Simulation Analysis of RBW Parameters of Spectrum Analyzer Based on Convolution Approach

Dongchu Su 1*, Jian Yang 1, Chunxing Yuan 1, Bowei Chang 1, Siwei Luo 1, and Chenyong Li 1

1China Huayin Weapon Test Center, Huayin, Shaanxi, 714200, China
*Corresponding author’s E-mail: sudongchu@nudt.edu.cn

Abstract: Resolution Band Width (RBW) represents the 3 dB bandwidth of the internal IF filter of the spectrum analyzer, the setting of which greatly affects the clarity of the output spectrum line of the spectrum analyzer. Its reasonable value is essential to correctly distinguish the signals of different frequencies, especially in the case of aliasing of the output spectrum. Thus, it is of great significance to study the relationship between the setting of RBW and the output spectrum. Due to the expensive spectrum analyzer, the RBW adjustment range, frequency range and output accuracy are limited, so this paper will apply an economic, RBW arbitrary adjustable, high accuracy equivalent convolution method for the simulation of the RBW parameters of the spectrum analyzer, and evaluate the effect of RBW and filter type on the degree of output spectrum aliasing based on a typical equal-amplitude two-tone signal input, and finally give setting suggestions on RBW and filter type.

1. Introduction

(1) The basic structure of a swept spectrum analyzer

![Figure 1 Structure of swept spectrum analyzer](image)

The structure of the conventional swept spectrum analyzer is shown in Figure 1[1][2][3][4]. Radio Frequency (RF) signal and noise signal through the feeder, by the RF front-end for amplification, filtering and other pre-processing operations, will get a more pure RF signal, when introduced into the
mixer and the local oscillator (LO) for mixing, the output signal spectrum has been shifted, the obtained signal through the bandwidth of the RBW IF filter, filtered out high frequency and useless signal, and then carried on logarithmic amplification, detection, video filtering and other processing, and finally obtained the RF signal spectrum, and the corresponding spectral line amplitude, as the Y-axis of the screen, while the frequency value of the LO by time step is used as the X-axis value of the screen refresh[6].

(2) Analysis of the signal processing process of the swept spectrum analyzer

It is assumed that the RF signal with analysis is \( s(t) \), the LO signal is \( f_c(t) \), and the LO period is \( T_c = \frac{1}{f_c} \). In order to facilitate the analysis of the expansion of the RF signal, it is needed to make \( s(t) \) as \( T_c = nT_c \) (\( n \) is a natural number) for the period of the extended topology, \( \tilde{s}(t) \) will be obtained by the periodic signal, and Fourier series expansion will be obtained as follows:

\[
\tilde{s}(t) = a_0 + \sum_{n=1}^{\infty} \left[ a_n \cos(nw_c t) + b_n \sin(nw_c t) \right]
\]

Where, \( a_0 \) is the signal DC component, \( a_n \) and \( b_n \) are Fourier series, \( w_c \) is the amplitude of the LO.

The output signal \( s_i(t) \) is obtained by mixing \( \tilde{s}(t) \) with \( f_c(t) \):

\[
s_i(t) = \tilde{s}(t) \cdot f_c(t) = \tilde{s}(t) \cdot \left[ A_c \cos(w_c t) \right]
\]

\[
= a_0 A_c \cos(w_c t) + A_c \sum_{n=1}^{\infty} \left[ a_n \cos(nw_c t) \cos(w_c t) + b_n \sin(nw_c t) \cos(w_c t) \right]
\]

Where, \( A_c \) is the amplitude of the LO.

An alternative expression of \( s_i(t) \) obtained from the prosthaphaeresis of trigonometric functions:

\[
s_i(t) = a_0 A_c \cos(w_c t) + \frac{A_c}{2} \sum_{n=1}^{\infty} \left[ a_n \cos(nw_c t + w_c t) + a_n \cos(nw_c t - w_c t) + b_n \sin(nw_c t + w_c t) - b_n \sin(nw_c t - w_c t) \right]
\]

\[
= C_0 \cos(w_c t) + \sum_{n=1}^{\infty} \left[ C_n \cos(nw_c t + w_c t + \varphi_1) + D_n \cos(nw_c t - w_c t + \varphi_2) \right]
\]

Where, \( C_0 \), \( C_n \) and \( D_n \) represent the amplitude of the frequency components, \( \varphi_1 \) and \( \varphi_2 \) are the phase generated after merging the same frequency trigonometric function, and are constants.

Via the analysis of the frequency components in the \( s_i(t) \), it is known that when \( n = 1 \), the \( D_0 \) amplitude of the zero frequency components can be obtained, and the value is proportional to the amplitude value of the spectral lines \( f = f_c \) in the spectrum \( s(t) \). So, the process of obtaining \( D_0 \), also called frequency screening, \( D_0 \) can be used as a reference value for the output amplitude of the spectrum analyzer.
It should be noted that in practical applications, \( s(t) \) is usually used for high carrier frequency signals, and after mixing with the frequency \( f_c \), the DC component of the corresponding frequency cannot be directly obtained, but the IF component with the amplitude of \( D_0 \) and the frequency of \( f_0 - f_c \) (\( f_0 \) is assumed to be RF signal carrier frequency), needs to go through the IF filtering, logarithmic amplification, detection and other operations, thereby obtaining the relative value of \( D_0 \) as the Y-axis value of the spectrum.

