Frequency measurement technique based on frequency conversion

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Abstract: To measure the signals with high frequency(>500 MHz), a sampling frequency down conversion method is introduced. This paper analyzes the intermodulation signals and figures out the relationship between the intermodulation signal and intermediate frequency signal. Based on the frequency conversion technology, an exclusion algorithm is proposed and the actual implementation of the algorithm is given. The application results show that the exclusion algorithm can identify the intermodulation signal exactly and eliminate the bad influence on the frequency measurement.

Key words: frequency mixing; intermodulation signal; intermediate frequency; local oscillator; harmonic order

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Traditionally, the frequency measurement usually adopts counting method[1-3]. But when measuring the signals with high frequency (>500 MHz), there is no way to count the cycles directly. To solve this problem, a frequency down conversion method can be used to convert the measured signal frequency into intermediate frequency using a mixer[4-5]. In the process of frequency mixing of high power signals, the intermodulation signals inevitably lead to frequency measurement error. So, it is very important to identify the intermodulation signals and eliminate the impact of these signals.

Intermodulation signals are produced when the frequency mixing is in progress. If the intermodulation signals are just in the intermediate frequency band, they may be mistaken as the intermediate frequency signals. Thus wrong measurement results occur. Fig. 1 shows a typical frequency measurement example which is effected by the intermediate frequency.

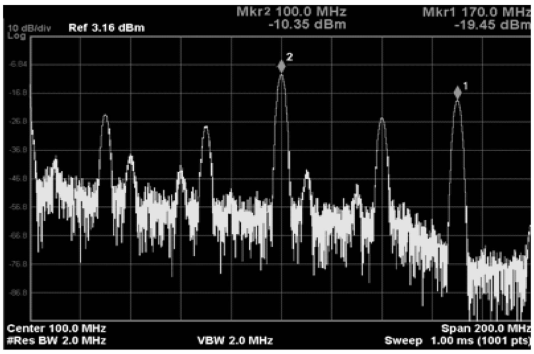

Fig. 1 Classic intermodulation signal

In Fig. 1, the frequency of the measured signal is 1.4 GHz and 3-order harmonious signal frequency of local oscillator (LO) is 1 230 MHz, so the mixed signal frequency is 170 MHz, which is not located in the intermediate frequency band (84 – 114 MHz). And then 3-order harmonious signal with 170 MHz is generated. After mixed with the LO signal with 410 MHz, a 100 MHz signal is produced, which is just located in the intermediate frequency band. Thus it will be mistaken as the real intermediate frequency signal, which leads to a wrong result of 4.2 GHz. Therefore, the key is to eliminate the effect of the intermodulation signals.

1 Relationship between intermodulation signal and intermediate frequency signal

There are two kinds of intermodulation signals which affect the frequency measurement.

One is a newly generated signal produced by the harmonious signal with intermediate frequency mixed with LO signal, which is located in the intermediate frequency band.

The other is the harmonious signal with intermediate frequency located in the intermediate frequency band.

To avoid the bad effect of the intermodulation signals, the relationship between the intermodulation signals and the intermediate frequency signal must be firstly given. We name the measured signals within the intermediate frequency band the inter-

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modulation signals, which are expressed as f'_{IF1} and f'_{IF2}, respectively. The harmonic order of LO frequency affected by the intermodulation signals is expressed as N'. The frequency calculated according to the intermodulation signal is expressed as f'_{in}. The real intermediate frequency signals are expressed as f_{IF1} and f_{IF2}, respectively. The real harmonic order of LO frequency is expressed as N. The order of the intermodulation signal is M. The LO signals are expressed as f_{LO1} and f_{LO2}, respectively. f'_{in} can be calculated by

$$f'_{in} = N' \times f_{LO1} + Sign' \times f'_{IF1} = N' \times f_{LO1} + Sign' \times | f_{LO1} - M \times f_{IF1} |. \quad (1)$$

1.1 For the first kind of intermodulation signal

The frequency of the first kind of intermodulation signal has the following form

$$f'_{IF1} = | M \times f_{IF1} - f_{LO1} |. \quad (2)$$

Then the following expression can be got

$$f_{IF1} = \begin{cases} \dfrac{f_{LO1} + f'_{IF1}}{M}, & M \times f_{IF1} > f_{LO1}, \\ \dfrac{f_{LO1} - f'_{IF1}}{M}, & M \times f_{IF1} < f_{LO1}. \end{cases} \quad (3)$$

