Research on Interference Test of 24GHz Millimeter Wave Radar to 5G Equipment

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Abstract. The millimeter wave frequency band tends to be developed with the application of radar and communication systems for civil use. It is necessary to analyze the interference coexistence between millimeter wave communication system and radar system. In order to make good use of frequency planning for the millimeter wave frequency band, a microwave anechoic room experiment is tested in this paper. The experiment includes a 24GHz 5G base station, a 24GHz 5G test terminal and a radar to verify the interference of 24GHz millimeter-wave radar to 5G equipment operating at nearby frequencies. This experiment tests and evaluates the detection capability of a single target in the limit state as much as possible and data of base station sensitivity, 5G uplink throughput and 5G downlink throughput have been tested in multiple situations to verify the accuracy and feasibility to this design of radar system. Therefore, the reference and support for 24GHz spectrum allocation can be provided through this method.

1. Introduction
The millimeter wave has a narrow beam, strong detection capability and strong confidentiality. So the radar system is gradually developing towards millimeter wave penetration. At present, all automotive millimeter wave radar products are mainly concentrated in the 24GHz and 77GHz range [1]. The 24GHz of automotive radar usually includes 24GHz ISM band and 24GHz UWB conversion. The 24GHz UWB used in different countries may be different [2-4]. The European 24GHz UWB radar works in the 21.65-26.65GHz and 24.25-26.65GHz bands. Because other applications operating at 24GHz may be subject to interference from 24GHz automotive radars, in order to reduce interference from automotive radars to other services, the EU will Radar is only used for short-distance transmission[5-6]; the United States operates 24GHz UWB radar between 22.00-29.00GHz and 23.12-29GHz[7]; China announced that it planned to use the 24.25-26.65GHz band for 24GHz short-range vehicle radar in 2012, and the 24.25-26.65 GHz frequency band is planned for 24GHz short-range vehicle radar, and in June 2017, public opinions were sought for 5G millimeter wave propagation [8]. According to the international plan for the use of 24GHz UWB coaxial, there is a certain probability that the communication system will use the serial port with some radar systems at the same time. So it is necessary to analyze the interference coexistence between two systems. This provides a certain reference for future spectrum planning and equipment deployment.
2. Millimeter wave radar system model

2.1. Frequency Modulated Continuous Wave (FMCW) Vehicle Radar Mechanism

A common application scenario of vehicle millimeter wave radar is automobile collision avoidance. It has the characteristics of all-weather operation than traditional laser radar. Triangular linear frequency modulation continuous wave is a commonly used waveform of vehicle millimeter wave radar systems [9-11]. The triangle FM signal is divided into two scanning wavelengths, and the related mathematical expression is as follows.

\[ x_1(t) = x_1(t) \cdot \exp\left(\frac{j \pi \beta t^2}{t_0}\right) \]

(1)

\[ x_2(t) = x_2(t) \cdot \exp\left(-\frac{j \pi \beta (t-2t_0)^2}{t_0} + j2\pi \beta t_0\right) \]

(2)

Among them, \( x_1(t) = \begin{cases} 1, & (0 < t < t_0) \\ 0, & \text{else} \end{cases} \)

\( x_2(t) = \begin{cases} 1, & (t_0 < t < 2t_0) \\ 0, & \text{else} \end{cases} \)

The expression of the triangle FM signal is.

\[ x(t) = \left[x_1(t) \cdot \exp\left(\frac{j \pi \beta t^2}{t_0}\right)\right] + \left[x_1 \cdot (2t_0 - t) \cdot \exp\left(-\frac{j \pi \beta (t-2t_0)^2}{t_0} + j2\pi \beta t_0\right)\right] \]

(3)

The FMCW vehicle radar schematic and signal structure are shown in Figure 1 and Figure 2, respectively.

Figure 1. FMCW vehicle radar schematic.  
Figure 2. FMCW vehicle radar signal structure.

2.2. Analysis of radar system interference to 5G equipment

Radar system interference to 5G equipments can be calculated by the following formula.

\[ I_{RB-\text{interference}} = P_{RT} + G_{RT} + G_{BR} - L_{PL} \]

(4)

\[ I_{TB-\text{interference}} = P_{RT} + G_{RT} + G_{TR} - L_{PL} \]

(5)

Among them,

\( I_{RB-\text{interference}} \): 5G base station receives the interference power of the radar system in dBm.

\( I_{TB-\text{interference}} \): 5G terminal receives the interference power of the radar system in dBm.

