Influence of Public Mobile Communication System on the Frequency of S-Band Radars

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Abstract: Given the interference between public mobile communication system and S-band radars, an applicable interference analysis model was established, the typical frequency parameters of radar and the key parameters of the base station were sorted out, the radiation parameters of the mobile terminal (MT) were tested practically, and the interferences of the base station and MT to radar were calculated. Further, the Monte Carlo method was taken to simulate the system-level lumped interference of the communication system to radar, and an analysis was made on the influence of the communication system on the frequency of radar. The results revealed that the public mobile communication system had severe lumped interference with radar, which may affect radar frequency. Therefore, it is necessary to take measures to protect radar.

1 Introduction
Since being used for actual combat in 1936, radars have been developed into conventional pulse monostatic radars from the initial bistatic meter-wave radars. As needed, many new system radars have also been developed, such as the pulse compression radar, pulse-Doppler radar, synthetic aperture radar, frequency-agile radar and phased array radar. With outstanding reconnaissance and positioning functions, radars have been provided on various combat platforms on land, sea, air, and space for modern electronic warfare, becoming an indispensable part of modern weapons and equipment. The military has deployed a certain number of radars in each frequency band. Due to the intrinsic transmission characteristics of electromagnetic waves, the radars deployed in the 2 - 4 GHz frequency band (S-band) are mainly used for surveillance, alert, early warning and other combat missions. In the actual battlefield, S-band radar can play its due combat effectiveness and ensure China's national defense security only when it is not interfered by other electromagnetic signals.

In recent years, public mobile communication systems have been widely used worldwide because of their characteristics such as high speed, low latency, and large connections. To present, China has initially built up the largest public mobile network in the world. Public mobile communication requires a large amount of radio spectrum resources due to its unique technical characteristics. In the light of this condition, China has successively allocated the spectrums of 2,500 - 2,690 MHz, 3,300 - 3,600 MHz and other frequency bands to construct public mobile communication. Whereas there are spectrums shared by public mobile communication and S-band radars, the public mobile communication system is quite likely to pose co-frequency, adjacent-frequency, and spurious interferences to S-band radars, affecting the effectiveness of Chinese military radars.

In China and foreign countries, there is much research on the interference and anti-interference of radar[1-2] and much analytical research on the coexistence between communication systems and radar

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But in most of the research, simulating calculation was made based on the theoretical parameters of the communication system, resulting in non-convincing results with less practical application value. Few researchers adopted the measured radiation parameters of the equipment to study the interference between communication systems and radar. In this paper, the measured radio frequency characteristics of MT and the typical parameters of radar will be used to study the influence of communication systems on the frequency of S-band radars.

2 Theoretical Analysis of the Interference with Radar from Public Mobile Communication

2.1 Analysis of the Interference Mechanism

Fig. 1 shows the coupling path in which public mobile communication interferes with S-band radars. When a target is detected and monitored by the radar, the signal entering the frequency band of the radar receiver is not only a radar echo signal, but also contains the uplink/downlink signal of the communication system. When the interference with radar from the communication system reaches a certain threshold, the interference may become harmful to the radar and affect the normal functioning of the radar system.

![Fig. 1 The mechanism of interference with radar from the public mobile communication system](image)

2.2 Interference Analysis Model

To ensure radar exerts combat effectiveness in a complex electromagnetic environment, the interference-to-noise ratio (I/N) protection criterion (a conservative principle) should be reached under the sensitivity condition of the radar receiver [4].

The co-frequency and adjacent-frequency interferences with radar from a base station or terminal device of the communication system were calculated by the following equation [5].

\[ I_I = P_T + G_T + G_R - L_p(d) - FDR(\Delta f) \]  

(1)

Where,
- \( I_I \) is the power of interference with radar from a base station/terminal device \( i \), in dBm;
- \( P_T \) is the transmit power of the base station/terminal device, in dBm;
- \( G_T \) is the transmitting antenna gain of the base station/terminal device in the direction to the radar, in dBi;
- \( G_R \) is the receiving antenna gain of the radar in the direction to the base station/terminal device, in dBi;
$L_p(d)$ is the path loss when the distance between the base station/terminal device and the radar is $d$, dB. Due to the mobility of the terminal device, the distance may be short; hence the loss can be calculated using the Okumura-Hata propagation model. As the base station is generally far from the radar, the loss can be calculated using the ITU-R P.1546 propagation model.

$FDR(\Delta f)$ is the frequency suppression factor, in dB; it is defined as:

$$FDR(\Delta f) = -10 \log \left( \frac{\int_{-\infty}^{+\infty} P(f) | H(f + \Delta f) |^2 df}{\int_{-\infty}^{+\infty} P(f) df} \right) \text{ dB}$$

(2)

Where,

- $P(f)$ is the power spectral density of base station/terminal device signal, in W/kHz;
- $H(f)$ is the frequency response of the intermediate-frequency (IF) filter for the radar receiver;
- $\Delta f$ is the frequency interval between the radar receiver and the base station/terminal device, in kHz; when $\Delta f = 0$, the interference is co-frequency interference.

