Passive Intermodulation Interference in Helicopter Platform RF Communication System

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Abstract. This paper discusses the research status of Passive Intermodulation (PIM) on helicopter platforms, and mainly analyzes the reasons for the formation of PIM interference on it. RF devices that may generate PIM interference are analyzed at the same time. Taking the PIM interference of L-band antenna as an example, the existence of PIM problem on the helicopter platform was verified by means of electromagnetic simulation. The PIM Product (PIMP) of the RF device commonly used on the helicopter was tested to further prove that the PIM problem on it should be taken seriously.

Introduction

Intermodulation products (IMP) are generated when the two-tone signal passes through the components. When this phenomenon happens on passive components, it will be called by Passive Intermodulation (PIM). PIM problems tend to occur in the following three scenarios: (1) some relatively small spaces, (2) high power RF signal scene, (3) scenes with a large number of nonlinear effects sources. Helicopter platform meets the above three conditions. At the same time, in order to meet the needs of long-distance communication and multi-band communication, many high-sensitivity receivers is equipped in the helicopter. When the PIMP falls exactly within the receiver’s frequency band, receiver sensitivity would be greatly affected and sometimes even the whole communication system would be damaged [1]. Under normal circumstances, there will be set more than ten kinds of antennas. In order to increase space utilization, many antennas adopt a common structure. Using this form of antenna will further increase PIMP in the system.

Various types of helicopters are not only widely used in various military and naval services, but also have a wide range of applications in the civilian field. Wide range of applications means high environmental diversity. At the same time, due to the relatively long service life of helicopter platforms, the aging of the devices is more serious. A variety of changes in conditions lead to a significant increase in PIMP. With the continuous development of modern communication technology, both military and civilian fields require helicopter to have longer communication distances and better communication quality. Therefore, the problem of PIM cannot be ignored in a space-constrained helicopter.

This paper mainly analyzes the components and devices that may produce PIM on helicopter platform. Based on the perspective of PIM mechanism, analysis of the mechanisms that may affect the type and intensity of PIMP on helicopters.

PIM in Helicopters

PIM Introduction

PIM has been named as ‘Rusty bolt effect’, this phenomenon was first observed on ships that required receiving antennas and transmitting antennas to coexist in a limited space. At that time, it was caused by corrosion of the antenna structural elements [2].

We cannot avoid such interference in helicopters. When two or more frequency signals pass through the same passive RF component, the transmitted signal will be coupled and distorted due to
the non-linear voltage-current relationship in the component. At this point, we can express the transfer function of the component as:

\[ f(x) = k_1 x_1 + k_2 x_2 + k_3 x_3 + \ldots \]  \hfill (1)

Where \( x \) is the input signal, \( f(x) \) is the output signal and \( k_1, k_2 \) are coefficients that depend on nonlinear device.

We assume that there are \( N \) carriers and their input frequencies are \( f_1, f_2, \ldots, f_n \). The intermodulation product (IMP) can be defined as:

\[ f_{\text{pim}} = m_1 f_1 + m_2 f_2 + \ldots + m_n f_n. \]  \hfill (2)

Where \( f_{\text{pim}} \) is the PIMP's frequency.

The order of PIMP can be defined as:

\[ C = \Sigma_{i=1}^{\infty} |m_i|. \]  \hfill (3)

Where \( C \) is the order of PIMP.

**PIM Mechanism**

PIM is fundamentally due to the passive nonlinear effects of linear components which are commonly considered. The PIM in RF band communication systems mainly comes from contact non-linearity and material non-linearity. Contact non-linearity represents any contact-induced nonlinear problem with nonlinear current/voltage behavior such as loose contact point, oxidation and corrosion of mental connections. Material non-linearity refers to the non-linearity caused by materials with inherently nonlinear conductive properties like the non-linearity of ferromagnetic materials and carbon fiber [3].

In the design stage of the device, the use of ferromagnetic materials and other materials which tend to generate non-linearity are generally avoided. In the requirements of the US military specification MIL-C-39012B and the Chinese military standard GJB681A for materials, it is stipulated that all parts (outside of the gas-sealed connectors) should be made of non-magnetic materials, and the material permeability should be less than 2.0. These standards also specify the materials used for the contact center and housing, the type of plating metal and the thickness of the plating. By these means, PIM can be effectively avoided. Therefore, when we study the PIM of helicopter platforms, we mainly consider the effects of contact non-linearity.

When two conductive connectors are connected, there will exist four contact states as follows: 1) Metal-Metal contact (MM), 2) Metal-Oxide-Metal Contact (MOM), 3) Metal-Insulating Media-Metal (MIM), 4) Air gap.

The contact method is shown in Figure 1.

The point effects on the contact surface mainly include three effect of resistance effect, capacitance effect and tunneling effect [4].

We can usually model the equivalent circuit of this kind of micro contact. Through the analysis of the physical contact surface, the contact surface is in parallel with the non-contact surface. Because the current is mainly transmitted through the solid-state contact points and the non-contact blank area current is small enough to neglect. So the non-contact area is considered as an open circuit analysis [5]. The equivalent circuit is shown as Figure 2.
Where $R_S$ is the shrinkage resistance, $R_{MM}$ is the MM resistance, $R_T$ is the tunneling effect resistance, $R_{NC}$ is the non-contact resistance, $C_C$ is the contact capacitance, $C_{NC}$ is the non-contact capacitance.

**L-band PIM Analysis on Helicopter**

The helicopter platform has a limited volume. The largest known helicopter is the Soviet Union’s Mi V-12 heavy-duty transport helicopter with a 37-meter fuselage length. General helicopters are generally less than 20 meters in length. In a limited space, the helicopter system is equipped with several types of RF equipment. The interference generated by these systems will not only exist within the system, but also between systems. This paper takes a helicopter L-band communication system as an example to analyze the PIM problem may exist in the helicopter platform.

**L-band PIM Frequency Analysis**

The L-band antenna has a frequency range of 960 ~ 1224 MHz. In this band, there are abundant RF transceivers, including omnidirectional antennas, answering machines, and navigation antennas. The composition of the L-band communication system is shown as Figure 3.

The PIMP are easily generated in the multi-coupler, cables and connectors used to transmit the high power signals. Assume that the center frequencies of ration stations $R_{S1}$ and $R_{S2}$ are $f_1 = 1030$ MHz and $f_2 = 1040$ MHz. When two RF stations share one antenna for transmission, PIM3 products will generate at $f_{P31}$ and $f_{P32}$.

\[
\begin{align*}
    f_{P31} &= 2f_1 - f_2 \\
    f_{P32} &= 2f_2 - f_1
\end{align*}
\]

The spectrogram of signals and PIMP are shown in Figure 4.

When the antenna’s receive band covers the PIMP frequency point, L-band radio’s performance will be affected.

**L-band Antenna Radiation Analysis**

This paper analyzes the near-field environment of L-band antenna and analyzes the PIM problem that may occur when the antenna is shared.
The transmission power for airborne L-band radios is 60 W. The simulation band is set at 900–1300 MHz. The near-field effect of the antenna is calculated by using the MLFMM algorithm. The near-field effect’s simulation results are shown in Figure 5.

![Figure 5. Electric Field Distribution at f = 1020 MHz, y = 0.64m.](image)

When the L-band antenna can receive and transmit signals at the same time, the PIMP radiated from the L-band antenna is likely to fall within its own receiving frequency band, thereby receiving self-interference signal interference from itself and causing the communication link performance to deteriorate.

**Experimental Verification and Analysis**

This study is validated by experimental analysis. We make the 1m long RF coaxial cable used 6 month and the N-type coaxial connector as the DUT. And we use the standard part which PIMP3’s power equals -110 dBm for comparison. PIM test methods are mainly divided into transmission method and reflection method [6]. When testing dual-port devices, reflection method will be the more accurate one. The schematic of the transmission method is shown as Figure 6.

![Figure 6. Reflection Method Test System.](image)

The power of the dual-tone signal is $2 \times 43$ dBm, and the test system uses a low intermodulation test fitting with an intermodulation value of -165 dBc. The PIM3 amplitudes of the coaxial cable and the coaxial connector under this band were measured in the range of 1020 ~ 1050 MHz. At the same time, the change in PIM3 within 15 seconds was also tested at $f = 1020$ MHz. The test data is shown in Figure 7.

The cables and connectors under test simulate the state of the radio components of the helicopter platform in normal use. In the actual installed state, there may be more severe conditions due to the lack of corresponding design standards for the RF components on the helicopter platform.

From the test data, the PIM3 generated by the coaxial cable and the coaxial connector is higher than the limit value. The limit value depend on the sensitivity of the receiver. When the amplitude of PIM3 is higher than the sensitivity of the receiver, it will have a significant impact on the system. Receiver sensitivity is typically less than -75 dBm.
The data shows that our PIM3 to be tested is around -105 dBC, that is, when the transmit power is 47 dBm, PIM3 is -62 dBm. This result obviously does not meet the requirements.

Conclusion
When the helicopter performs tasks in a relatively harsh environment, RF devices used on it are easily degraded. For this reason, RF devices generate PIMP when exposed to high power signals. This research combines the means of simulation and experiment to demonstrate the PIM problem on the helicopter platform. Developed a foundation for further research on PIM of airborne RF equipment.

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References
[1] Zhang shiquan, Ge Debiao, Intermodulation interference due to passive nonlinearity in communication systems, J. Journal of Shanxi Normal University. 32 (2004) 58-62.
[2] Wang Haining, Liang Jianguang, Wang Ji Qin, Zhang Chenxin, Review of Passive Intermodulation in HPM Condition, J. Journal of Microwaves. 21 (2005) 1-6.
[3] Luo Yifeng, Approach to Passive Intermodulation in Ship Communication System, J. Modern Electronics Technique. 23 (2010) 39-44.
[4] Jiang Jie, On Mechanical-Thermal-Electrical Effect of Passive Intermodulation in Microwave Devices, D. Xidian University, 2016.
[5] Wan Lipeng, Zhao Xiaolong, Cao Zhi, He Yongning, Calculation and Verification of Passive Intermodulation Caused by Electrothermal Coupling on Microstrip Transmission Line, J. Journal of Xi’an Jiaotong University. 52 (2018) 58-62+109.
[6] Zelenchuk D E, Shitov A P, Schuchinsky A G, et al. Passive intermodulation generation on printed lines: near-field probing and observations, J. IEEE Transcactions on Microwave Theory and Techniques. 12 (2008) 3121-3128.