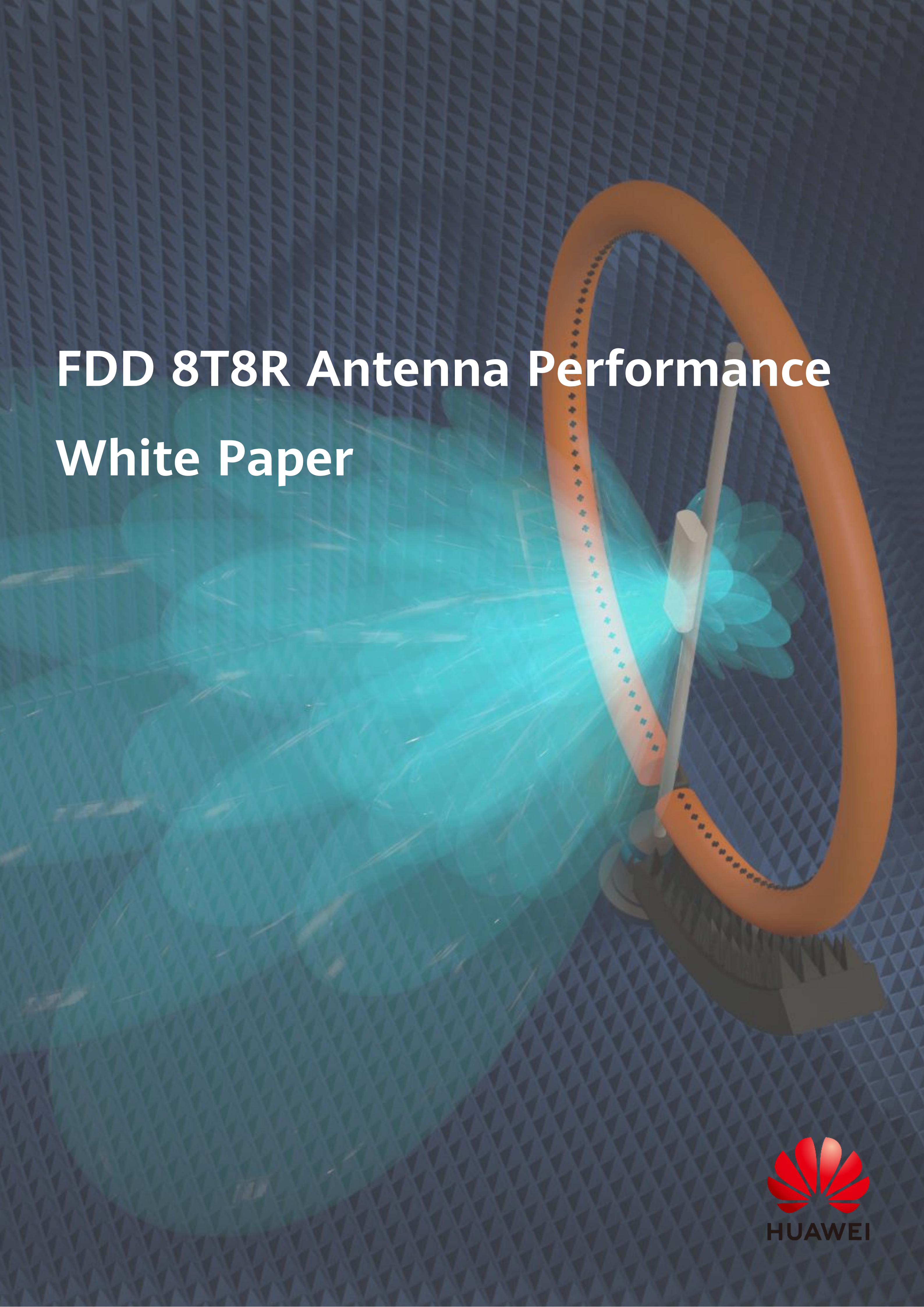
# FDD 8T8R Antenna Performance White Paper



HUAWEI

# Abstract

FDD 8T8R is key to providing continuous experience on 5G networks and play an important role in 5G fundamental network construction. This document describes the requirements of FDD 8T8R antenna capabilities, new antenna specifications, and test methods based on FDD 8T8R technical characteristics and 3GPP specifications.