N' and N can be represented as

$$N' = \left| \frac{f'_{IF1} - f'_{IF2}}{f_{LO1} - f_{LO2}} \right| = \left| \frac{M \times (f_{IF1} - f_{IF2})}{f_{LO1} - f_{LO2}} - 1 \right|,$$

$$N = \left| \frac{f_{IF1} - f_{IF2}}{f_{LO1} - f_{LO2}} \right|. \quad (4)$$

Furthermore, the relationship among N', N and M is described as

$$N' = \begin{cases} | M \times N - 1 |, & \dfrac{f_{IF1} - f_{IF2}}{f_{LO1} - f_{LO2}} > 0, \\ | M \times N + 1 |, & \dfrac{f_{IF1} - f_{IF2}}{f_{LO1} - f_{LO2}} < 0, \end{cases}$$

$$= \begin{cases} M \times N - 1, & \dfrac{f_{IF1} - f_{IF2}}{f_{LO1} - f_{LO2}} > 0, \\ M \times N + 1, & \dfrac{f_{IF1} - f_{IF2}}{f_{LO1} - f_{LO2}} < 0 \end{cases} \quad (5)$$

$$N = \begin{cases} \dfrac{N' + 1}{M}, & \dfrac{f_{IF1} - f_{IF2}}{f_{LO1} - f_{LO2}} > 0, \\ \dfrac{N' - 1}{M}, & \dfrac{f_{IF1} - f_{IF2}}{f_{LO1} - f_{LO2}} < 0. \end{cases} \quad (6)$$

1.2 For the second kind of intermodulation signal

The frequency of the second kind of intermodulation signal has the following form

$$f'_{IF1} = M \times f_{IF1}. \quad (7)$$

Then the following expression can be got

$$f_{IF1} = \frac{f'_{IF1}}{M}. \quad (8)$$

Furthermore, N' and N can be calculated and the relationship among N', N and M can be described as

$$N' = \left| \frac{f'_{IF1} - f'_{IF2}}{f_{LO1} - f_{LO2}} \right| = M \times \left| \frac{f_{IF1} - f_{IF2}}{f_{LO1} - f_{LO2}} \right| = M \times N, \quad (9)$$

$$N = \frac{N'}{M}. \quad (10)$$

Eqs. (6) and (10) present the relationship among N', M and N, respectively. If the measured signal in the intermediate frequency band is the intermodulation signal, N' and N absolutely have the abovementhioned relationship.

2 Frequency conversion algorithm to eliminate intermodulation signals

With increase of the harmonious time, the amplitude of the intermodulation signals will decrease dramatically. The high order intermodulation signals will no longer affect the frequency measurement. The practice show that only 2-order and 3-order intermodulation signals have impact on the measurement. So only the lower order intermodulation signals need to be identified. In order to completely eliminate the bad influence of the intermodulation signals, this paper analyzes the 2, 3 and 4 order intermodulation signals.

2.1 Enumeration and analysis of frequency of input signal under the influence of intermodulation signals

Due to not knowing whether the signal located in the intermediate frequency band is the intermodulation signal, supposing that all the measured signals within intermediate frequency band are the intermodulation signals. The remaining work is to validate and exclude them one by one.

In Eqs. (6) and (10), N' is known, and all the states of the two kind of intermodulation signals can be listed when M equals 2, 3 or 4. As is known that N', M and N are the positive integers. All the cases that N is non-integer can be excluded directly. And then N is picked out when it is integer. For any value of N, the possible values of intermediate frequency can be calculated according to the intermodulation signals (the intermediate frequency is expressed as the expected value, f_{IFHope}), and then the measured frequency of the signal is calculated, which is expressed as f_{inHope}.

For the first kind of intermodulation signal, f_{IFHope} and f_{inHope} can be calculated by

$$\begin{cases} f_{\mathrm{IFHope}} = \dfrac{f_{\mathrm{LO}} + f'_{\mathrm{IF}}}{M}, \quad M \times f_{\mathrm{IFHope}} > f_{\mathrm{LO}}, \\ f_{\mathrm{inHope}} = N \times f_{\mathrm{LO}} + sign \times f_{\mathrm{IFHope}}, \end{cases} \tag{11}$$

$$\begin{cases} f_{\mathrm{IFHope}} = \dfrac{f_{\mathrm{LO}} - f'_{\mathrm{IF}}}{M}, \quad M \times f_{\mathrm{IFHope}} > f_{\mathrm{LO}}, \\ f_{\mathrm{inHope}} = N \times f_{\mathrm{LO}} + sign \times f_{\mathrm{IFHope}}. \end{cases} \tag{12}$$

For the second kind of intermodulation signal, f_{IFHope} and f_{inHope} can be calculated by

$$\begin{cases} f_{\mathrm{IFHope}} = \dfrac{f'_{\mathrm{IF}}}{M}, \\ f_{\mathrm{inHope}} = N \times f_{\mathrm{LO}} + sign \times f_{\mathrm{IFHope}}. \end{cases} \tag{13}$$

