Analysis of Mechanism of Blocking Interference Using Power Series Method

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Abstract: In the complex electromagnetic environment, blocking interference is one of the most important reasons that cause the performance of Radio equipment to degrade. In this paper, the gain compression principle caused by blocking interference is analyzed with the power series method. The results show that the gain of the useful signal is compressed by strong off-band interference, and the stronger the interference signal, the more severe the gain compression. In order to verify the theoretical analysis, experimental research is carried out with PPI display radar. The experimental results are consistent with the theoretical analysis.

1. Introduction

With the rapid development of electronic technology, more and more measurement and sensing equipment uses electromagnetic waves as the carrier of signals. The large number of applications of radio equipment makes the spectrum resources increasingly tense. Coupled with natural and man-made electromagnetic sources, radio equipment is facing increasingly complex electromagnetic environment [1]. Interference between radio devices that are heavily used in a certain space often occurs, resulting in their failure to function properly. The blocking interference discussed in this paper is one of the main causes of this problem.

2. Analysis of the mechanism of blocking interference

When a useful signal and a strong interference signal enter the receiver at the same time, the strong interference signal pushes the device that originally operates in the linear region into the nonlinear region, causing nonlinear distortion and even saturate the device. It will result in sensitivity reduction of the victim receiver which will completely lose the ability to receive the signal in severe cases. This phenomenon is the receiver blocking, and the corresponding interference is called blocking interference [2].

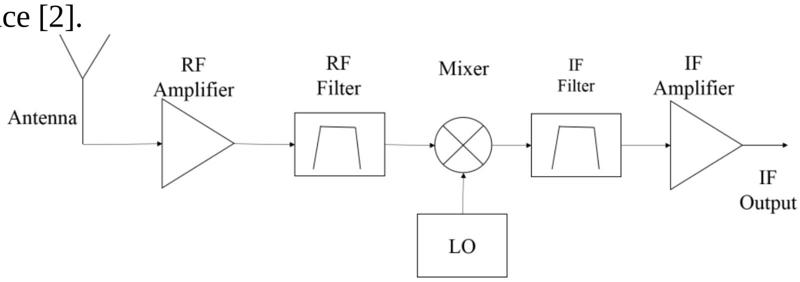

Fig.1 Block diagram of a typical super heterodyne receiver

Blocking interference typically occurs at amplifier of receiver RF front-end (see Fig.1). RF amplifiers enter nonlinear region due to large signal intrusions. As shown in Fig.2, its input and output characteristics can be analyzed using the power series method [3].

$$u_o = b_0 + b_1 u_i + b_2 u_i^2 + b_3 u_i^3 + \cdots \tag{1}$$

Where u_o is the output signal. u_i is the input signal. b_n is a series of factors related to the characteristics of the device.

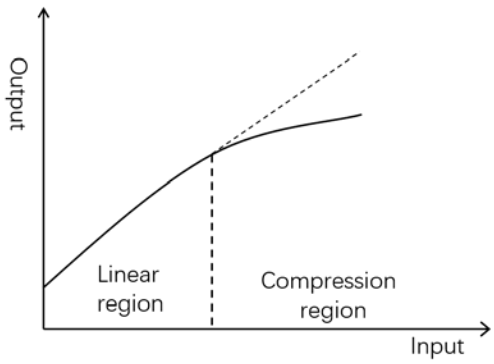

Fig. 2 Characteristic curve of RF amplifier

If the input signal is small, the amplifier operates in the linear region. The input and output characteristics of the device can be described by taking only the first two elements of the power series.

$$u_o = b_0 + b_1 u_i \tag{2}$$

At this point, the output signal will vary proportionally with the input signal. This is the ideal operating state for the amplifier. Assuming that the gain of the amplifier is G, then

$$G = 20\log_{10}(b_1) \tag{3}$$

When the input signal amplitude is large, the amplifier will operate in a nonlinear region (see Fig.2). The relationship between the input signal and the output signal must be described by using the formula (2) instead of the formula (1). Considering the accuracy and simplicity of calculation, the first four items of the power series are generally taken in engineering.