# Content

# 01 Introduction of 8T8R

## 1.1 Necessity of FDD 8T8R Evolution

As the scale of 5G commercial use continues to expand and 5G user penetration continues to increase, users' requirements for 5G coverage and network rate are also increasing. This poses higher requirements on operators' 5G network, that is, providing continuous 5G coverage and optimal user experience.

From the spectrum perspective, low-frequency (sub-1 GHz) signals have strong penetration capabilities and are easy to achieve continuous coverage. However, limited spectrum resources make it difficult to meet 5G experience requirements. Medium and high frequency bands (above 3 GHz) have abundant spectrum resources and can provide large bandwidth to achieve ultimate rates, however, the path loss fading and penetration loss of medium and high frequency bands are large. Therefore, it is difficult to provide continuous coverage and good indoor coverage on existing sites. Sub3-GHz medium frequency bands are mainly FDD frequency bands, which have balanced bandwidth and coverage performance. They have larger bandwidth than low frequency bands and stronger coverage capability than high frequency bands. Therefore, they have the best comprehensive capability. In the future, 5G network will incorporate all frequency bands. All frequency bands will be coordinated to provide continuous superb experience.

From the perspective of multi-antenna technology evolution, the 4T4R antenna technology has been widely used on FDD frequency bands in the 4G era. 5G user number keeps increasing, but it is difficult for operators to deploy new sites and there is no new spectrum on the FDD frequency band, further evolution of the multi-antenna technology becomes the key to improving network capacity and coverage. 8T8R will be an important evolution step as a basic configuration for beamforming. It supports user-level precise narrow beams to achieve higher network capacity and better user experience.

FDD 8T8R will play a unique role in 5G networks and become the backbone of 5G fundamental networks. This document describes the requirements of FDD 8T8R antenna performance based on the technical features of FDD 8T8R and related definitions in 3GPP specifications, provides reference for FDD 8T8R antenna design.

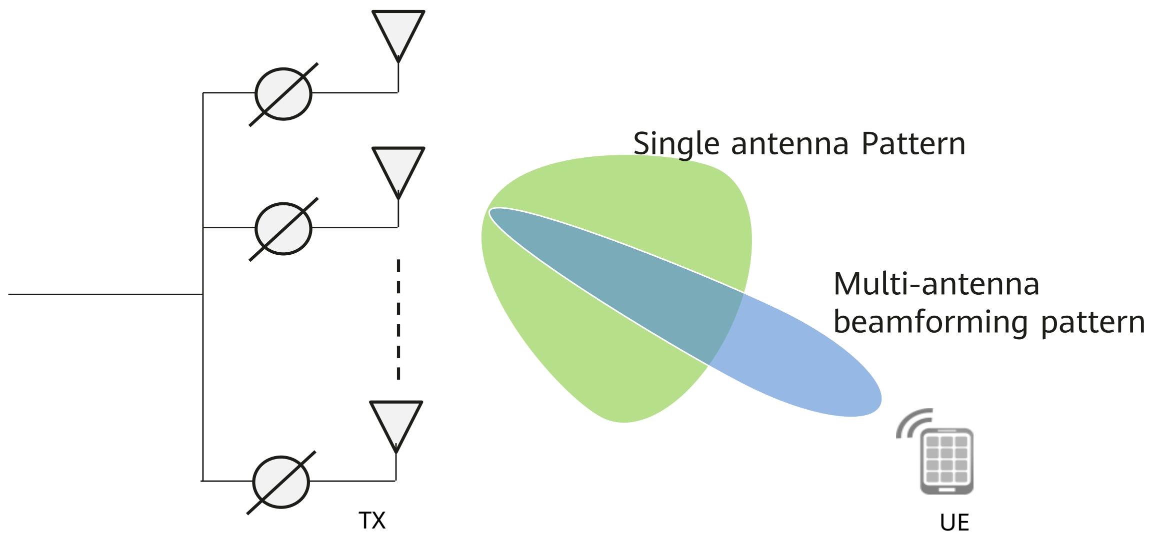
## 1.2 Key Technologies of 8T8R

The key technologies of 8T8R include beamforming, SU-MIMO (single-user MIMO), and MU-MIMO (multi-user MIMO).

