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Report

Initial results of Husafell solar radio spectrograph

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Abstract: Observing the moon surface and subsurface materials using various radio frequencies is very important for investigating the physical properties of the moon. In particular, the frequency dependence of the dielectric constant of surface and subsurface materials provides information on the density profile. Because the dielectric constant is identified by measuring the reflectivity of the radio waves, we attempted to observe direct solar radio bursts in Iceland and reflected solar radio bursts in Iitate simultaneously.

A new solar radio spectrograph to observe solar radio bursts has been installed at Husafell station in Iceland. The spectrograph covers two frequency bands in the ranges of 18 MHz to 38 MHz and 190 MHz to 350 MHz. Since September 2004, several successful observations have been made: 30 events of Type-I, -II, -III, and -IV bursts have been found in data obtained between September 2004 and August 2005. The flux density of the solar radio bursts detected in this study was within the range of 10 to 100 s.f.u. We previously confirmed that when strong solar burst phenomena occur in the UHF range, the reflected wave signal from the moon surface can be detected using the Iitate Planetary Radio Telescope, installed in Japan.

key words: Husafell solar radio spectrograph

1. Introduction

As a result of the release of high-speed plasma into the interplanetary medium during solar flares, the sun emits various kinds of intense electromagnetic waves that have been named Type-I, -II, -III, -IV and -V solar burst emissions (Wild and McCready, 1950; Boischot, 1959; Wild *et al.*, 1959b). These emissions are the most intense forms of electromagnetic radiation in the solar system. Because solar activities have significant influence on auroral and geomagnetic phenomena, the observation of solar radio bursts provides important information contributing to our understanding of the climate and weather of the sun-earth system.

Since the discovery of solar radio bursts by Hey in 1942 (Hey, 1946), many ground-based radio observations have been performed to study radiation from solar thermal and non-thermal emissions. Many researchers have proposed mechanisms for the generation of solar bursts (*e.g.* Mclean and Labrum, 1985); in particular, Type-III bursts are believed to be generated by plasma instability caused by high-speed electron beams in the coronal atmosphere (Wild *et al.*, 1954, 1959a; Melrose, 1985).

In addition to monitoring solar activity in Iceland, we attempted to determine the reference power flux of the solar bursts by comparing them with moon-reflected solar radio waves observed in Japan. Because the solar radio bursts are very intense, the reflected waves retain enough power to be detected from the ground. If both the direct solar radio bursts and the reflected radio waves can be detected at the same time, the albedo of the moon surface for the radio waves could be identified. Several trials based on a similar idea have performed to identify the moon's reflectivity using a radar technique from the ground in various frequency ranges (Davis and Rohlfs, 1964; Evans, 1969); however, the results of these previous measurements show significant ambiguities, suggesting that radar techniques from the earth may be limited. Because of the intense power of the solar burst emissions, the observation of solar radio bursts and reflected radio waves from the moon makes it possible to realize an accurate reflectivity measurement of the moon's surface, providing data on the dielectric property of the moon. Moon-reflected solar radio bursts can be observed at the Iitate Planetary Radio Telescope (IPRT), the observation threshold of which is 0.05 Jy ($1\,\mathrm{Jy}=10^{-26}\,\mathrm{W/m^2/Hz}$) at 325 MHz, installed at the Iitate observatory (37°42′N, 140°41′E) of the Planetary Plasma and Atmospheric Research Center (PPARC) of Tohoku University (Misawa *et al.*, 2001). Thus, we felt that it would be worthwhile to install a solar radio spectrograph at Husafell station in Iceland. In this paper, the instrumentation of the solar radio spectrograph system in Iceland is described in Section 2, initial observation results are outlined in Section 3, and a discussion and summary are given in Sections 4 and 5.