$$u_o = b_0 + b_1 u_i + b_2 u_i^2 + b_3 u_i^3 \tag{4}$$

The mechanism of blocking interference is analyzed with the formula (4). Supposing the input signal for RF amplifier is

$$u_i = U_1 \cos\omega_1 t + U_2 \cos\omega_2 t \tag{5}$$

Where $u_1=U_1\cos\omega_1 t$ is the useful signal, and $u_2=U_2\cos\omega_2$ is the interference signal. Using formula (4) and formula (5), the output signal u_o can be obtained. The results are simplified by triangular function formula.

$$
\begin{aligned}
u_o &= b_0 + \frac{1}{2}b_2U_1^2 + \frac{1}{2}b_2U_2^2 \\
&+ (b_1U_1 + \frac{3}{4}b_3U_1^{\,3} + \frac{3}{2}b_3U_1U_2^{\,2})\cos\omega_1 t \\
&+ (b_1U_1 + \frac{3}{4}b_3U_1^{\,3} + \frac{3}{2}b_3U_1^{\,2}U_2)\cos\omega_2 t \\
&+ \frac{1}{2}b_2U_1^2\cos 2\omega_1 t + \frac{1}{2}b_2U_2^2\cos 2\omega_2 t \\
&+ b_2U_1U_2[\cos(\omega_1+\omega_2)t + \cos(\omega_1-\omega_2)t] \\
&+ \frac{1}{4}b_3U_1^{\,3}\cos 3\omega_1 t + \frac{1}{4}b_3U_2^{\,3}\cos 3\omega_2 t \\
&+ \frac{3}{4}b_3U_1^{\,2}U_2[\cos(2\omega_1+\omega_2)t + \cos(2\omega_1-\omega_2)t] \\
&+ \frac{3}{4}b_3U_1U_2^{\,2}[\cos(2\omega_2+\omega_1)t + \cos(2\omega_2-\omega_1)t]
\end{aligned} \tag{6}
$$

The first line in the formula (6) is the DC component. The second and third lines are the useful signal and interference signal components. The fourth line is the second harmonic component. The fifth line is the second-order intermodulation component. The sixth line is the third harmonic component, and the seventh and eighth line is the third-order intermodulation components. It shows that when the useful signal and the strong interference signal are fed into the receiver RF amplifier at the same time, due to the nonlinear effect of the device, the output signal contains DC, base wave component ω_1, ω_2, Second and third harmonic component $2\omega_1$, $2\omega_2$, $3\omega_1$, $3\omega_2$, second-order intermodulation component $\omega_1 \pm \omega_2$, and third-order intermodulation component $2\omega_1 \pm \omega_2$, $2\omega_2 \pm \omega_1$.

Using (6), the gain of useful signal can be calculated as

$$
\begin{aligned}
G_1 &= 20\log_{10}\left[\frac{(b_1U_1 + \frac{3}{4}b_3U_1^{\,3} + \frac{3}{2}b_3U_1U_2^{\,2})\cos\omega_1 t}{U_1\cos\omega_1 t}\right] \\
&= 20\log_{10}(b_1 + \frac{3}{4}b_3U_1^{\,2} + \frac{3}{2}b_3U_2^{\,2})
\end{aligned} \tag{7}
$$

It is known that b3 is a small negative number [4]. Then, there is G1<G. It indicates that the presence of strong signal compresses the gain of the useful signal. And the stronger the interference signal, the more severe the gain compression. This is the gain compression principle caused by blocking interference.

From another perspective, owing to the nonlinear effects of the device, harmonics and intermodulation frequency components appear in the output signal. These newly generated frequency components take up a portion of the energy provided by the RF amplifier, while the energy provided by the amplifier is limited. Therefore, from the perspective of energy conservation, it can also be explained why the gain of the useful signal is compressed. These harmonic and intermodulation frequency components can bring great damage to the receiving performance of the receiver, which is the main reason for the performance degradation of the receiver due to blocking.