### 1.2.1 Beamforming

Beamforming is a technology that adaptively adjusts the radiation pattern of a multi-array antenna based on specific scenarios. The basic principle is that the transmitter weights data and then transmits the data to generate a beam targeted at the target UE, as shown in Figure 1.

Figure 1 Beamforming diagram



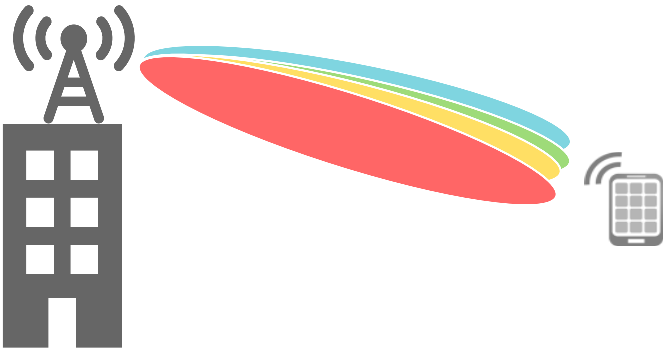

In this case, transmit signals of multiple antennas are coherently superimposed on a target UE, thereby improving the receive level of UE and improving the demodulation signal-to-noise ratio. This will ensure good signal quality even if the target UE is far away from the base station, improving user experience at the cell edge.

Beamforming is the basis for improving 5G coverage. It is one of the key multi-antenna technologies to achieve array gains, multiplexing gains, and interference suppression gains.

### 1.2.2 SU-MIMO

SU-MIMO and MU-MIMO are two space division multiplexing technologies. In SU-MIMO, the same time-frequency resource is scheduled to a single UE for sending multiple parallel data streams to improve the transmission rate and spectrum efficiency. In SU-MIMO mode, the time-frequency resource allocated is exclusively occupied by the UE, as shown in Figure 2.
SU-MIMO can effectively improve the experience of a single UE and increase the cell capacity.

Figure 2 SU-MIMO diagram



### 1.2.3 MU-MIMO

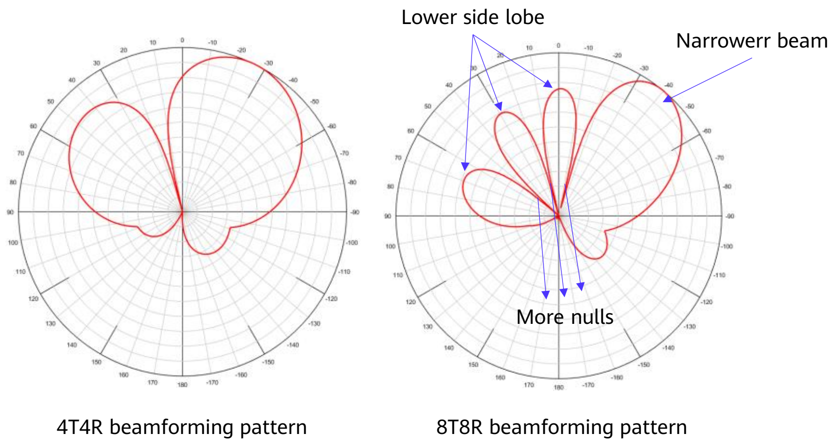
MU-MIMO enables multiple UEs to transmit multiple data streams in parallel by using the same time-frequency resource. In MU-MIMO mode, multiple UEs reuse the same time-frequency resource in space division multiplexing manner, so that cell capacity can be effectively improved. Low channel correlation between multiple UEs is a prerequisite for MU-MIMO.

