Electromagnetic Compatibility Effects on Antenna Pattern of Spaceborne SAR

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Abstract. Due to the limitation of satellite size, electromagnetic compatibility (EMC) effects on the antenna pattern should be taken into account, especially in the case of small satellite platform. In this paper, the property of SAR antenna pattern is discussed firstly. Then, the effects on antenna pattern is studied and analyzed, which results in antenna pattern distortion. Moreover, considering the antenna pattern distortion, the influence on SAR image quality is present as well. Finally, simulations are performed to validate the effects caused by EMC.

Introduction

State-of-the-art spaceborne SAR systems have been widely applied in both military and civilian areas, such as monitoring [1], recognition [2], interferometry [3], rescue [4], tomography [5], and so on. With the development of spaceborne SAR technique, high-resolution, multifunction and miniaturization are the future development trends of spaceborne SAR, such as the small SAR satellite constellation, which is more flexible and can be used for meeting the requirement of different applications [6, 7].

However, due to the limitation of satellite size, the devices, such as high power emitting device, sensitive receiving device, antenna, solar arrays, are set up on satellite with close distance, which rises a challenge for electromagnetic compatibility (EMC) design. Therefore, in order to obtain high quality SAR image result, EMC design should be taken into account, especially the effects on antenna pattern caused by EMC.

The effects on radar system due to EMC have been researched in past years. A review of the technical requirements of radar engineering design and electromagnetic compatibility was present in [8], as well as some standards. To analyze the EMC effects on pulse-Doppler radar system, a novel approach for evaluating EMC performance was proposed in [9], which provided a model for describing the receiver two-signal selectivity characteristics. In [10], a measurement model was provided for radar electromagnetic compatibility analysis, which analyzed the attenuation coefficient of radar maximum range by considering the EMC. The impact on ultra wide band radar (UWBR) systems was presented in [11], discussing the electromagnetic interference and compatibility aspects pertaining to UWBR systems. Moreover, EMC effects on airborne radar and shipborne radar system were studied in [12] and [13] respectively, which supports the system optimal design and is benefit for improving the system performance. However, the EMC effects on spaceborne SAR antenna pattern have not been sufficiently discussed. As an active microwave imaging radar, SAR antenna pattern have direct influence on the imaging quality. Therefore, it is very meaningful to analyze EMC effects on SAR antenna pattern.

In this paper, we focused on the research of the effects on spaceborne SAR antenna pattern caused by EMC, which is organized as follows: The characteristic of SAR antenna pattern is reviewed in Section II. In Section III, the effects on SAR pattern is analyzed, as well as the discussion of the
influence on SAR image quality. Simulation are performed in Section IV, and the conclusions are provided in Section V.

**Characteristic of SAR Antenna Pattern**

In order to realize high-resolution and improve the compression gain, linear frequency modulation (LFM) signal is used to obtain high-resolution in range dimension combined with matched filtering technique, and the synthetic aperture technique is adopted to achieve high-resolution in azimuth dimension. Therefore, considering the modulation of antenna pattern, the echo signal $S(\tau,t)$ can be written as follow:

$$S(\tau,t) = A_a(\theta_a) \cdot A_r(\theta_r) \cdot p \left( \frac{\tau}{T} \right) \cdot \exp \left\{ -j \cdot \pi \cdot b \cdot \left( \frac{\tau - \frac{2r(t)}{c}}{c} \right)^2 \right\} \cdot \exp \left\{- j \frac{4\pi r(t)}{\lambda} \right\}$$ (1)

where $A_a$ and $A_r$ represent the azimuth antenna pattern and range antenna pattern respectively. $\theta_a$ and $\theta_r$ represent azimuth and range off-bore-sight angles. $\tau$ is the range time, $t$ is the azimuth time, $b$ is the signal frequency modulation rate, $c$ is the light speed, $\lambda$ is the wavelength, $r(t)$ is the instantaneous distance between target and satellite, and $p[\cdot]$ is the envelope of LFM.

Since antenna pattern have significant influence on SAR image quality, we should discuss the characteristic of antenna pattern. Taking azimuth antenna pattern for example, theoretically, antenna pattern can be simply calculated by

$$A_a(\theta_a) = \frac{\sin \left( \frac{\pi L}{\lambda} \theta_a \right)}{\frac{\pi L}{\lambda} \theta_a}$$ (2)

where $L$ is antenna length.

However, in practice, the phased array antenna is usually used in spaceborne SAR system. Therefore, the antenna pattern is determined by feed array configuration, which can be calculated by

$$A'_a(\theta_a) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \exp \left\{ \frac{2\pi}{\lambda} \cdot d \cdot \left[ (n-1) \cdot M + m - 1 \right] \cdot \sin(\theta_a) - \frac{2\pi}{\lambda} \cdot d \cdot \left[ (n-1) \cdot M \right] \cdot \sin(\theta_{\text{max}}) \right\}$$ (3)

where $d$ is the distance between two adjacent feeds, $N$ represents the number of Transmitter and Receiver (T/R) module, and $M$ represents the number of feed of each T/R module.

According to the Eq. 3, if the T/R modules are affected due to EMC, the distortion of antenna pattern will occur, which may result in the antenna gain loss and the antenna pointing error.

**EMC Effects on SAR Antenna Pattern**

Taking EMC effects into account, the interference signal will be introduced in every feed, which lead to the distortion of antenna. In this paper, we assume that the interference signal of each feed are statistically independent, and they obey the Gauss distribution with zero-mean. Thus, the statistically distribution of interference signal is given by
\[ g(x) = \frac{1}{\sqrt{2\pi \delta_i}} \exp\left\{ -\frac{x^2}{2\delta_i^2} \right\} \] (4)

where \( \delta_i^2 \) is the variance of interference signal corresponding the \( i \)th feed.

In order to analyze the EMC effects, we perform a simple simulation with the parameters listed in Table 1. As shown in Fig. 1, under different conditions, the antenna pattern have significant difference, especially in amplitude and antenna pointing, which will affect the SNR and ambiguities to signal rate (ASR) of SAR image [14].

![Antenna pattern under different conditions](image)

Figure 1. Antenn pattern under different conditions.

**Simulation**

In order to illustrate the effects caused by EMC, simulations are employed in this section, with the parameters list in Table 1. Moreover, the EMC effects on SNR and ASR are also analyzed, as shown in Fig. 2. According the simulation results, the effects on SNR and ASR caused by EMC cannot be ignored, which should be taking into account during system design.

| Parameters               | Values |
|--------------------------|--------|
| Wavelength               | 0.03 (m) |
| Antenna length           | 3.0 (m) |
| Number of T/R modules    | 10     |
| Number of feeds          | 10     |
Summary
In this paper, EMC effects on antenna pattern was studied. First, the characteristic of the phased array antenna was discussed, and the antenna pattern calculation method was provided as well. Combined with the antenna pattern, the EMC effects on antenna pattern, as well as the SNR and ASR were analyzed supported by simulation results. Finally, the conclusions are drawn which is benefit for system optimal design.

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