2.2 Theory of frequency conversion and control flow in the process of eliminating effect of intermodulation signals

For any expectation of input frequency f_{inHope}, a group of ideal frequencies of LO signals can be calculated to measure this frequency. Setting the LO frequency as the ideal value and comparing the expected frequency value with the actual measured frequency value, if the two values are identical, the supposition is correct. That is to say, the signals located in the intermediate frequency band are the intermodulation signals. Thus scanning LO frequency should stop and it should be an ideal LO frequency to be measured[6], or else the supposition is wrong. Other supposed cases are sequentially validated. If all the supposed cases are excluded, it can be sure that the measurement is immune from intermodulation signals and the result is adoptable. Only local oscillator needs to be set and frequency measurement needs to be done. From the above procedure, it can be seen that the validation and exclusion of the intermodulation signals are realized at the same time.

Under the influence of the intermodulation signals, the effective frequency conversion of the LO signal can be realized rapidly and its impact can be excluded. Thus the signal frequency can be measured correctly. The second kind of intermodulation signal is relatively simple, so it is firstly validated. The exclusion procedure of the second kind of intermodulation signal is shown in Fig. 2. The exclusion procedure of the first kind of intermodulation signals is shown in Fig. 3.

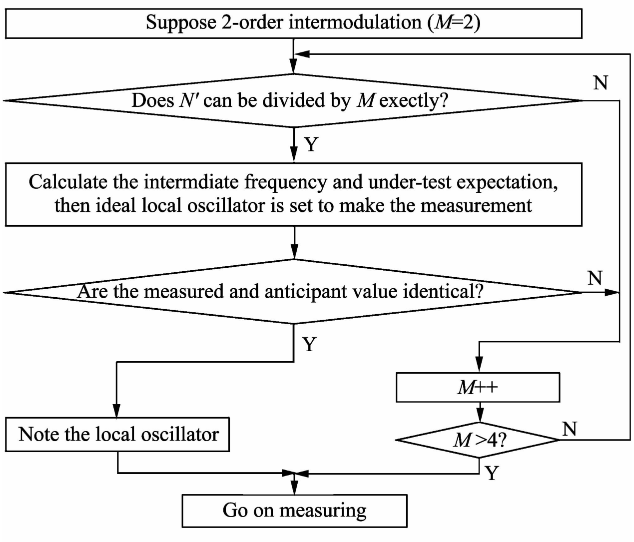

Fig. 2 Exclusion procedure of the second kind of intermodulation signal

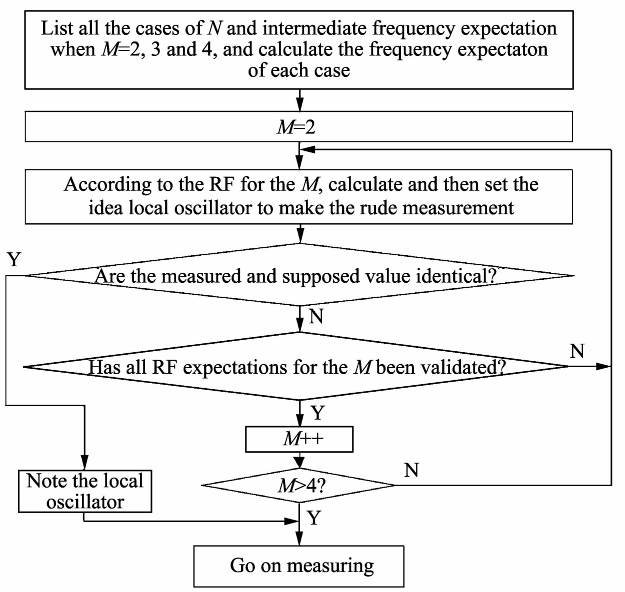

Fig. 3 Exclusion procedure of the first kind of intermodulation signal

3 Conclusion

If frequency measurement uses sampling down conversion method, the influence of the intermodulation signals will be more and more obvious with the increasing power of the measured signal. According to the relationship among N, N' and M, when LO frequency conversion is controlled effectively, the intermodulation signals can be validated and excluded rapidly. The actual applications prove that this frequency conversion method can eliminate the intermodulation signals that affect the frequency measurement and ensure the frequency measurement precision, especially for the higher power signals. The measuring effect is better than the traditional radio frequency validation method. This method can measure the frequency of the signal with a power of 20 dBm. The dynamic range of power measurement is expanded and the measurement precision is improved. Table 1 shows the contrast of power range of frequency measurement instruments.

Table 1 Contrast of power range of frequency measurement Instrument

	This case	Agilent 53150A
Input power range of the signal under-test	−32—+20 dBm	50 MHz—2 GHz: −33—+5 dBm 2—20 GHz: −33—+13 dBm

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