Parameter Configuration and Data Accuracy Analysis for Real-Time RFI Detection

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Abstract – Real-time detection of radio frequency interference requires the spectrum analyzer to have a high sweep speed and high data accuracy at the same time. We first analyzed key parameters and the measurement-time calculation method of the spectrum analyzer, then proposed a measurement-parameter configuration method. With this method, the actual measurement time and measurement uncertainty were tested and analyzed using three kinds of spectrum analyzers. The test results showed that the actual measurement time and measurement uncertainty of Instrument C are below 70 ms and 0.031 dB, respectively, from 100 MHz to 13 GHz, which can be better applied to real-time detection of radio frequency interference.

1. Introduction

Radio astronomy telescopes are more and more susceptible to radio frequency interference (RFI) inside and outside their sites, as their sensitivity is constantly improving [1, 2]. With the development of space radio technology and the continuous increase of electronic equipment [3], the electromagnetic environment has become particularly complex [4, 5]. In order to monitor the electromagnetic environment of the site, the Square Kilometre Array developed an RFI test protocol [6] and ran a large number of tests for site selection [7]. This test method was widely used in site selection for other radio telescopes [8–14], but it is better used to monitor stable interference due to the lack of real-time information on signals. The source of stable interference signals can usually be tracked easily, because they obey the assigned frequency bands. However, transient RFI is broadband and intermittent, and it is difficult to identify [15]. Conventional electromagnetic environment monitoring cannot reflect the spectral characteristics of transient RFI.

The development of a real-time electromagnetic environment measurement system based on a commercial spectrum analyzer could effectively improve the ability to detect transient RFI. Commercial spectrum analyzers have mature functions, high accuracy, and strong stability, which can shorten the development cycle and reduce development costs, and they have strong system stability and practical value. In order to realize real-time RFI detection, the spectrum analyzer needs a fast sweep speed to capture the interference signals quickly. But when the sweep speed is too fast, the resolution bandwidth filter cannot fully respond, which will lead to deviation of display values for signal amplitude and frequency. In addition, different spectrum analyzers perform differently, and different parameter configurations have a great impact on the test results. Therefore, configuring the measurement parameters of a spectrum analyzer to achieve fast sweep speed and high data accuracy is a critical problem to be solved. Based on a commercial spectrum analyzer, this article deeply analyzes the key measurement parameters and proposes a parameter configuration method for real-time RFI detection which can improve the measurement time resolution and data reliability.

2. Key-Parameter Analysis

Real-time RFI detection requires the spectrum analyzer to have a low sweep time, to scan and capture data several times within a period. Due to the use of analog or digital filters, the sweep speed is limited by the transient response time of the intermediate frequency filter and video filter. In general, the transient response time of a spectrum analyzer is expressed as

$$T_{\text{sweep}} = k\frac{\Delta f}{W_{\text{RB}}^2} \tag{1}$$

but in the actual test the influence of the transient response time of the video filter needs to be considered as well, so the transient response time of the spectrum analyzer can be expressed as

$$T_{\text{sweep}} = k\frac{\Delta f}{W_{\text{RB}}W_{\text{VB}}} \tag{2}$$

where Δf is the sweep bandwidth, W_{RB} is the resolution bandwidth, W_{VB} is the video-filter bandwidth, and k is a proportional coefficient. When Δf is the resolution bandwidth, T_{sweep} is the minimum sweep time required within the resolution bandwidth.

The sweep time of a spectrum analyzer is the time required to scan the entire frequency range and complete the measurement. Therefore, the total sweep time within the sweep frequency bandwidth can be given by

$$\text{SWT} = T_{\text{sweep}}\frac{S_{\text{PAN}}}{W_{\text{RB}}} \tag{3}$$

where SWT is sweep time and S_{PAN} is the sweep frequency bandwidth, defined as

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Table 1. Settings of resolution bandwidth (W_{RB}) and video-filter bandwidth (W_{VB}) in different frequency bands

