Analysis of Interference Cancellation Ratio Requirement for Co-site Interference Mitigation between AM and FM Systems

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***Abstract*—In mobile platforms such as vessels, because the antenna spacing between the different transceivers is small, when several transceivers are simultaneously transmitting and receiving, mutual interference will occur. At present, the most effective method to solve this problem is to adopt adaptive interference cancellation technique. The analysis of the interference mechanism and the cancellation requirement has important guiding significance for designing the cancellation system. In this paper, we focus on amplitude modulation (AM) and frequency modulation (FM) systems. We present comprehensive mathematical models for the interference mechanism of AM and FM systems, based on which a closed formula is proposed to calculate the interference cancellation ratio requirement. Numerical results show that the analytical models proposed in this paper are more accurate than the existing models.**

Keywords—adaptive interference cancellation; AM; FM; interference mechanism; interference cancellation ratio requirement

I. INTRODUCTION

Adaptive interference cancellation technology is an effective method to solve the problem of co-site radiated interference [1-2]. The adaptive interference cancellation system has different requirements to achieve interference cancellation performance according to the different communication systems and interference signal power intensity. In general, we can use the interference cancellation ratio, i.e., the ratio of the interference signal power before and after the cancellation, to measure the performance. Because co-site interference may have strong signal power which may saturate the Low Noise Amplifier (LNA) work in nonlinear region without an ideal output. So it is desperately in need to analyze the interference mechanism and put forward the corresponding specific interference cancellation ratio requirement to the different interferences.

In existing studies, the researchers always take the single frequency signal as a starting point to analyze the interference mechanism, and separately analyze the interference mechanism of AM and FM communication systems[3]. In this paper, we analyze the mechanism of the wideband interference and unify the interference mechanism of AM and FM communication systems. In [3], the interference mechanism mathematical model of the Short Wave (SW) and Ultrashort Wave (USW) is deeply studied and the relationship between the interference cancellation ratio requirement and the interference signal power intensity is put forward. But the author make some assumptions during the analytical derivation and just get the simplified analytical results, while the curve between the interference cancellation ratio requirement and the intensity power of the interference signal is given, but it can only meet the general trend and the error is big.

In this paper, we first analyzed the interference model and the interference cancellation ratio requirement of the communication systems. Then we carried on the detailed analytical derivation of the interference cancellation ratio requirement between the FM and AM systems. Thirdly, we made simulation verification on the analytical derivation combined with numerical simulation and given out the curve of the interference cancellation ratio requirement of the AM and FM communication systems with a comparative analysis for the model in reference [3]. At last, we made a summary for the whole article.

II. INTERFERENCE MODEL AND INTERFERENCE CANCELLATION RATIO REQUIREMENT

The co-site interference model for AM or FM radio is shown in Fig.1. In the communication platform such as ships, because the limited space, the close range between the sending and receiving antennas can cause a low space isolation degree. Due to the power of co-site transmitter is large, the signal of transmitter will couple into the receiver through space when the other communication equipment work at the same time.

In practice, the bandwidth of the AM and FM radio is wide, i.e., the bandwidth of the pre-select filter of the receiver's RF front-end is also wide. Therefore, the emission signal can directly couple into the LNA through the pre-select filter when the other transmitter work at the same time. Due to the limited linear area of the LNA, the strong interference can cause the LNA will work in the nonlinear area, even saturate. The nonlinear effect of the LNA will produce new frequency component such as the same frequency interference, harmonic

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interference and intermodulation (IM) interference. When the LNA's output go through the down-conversion and filter processing, most of the out-of-band signals can be get rid of, and ultimately the same frequency interference which produced mainly by the nonlinear effect of the LNA can cause interference to the useful signals. Here the function of the ICR device is to suppress the interference.