(3) Equivalent RBW simulation modeling analysis

It is supposed that the amplitude response of the IF filter is \( H(f) \), the input RF signal \( s(t) \) is a single-tone signal with the frequency of \( f_0 \). After the above mixing process, two frequency components are obtained with frequency of \( f_0 + f_c \) and \( f_0 - f_c \), both amplitudes of which are \( D_0 \). While the IF filter only retains \( f_0 - f_c \) component, the amplitude response value at \( f_0 - f_c \) frequency is \( H(f_0 - f_c) \). When the value of \( f_c \) changes, the component \( f_0 - f_c \) will sweep the amplitude response of the filter, so that the amplitude of the output spectrum is affected by \( H(f) \) and \( D_0 \) of the joint modulation of the spectrum analyzer, and the final output spectrum of the spectrum analyzer is:

\[
S_{out}(f) = \sum_{f_0 - f_c}^{f_c} D_0 \delta\left(f - (f_0 - f_c)\right) \cdot H(f)
\]

Where \( f_1 \) is the starting point of the frequency sweep, and \( f_2 \) is the ending point of the frequency sweep. It is assumed that the \([f_1, f_2]\) interval is divided into equal parts, so that \( f_c = f_1 + \frac{i}{n}(f_2 - f_1), (i \in [0, n], \mathbb{I} i \in \mathbb{Z}) \) and the step frequency is noted as \( \Delta f_c = \frac{f_2 - f_1}{n} \), when \( \Delta f_c \) tends to be infinitesimal, the above equation can be rewritten as:

\[
S_{out}(f) = \lim_{n \to \infty} \sum_{i=0}^{n} D_0 \delta\left(f + f_0 - f_c\right) \cdot H(f) \cdot \Delta f_c
\]

\[
= \lim_{n \to \infty} \sum_{i=0}^{n} D_0 \delta\left(f + f_0 - f_c\right) \cdot H(f_c - f_0) \cdot \Delta f_c
\]

\[
= D_0 \int_{f_1}^{f_2} \delta\left(f + f_0 - \tau\right) H(\tau - f_0) d\tau
\]

\[
= D_0 \delta\left(f + f_0\right) * H(f - f_0)
\]

\[
= D_0 H(f)
\]

The above results show that: after the single-tone signal is subsequently processed by the IF filter and the spectrum analyzer, the spectrum is obtained as the convolution of the amplitude response of the IF filter and the single-tone signal. Since the periodic signal can be expanded in steps, the general signals can be decomposed into the sum of several single-tone signals after the periodic extension. The conclusion can be easily extended to the case where the general signal functions as the input, that is, the results of the convolution of the input signal spectrum and the amplitude response of the IF filter functions can be regarded as the output of the spectrum analyzer, which is also the theoretical basis for the simulation.
(4) RBW simulation model flow

![Simulation flow chart](image)

The simulation process is shown in Figure 2\cite{5,7}. First, the finite impulse response (FIR) bandpass filter with a specific RBW is designed as the IF filter of the spectrum analyzer, and then after the spectrum of the input signals and the amplitude response of the IF filter correspond to the frequency axis, they are jointly entered into the convolution module, and the convolution results are output on the screen. It is needed to evaluate the degree of aliasing will be evaluated by the ratio of the peak and bottom values of the output spectrum, record the value and RBW, and then determine whether the 0 dB aliasing point is reached, if it is reached, the peak and bottom values of the output spectrum are equal. At this time, it is impossible to distinguish the signals of different frequencies, and then the test enters the end of the program phase, otherwise the RBW will be changed and the test is returned to the filter design phase to continue to run the program.

(5) Typical signal RBW simulation
The single-tone RBW simulation is shown in Figure 3, the single-tone frequency is 20 MHz and the bandpass filter ranges from 10MHz to 30MHz, i.e., RBW=20MHz. The shape of the convolution result is consistent with the IF filter amplitude response, which also shows that the convolution process does not change the center frequency of the signal, but makes the bandwidth of the spectral line “expand” into the bandwidth of the IF filter (RBW).

Figure 4 shows the simulation of two-tone RBW, and the input signal frequency contains 15MHz, 25MHz. The spectral line spacing is 10MHz, and the bandpass filter ranges from 10MHz to 30MHz, RBW = 20MHz. The simulation results show that the input signal frequency spacing and IF filter bandwidth (RBW) together determine the degree of aliasing of the simulation output spectral line. When the input signal frequency spacing is larger or RBW is smaller, the degree of signal aliasing is lower.