The lumped interference with radar from the communication system was calculated using the following equation:

$$I_{\text{total}} = 10 \times \log \left( \sum_{i=1}^{n} 10^{\frac{I_i}{10}} \right)$$

(3)

Where, $I_{\text{total}}$ is the lumped interference with radar from $n$ terminal devices in the communication system, in dBm;

The bottom noise of the radar receiver is mainly produced by the thermal motion of charged particles; the noise power is:

$$N = -174 + 10 \log B + NF$$

Where, $B$ is the IF bandwidth, in Hz; and $NF$ is the noise factor, in dB.

$I/N$ determines the maximum detection range of radar, which is related to the characteristic parameters of the radar, the parameters of the interference signal, the propagation environment of radio waves and other factors. This index can comprehensively evaluate the degree of interference with radar.

3 Typical Parameters

3.1 Basic Parameters of S-Band Radars

S-band radars are mainly used for surveillance, alert, early warning and other combat missions. Without loss of generality, this paper takes the Recommendation ITU-R M.1464 for reference [4]. The typical frequency parameters of the radar in the S-band (Table 1) are used to calculate the interference with radar from the public mobile communication system. The $I/N$ protection criterion of radar is -10 dB. In the following simulating calculation, these typical parameters of radar are adopted for analytical calculation.

| Parameter                | Value                                      |
|--------------------------|--------------------------------------------|
| Frequency                | 2,700 - 3,400 MHz                          |
| Platform type            | Ground and air defense platforms           |
| Transmit power           | 60 kW                                      |
| Pulse width              | 0.4 - 40 $\mu$s                            |
| Rise/fall time of the pulse | 10 - 30 $\mu$s                        |
| Repetition rate of the pulse | 550 - 1,100 Hz                      |
| Duty ratio               | <2.5                                       |
| RF transmit bandwidth    |                                            |
| - 20 dB                  | 3.5                                        |
| - 3 dB                   | 2.5                                        |
3.2 Basic Parameters of Public Mobile Communication System

(1) Parameters of Base Station

The base station of the communication system can achieve long-distance, large-scale signal coverage, which may affect S-band radars. According to the 3GPP TS.101 \cite{6} and TS.104 \cite{7} standards, the key parameters of the base station for the communication system were sorted out, as shown in Table 2.

| Parameter                          | Value       |
|------------------------------------|-------------|
| Frequency                          | 2,500 - 2,690 MHz |
| Carrier bandwidth                  | 5/10/20 MHz |
| Subcarrier spacing                 | 15 kHz, 30 kHz |
| Antenna type                       | 65° directional antenna |
| Maximum transmit power             | 43/46/46 dBm |
| Maximum gain of the antenna        | 18 dBi      |
| Antenna height                     | 30 m        |

The base station adopts a three-sector structure and 65° directional antenna. The antenna equation is as follows:

\[
A(\theta) = -\min \left[ 12 \left( \frac{\theta}{\theta_{3dB}} \right)^2, A_m \right]
\]

Where, \( \theta \) ranges from \(-180°\) to \(180°\); \( \theta_{3dB} \) refers to the width of the 3dB beam corresponding to an angle of \(65°\); \( A_m \) is the maximum attenuation of the antenna, 20. The directivity diagram of the antenna is shown in Fig. 2.

![Directivity diagram of the antenna for the basis station of public mobile communication system](image)
Fig. 3 presents the spectrum pattern of the base station when the bandwidth is 20 MHz.

(2) Parameters of MT

Considering the specific deviation between the actual radiation parameters and theoretical radiation characteristics of MT device, general-purpose tester, spectrum analyzer and other test instrumentation for public mobile communication system were used to test the radiation characteristics of MT device at different frequencies and bandwidths in conduction testing method [8][9][10]. The block diagrams of the conduction test and the spurious emission power detection are illustrated in Fig. 4 and Fig. 5. And the obtained radiation parameters of the MT device are displayed in Table 3. In the following simulating calculation, the actual test parameters in Table 3 are used for analytical calculation.
Fig. 5 Block diagram of terminal spurious emission power detection

Table 3 Test Results of the Radio Frequency Characteristics of Mobile Phone

| Parameter                        | Value            |
|----------------------------------|------------------|
| Frequency                        | 2,500 - 2,690 MHz|
| Frequency error                  | -4 Hz            |
| Frequency tolerance              | -0.002 ppm       |
| Maximum output power             | 21.6 dBm         |
| Minimum output power             | -46.9 dBm        |
| Occupied bandwidth               | 17.73 MHz        |
| Spectrum radiation pattern       | Carriers frequency range \(\Delta f_{\text{OOB}}\) | Limit, in dBm |
|                                 | 0 - 1 MHz        | -19.5          |
|                                 | 1 - 5 MHz        | -8.5           |
|                                 | 5 - 20 MHz       | -11.5          |
|                                 | 20 - 25 MHz      | -23.5          |
| Spurious emission power          | Maximum gain of the antenna | 0 dBi          |
|                                 | Antenna height   | 1.5 m          |

4 Simulating Calculation

4.1 Interference with Radar from Base Station
According to the mechanism of interference with radar from public mobile communication base station, the interference of base station to radar is mainly from the downlink and mainly affects the
main lobe and first side lobe of the radar antenna. Hence, the simulating calculation in this section is mainly made on the interference of the base station to the main lobe and first side lobe of radar (Fig. 6 and Fig. 7).