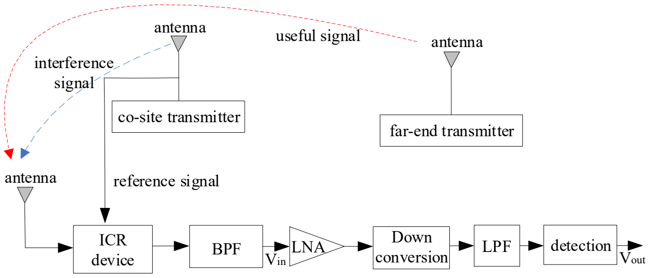


Fig.1 Model of co-site interference

In this section, we first conduct the model of nonlinear effect of the LNA, and get the relationship between the output Signal to Interference Ratio (SIR) and the input SIR of the for the receiver, then make an analytic analysis on the interference cancellation ratio requirement.

A. *The LNA's nonlinear model*

The nonlinear of the LNA can be described as follows[2,4]:

$$f(x)=\sum_{n=0}^{\infty} a_n x^n \tag{1}$$

In Eq.1, $f(x)$ is the output of the LNA, x is the input of the LNA, a_n is the nonlinear factor. In general, we can ignore the components because the power of the dc component and nonlinear component exceed the third order is relatively very low.

Let's suppose that V_{in} is the input voltage of the LNA, then the output can be described as follows:

$$V_{\text{out}}=a_1 V_{\text{in}}+a_2 V_{\text{in}}^2+a_3 V_{\text{in}}^3 \tag{2}$$

In Eq.2, a_1、a_2、a_3 are depend on the gain of the LNA[5].

$$a_1=10^{G/20}, a_2=a_1/10, a_3=-4a_1/\left(3A_{IP3}^2\right) \tag{3}$$

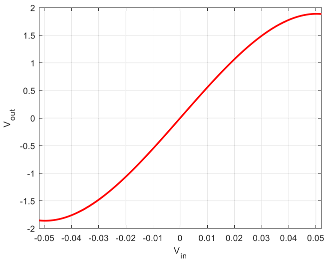


Fig.2 Relationship between the LNAs' input and output voltage

Let's suppose that ω_1 is the carrier frequency of the useful signal, ω_2 is the carrier frequency of the interference signal, $z_1(t)$ and $z_2(t)$ are respectively the complex envelope of the useful signal and interference signal, so the input of the LNA can be expressed as follows:

$$V_{\text{in}}=\mathrm{Re}\left\{\sqrt{2}z_1(t)e^{j\omega_1 t}+\sqrt{2}z_2(t)e^{j\omega_2 t}\right\} \tag{4}$$

Then take the Eq.4 into the Eq.2, we can get all the frequency components of the LNA. In fact, only the same frequency component which contain frequency ω_1 can fall into the in-band of the receiver. So the Signal to Interference Noise Ratio(SINR) can be expressed as follows:

$$\begin{aligned} SINR_{out} &= \frac{\mathrm{E}\left\{\alpha_1^2\left|z_1(t)\right|^2\right\}}{\mathrm{E}\left\{\left|\frac{3\alpha_3}{2}z_1(t)\left|z_1(t)\right|^2+3\alpha_3 z_1(t)\left|z_2(t)\right|^2+w(t)\right|^2\right\}} \\ &= \frac{\alpha_1^2 m_{z_1,2}}{\frac{9\alpha_3^2}{4}m_{z_1,6}+9\alpha_3^2 m_{z_1,4}m_{z_2,2}+9\alpha_3^2 m_{z_1,2}m_{z_2,4}+\sigma_w^2} \end{aligned} \tag{5}$$

In Eq.5, m_k is the kth moments of the random variable, so the second, fourth and sixth order moments of $z_1(t)$ and $z_2(t)$ are $m_{z_1,2}=\mathrm{E}\left\{\left|z_1(t)\right|^2\right\}$, $m_{z_1,4}=\mathrm{E}\left\{\left|z_1(t)\right|^4\right\}$, $m_{z_1,6}=\mathrm{E}\left\{\left|z_1(t)\right|^6\right\}$, $m_{z_2,2}=\mathrm{E}\left\{\left|z_2(t)\right|^2\right\}$ and $m_{z_2,4}=\mathrm{E}\left\{\left|z_2(t)\right|^4\right\}$ respectively.

B. *Interference cancellation ratio requirement analysis*

Also in Fig.2. The mixed useful signal and interference signal from the receiver antenna and the reference signal from the co-site transmitter antenna altogether will enter into the LNA after the interference cancellation, then the interference will be suppressed so as to ensure the LNA work in the linear area.

Let's suppose that the cancellation ratio is ρ, then the power after interference cancellation is $\rho E(|z_2(t)|^2)$, so when we put it into the Eq.5, the SINR of the output signal can be obtained as follows:

$$SINR=\frac{\alpha_1^2 m_{z_1,2}}{\frac{9\alpha_3^2}{4}m_{z_1,6}+9\rho\alpha_3^2 m_{z_1,4}m_{z_2,2}+9\rho^2\alpha_3^2 m_{z_1,2}m_{z_2,4}+\sigma_w^2} \tag{6}$$

When the output SINR is known, the Interference Cancellation Ratio (ICR) requirement ρ can be obtained as follows:

$$\rho=\frac{-9\alpha_3^2 m_{z_1,4}m_{z_2,2}SINR+\sqrt{\left(9\alpha_3^2 m_{z_1,4}m_{z_2,2}SINR\right)^2-36\alpha_3^2 m_{z_1,2}m_{z_2,4}SINR\left(\frac{9\alpha_3^2}{4}m_{z_1,6}SINR+\sigma_w^2 SINR-\alpha_1^2 m_{z_1,2}\right)}}{18\alpha_3^2 m_{z_1,2}m_{z_2,4}SINR} \tag{7}$$

From the Eq.7, the ICR requirement has the strong relationship between the second, fourth and sixth order moments of the useful signal and interference signal, so the ICR requirement depend on the modulation form of signal. In the next part, we will analyze the ICR requirement between AM and FM systems.

III. ANALYSIS ON ICR REQUIREMENT OF CO-SITE AM AND FM RADIOS

A. *Co-site FM radio interference*

FM signal[6] can be represented as:

$$a(t)=A_c\exp\left\{j2\pi f_\Delta\int_{t_0}^{t}x(t)\,dt\right\}\exp(j\omega t) \tag{8}$$

In Eq.8, A_c represents the signal amplitude, $x(t)$ represents the modulation signal, f_Δ represents the frequency deviation, ω represents the signal carrier frequency, $2\pi f_\Delta\int_{t_0}^{t}x(t)\,dt$ represents the instantaneous frequency.

Let's suppose that the waveform of the useful signal is $z_1(t)\exp(j\omega_1 t)$ and the waveform of the interference signal is $z_2(t)\exp(j\omega_2 t)$. Because the FM signal has the uniform envelope, so the second, fourth and sixth moment are $m_2{=}A_c^2$, $m_4{=}A_c^4$, $m_6{=}A_c^6$ .So the moments of the useful signal and interference signals are $m_{z_1,k}{=}A_{c1}^k$ and $m_{z_2,k}{=}A_{c2}^k$ respectively.

B. *Co-site AM radio interference*

AM signal[6] can be represented as:

$$a(t)=A_c\left[1+\mu x(t)\right]e^{j\omega t} \tag{9}$$

In Eq.9, A_c represents the signal amplitude, μ represents the modulation depth, ω represents the signal carrier frequency, $A_c[1+\mu x(t)]$ represents the complex envelope, $x(t)$ represents the modulation signal, it is the gaussian distribution with the zero mean and σ^2 variance.

