msec. This latter system has recently been re-programmed to operate with a sweep-rate of 500 Hz over a 4 MHz band giving an effective single frequency time resolution of about 8 msec. Fine structures, having durations of some 10 to 40 msec, have been observed in solar noise storms and also associated with type III, type IV, and type V bursts. These very short duration bursts, referred to here as solar S-bursts, have been seen to occur individually as well as in small groups where they may display a quasi-periodicity of a few milliseconds. Generally, the S-bursts are not very intense relative to the associated background emission. Frequency drifts are predominantly negative and there are indications that the S-bursts display similar characteristics regardless of the type of main solar burst with which they may be associated.

I. Introduction
There have been indications of very short duration structures in the solar radio emission for a number of years, but relatively little has been documented in detail as most receiving systems have not had sufficient resolution to allow a quantitative observation. Some of the earliest observations were, in fact, made by Jupiter workers already equipped for the study of jovian millisecond pulses or S-bursts as they are often called. These observations were confined to the decametre-wave region, however, as the Jupiter emission does not extend above 40 MHz. Thus Barrow and Saunders (1972) reported structures of a few milliseconds duration associated with type III bursts at 18 MHz. These structures appeared to be narrow-banded and sometimes showed rapid polarization reversals. More recently, McConnell (1980) has measured fine structures in the decametric region with 1 msec
time resolution and 2 KHz frequency resolution. He finds bursts having durations of some 5 to 85 msec and bandwidths of 30 to 200 KHz in the frequency range 33 to 44 MHz. By analogy with the fast structures in the Jupiter radiation, McConnell refers to these as solar S-bursts, implicitly with respect to their short durations rather than any possible association with other types of solar burst. This nomenclature is followed here.

Some terminology is defined in Figure 1 which is a modified version of a diagram given by Tarnstrom and Philip (1971). A burst,

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**Fig. 1:** Schematic representation of a solar S-burst as seen by a fixed frequency receiver of bandwidth Δf

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represented by two intensity contours in the time-frequency plane, is observed by a fixed frequency receiver of bandwidth \( \Delta f \). The shaded areas represent what can be measured by the receiver. In addition, the burst may appear to be shaped somewhat if the receiver passband is not flat. At metre-wavelengths, in a two-stage study at the ETH Zürich-Bleien Radioastronomy Observatory over the frequency range 261 to 264 MHz, we have been able to improve upon the measurement of the fixed frequency duration \( d_f \) to about 5 msec resolution and to make reasonable estimates of \( df/dt \) although we cannot say much about the overall frequency extent \( b_o \). These very short duration metric bursts are difficult to observe as they are usually superimposed upon some other intense solar burst background and they appear to be less well-defined than at decametric frequencies.

II. Equipment and Observations

The receiving equipment specifications are listed in Table I.

<table>
<thead>
<tr>
<th>Receivers:</th>
<th>IKARUS Digital Spectrometer (2000 measurements/sec)</th>
<th>Flagg Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (MHz)</td>
<td>250-273</td>
<td>261-264</td>
</tr>
<tr>
<td>Bandwidth (MHz)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sweep-rate (Hz)</td>
<td>80</td>
<td>500</td>
</tr>
<tr>
<td>Overall frequency resolution</td>
<td>1 MHz</td>
<td>1 MHz</td>
</tr>
<tr>
<td>Single frequency time resolution (msec)</td>
<td>( \sim 50 )</td>
<td>( \sim 8 )</td>
</tr>
<tr>
<td>Antennas:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dish diameter (m)</td>
<td>5</td>
<td>7</td>
</tr>
</tbody>
</table>

The 264 MHz receiver was built by Richard Flagg, based upon a model used previously for the study of jovian S-bursts in the decametric range (Krausche et al., 1976). This receiver has already been describ-
ed elsewhere by Barrow, Perrenoud and Flagg (1982). Essentially, the
2 MHz frequency band is mixed down to base-band and recorded directly
on analog magnetic tape. The tape is then played back, slowed 128
times, to compress the frequency band which is analyzed using a 200-
channel real-time spectrum analyzer in the audio frequency range at
about 25% efficiency. The output Z-modulates an oscilloscope and can
be recorded on continuously moving 35 mm film to give a conventional
time-frequency-intensity dynamic spectrum. The sensitivity is greater
than that of the IKARUS system. This latter system, which has been
described in detail by Perrenoud (1982), has recently been re-pro-
grammed to have a sweep-rate of 500 Hz over the band 261 to 264 MHz.
Thus, if at least three successive non-zero (with respect to baseline)
values are required to define a burst, baseline durations down to
8 msec should, in principle, be measurable. Observations are displayed
either as time-intensity profiles 1 MHz apart or as digital spectra.
Background subtraction is available for each of these.

An example of an early digital spectrum is shown in Figure 2

![Figure 2: Digital spectrum of a section of a solar noise storm
recorded on September 5, 1978](image-url)
where a section of the noise storm of September 5, 1978 is presented. A number of type I bursts can be seen, displaying both positive and negative drifts. The single frequency time-resolution in this spectrum is about 50 msec. A section of the corresponding high time-resolution spectrum, taken with the Flagg receiver, is shown in Figure 3 (upper section), compared with an example of solar S-bursts associated with a type III,V event recorded on December 4, 1978 (lower section).