2. Observation system

The new radio spectrograph for monitoring solar radio bursts was installed at Husafell station (64.67°N, 21.13°W), where a comprehensive observation system for auroral phenomena, including an Aurora Imager for conjugate aurora observations has been installed (Sato *et al.*, 1998). The present observation system was designed to detect wideband solar radio burst spectra and has high resolutions for both time and frequency, enabling various types of solar radio bursts to be investigated. The system comprises two antennas for observations in the HF range (decameter wavelength) and UHF range (decimeter wavelength). The HF antenna is a two-element Yagi antenna with a tip-to-tip length of 7.4 m, which is long enough to detect radio waves in the range of 20 MHz to 40 MHz. The center of the field-of-view of the antenna beam is fixed toward the south. On the other hand, the UHF system uses a 17-element log-periodic antenna (CLP5130-2; Creative Design Corp.) covering a frequency range from 105 MHz to 1300 MHz; this antenna is also directed toward the south. Together, these two antennas cover a wide frequency range of the solar radio burst spectrum. Each antenna has its own low-noise preamplifier. The main receiver and data processing components are shared by the two subsystems, as shown in Fig. 1.

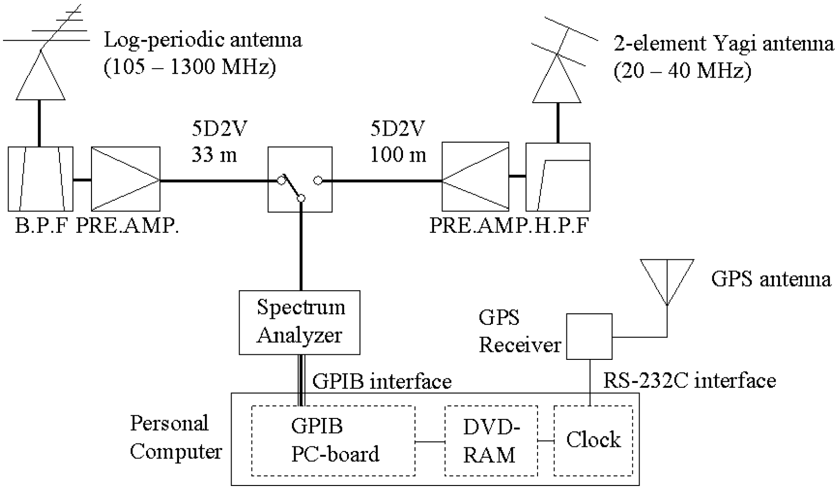

Fig. 1. Block diagram of Iceland solar radio spectrograph.

In the HF system, the signal from the antenna is fed to the preamplifier after passing through a high-pass filter with a cut-off frequency of 15 MHz. In the UHF system, the signal from the antenna is fed to the preamplifier after passing through a 190 MHz to 350 MHz band-pass filter to remove intense communication signals. By passing through the preamplifier (A-11; R&K Corp.), the RF signal is amplified by 27 dB. A spectrum analyzer (E4411B; Agilent Technologies) is used for the main receiver. The receiving band widths were set at 10 kHz (HF system) or 30 kHz (UHF system). Using the HF system, the dynamic spectrum of the RF signal from 18 MHz to 38 MHz is obtained every 4 s. With the UHF system, the dynamic spectrum of the RF signal from 190 MHz to 350 MHz is obtained every 4 s.

The total system gain, including the cable and filter losses and the gain of the preamplifier, is 22.9 dB for the HF system (25 MHz). For the UHF system, the system gain is 18.5 dB (325 MHz). We also examined the antenna gain using antenna simulator software (MMANA) and performed a field test using a calibration signal. The result of the calibration showed that the HF antenna gain is 2.7 dBi (25 MHz) and that the UHF antenna gain is 12.1 dBi (325 MHz) at the peak of the antenna pattern, as shown in Fig. 2. Based on these receiving system parameters, we determined the flux density of the solar radio bursts. All the receiver parameters, such as the selection of the starting and stopping frequencies, receiving band width, video filter, and sweep time, are automatically controlled by software installed in the personal computer *via* the GPIB (General Purpose Interface Bus) interface. Data acquisition is also performed *via* the GPIB interface every 4 s. The data are recorded on a DVD-RAM medium that is capable of storing observation data obtained over the course of more than one month. The DVD-RAM is changed about once a month by an operator.