\( P_{RT} \): Radar system transmitted power in dBm.

\( G_{RT} \): Antenna gain of the radar transmitter in dBi.

\( G_{BR} \): The antenna gain received by the 5G base station in dBi.

\( G_{TR} \): The antenna gain received by the 5G terminal in dBi.

\( L_{PL} \): Path loss in dB.

3. Interference test program of 24GHz millimeter wave radar on 5G equipment

3.1. Test requirements analysis

In order to verify the interference of 24GHz millimeter-wave radar to 5G equipment operating at or
near the frequency, this article uses two test methods to analyze and evaluate the interference situation of 5G equipment.

- The impact on the sensitivity of 5G equipment. Because the test terminal is a non-commercial terminal and there is no corresponding RF test software version, this test only includes the impact test on the sensitivity of the 5G base station, and the interference condition is tested with the radar signal source and the real radar.

- Impact on system uplink and downlink throughput: uplink service throughput test focuses on radar interference to 5G base stations (same as uplink sensitivity networking, except that the signal source is replaced by test terminals); downlink service throughput test focuses on radar pair test Terminal interference (the radar emission direction is aligned with the test terminal, facing away from the 5G base station).

Based on the above analysis of test requirements, this test includes the following test scenarios, which is shown in Table 1.

| Test Data                  | Testing scenarios                                      |
|----------------------------|--------------------------------------------------------|
| 5G base station sensitivity| Radar signal source interference                       |
| 5G uplink throughput       | Radar interference                                     |
| 5G downlink throughput     | Radar interference                                     |

3.2. Basic parameters of base station

The basic parameters of the base station test are as follows.

- Bandwidth and subcarrier interval selection: the signal occupies a bandwidth of 200MHz and the subcarrier interval is 120kHz.

- Frequency point selection: The base station complies with the 3GPP protocol and can support the full n258 frequency band, namely 24.25GHz-27.5GHz. This test selects two frequency points. One is the frequency point closest to the radar. Considering the 200MHz bandwidth, the center frequency point is selected to be 24.35GHz; the other center frequency point is 24.85GHz. The 24GHz band is shown in Figure 3.

3.3. Interference assessment criteria

24GHz millimeter-wave radar transmitting signals have near-end interference and far-end interference on the reception of 5G base stations. Due to interference from different systems, the interference needs to be controlled within a reasonable range. The specific interference evaluation criteria are as follows.

- Sensitivity test interference criterion: Based on the sensitivity index of the 5G base station in the absence of interference, the interference signal does not affect the sensitivity of the base station.

- Throughput test interference criteria: Based on the throughput indicators of 5G base stations and test terminals in the absence of interference, the impact of interference signals on the throughput of 5G communication networks. Here, a 5% throughput loss index is selected as a measure of coexistence. 5% throughput loss refers to the loss of 5% of the throughput of the
interfered system after adding the interfered system. It is believed that the throughput loss of less than 5% means that the two systems can coexist. The throughput loss can be expressed as.

$$T_{\text{HP loss}} = 1 - \frac{T_{\text{HP interference}}}{T_{\text{HP no interference}}}$$

(6)

Among them,
- $T_{\text{HP interference}}$: Throughput in the presence of adjacent channel interference.
- $T_{\text{HP no interference}}$: Throughput without adjacent frequency interference.

If $\text{SINR}$ is mapped to throughput using Shannon’s formula, then.

$$T_{\text{HP}} = \begin{cases} 0, & \text{SINR} < \text{SINR}_{\min} \\ \propto \cdot W \log_2 (1 + \text{SINR}), & \text{SINR}_{\min} \leq \text{SINR} \leq \text{SINR}_{\max} \\ T_{\text{HP max}}, & \text{SINR} > \text{SINR}_{\max} \end{cases}$$

(7)

Among them,
- $\propto$: Attenuation factor (uplink0.4, downlink0.6).
- $W$: Bandwidth of the interfered system.
- $\text{SINR}$: SNR of the measured signal, linear value.
- $\text{SINR}_{\min}$: (uplink-10, downlink-10), the unit is dB.
- $\text{SINR}_{\max}$: (uplink22, downlink30), the unit is dB.

4. **Interference test results of 24GHz millimeter wave radar on 5G equipment**

The length, width, and height of the microwave darkroom used in this test were 10m, 6m, and 4.5m, respectively.