Fig. 3: High time resolution spectra of S-bursts observed with the Flagg receiver, during the noise storm on September 5, 1978 (upper section) and during a type III,V event on December 4, 1978 (lower section).

In both cases, the S-bursts have comparable durations of a few milliseconds and show a negative frequency drift. In the record for December 4, 1978 a few of the S-bursts seem to form a small group in
which a quasi-periodicity of a few milliseconds can be seen. Because of the relatively intense burst background, the S-bursts are not well-defined and image processing techniques were used to produce these high resolution spectra.

A more recent observation of fast structures in type I bursts is shown in Figure 4. In these latter records, made with the reprogrammed IKARUS system, a section of digital spectrum is compared with the corresponding time-intensity profiles. The main type I burst background

**Fig. 4:** A section of digital spectrum compared with time-intensity profiles of fast structures in type I bursts recorded on May 7, 1982. The error bar is based upon a three times RMS noise criterion where the background noise has been taken from the peak of the type I background during the period shown. The background has been subtracted from the time-intensity profiles but not from the spectrum. High intensity is white on the digital spectrum.
MAY 7, 1982

MHz

261

262

263

264

13 08 55 UT

0.1 SEC

Fig. 5: Magnified section of the time-intensity profiles shown in Figure 4
has been subtracted out of the time profiles but not from the digital spectrum. The time profile error bar is based upon the usual 3σ criterion, where RMS noise is calculated from the digital flux values for the accompanying type I burst which is regarded as background noise to the S-bursts. Several S-bursts can be seen, having half-height durations of some 10 to 40 msec, while the spectrum indicates a very short duration negatively drifting structure, perhaps crossing the main type I burst. A short section of the background subtracted time-profiles is shown magnified in Figure 5. It can be seen that, although the intensity increases briefly over all four frequencies, the actual structures appear to be different from one frequency to the next.

III. Identification

For the benefit of non-observers, it may be appropriate to outline some considerations regarding the identification of the S-bursts, both with respect to our own observations and to observations made elsewhere. We have seen that, in the time-frequency-intensity spectra, S-bursts display a distinctive form characterized by a negative frequency drift, very short duration and a relatively narrow frequency bandwidth. The most commonly observed forms of terrestrial interference are broadcast stations, static pulses and interference from defective electrical equipment. Each of these three has a characteristic spectrum very different from that of an S-burst. Broadcast stations appear as narrow straight lines parallel to the time axis. Electrical interference causes a broad band of emission parallel to the time axis, perhaps containing the mains frequency or some other periodic modulation and often starting and finishing abruptly. Static pulses give rise to short-duration broad bands of non-drifting emission which appear as long straight lines perpendicular to the time axis. Fixed frequency records of static pulses (unpublished observations by Barrow, 1971) show a profile and duration quite different from S-bursts. Static pulses have a very fast rise with a relatively flat but structured peak lasting for some 50 msec or more. The decay appears to be slower, perhaps exponential.
In the decametric range there is also the possibility of confusion between jovian and solar S-bursts if Jupiter is close to conjunction. Jovian S-bursts are very intense and show a number of similarities to solar S-bursts (Barrow, 1974). Decametric antennas tend to have fairly broad reception patterns and side-lobe reception is always possible. Although Jupiter appears to be least active during sunspot maximum some caution should be exercised in assessing solar S-bursts if jovian contamination is possible. At metric frequencies this problem does not arise, however, as the jovian emission is confined to frequencies below 40 MHz.

IV. Discussion

Solar S-bursts, having durations of some 10 to 40 msec, have been observed on several occasions during type I, type III and other activity. The S-bursts appear to be a relatively uncommon phenomenon, however, as they are certainly not present during all or even most solar bursts although they always appear to be associated with some other solar burst type as a superimposed phenomenon. We have been able, approximately, to assess frequency drift rates from some of the Flagg spectra as well as from the digital spectra and the numerical values for the digital time-intensity profiles. So far, these drifts have always been negative with values of about -50 to -80 MHz/sec. Interestingly, the general characteristics of single frequency duration, bandwidth and drift-rate seem to be roughly the same, no matter what the associated solar burst type may be. Sometimes the S-bursts appear in small groups where they may display a quasi-periodicity of a few milliseconds. Clearly, there is much interesting work to be undertaken in this area in the future as the solar S-burst morphology appears to be complex. Investigation is difficult, however, as the S-bursts are usually superimposed upon a relatively intense main burst background.

A further consideration is the coronal transient response which has a finite duration due to the effects of scattering and reflection. Investigations by Riddle (1974) and by Steinberg et al (1971) indicate that this duration is dependent upon both the longitude of the source.
and the density of the scattering inhomogeneities. For 169 MHz emission from the 115 and 158 MHz plasma levels the response varies between 20 and 200 msec. Thus, as McConnell (1980) points out, before the S-bursts can be investigated theoretically, it is necessary to know if the emission is at the fundamental or the harmonic plasma frequency.

Acknowledgements

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References: