Postprint: Analysis of Observable Frequency Bands for L-band Solar Radio Flux Using a Combined Simple Thresholding and CUSUM Algorithm

Authors: Yang Hang, Dong Liang, He Lesheng

Date: 2022-09-19T00:00:00+00:00

Abstract

L-band solar radio bursts represent potential influencing factors for navigation system instability. Real-time detection of navigation interference events caused by solar radio bursts can be achieved through monitoring of precise solar radio flux within the L-band. For this purpose, the headquarters of Yunnan Observatories intends to establish an L-band multi-frequency solar radio monitoring system. Effective assessment of the radio environment is essential for ensuring stable acquisition of observational data from this monitoring system. This paper presents the radio monitoring preparatory research for this monitoring platform, conducted through 100 hours of testing of the L-band radio environment in the Fenghuangshan area at the headquarters of Yunnan Observatories. An improved threshold algorithm based on the Simple Thresholding algorithm and the CUSUM algorithm is proposed, which selected seven 5-MHz radio passbands with minimal radio interference between the BeiDou B1, B2, B3 frequency points and GPS L1, L2 frequency points, specifically: 1551 MHz–1555 MHz, 1596 MHz–1600 MHz, 1161 MHz–1165 MHz, 1221 MHz–1225 MHz, 1246 MHz–1250 MHz, 1291 MHz–1295 MHz, and 1231 MHz–1235 MHz. These passbands exhibit cleanliness rates of 98.329%, 98.301%, 98.315%, 98.335%, 98.224%, 97.650%, and 98.260%, respectively, all of which satisfy solar observation requirements. This work provides a foundation for subsequent receiver design and signal processing.

Full Text

Research on Observable Frequency Band Analysis of L-Band Solar Radio Flux Based on a Joint Simple Thresholding and CUSUM Algorithm

YANG Hang[1], **DONG Liang**[2], **HE Lesheng**[1],* [1]Yunnan University, Kunming, Yunnan 650504 [2]Yunnan Astronomical Observatory, Chinese Academy of Sciences, Kunming, Yunnan 650216

Abstract

L-band solar radio bursts represent a potential influencing factor on navigation system stability. Real-time monitoring of precise solar radio flux within the L-band can enable the timely detection of navigation interference events caused by solar radio bursts. To this end, the Yunnan Astronomical Observatory headquarters plans to establish an L-band multi-frequency solar radio monitoring system. Effective assessment of the radio environment is crucial for ensuring stable acquisition of observational data from this monitoring system. This paper introduces the radio monitoring preparation research for the platform, presenting results from a 100-hour test of the L-band radio environment conducted in the Fenghuangshan area of the Yunnan Astronomical Observatory headquarters.

We propose an improved threshold algorithm based on the Simple Thresholding algorithm and the CUSUM algorithm to select seven 5 MHz radio passbands with minimal radio interference, situated between the BeiDou B1, B2, and B3 frequency points and the GPS L1 and L2 frequency points. The selected passbands are: 1551–1555 MHz, 1596–1600 MHz, 1161–1165 MHz, 1221–1225 MHz, 1246–1250 MHz, 1291–1295 MHz, and 1231–1235 MHz, with cleanliness rates of 98.329%, 98.301%, 98.315%, 98.335%, 98.224%, 97.650%, and 98.260%, respectively—all meeting solar observation requirements. These results provide a foundation for subsequent receiver design and signal processing.

Keywords: L-band; monitoring systems; radio environment; threshold; cleanliness rates

Solar activity is the source of space weather, and coronal mass ejection (CME) events constitute the primary factor affecting the Sun-Earth space environment. Radio observations reflect plasma information at different coronal heights, including density and magnetic field parameters. As plasma is ejected from the Sun, its density decreases with distance, and the radio frequency emitted by CME material correspondingly decreases. Consequently, the solar physics community widely accepts that the lower the frequency of radio bursts observable by ground-based solar radio telescopes, the closer the CME material is to Earth. Therefore, observing solar radio emissions at different frequencies can necessarily retrieve dynamic information at various coronal heights.

Long-term solar radio flux monitoring has revealed that flux variations across different frequency bands are highly correlated with the solar activity cycle, making it an important space weather observation indicator. However, radio observation frequencies overlap with civilian radio usage bands, creating significant potential for interference and misjudgment. Radio environment testing and assessment before radio telescope construction are particularly critical. Unlike observations of pulsars or active galactic nuclei (AGN) variability that require broadband monitoring, high-time-resolution solar radio flux observations are less sensitive to sporadic interference. Such short-duration "bad points" can be eliminated through later comparison with solar optical data.

L-band solar radio bursts are potential interference factors for navigation communications. Unlike other space weather events, solar burst signals propagate at the speed of light, representing the fastest-acting space weather phenomenon, and theoretically all navigation receivers on the sun-facing side may be affected. Dong Liang, Huang Wengeng, Yan Xiaojuan, and others have proposed using multi-channel precision solar radio telescopes in the L-band for synchronized monitoring to track solar radio flux in real time and issue early warnings during the initial stages of bursts.

However, the L-band contains numerous radio interferences. Before telescope construction, it is necessary to evaluate the distribution patterns of radio interference signals within MHz-level observation bands, determine observable solar time periods, and investigate channels occupied by interference for extended durations to prevent false alarms. This paper introduces the radio testing results for the site, the observation band selection methodology, and the selected radio passbands for the precision flux solar radio telescope to be constructed at the Fenghuangshan headquarters of Yunnan Astronomical Observatory (intended for research on the middle and high corona, early warning of solar radio burst interference with navigation communications, and as a backup for the Langfang solar radio telescope).

1.1 System Composition

The test system consists of an HL050 antenna, low-noise amplifier, regulated power supply, FSU26 spectrum analyzer, and computer. The system block diagram is shown in [Figure 1: see original paper].

In the system block diagram, signals collected by the HL050 antenna are amplified by the low-noise amplifier and then transmitted to the FSU26 spectrum analyzer for conversion into spectral data, which is subsequently sent to the computer for display and storage. The regulated power supply provides stable voltage to the amplifier to ensure data accuracy. The computer uses LabVIEW graphical programming to control the frequency range and polarization mode, comprising two main components: HL050 antenna frequency control and spectrum analyzer control programs.

1.2 Test Equipment and Parameters

The antenna employs the HL050 logarithmic periodic antenna, with parameters listed in . The HL050 antenna is widely used due to its simple structure, wide frequency band, high power capacity, and convenient adjustment and operation.

The spectrum analyzer is the R&S FSU26 from Rohde & Schwarz, with an operating frequency of 20 Hz–26.5 GHz and an average noise level of -158 dBm. Its parameters are also listed in .

The computer implements control through LabVIEW software graphical programming, which allows adjustment of the test frequency start point, polarization mode, resolution bandwidth, integration time, and execution count. Acquired signals are saved to a preset address for subsequent processing and analysis.

1.3 Monitoring Process

Testing was conducted at the Fenghuangshan headquarters site of Yunnan Astronomical Observatory, Chinese Academy of Sciences, located in Kunming, Yunnan (25°1' 48.538' 'N, 102°48' 14.180'' E). The L-band radio environment was tested in four directions (east, west, south, and north). The system frequency range was set to 1–2 GHz, with the spectrum analyzer sweep width configured at 1000 MHz. The display bandwidth and resolution bandwidth were set to 300 kHz, with a scan time of 30 seconds. Each of the four directions was tested four times for over eight hours, totaling 16 tests, with each dataset containing more than 800 groups. Specific test dates and group counts are shown in .

2 Data Processing

This section introduces the data acquisition format, threshold selection and determination, and the final channel selection process.

2.1 Data Format

The collected data were recorded in TXT file format with units of dBmV to reduce absolute numerical values for convenient recording. Since the spectrum analyzer was configured to output two traces during testing, each dataset contains two columns, as shown in [Figure 2: see original paper]. The first column represents the maximum hold values of the collected data, while the second column shows the average values within the scan time, used to evaluate system stability during each test. Data are stored in a nonlinear logarithmic format with base 10, following the mathematical relationship $P(dBmV) = 10\log_{10}(P/P_0)$. Therefore, subsequent data processing requires linear transformation of the data.

2.2 Threshold Selection Scheme

For the L-band precision flux solar radio telescope to be constructed at the Fenghuangshan headquarters of Yunnan Astronomical Observatory, we selected seven 5 MHz radio passbands with minimal interference between the BeiDou B1 (1559.052-1591.788 MHz), B2 (1166.220-1217.370 MHz), and B3 (1250.618-1286.432 MHz) frequency points and the GPS L1 (1574.397-1576.443 MHz) and L2 (1226.577-1228.623 MHz) frequency points. Note that GPS L1 falls within the BeiDou B1 range, and the difference between B2 and L2 is less than 10 MHz, making it impossible to select two relatively clean 5 MHz passbands without overlap. Consequently, the selected passband near B2' s right side coincides with that near L2' s left side, resulting in seven channels (with no interference signals within the monitored radio environment) that intersperse all BeiDou and GPS communication frequency points.

The objective is to select usable channels with cleanliness rates (percentage of time with radio interference relative to total monitoring time) above 95%. Selection involves visually identifying relatively clean channels from spectral waterfall plots and determining spectral cleanliness rates by calculating the proportion of observation data exceeding the threshold. Channels with cleanliness rates exceeding 95% are deemed usable. The processing workflow is as follows:

1. Select a short-term "quiet" observation band as the threshold calculation data sample.
2. Calculate the threshold using the proposed algorithm on this sample.
3. Apply this threshold to traverse remaining observation period data, comparing against the threshold to determine the proportion of interference signals.
4. Evaluate the seven selected 5 MHz passbands using the algorithmically determined threshold.

2.2.1 Threshold Calculation Method Threshold analysis methods are widely applied due to their simplicity and high detection accuracy. Representative methods include the CUSUM (cumulative sum) method and Simple Thresholding method. When detecting observation data in a row or column, the CUSUM algorithm estimates threshold through cumulative sample variance and mean, while Simple Thresholding uses the median of the row/column as its threshold.

Since our monitored data are logarithmically transformed, which compresses variable scales, enhances data stability, and reduces model collinearity and heteroscedasticity without changing data properties or relationships, linearization is required for threshold calculation, as shown in Equation (1):

$$P_{\text{linear}} = 10^{(x/10)}$$

where x is the measured value in dBmV.

Sample variance is a crucial estimator for statistical anomalies representing radio frequency interference (RFI). Since median absolute deviation (MAD) and median are the most effective estimators for eliminating outliers, this paper proposes an improved threshold algorithm combining Simple Thresholding and CUSUM algorithms to select observation bands from L-band radio test results. Channels with threshold levels exceeding T_h are considered RFI-contaminated, as shown in Equation (2):

$$T_h = \bar{X} - \alpha \times \text{MAD}$$

where T_h is the linear threshold from the CUSUM algorithm, $\bar{X}$ is the mean of linear data, and α is a parameter with $0.0 < \alpha < 5.0$ (default $\alpha = 3.0$). The variance estimator MAD used in Simple Thresholding is defined by Equation (3):

$$\text{MAD} = 1.4286 \times \text{med}(|x_i - \text{med}(x)|)$$

where $\text{med}(x)$ is the median of the original sample array. This median is subtracted from each element to create a modified sample, whose median is then calculated and multiplied by the constant scaling factor 1.4286 to align the estimate with an expected Gaussian distribution.