Frequency band	W_{RB} (kHz)	W_{VB} (kHz)
100 MHz–2 GHz	30	300
2–5 GHz	100	300
5–13 GHz	300	1,000

$$S_{\mathrm{PAN}} = W_{\mathrm{RB}} \frac{C_{\mathrm{points}}}{N} \quad (4)$$

where C_{points} is the sweep points and N is the sample points within each W_{RB}. Thus, the relationship between SWT and C_{points} can be described as

$$\mathrm{SWT} = T_{\mathrm{sweep}} \frac{C_{\mathrm{points}}}{N} \quad (5)$$

It can be seen that SWT is related to W_{RB}, W_{VB}, S_{PAN}, and C_{points}. The value of W_{RB} is determined by the bandwidth of the intermediate frequency filter. In order to truly describe the spectrum of signals and distinguish two signals with very close frequencies, narrower values of W_{RB} are the better. A narrower W_{RB} can decrease the noise of the instrument itself, enhance its ability to detect weak signals, and improve the measurement accuracy [16]. But if the bandwidth is too narrow, the signal passing through the filter may not reach its peak value, which will result in inaccurate measurement results and a long SWT. W_{VB} is the bandwidth of the low-pass filter (video filter) after an intermediate frequency detector. The video filter can reduce the output noise variation of the detector and smooth the noise [17]. In order to improve the measurement sensitivity, W_{VB} should be reduced, but this will also make SWT longer. At the same time, for high measurement-time resolution, the single-screen test is expected to have a wide S_{PAN}. A wider S_{PAN} and larger C_{points} will make SWT longer too.

Therefore, SWT cannot be reduced indefinitely. Otherwise, the resolution bandwidth filter of the spectrum analyzer cannot fully respond, and the intermediate frequency filter or video filter cannot reach a stable state. This will cause amplitude distortion and frequency offset of the displayed signal, and affect the data accuracy. In order to ensure that real-time RFI detection has high measurement-time resolution and data reliability, it is necessary to set W_{RB}, W_{VB}, S_{PAN}, C_{points}, and SWT reasonably to improve the sweep speed and measurement accuracy of the spectrum analyzer.

3. Parameter Configuration Method

In radio astronomy observation, real-time electromagnetic environment measurement is mainly divided into three frequency bands: 100 MHz–2 GHz, 2–5 GHz, and 5–13 GHz. The spectrum analyzer's response time and measurement data accuracy are two important performance aspects for real-time RFI detection. The optimal parameter configuration in different frequency bands can be formulated through testing the actual measurement time and the measurement uncertainty of the spectrum analyzer under different measurement parameters.

From the analysis in Section 2, the key spectrum-analyzer parameters that need to be configured are W_{RB}, W_{VB}, S_{PAN}, C_{points}, and SWT. To effectively isolate RFI in different frequency bands, W_{RB} and W_{VB} can be selected according to the Square Kilometre Array RFI test protocol, as shown in Table 1. We focus on the configuration of C_{points} and SWT, so each frequency band uses a fixed S_{PAN} of 1 GHz. Thus, we mainly need to test the actual measurement time and measurement uncertainty when the spectrum analyzer sets different values for C_{points} and SWT in different frequency bands. The measurement link and process are shown in Figure 1.

3.1 Measurement 1: The Actual Measurement Time

As shown in Figure 1, the computer is connected to the spectrum analyzer through the network. The