Let's suppose that the waveform of the useful signal is $A_{c1}[1+\mu_1 x_1(t)]\exp(j\omega_1 t)$ and the waveform of the interference signal is $A_{c2}[1+\mu_2 x_2(t)]\exp(j\omega_2 t)$ .So the second, fourth and sixth moment are as follows:

$$m_2{=}E\left\{\left(A_c\left|1+\mu x(t)\right|\right)^2\right\}=A_c^2\left(1+\mu^2\sigma^2\right)$$

$$m_4{=}E\left\{\left(A_c\left|1+\mu x(t)\right|\right)^4\right\}=A_c^4\left(1+6\mu^2\sigma^2+3\mu^4\sigma^4\right)$$

$$m_6{=}E\left\{\left(A_c\left|1+\mu x(t)\right|\right)^6\right\}=A_c^6\left(1+15\mu^2\sigma^2+45\mu^4\sigma^4+15\mu^6\sigma^6\right)$$

So the moments of the useful signal and interference signals are $m_{z_1,2}$, $m_{z_1,4}$, $m_{z_1,6}$, $m_{z_2,2}$, $m_{z_2,4}$.

C. *Analysis on ICR requirement*

In this part, the output SINR of the receiver and the ICR requirement of the interference system to the victim system are derived with the moments information as follows.

1. FM to FM

$$SINR=\frac{a_1^2A_{c1}^2}{\frac{9a_3^2A_{c1}^6}{4}+9a_3^2A_{c1}^4A_{c2}^2+9a_3^2A_{c1}^2A_{c2}^4+\sigma_n^2} \tag{10}$$

$$\rho=\frac{-9\alpha_3^2A_{c1}^4A_{c2}^2SINR+\sqrt{\left(9\alpha_3^2A_{c1}^4A_{c2}^2SINR\right)^2-36\alpha_3^2A_{c1}^2A_{c2}^4SINR\left(\frac{9\alpha_3^2}{4}A_{c1}^6SINR+\sigma_n^2SINR-\alpha_1^2A_{c1}^2\right)}}{18\alpha_3^2A_{c1}^2A_{c2}^4SINR} \tag{11}$$

2. AM to AM

$$SINR=\frac{a_1^2m_{z1,2}}{\frac{9a_3^2}{4}m_{z1,6}+9a_3^2m_{z1,4}m_{z2,2}+9a_3^2m_{z1,2}m_{z2,4}+\sigma_n^2} \tag{12}$$

$$\rho=\frac{-9\alpha_3^2 m_{z_1,4}m_{z_2,2}SINR+\sqrt{\left(9\alpha_3^2 m_{z_1,4}m_{z_2,2}SINR\right)^2-36\alpha_3^2 m_{z_1,2}m_{z_2,4}SINR\left(\frac{9\alpha_3^2}{4}m_{z_1,6}SINR+\sigma_n^2 SINR-\alpha_1^2 m_{z_1,2}\right)}}{18\alpha_3^2 m_{z_1,2}m_{z_2,4}SINR} \tag{13}$$

3. AM to FM

$$SINR=\frac{a_1^2A_{c1}^2}{\frac{9a_3^2}{4}A_{c1}^6+9a_3^2A_{c1}^4m_{z2,2}+9a_3^2A_{c1}^2m_{z2,4}+\sigma_n^2} \tag{14}$$

$$\rho=\frac{-9\alpha_3^2A_{c1}^4m_{z_2,2}SINR+\sqrt{\left(9\alpha_3^2A_{c1}^4m_{z_2,2}SINR\right)^2-36\alpha_3^2A_{c1}^2m_{z_2,4}SINR\left(\frac{9\alpha_3^2}{4}A_{c1}^6SINR+\sigma_n^2SINR-\alpha_1^2A_{c1}^2\right)}}{18\alpha_3^2A_{c1}^2m_{z_2,4}SINR} \tag{15}$$