Figure 5 shows the simulation of BPSK signal RBW, the input signal is a BPSK signal with a symbol rate of 2 MHz, and the bandpass filter ranges from 10MHz to 30MHz, RBW = 20MHz. The simulation results show that the BPSK signal spectrum is concentrated in two frequency bands, and the degree of signal aliasing is lower.
Figure 6 BPSK signal RBW simulation (RBW=2 MHz)

The above figures show the BPSK RBW simulation with the center carrier frequency of 20MHz and code rate of 2Mbps. When RBW=20MHz, the output spectral peaks are mixed with each other and only one spectral peak can be observed; when RBW=2MHz, multiple spectral peaks can be clearly observed. Therefore, when observing signals with multiple spectral peaks, RBW can be reduced appropriately to reduce the degree of spectral peak aliasing.

2. Simulation analysis of the effect of RBW setting on the output spectrum aliasing

In order to quantify the specific relationship between the RBW setting and the degree of output spectral peak aliasing, the output spectrum of the equal-amplitude two-tone signal in the spectrum analyzer is taken as the subject of study hereby, and the corresponding value of the peak of the output spectrum is set to peak and the corresponding value of the bottom value of the spectrum is set to bottom, as shown in Figure 7(a). The ratio of the two is used to measure the degree of aliasing and expressed in logarithm:

\[ Alia = 10 \log_{10} \frac{\text{bottom}}{\text{peak}} \]

Then the RBW is traversed for simulation, and the relationship between the RBW and the degree of aliasing can be obtained as shown in Figure 7(b), which uses the type of filter as the equal sound wave filter. When the \( Alia \) value is 0dB, \( peak = \text{bottom} \), the two spectral peaks cannot be distinguished at this time; when \( Alia = -3dB \), the bottom value of the aliasing bottom is about half of the height of the spectral peaks, and in the spectrum analyzer with decibels indicating the spectral peaks, it is also commonly used to distinguish the maximum degree of aliasing of the two spectral peaks, when
3. Simulation analysis of the effect of different filter types on the output spectrum aliasing

The derivation process of the above equivalent convolution simulation method yields that the sound wave jitter degree and roll-off range of the IF filter [8] have a huge impact on the output spectrum, and these two indicators vary greatly in different types of filters. The simulation was performed by changing the filter types, and the results are shown in Table 1.

| Filters types | -3dB   | -6dB   | -10dB  | -20dB  | -25dB  |
|---------------|--------|--------|--------|--------|--------|
| Butter        | 27.561 | 24.325 | 20.860 | 14.395 | 12.154 |
| Cheby1        | 35.283 | 32.403 | 28.623 | 19.815 | 16.130 |
| Cheby2        | 23.030 | 19.948 | 16.947 | 12.486 | 11.439 |
| Ellip         | 33.670 | 30.224 | 26.150 | 18.793 | 16.828 |
| Equiripple    | 16.740 | 14.082 | 12.199 | 10.311 | 9.988  |
| Kaiserwin     | 13.670 | 12.445 | 11.466 | 10.307 | 10.079 |

From the above table, it can be analyzed that the RBW of the Cheby1 type is larger when the same degree of aliasing is reached, which indicates that this type of filter has a more generous range of RBW settings. The output spectrum through this type of filter with the same RBW settings has a lower degree of aliasing, and it is easier to distinguish different spectral peaks, so the Cheby1 filter can be used as the IF filter of the spectrum analyzer.

4. Conclusion

In this paper, the principle of the swept spectrum analyzer is firstly introduced and its signal processing process is theoretically analyzed, with emphasis on the fact that after the signal is subsequently processed by the IF filter and the spectrum analyzer, the spectrum is obtained by the convolution of the amplitude response of the IF filter, which could be considered as the theoretical basis for the simulation experiments. The simulation experiment mainly takes the equal-amplitude two-tone signal as the research subject and considers the influence on the degree of output spectrum aliasing from the RBW and filter settings respectively. Suggestions are proposed on the RBW setting and filter type selection, that is, the RBW is set to be less than the frequency difference between the two closest spectral peaks, and the filter can choose Cheby1-type filter, in the future work, it is recommended to include the effects such as the background noise into the simulation experiments. The trade-off between the RBW setting and filter selection is made in more dimensions.

References

[1] Wang W P. The basic principle of spectrum analyzer [J]. Modern Television Technology, 2000(01):33-46.
[2] Liang Q. The design of RF spectrum analyzer [D]. Hefei University of Technology, 2006.
[3] Wei J P. Time-frequency analysis technology and application [D]. Xi’an University of Electronic Science and Technology, 2005.
[4] Ban W R. The principle and development of spectrum analyzer [J]. Modern Electronics Technology, 2005(07):101-102.
[5] Dou LT, Cheng JQ, Li SM. Simulation of radar signal processing system based on Matlab [J]. Command Control and Simulation, 2006(02): 78-82.

[6] Fang XL. Application of spectrum analyzer and testing skills [J]. Cable television technology, 2006(05): 105-108.

[7] Wang DW, Jia RC, Wang HY. Design of Butterworth low-pass filter based on Matlab [J]. Modern Electronics Technology, 2012, 35(21): 71-72+75.

[8] Zhang JW, Zhan XM. Design and implementation of FIR digital filters [J]. Radio Engineering, 2010, 40(06): 54-56.