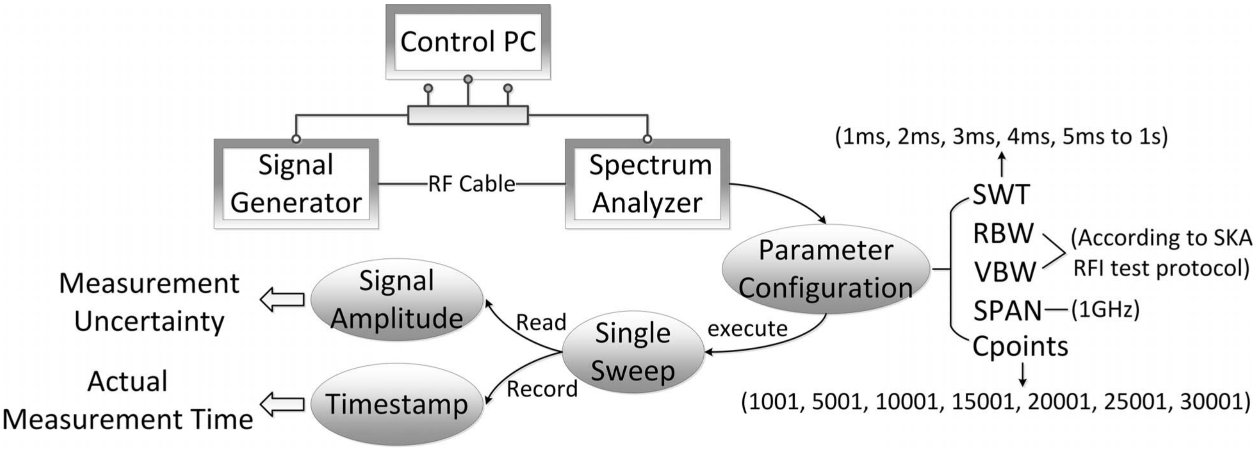

Figure 1. Measurement link and process.

spectrum analyzer is controlled to configure different parameters and then execute a single sweep. After the sweep is completed, we obtain and record the time stamp of the spectra to calculate the actual measurement time. As the sweep speed is relatively fast, the time stamp can accurately record the measurement time of the spectra and effectively determine whether the timing of the measurement data is correct.

The W_{RB} and W_{VB} values in each frequency band are configured according to Table 1. The configurations of C_{points} and SWT are shown in Figure 1. We select seven different C_{points} values which are commonly used in electromagnetic environment measurement. The setting of SWT increases from 1 ms to 1 s. When each frequency band is tested, SWT is changed in turn under different C_{points} to test the actual measurement time of the spectrum analyzer. The number of tests required for each frequency band is therefore $7 \times 1000 = 7000$.

Due to the large number of tests, we designed a program to implement them. The design process was as follows: (1) Control the spectrum analyzer to set sweep frequency, W_{RB}, and W_{VB}. (2) Design a loop to set different C_{points}. (3) Design another loop under the loop in step 2 to set different SWT. (4) Control the spectrum analyzer to execute a single sweep and read the time stamp under the loop in step 3. (5) Calculate the actual measurement time based on the time stamp.

3.2 Measurement 2: The Measurement Uncertainty

As shown in Figure 1, the computer is connected to the signal source and the spectrum analyzer through the network. The signal source is controlled to transmit signals in different frequency bands, and the spectrum analyzer is controlled to configure different parameters and then execute a single sweep. After the sweep is completed, we read and record the measured signal amplitude to calculate the measurement uncertainty by the amplitude's deviation.

The signal source is set to output a fixed signal of –30 dBm in each frequency band. The spectrum analyzer is set to sample detector, which can better reflect the randomness of the signal fluctuation and has higher signal authenticity. The other parameter settings of the spectrum analyzer are the same as for Measurement 1. The test process is similar to that for Measurement 1. In the test of each frequency band, SWT is changed successively under different C_{points} to test the actual measured signal amplitude of the spectrum analyzer.

Using statistical analysis, the measurement uncertainty is calculated as

$$\text{Uncertainty} = \left| U_i - \overline{U} \right| \tag{6}$$

where U_i is the amplitude value measured under the SWT setting and $\overline{U}$ is the average of the amplitude value measured under all SWT settings, calculated as

$$\overline{U} = \frac{\sum_{i=1}^{n} U_i}{n} \tag{7}$$

After all measurements are completed, the optimal parameter configuration in different frequency bands can be obtained by analyzing the test results. The goals are shorter response time and higher data accuracy in real-time measurements.

4. Experimental Results

In order to verify the parameter configuration method, we tested three different brands and models of commercial spectrum analyzers (Instruments A, B, and C) on Measurements 1 and 2 to select the most suitable one and the optimal parameter configuration for real-time RFI detection.

The test results showed that the smaller the value of C_{points}, the lower the actual measurement time but the higher the measurement uncertainty. This is consistent with the analysis in Section 2. Combining the test requirements of different frequency bands, the selections of C_{points} are as follows:

- 100 MHz–2 GHz: In this band, different C_{points} values have little influence on measurement uncertainty. But because of the slow processing speed of the hardware at these low frequencies, we select a small C_{points} of 10,001 to reduce the actual measurement time of the spectrum analyzer.
- 2–5 GHz: Since there is much transient RFI in this band, the selection of C_{points} is 15,001 to meet the demands of actual measurement time and measurement uncertainty at the same time.
- 5–13 GHz: As the sweep speed of the spectrum analyzer is fast in this band, we select a large C_{points} of 25,001 to ensure short actual measurement time and decrease the measurement uncertainty.