4.1. **Radar signal source interferes with 5G base station sensitivity**

4.1.1. **Test networking.** The signal source is used to simulate radar interference signals and useful signal characteristics (signal level, signal bandwidth and frequency). The 5G base station reports the throughput statistics after receiving the signal. Calculate the center frequency point according to the 3GPP protocol. When the subcarrier interval is 120 kHz, the base station frequency point number must be an odd number, so the center frequency point of the 5G signal source is calculated It is 24.35GHz, 24.85GHz. The sensitivity is the signal strength when the throughput is 5% lower than the ideal value. The tools and meters used in the test and the networking of the test are shown in Table 2.

| Category               | Quantity | Description                                                                 |
|------------------------|----------|-----------------------------------------------------------------------------|
| Signal source          | 2        | Signal source A is used to send 5G uplink signals; Signal source B is used to send radar analog signals |
| 5G base station        | 1        | 5G high frequency base station, support n258 frequency band (24.25GHz – 27.5GHz) |
| 24GHz band antenna     | 2        | Used to transmit the signal from the signal source, gain 21dBi               |

The test networking diagram is shown in Figure 4.

**Figure 4.** 5G base station sensitivity (radar signal source interference)—Test networking diagram.
4.1.2. Test parameters. According to the test network diagram, the relevant parameters are shown in Table 3 and Table 4, respectively.

**Table 3.** Network parameters (signal source A).

| Networking (Signal Source A)                          | Value  |
|-------------------------------------------------------|--------|
| Signal source A antenna gain                          | 21dBi  |
| Signal source A feeder antenna loss                   | -5dB   |
| Spatial attenuation of signal source A to 5G base station | -80dB  |

**Table 4.** Network parameters (signal source B).

| Networking (Signal Source B)                          | Value  |
|-------------------------------------------------------|--------|
| Signal source B occupied frequency range              | 24.05-24.25GHz |
| Source B waveform width                               | 38us   |
| Signal source B waveform repetition period (waveform continuous transmission) | 38+9us |
| Signal source B antenna port transmit power           | 20dBm  |
| 5G base station antenna port receive power            | -60dBm |
| Spatial attenuation of signal source B to 5G base station | -80dB  |

The domains of signal source B is shown in Figure 5.

![Figure 5. Signal source B time domain.](image)

4.1.3. Test results. The interference test results of radar signal source on 5G base station sensitivity are shown in the Table 5.

**Table 5.** 5G base station sensitivity (radar signal source interference)—Test results.

| Base station frequency (GHz) | Radar transmit power (dBm) | Sensitivity degradation (dB) | Remark                          |
|-----------------------------|---------------------------|-----------------------------|--------------------------------|
| 24.35                       | 20                        | 3.8                         | Signal source continuous phase |
| 24.85                       | 20                        | 2.5                         | Signal source continuous phase |

From the test results, it can be seen that the radar signal affects the uplink sensitivity demodulation performance of the 5G base station, causing the base station's uplink sensitivity to deteriorate by 3.8dB in the 24.35GHz band, and the 2.5.

4.2. Radar signal source interferes with 5G base station sensitivity

4.2.1. Test networking. The tools and meters used in the test and the networking of the test are shown in the Table 6.
Table 6. 5G base station sensitivity (radar interference)—List of test tools and instruments.

| Category          | Quantity | Description                                                                                           |
|-------------------|----------|-------------------------------------------------------------------------------------------------------|
| Signal source     | 2        | Signal source A is used to send 5G uplink signals                                                    |
| 5G base station   | 1        | 5G high frequency base station, support n258 frequency band (24.25GHz – 27.5GHz)                     |
| 24GHz band antenna| 2        | Transmit the signal from the signal source, or receive the signal to the spectrum analyzer for analysis|
| Spectrum Analyzer | 1        | Used to analyze the characteristics of radar waveform signals. The radar is 1.5m away from the horn antenna of the spectrum analyzer (far field) during signal analysis. |
| Radar             | 1        | Transmits 24GHz radar signals to interfere with 5G base stations, including radar host PC            |

The test environment remains unchanged, with signal source B turned off. The test network is shown in Figure 6.

Figure 6. 5G base station sensitivity (radar interference)—Test networking diagram.

4.2.2. Test parameters. The settings of the network parameters (signal source A) are the same as those in Table 3. The configuration of the network parameters (radar) is shown in Table 7.