After obtaining the linear threshold T_h, logarithmic conversion is required to calculate passband cleanliness rates in the monitored data, as shown in Equation (4):

$$T^* = 10 \times \log_{10}(T_h)$$

The complete threshold algorithm block diagram and pseudocode are presented in [Figure 3: see original paper].

2.2.2 Channel Selection and Data Comparison First, a short-term "quiet" observation band is selected as the threshold calculation sample. From , the test with the most data groups was chosen for initial selection: the westward fourth test on April 27, which collected 2,219 data groups. The "quiet" observation band was selected from the spectral waterfall plot of this dataset, shown in [Figure 4: see original paper] through [Figure 6: see original paper].

Second, the threshold is calculated using the aforementioned algorithm on this sample.

Third, this threshold is applied to traverse other observation period data to determine interference proportions, with comparison results shown in .

Fourth, the algorithmically determined threshold evaluates the seven selected 5 MHz passbands.

In [Figure 4: see original paper], the horizontal axis represents the L-band from 1–2 GHz, the vertical axis shows data sample groups, and the depth axis indicates signal strength. This visualization method was adopted for all L-band tests as it clearly reveals interference conditions in the required frequency bands. [Figure 5: see original paper] provides a right-side view of the L-band spectral waterfall, clearly showing signal strength across all test groups and intuitively displaying interference conditions for required bands, aiding preliminary screening of "quiet" observation bands. [Figure 6: see original paper] shows a bottom view of the L-band spectral waterfall, marking BeiDou B1, B2, B3 and GPS L1, L2 frequency points to assist subsequent passband selection.

Using the threshold algorithm, the final seven 5 MHz passbands between BeiDou and GPS frequency points were determined from multiple candidate passbands, as shown in [Figure 8: see original paper]. The channel selection flow diagram is presented in [Figure 7: see original paper]. Initially, 13 passbands were selected, but after final channel selection, seven 5 MHz passbands with minimal radio interference were confirmed.

The selection process primarily aimed to identify seven 5 MHz passbands between BeiDou B1, B2, B3 and GPS L1, L2 frequency points. Starting with the preliminary selection of the relatively clean 1161–1165 MHz band from the L-band spectral plots in [Figure 4: see original paper]–[Figure 6: see original paper] as the threshold determination channel, the algorithm calculated thresholds and evaluated cleanliness rates through threshold traversal comparison. The cleanliness rates for the selected 1161–1165 MHz band across all 16 L-band tests are shown in , all exceeding 95% and meeting solar observation requirements. Therefore, this threshold was adopted for evaluating all seven selected passbands.

The final seven selected 5 MHz passbands and their cleanliness rates are:

- BeiDou B1/GPS L1 bands: 1551–1555 MHz (98.329%) and 1596–1600 MHz (98.301%)
- BeiDou B2 bands: 1161–1165 MHz (98.315%) and 1221–1225 MHz (98.335%)
- BeiDou B3 bands: 1246–1250 MHz (98.224%) and 1291–1295 MHz (97.650%)
- GPS L2 bands: 1221–1225 MHz (98.335%) and 1231–1235 MHz (98.260%)

All selected passbands exhibit cleanliness rates above 95%, satisfying solar observation requirements. Detailed rates are provided in .

3 Summary and Outlook

For the L-band precision flux solar radio telescope to be constructed at the Fenghuangshan headquarters of Yunnan Astronomical Observatory, this paper proposes an improved threshold algorithm based on Simple Thresholding and

CUSUM algorithms. Through radio environment testing and observation band selection, seven 5 MHz passbands with minimal interference were identified between BeiDou B1, B2, B3 and GPS L1, L2 frequency points: 1551–1555 MHz, 1596–1600 MHz, 1161–1165 MHz, 1221–1225 MHz, 1246–1250 MHz, 1291–1295 MHz, and 1231–1235 MHz, with cleanliness rates of 98.329%, 98.301%, 98.315%, 98.335%, 98.224%, 97.650%, and 98.260%, respectively. All passbands meet solar observation requirements, providing a basis for subsequent receiver design and signal processing.

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