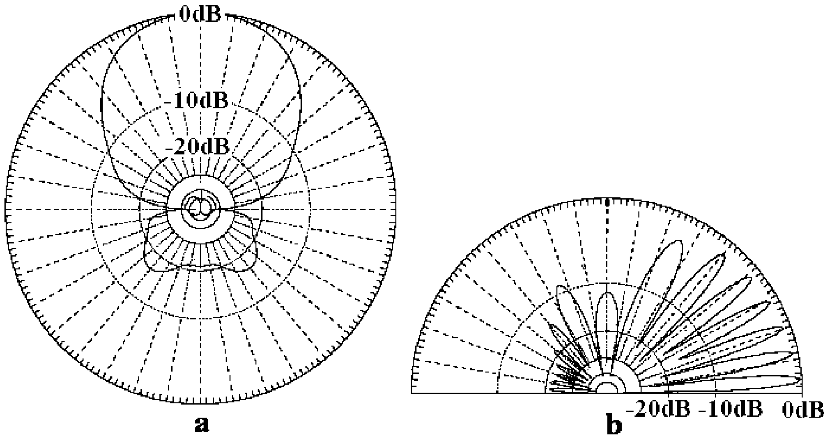

Fig. 2. UHF antenna beam patterns (azimuth and elevation) calculated by MMANA. (a) Azimuthal beam pattern at an elevation = 4°. (b) Elevational beam pattern. In each panel, 0 dB means 12.1 dBi.

3. Initial results

The observation of solar radio bursts has been successfully performed since September 21, 2004. The HF system was operated within a limited period in September 2004. Observation using the UHF system was continued throughout the day. As of the time of writing, observation data have been obtained for over 1 year (September 2004–August 2005).

Typical examples of the detected solar radio bursts corresponding to Type-I, -III and -IV in the VHF-UHF band and Type-II in the HF band are given in Figs. 3–6. The dynamic spectrum of the Type-I solar radio burst shown in Fig. 3 was obtained on February 16, 2005. As shown in Fig. 3, some line spectrums caused by man-made noise appeared as horizontal strait lines; however, the naturally originating radio waves are easy to identify. The Type-I bursts appeared from 1410 to 1630 UT, with burst signatures in the lower frequency range from 200 MHz to 250 MHz. Within the time period from 1550 to 1610 UT, the spectrum of the present Type-I burst appeared in a high-frequency band of about 290–330 MHz. Type-I noise storms usually continue for several hours or days; however, the present event continued for only one hour. In the decameter wavelength range, the structure of Type-I radio bursts is usually impulsive (Aoyama and Oya, 1987). In the UHF frequency range, the structure of Type-I radio bursts is not impulsive, but a complicated dynamic spectrum.

Figure 4 shows a typical Type-III radio burst event that was detected on October 30, 2004. As shown in Fig. 4, the Type-III burst appeared at 1113 UT and 1140–1151 UT in the UHF range. In the MF range spectrum measured by the Wind spacecraft (Bougeret *et al.*, 1995), on the other hand, three burst groups appeared at 1113, 1120–1130 and 1140–1200 UT, as shown in Fig. 4. Type-III radio bursts typically form a group consisting of many individual bursts in the UHF spectrum. This pattern suggests a complicated generation process involving electron beams inside the coronal