Table 7. Network parameters (radar).

| Networking (radar) | Value               |
|--------------------|---------------------|
| RF point and bandwidth | 24.00-24.20GHz  |
| Output waveform width   | 25ms                |
| Waveform repeat period (waveform continuous transmission) | 20+25ms |
| Antenna size       | 45.2mm*30.9mm       |
| 5G base station antenna port receive power | -60dBm |
| Far-field distance  | 0.43m               |
| Transmit power      | 20dBm               |
| Radar signal strength received by 5G base station | -60.1dBm |

When the radar sends signals for testing, the relevant parameters of the spectrum analyzer are shown in Table 8.

Table 8. Spectrum analyzer parameters.

| Spectrum analyzer parameters | Value               |
|------------------------------|---------------------|
| Antenna gain                | 21dBi               |
| Free space loss             | 63.7dB              |
| Power bias                  | 61.8dB              |
| Antenna to input port attenuation (attenuator + feeder) | 20.1dB |
| The distance between the receiving antenna port and the radar | 1.5m |
The Figure 7 shows the time domain graph, which contains the above two graphs as well as the waveform graph and FM accuracy extracted from the waterfall graph.

![Time domain plot](image)

**Figure 7.** Time domain plot.

4.2.3. **Test results.** The interference test results of the real radar on 5G base station sensitivity are shown in the Table 9.

| Base station frequency (GHz) | Radar transmit power (dBm) | Sensitivity degradation (dB) | Remark       |
|-----------------------------|-----------------------------|-----------------------------|--------------|
| 24.35                       | 20                          | 3.8                         | Radar prototype |
| 24.85                       | 20                          | 2                           | Radar prototype |

From the test results, it can be seen that the real radar signal will affect the uplink sensitivity demodulation performance of 5G base stations, causing the base station's uplink sensitivity to deteriorate by 3.8dB and the 24.85GHz band's uplink sensitivity by 2dB.

4.3. **Radar interference 5G uplink throughput**

4.3.1. **Test networking.** The tools and meters used in the test and the networking of the test are shown in Table 10.

| Category                        | Quantity | Description                                                                 |
|---------------------------------|----------|-----------------------------------------------------------------------------|
| 5G base station                 | 1        | 5G high frequency base station, support n258 frequency band (24.25GHz ~ 27.5GHz) |
| 5G test terminal                | 1        | 5G high-frequency test terminal, support n258 frequency band (24.25GHz ~ 27.5GHz) |
| Radar                           | 1        | Transmits 24GHz radar signals to interfere with 5G base stations, including radar host PC |
| Shield bezel                    | 1        | Length and width: 1.5m * 1.5m                                              |

The test environment remains unchanged, where signal source A is replaced with a test terminal and signal source B is turned off. The path loss is increased by adding a shielding baffle on the path between the 5G base station and the test terminal to construct a scene where the terminal is at the midpoint of the cell. The radar and the test terminal are arranged up and down on the same vertical plane, 10m. For radar waveform characteristics, see section 4.2.2. When constructing the far point, the shielding baffle needs to be placed on the 5G base station side, but the radar interference signal is also attenuated at this time, so the far point scenario cannot be effectively evaluated in the uplink throughput test. The test network is shown in Figure 8.
4.3.2. **Test parameters.** 5G test system basic parameters are as follows.

- Bandwidth and subcarrier interval selection: the signal occupies a bandwidth of 200MHz, and the subcarrier interval is 120kHz.
- Frequency point selection: 24.35GHz, 24.85GHz.

4.3.3. **Test results.** The interference test results of radar on 5G uplink throughput are shown in the Table 11.

| The distance from the radar to the 5G base station is 10m | Band station frequency (GHz) = 24.35/24.85 |
|--------------------------------------------------------|-------------------------------------------|
| Base station frequency (GHz) = 24.35/24.85              | Near-point unblocked                      |
| Radar does not power on                                 | Radar power on                            |
| RSRP(dB)                                               | Radar does not power on                   |
| -59/-59                                               | -83/-83                                   |
| SINR(dB)                                               | 28/28                                     |
| 29/29                                                  |                                           |
| Average THP(Mbps)                                      |                                           |
| 220.2/218.6                                           | 160.6/134.4                               |
| THP Loss(%)                                            | -0.01%/0.01%                              |
| -0.81%/0.05%                                           |                                           |

From the test results, the true radar signal 5G cell adjacent band uplink throughput may be considered to have no effect.