With the settings of C_{points}, we can obtain the actual measurement time and measurement uncertainty of three spectrum analyzers under different SWT settings in different frequency bands, as shown in Table 2. From the data in the table we can learn that the test results of the three spectrum analyzers are quite different. The actual measurement time of Instrument A in the frequency bands below 5 GHz is about 10–40 ms, but the measurement uncertainty is up to 59 dB and is relatively stable when SWT is set above 25 ms. In the 5–13 GHz range, the actual measurement time is long, about 200 ms. Therefore, Instrument A is not suitable for fast-scan measurement. The actual measurement time of Instrument B in the 100 MHz–2 GHz band is about 500–600 ms, which cannot meet the demand of high time resolution. But in the frequency bands above 2 GHz, it can be as short as 30 ms, and the measurement uncertainty has a small fluctuation range. Instrument B is therefore suitable for real-time measurement in high

Table 2. Actual measurement time (Time) and measurement uncertainty (Un) of three spectrum analyzers under different sweep-time settings in different frequency bands

		Instrument A		Instrument B		Instrument C	
Frequency band	SWT (ms)	Time (ms)	Un (dB)	Time (ms)	Un (dB)	Time (ms)	Un (dB)
100 MHz–2 GHz	1	20	22.82	642	0.01	70	0.001
	5	20	16.02	612	0.01	90	0.005
	10	20	12.01	481	0.05	100	0.001
	15	30	8.95	490	0.06	110	0.001
	20	30	4.96	501	0.05	121	0.002
	25	40	0.27	521	0.05	140	0.002
2–5 GHz	1	10	14.13	60	0.01	60	0.091
	5	20	59.03	463	0.02	90	0.097
	10	30	10.28	461	0.02	100	0.098
	15	20	2.75	483	0.02	101	0.099
	16	29	2.11	29	0.06	60	0.086
	20	30	0.63	30	0.03	59	0.031
	25	40	0.02	39	0.02	70	0.04
5–13 GHz	1	190	50.42	60	0.01	70	0.064
	5	201	6.29	523	0.06	91	0.064
	10	211	1.47	530	0.05	110	0.075
	15	221	0.45	531	0.05	119	0.074
	20	221	0.17	542	0.05	140	0.078
	25	231	0.13	564	0.05	159	0.075
	26	231	0.13	30	0.01	51	0.015
	30	231	0.14	40	0.02	60	0.044

frequency bands. Instrument C has a minimum actual measurement time of about 50–70 ms under different SWT settings and has relatively stable measurement uncertainty below 0.1 dB in each frequency band. So Instrument C is better employed for real-time RFI detection.

With this analysis and Table 2, the configurations of SWT in different frequency bands are as follows:

- 100 MHz–2 GHz: When SWT is set to 1 ms, Instrument C has the shortest actual measurement time, about 70 ms, and a measurement uncertainty of about 0.001 dB.
- 2–5 GHz: When SWT is set to 20 ms, Instrument C has the shortest actual measurement time and the lowest measurement uncertainty, about 59 ms and 0.031 dB.
- 5–13 GHz: When SWT is set to 26 ms, Instrument C has the shortest actual measurement time and the lowest measurement uncertainty, about 51 ms and 0.015 dB.

Combining the theoretical analysis, test results, and actual-measurement requirements, we formulated the high real-time measurement parameter configuration shown in Table 3.

Table 3. High real-time measurement parameter configuration

Frequency band	W_{RB} (kHz)	W_{VB} (kHz)	C_{points}	SWT (ms)
100 MHz–2 GHz	30	300	10,001	1
2–5 GHz	100	300	15,001	20
5–13 GHz	300	1,000	25,001	26

5. Conclusion

In this article, we deeply analyzed the key parameters of a spectrum analyzer and proposed a parameter configuration method. This method was applied to three different commercial spectrum analyzers, and we achieved a favorable parameter configuration scheme with respect to actual measurement time and measurement uncertainty which can be used for real-time RFI detection.

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