Fig. 6 The interference of base station to the main lobe of radar

Fig. 7 The interference of base station to the first side lobe of radar

Fig. 6 displays the influence of the base station signal on the I/N of radar when the signal enters the radar receiver through the main lobe of the radar antenna. When the operating frequency interval between the base station and radar is 20 MHz, and the distance between them is at least 26 km, the I/N of radar is -10 dB, which meets the I/N requirement for radar protection. The I/N requirement for radar protection is met once the frequency interval is 23 MHz and the distance is at least 20 km.
Fig. 7 shows the influence of the base station signal on the I/N of radar when the signal enters the radar receiver through the first side lobe of the radar antenna. When the operating frequency interval between the base station and radar is 20 MHz, and the distance between them is at least 19 km, the I/N of radar is -10 dB, which reaches the I/N criterion for radar protection. The I/N criterion for radar protection is reached only when the frequency interval is 23 MHz, and the distance is at least 15 km.

4.2 Interference with Radar from Terminal
The interference of mobile phone terminal to radar is mainly from the uplink, affecting the main lobe and first side lobe of the radar antenna. In this section, a simulating calculation is made on the interference of the mobile phone terminal to the main lobe and first side lobe of radar (Fig. 8 and Fig. 9).

![Fig. 8 The interference of terminal to the main lobe of radar](image1)

![Fig. 9 The interference of terminal to the first side lobe of radar](image2)
Fig. 8 demonstrates the influence of mobile phone terminal signal on the I/N of radar when the signal enters the radar receiver through the main lobe of the radar antenna. When the operating frequency interval between the terminal and radar is 25 MHz, and the distance between them is at least 4 km, the I/N of radar is -10 dB, meeting the I/N requirement for radar protection. The I/N requirement for radar protection can be met once the frequency interval is 35 MHz and the distance is at least 2 km.

Fig. 8 presents the influence of the mobile phone terminal signal on the I/N of radar when the signal enters the radar receiver through the first side lobe of the radar antenna. When the operating frequency interval between the terminal and radar is 25 MHz, and the distance between them is at least 3 km, the I/N of radar is -10 dB, reaching the I/N criterion for radar protection. The I/N criterion for radar protection can be reached once the frequency interval is 35 MHz and the distance is at least 2 km.

4.3 The Lumped Interference with Radar from Public Mobile Communication System

As shown in Fig. 10 (the cellular structure of the public mobile communication system), the distribution of base stations becomes increasingly denser, and the number of wireless mobile terminals is also increasing, resulting in a large number of dense and strong communication signals. These signals pose more and more serious interference with radars within a certain distance. Therefore, it is necessary to consider the lumped interference of the public mobile communication system to radar and analyze its influence on the frequency of radar more accurately.

Fig. 10 The cellular structure of public mobile communication system

Fig. 11 shows a public mobile communication system simulated in the Monte Carlo method [11] by random selection of terminals within a region of 10×10 km² beyond the distance $\Delta d$ from radar according to the topology of the base station [12].
Fig. 11 Simulated scenarios of public mobile communication system and radar

The height, frequency, power and other parameters of the terminal were generated randomly within a certain range to simulate the lumped interferences of the suburban base station and terminal device to the main lobe of radar, as shown in Fig. 12 and Fig. 13.

Fig. 12 The lumped interference with radar from the uplink of the public mobile communication system
Fig. 13 The lumped interference with radar from the downlink of the public mobile communication system

Fig. 12 and Fig. 13 respectively display the lumped interferences with radar from the uplink and downlink of the public mobile communication system. The following points are found by analysis: for the downlink, a distance of 47 km should be isolated from the radar; for the uplink, it depends. The larger the number of mobile phones in the region is, the larger the distance isolated from radar should be. When there are 100 terminals, a distance of 4 km should be isolated from the radar; when there are 1,000 terminals, the distance should be at least 8 km.

5 Conclusion
In this research, the radio frequency characteristics of public mobile communication terminals were measured. Based on this, the interferences of the base station and terminal to S-band radar were calculated, and the lumped interference of public mobile communication system to radar was simulated and analyzed in combination with the typical parameters of radar and the key parameters of the base station. The results show that certain distances and frequencies should be isolated from the radar without anti-interference measures to ensure that the radar has combat effectiveness. The isolated distance should be 8 - 47 km at least, and the isolated frequency should be no less than 35 MHz. In view of the application scenarios of radars, the dynamic changes of nearby personnel, and the increasingly tense spectrum resources, the radars can be protected by increasing the antenna gain, lowering the side lobe, varying the polarization, as well as rational planning and deployment of the public mobile communication system as per the actual terrain when the radars cannot be completely isolated from the required distance and frequencies. These measures contribute to the full exertion of the effectiveness of radar, the all-around construction of public mobile communication, and the in-depth development of civil-military integration.

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