4.4. **Radar interference 5G downlink throughput**

4.4.1. **Test networking.** The settings of the 5G downlink throughput (radar interference) test tools and instrument list are the same as those in Table 10. The test environment was changed to a test terminal 10m away from the base station for download services, and the radar distance test terminal was 0.62m (radar far field). The path loss is increased by adding a wave absorbing material or a shielding baffle on the path from the 5G base station to the test terminal to construct a scene where the terminal is at a midpoint or a far point of the cell. When constructing the midpoint, the absorbing material or shielding baffle is placed on the test terminal side, and when constructing the far point, the shielding baffle is placed on the 5G base station side. The test network is shown in Figure 9.

![Figure 9. 5G downlink throughput (radar interference) — Test networking diagram.](image)
4.4.2. **Test parameters.** The basic parameters of the 5G test system are the same as those in section 4.3.2.

4.4.3. **Test results.** The interference test results of radar on 5G downlink throughput are shown in the Table 12 and Table 13, respectively.

**Table 12. 5G downlink throughput (radar interference)—Test results one(blocked with absorbing material).**

| The distance from the test terminal to the radar is 0.62m | Near-point unblocked / Near-point unblocked | Blocked at mid-point (blocked by absorbing material) | Blocked at far-point (during the mid-point test, the absorbing material is moved, the attenuation changes, and the user becomes a far point) |
|---------------------------------------------------------|--------------------------------------------|-----------------------------------------------------|-------------------------------------------------------------|
| RSRP(dB)                                                | Radar does not power on                     | Radar does not power on                              | Radar does not power on                                      |
| SINR(dB)                                                | -60/-60                                    | -77/-79                                             | -89/-82                                                  |
| Average THP(Mbps)                                       | 1191.7/1188.7                              | 1190.7/1175.3                                       | 926.0/1015.8                                             |
| THP Loss(%)                                             | 0.00%/-0.06%                              | -5.02%/-7.26%                                       | -30.90%/-1.74%                                           |

**Table 13. 5G downlink throughput (radar interference)—Test results two(blocked with shield bezel).**

| The distance from the test terminal to the radar is 0.62m | Blocked at mid-point (first blocking) / Blocked at mid-point (second blocking) | Blocked at far-point (first blocking) / Blocked at far-point (second blocking) |
|---------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| RSRP(dB)                                                | Radar does not power on                                                        | Radar does not power on                                                        |
| SINR(dB)                                                | -79/-83                                                                         | -79/-100                                                                         |
| Average THP(Mbps)                                       | 950.0/1029.1                                                                    | 950.0/499.6                                                                     |
| THP Loss(%)                                             | -10.53%/-9.61%                                                                  | -5.26%/-19.93%                                                                  |

From the test results, it can be seen that the real radar signal has an impact on the downlink throughput of 5G users in adjacent frequency bands, which interferes with the downlink throughput of near-point users and mid-point users in the cell. Among them, the throughput of the mid-point users in the 24.35 GHz frequency band deteriorates. % ~ 10%, the mid-point user throughput of the 24.85GHz frequency band cell deteriorates by about 7%; it interferes with the downlink throughput of the far-point user in the cell, of which the far-end user throughput of the 24.35GHz frequency band cell deteriorates by 20% -30%, and the 24.85GHz frequency band The far-site user throughput in the cell deteriorated by about 19%. The throughput degradation fluctuates within a certain range because non-line-of-sight multipath scenes are constructed by blocking in a dark room. Multipath channels are random. The ratio of the reference signal received power to the signal interference noise is the average of each channel. The same mean does not mean that the channel conditions have not changed. In addition to the user's throughput, in addition to the signal quality, it is also affected by factors such as the data source, bit error rate, and scheduling level. The waveform and power of the radar interference signal are also changing, so the rate of the two tests in the interference scenario may vary.

5. **Conclusion**

This article conducts experimental demonstration and data analysis under various test scenarios. In summary,
The 24GHz millimeter wave radar signal has an impact on the uplink sensitivity demodulation performance and downlink throughput of 5G base stations (the two are 10m apart).

Radar signals caused the uplink sensitivity of the 5G base station to deteriorate at 24.35GHz by 3.8dB, and the uplink sensitivity of 24.85GHz by 2dB.

Radar signals caused 5G base stations to have 24.35GHz and 24.85GHz center mid-site users (RSRP = -83dBm, SINR = 26dB), and downlink throughput deteriorated by about 5% -10% and 7%, respectively.

Radar signals caused 5G base stations to have 24.35GHz and 24.85GHz center far-site users (RSRP = -99dBm, SINR = 13dB), and downlink throughput deteriorated by about 20% -30% and 19%, respectively.

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