Figure 3 MU-MIMO diagram

## 1.3 8T8R realizes better MIMO performance

SU-MIMO and MU-MIMO are key technologies to improve user experience and cell capacity. By leveraging the beamforming capability of 8T8R antennas, they can achieve better performance. This section compares the beamforming patterns of 8T8R and 4T4R antennas to explain why 8T8R can achieve better MIMO performance, as shown in Figure 4.

Figure 4 8T8R and 4T4R beamforming diagram




First, it can be seen that the beam width of the 8T8R pattern is narrower and the gain is higher. This means that transmitted signals is more focused on the target UE, which improves the signal-to-noise ratio of received signals, helps base station getting better coverage or UE getting higher throughput.

Second, the 8T8R pattern has lower side lobes. This means that when the beam is used to transmit data to the target UE, the interference to other UEs is lower, which increases other UEs' demodulation SNR to get higher throughput.

Third, the 8T8R pattern has more nulls. This means that there are more spatial directions in which other UEs are not interfered, which can increase MU-MIMO pairing success rate, and improve cell capacity.

In conclusion, 8T8R beamforming pattern has narrower beam width, higher gain, lower side lobe, and more nulls. This will finally bring higher user experience and cell capacity.

### ◆ Chapter summary

8T8R realizes network coverage, network capacity and user experience improvement through beamforming, SU-MIMO, and MU-MIMO technologies. The key capability of 8T8R antenna lies in how to support the better realization of the above-mentioned key technologies

# 02 FDD 8T8R Requirements for Antenna

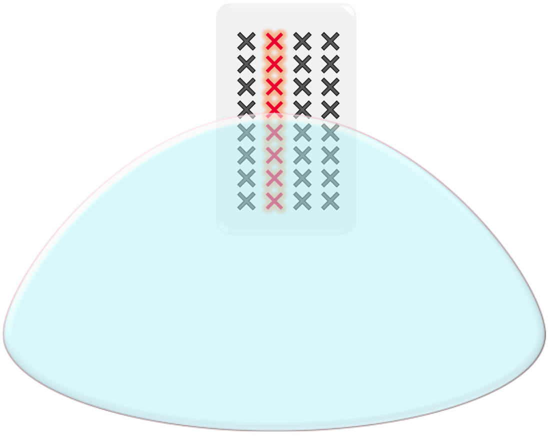
The performance requirements of FDD 8T8R antenna can be described in terms of three types of beams: single column beam, broadcast beam, and traffic beam. And hardware requirements of FDD 8T8R antenna is channel calibration capability.

## 2.1 8T8R Antenna Beams

### 2.1.1 Single Column Beam

A single column beam is the radiation pattern of each antenna array, and is the basis for combining broadcast beam and traffic beam in a multi-antenna system.

Figure 5 Single column beam



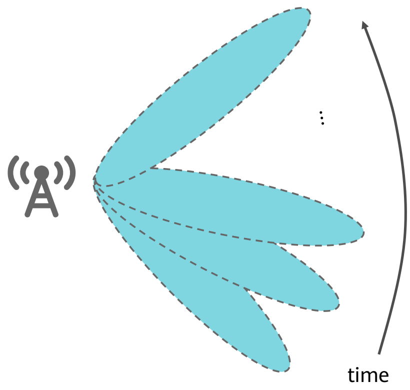
The characteristic of a single column beam can be specified comparable to a standard based station antenna beam. The following table list the parameters of a single column beam.

| | |
|---|---|
| Single column beam | Single column beam gain |
| | Horizontal beamwidth |
| | Vertical beamwidth |
| | Cross polarization ratio |
| | Front-to-back ratio ± 30° |
| | Upper side lobe suppression |