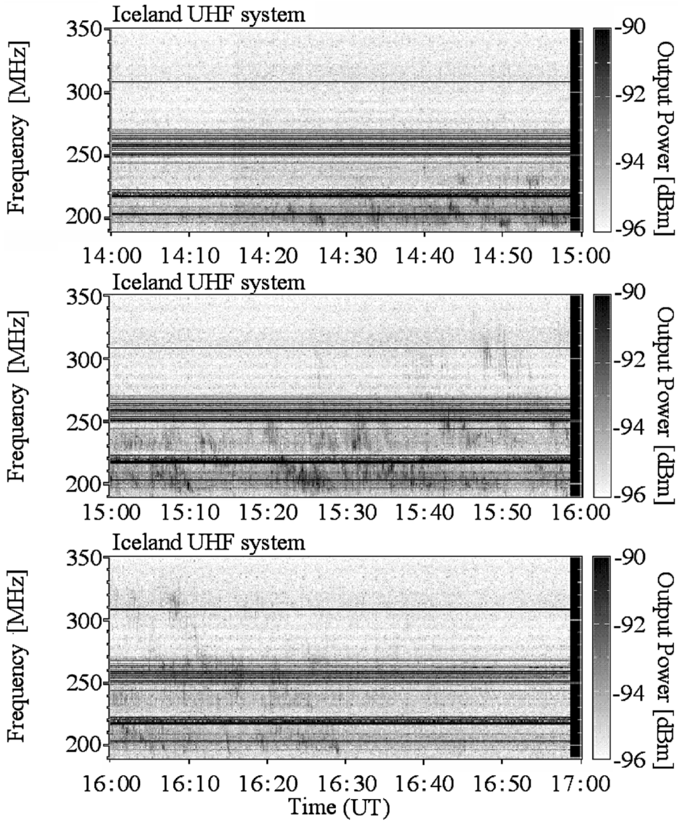

Fig. 3. Typical dynamic spectrum of a Type-I burst in the VHF-UHF frequency range. Power is indicated by the gray scale.

region. In the dynamic spectrum obtained in the HF range, burst features were also frequently observed. Considering the possible generation mechanism of Type-III bursts, the observation frequency can be regarded as the local plasma frequency in the source region, and UHF and HF band radio bursts are thought to be generated near the surface of the sun and in the outer corona of the sun, respectively. Simultaneously with the occurrence of the Type-III burst, as shown in Fig. 4, soft X-ray data obtained by the GOES-10 satellite showed a rapid increase. The WAVES instrument onboard the WIND spacecraft simultaneously observed a low-frequency component of the Type-III burst with a clear drifting nature, decreasing in frequency in the dynamic spectrum.

An example of intense Type-IV radio bursts detected on August 23, 2005, is shown in Fig. 5. The duration of Type-IV bursts is usually about 10 min to several hours. The observed Type-IV burst shown in Fig. 5 shows a continuous structure in the dynamic spectrum with a wide frequency and modulation features. Because the dynamic spectrum of the WAVES data shows no Type-III bursts, the modulation of the Type-IV burst found in the UHF spectra was not caused by a pile-up effect of Type-III bursts, but by a peculiar structure of Type-IV burst. The soft X-ray data from the GOES 10 satel-

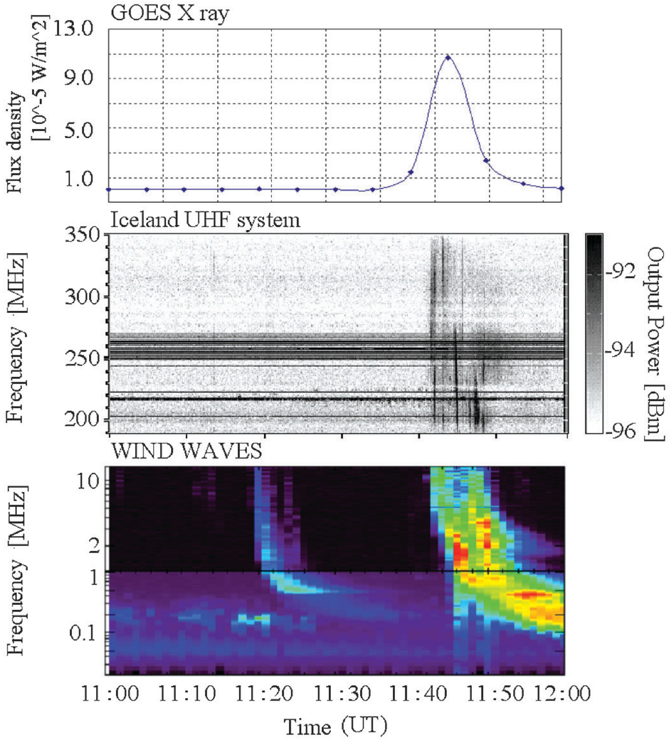

Fig. 4. *Typical example of a Type-III burst in the VHF-UHF frequency range (middle panel). Soft X-ray flux density observed by GOES-10 (top panel). Dynamic spectrum of RAD1 and RAD2 obtained by WAVES onboard the WIND satellite (bottom panel). Type-III bursts were the most common event.*

lite exhibits a slowly decreasing feature.