3. Experimental study on blocking interference effect

In order to study the influence of blocking interference on the victim receiver, we conducted experiment on a PPI radar. The experimental system consists of SMR20 signal generator (1~18GHz), RF coaxial line, 1~18GHz horn antenna, PPI radar, corner reflector, etc. The interference antenna is 3m away from the radar and the corner reflector is 90m away from the radar. The radar, the interference antenna, and the corner reflector are on a horizontal line 1m away from the ground. The experiment was carried out on an open test site. (See Fig.3)

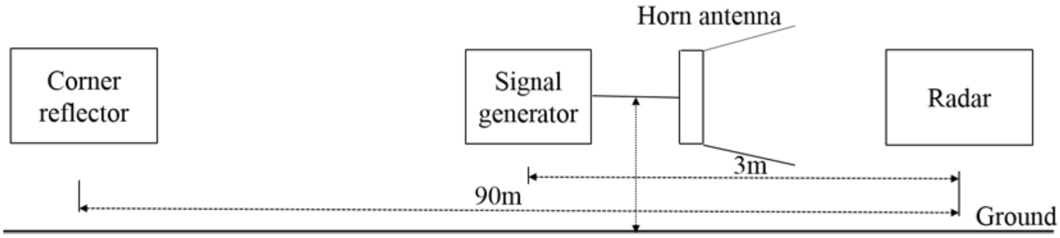

Fig. 3 Block diagram of the experimental system

3.1 Experimental procedure

Step1. Connect the equipment according to the test plan. Turn on the radar equipment. Observe the radar display and determine the imaging and position of the corner reflector.

Step2. Set the signal source waveform as single-frequency continuous wave, the frequency as f0+50MHz (f0 is the operating frequency of the radar.), and the power as -25dBm. Turn on the signal source RF output. Then observe the radar display imaging.

Step3. Gradually increase the power of the interfering signal source. Observe the radar display until the image of the corner reflector disappears completely on the radar display.

Step4. Continue to increase the power of the interfering signal source and observe the radar display changes.

3.2 Experimental phenomena and analysis

It was found in the experiment that when the interference was applied, the small target image on the radar display was first suppressed. As the interference power increased, the gray level of the corner reflector image became weak until it completely disappeared. In addition, the scanned image had a gap in the direction of interference. As the interference power continues to increase, the radar scan image was opened in multiple directions.

Fig. 4 blocking interference effect of PPI radar

With the principle of PPI radar imaging, the experimental phenomena are analyzed. For PPI display radar, only the targets whose return signal's amplitude is greater than the set threshold will be displayed on the screen. More specifically, the signal-to-noise ratio of the echo should be greater than a certain value [5]. Without interference, the target’s echo is amplified appropriately by the amplifiers in the receiver and the radar system work properly. When interference is applied, the useful signal is suppressed due to the blocking effect. Thus, output signal-to-noise ratio is lowered. Small targets are first compressed and can’t be imaged normally, because their echo is weak. Decrease in gain and the increase in noise make the signal-to-noise ratio of the weak signal unsatisfactory for normal operation. This phenomenon can be explained by formula (7).

As the interference power increases, the imaging of large targets begins to be suppressed. Additionally, the radar scanned image appears a gap in the direction of interference, indicating that the useful signal reception of the radar in the direction of interference is completely blocked. When we further increase the interference power, the radar scan image appears gap in the non-interference direction. It shows that strong blocking interference overloads the radar receiver which loses the receiving capability not only in the direction of interference but also in other direction (see Fig.4). This phenomenon indicates that when the radar is subjected to strong blocking interference, it takes a certain amount of time to resume normal operation.

4. Conclusion

In this paper, the mechanism of receiver blocking is analyzed and experimentally verified. Some useful conclusions are revealed.

(1) Power series method is used to analyze the mechanism of blocking interference. The results show that the nonlinear effect caused by out-of-band interference is the main reason of receiver blocking. Because of the nonlinear effect, harmonics and intermodulation components are generated in the output signal, and the gain of the desire signal is compressed. These effects reduce the receiver's output signal-to-noise ratio, which in turn affects the receiver's performance.

(2) Experimental results show that blocking interference will affect the detection performance of radar system. After being disturbed by a strong signal, the targets with weak echo signal first disappear on the radar display. Because of the gain compression effect and the increase in bottom noise, amplitude of these targets' echo is below the radar detection threshold after signal processing. Increasing the intensity of interference, more targets disappear on the radar display. The experimental results are consistent with theoretical analysis. Besides, experiments reveal that it takes some time for radar to return to normal from functional failure caused by strong signal blocking.

(3) In complex electromagnetic environments, blocking interference is a potential threat to any device that uses the electromagnetic spectrum, including measuring instruments, communications equipment, and sensors. Blocking interference should be taken into account when designing and using these devices.

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