4. FM to AM

$$SINR=\frac{a_1^2m_{z1,2}}{\frac{9a_3^2}{4}m_{z1,6}+9a_3^2m_{z1,4}A_{c2}^2+9a_3^2m_{z1,2}A_{c2}^2+\sigma_n^2} \tag{16}$$

$$\rho=\frac{-9\alpha_3^2m_{z_1,4}A_{c2}^2SINR+\sqrt{\left(9\alpha_3^2m_{z_1,4}A_{c2}^2SINR\right)^2-36\alpha_3^2m_{z_1,2}A_{c2}^4SINR\left(\frac{9\alpha_3^2}{4}m_{z_1,6}SINR+\sigma_n^2SINR-\alpha_1^2m_{z_1,2}\right)}}{18\alpha_3^2m_{z_1,2}A_{c2}^4SINR} \tag{17}$$

IV. SIMULATION RESULTS

In this section, we make the analytic comparison for the four kinds of combination of the signals after the above theoretical analysis. And the simulation parameters are as follows:

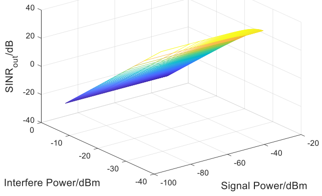
Tab. I Simulation Parameters

type	*parameters value*
LNA	a_1=56.23, a_2=5.623, a_3=-7497.33
FM	k_1=1, k_2=1
AM	u_1=0.6, u_2=0.6

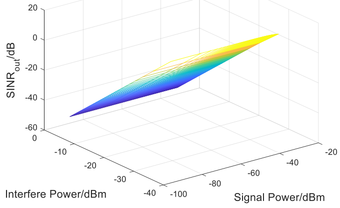
Where k_1 and k_2 are the phase-modulated sensitivity.

A Output of the receiver

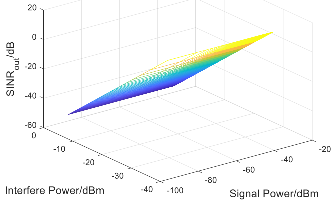
Through the Eq.10,12,14 and 16, we can get the SINR of FM or AM radio under the condition of FM or AM interference along with the power changing of the useful signal and interference signal is shown in Fig.4. These figures show that the effective output of SIR to a certain communication system will decrease along with the increasing input power of the interference signal and increase along with the input power of the useful signal. When the power of the useful signal is a fixed value, and in order to obtain a certain effective output. The interference can be eliminated or reduced to a certain intensity by the cancellation system, so as to realize the effective communication.



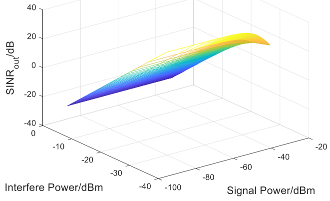
(a) FM to FM



(b) AM to AM



(c) FM to AM



(d) AM to FM

Fig.4 Three-dimension diagram of the output of the SINR

B Results of the ICR requirement

When the power of useful signal is -56.02dBm, the power of the noise is -105dBm, if we want to obtain the 10dB output SIR. The ICR requirement changes along with the changing of interference intensity through the Eq.11,13,15 and 17 are in Fig.5.

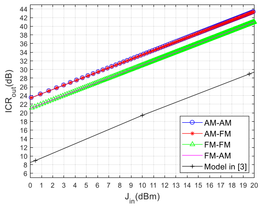


Fig.5 Relationship between the ICR and interference intensity

The Fig.5 shows that the ICR requirement increases along with the interference signal power intensity under the given condition. When the power of interference signal is 10 dBm, it approximately need 33.52dB ICR for the AM to AM systems and AM to FM systems. And it approximately need 31.02dB ICR for the FM to FM systems and FM to AM systems. From the Fig.5, it can easily notice that the ICR requirement is approximately same for the AM to AM system and AM to FM system and also the same for the FM to FM system and FM to AM system. And the ICR requirement obtained in this paper are all 11.7dB higher than the result in [3].

V. CONCLUSION

The method given in this paper is more accurate. And the ICR requirement is determined by the modulation mode of the interference signal but not on the modulation mode of the victim system. In addition, ICR requirement for AM interfere are 2.5dB higher than the FM systems under the same interference condition.

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