Type-II radio bursts were successfully observed using the HF system. An example of a Type-II burst observed by the HF system is shown in Fig. 6; the burst has an impulsive structure. On the other hand, the dynamic spectrum of the WAVES data shows a group of Type-III bursts. The Type-III bursts in the WAVES data may contain the structure of Type-II bursts; however, the entire impulsive structure in the HF range (18–38 MHz) in Fig. 6 was characterized as Type-II because the number of bursts in the HF and MF frequency ranges differed greatly.

4. Discussion

Within one year of observations of solar radio bursts at Husafell station in Iceland, typical solar radio bursts were detected in ranges from 190 MHz to 350 MHz and 18 MHz to 38 MHz. In the period between September 2004 and August 2005, 30 solar radio burst events were identified not only by our system, but also in the lists of Solar Geophysical Data provided by the Space Environment Center (SEC), data from Nancay observatory (http: //www.obs-nancay.fr/index.htm), and data from the WIND space-

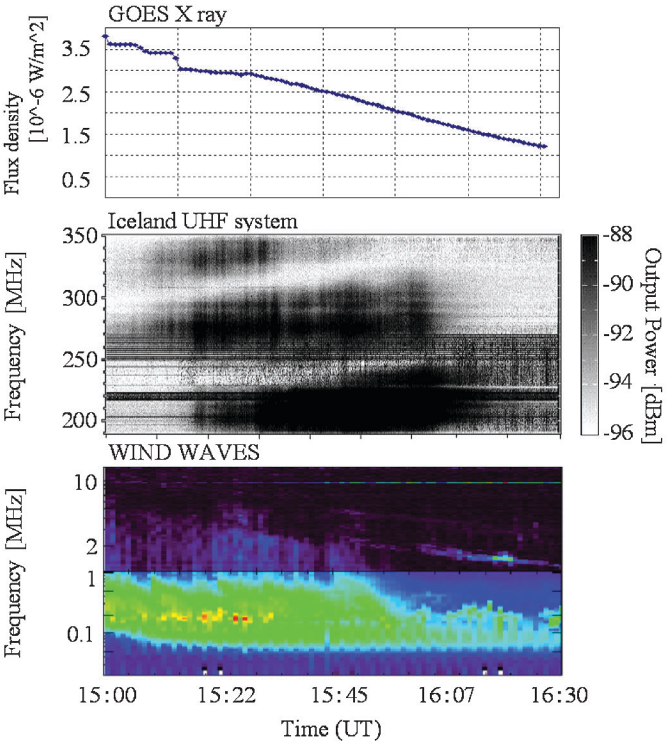

Fig. 5. Typical example of a Type-IV burst in the VHF-UHF frequency range. The format is the same as in Fig. 4. The duration of the Type-IV burst was more than one hour.

craft (http: //lep694.gsfc.nasa.gov/waves/waves.html). We analyzed 30 solar radio burst events with regard to their intensity at 325 MHz and the maximum intensity of the spectra. The flux density was calculated using calibrated data on the system and antenna gains. In their study, the antenna gain at the center of the main beam was used, and the beam pattern was ignored. Therefore, the estimated flux density represents the minimum value of the flux. The number of observed solar radio bursts as a function of the flux density is shown in Fig. 7. The flux densities of the solar radio bursts detected in this study were within a range from 10 to 100 s.f.u. (1 s.f.u. $=10^{-22}$ W/m^2/Hz). When these intensity data are taken into account, the flux density of the solar radio bursts reflected by the moon can be estimated. To evaluate the intensity of the moon-reflected waves, the reflectivity of the moon surface for 325 MHz was assumed to be 0.1 with an isotropic nature. Based on this assumption, the estimated flux density of the solar radio bursts reflected by the moon ranged between 0.2 and 2 Jy (1 Jy $=10^{-26}$ W/m^2/Hz) at the earth's surface. On the other hand, the sensitivity of the IPRT is 0.05 Jy as determined, by averaging for 10 s with a resolution band width of 5 MHz. Thus, the flux density of the solar radio bursts determined by the Husafell system was concluded to be sufficiently strong enough to be detected by the IPRT.

Although the flux of the solar radio bursts in the HF band was also very intense,

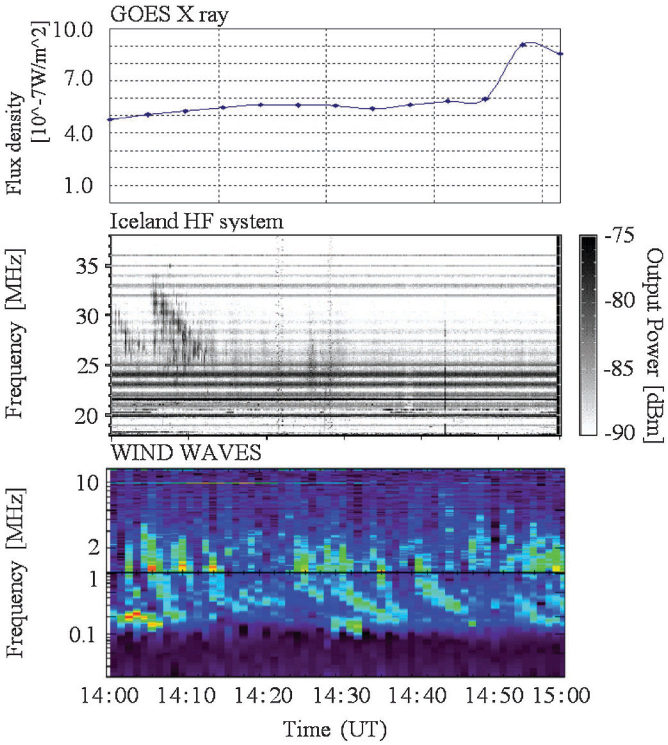

Fig. 6. Typical example of a Type-II burst in the HF frequency range. The format is the same as in Fig. 4.

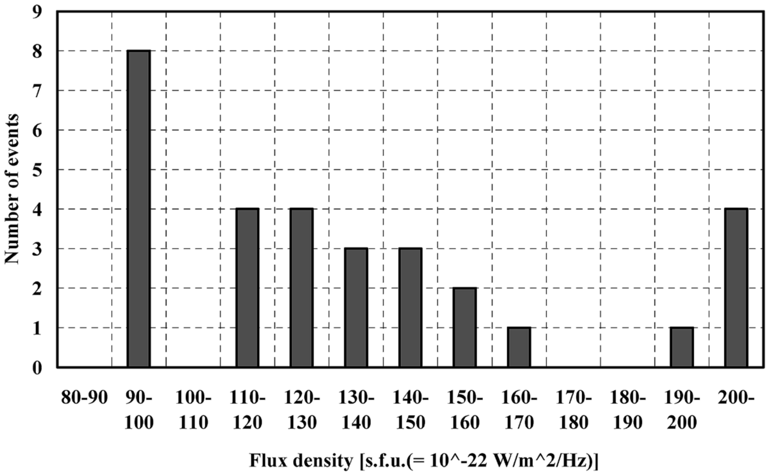

Fig. 7. Number of solar radio bursts at 325 MHz as a function of flux density.

intense galactic noise made it difficult to detect the weak reflected solar radio signals. To observe solar radio bursts and Jovian decametric radiation, a Wideband Dynamic Polarimeter system and an Array antenna system were installed at the Iitate observatory. The Wideband Dynamic Polarimeter can detect weak solar radio bursts and jovian decametric radiation, but the observation threshold is more than 10^{-21} W/m^2/Hz. Thus, weak reflected solar radio bursts cannot be detected. On the other hand, the Array antenna system can detect weak signals using the fringe correlation method (Oya and Iizima, 2003). The threshold of the signal intensity using this method has been evaluated to be about 10^{-22} W/m^2/Hz. Reflected radiation from intense solar radio bursts with more than 5×10^{-17} W/m^2/Hz can be detected by the present antenna system. However, sufficiently intense solar radio bursts are rare. From this point of view, the observation of solar radio bursts in the UHF band should be continued.

5. Summary

A new system for observing solar radio bursts has been installed at Husafell station. Initial observations by the Husafell solar radio spectrograph were performed between September 2004 and August 2005, and the solar radio bursts of 30 events were identified. The flux density of the bursts was estimated to be sufficient to detect radiation reflected from the lunar surface using the Iitate Planetary Radio Telescope on the earth's surface. In the future, simultaneous observations with IPRT showed provide information on the moon's albedo, making it possible to identify the dielectric property of the moon's surface materials in the UHF frequency range.

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