### 2.1.2 Broadcast Beam

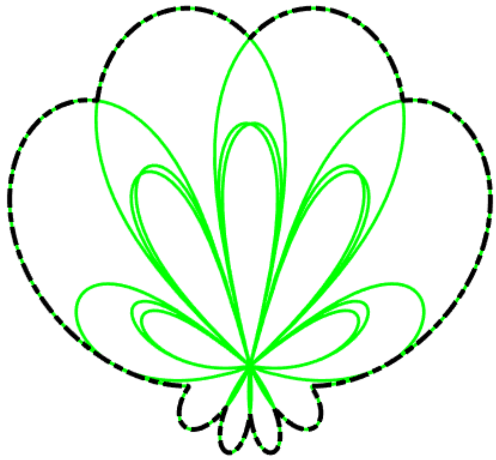
The NR broadcast beam uses multi-antenna for coverage enhancement, that is, multi-antenna beamforming is used to form narrow beams with more energy concentration for coverage. However, a single narrow beam cannot cover the entire cell. Therefore, beam scanning is introduced to NR for coverage, that is, the base station sends a narrow beam to cover one direction at a time slot and covers the entire cell in polling mode. As shown in Figure 6.

Figure 6 NR broadcast beam sweeping process




The NR broadcast beam coverage capability can be indicated by using envelope of all broadcast beams. Figure 7 is a design example of four broadcast narrow beams. The envelope of the NR broadcast beam can replace the single column beam pattern to represent the broadcast coverage capability of the antenna.

Figure 7 NR broadcast beam design example



### 2.1.3 Traffic Beam

Space division multiplexing is a key technology that brings capacity and experience improvements. It has high requirements on channel correlation, that is, the interference between correlated traffic beams is low enough.

FDD traffic beam weights have been defined in 3GPP specifications. Traffic beams that can be triggered by UEs can be selected only from a pre-defined group. In MU-MIMO and SU-MIMO multiple stream transmission scenarios, multiple beams are triggered on the same time-frequency resource. All possible beam combinations are also defined in 3GPP specifications. Therefore, we can analyze beams in combinations and relationships between beams defined in 3GPP specifications to deduce the requirements of traffic beams on antenna specifications.

We can define a new parameter - beam isolation to describer spatial independence of beams in a beam group. High beam isolation means that the interference between beams is lower and the advantages of space division multiplexing can be better exploited. Detailed definitions of beam isolation are described in Section 3.

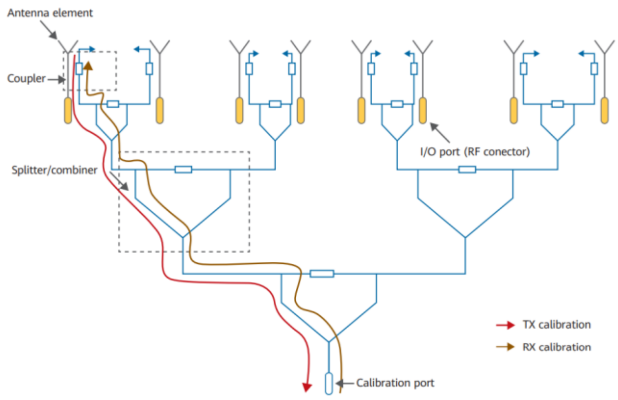
## 2.2 Channel Calibration Capability

According to the description of traffic beams in section 2.1.3, the weights sent by the baseband processing unit to the antenna ports are defined in 3GPP specifications. In an ideal model, the amplitude and phase characteristics and delays of multiple RF channels are the same. Otherwise, problems such as beam direction deflection, coverage error, and zero depth reduction occur, affecting the beamforming effect in a cell.

RF signals are transmitted to antenna ports through RF chains. The amplitude and phase characteristics and delays of RF channels cannot be consistent due to factors such as amplitude and phase fluctuation of active components over a long path, the path length of the analog end of each channel, and duplexer group delay difference.

Therefore, signals arriving at the antenna port need to be calibrated. Antenna calibration, also called channel calibration, aims to ensure the consistency of data delays and phases between channels in a multi-channel system. In principles, the phase, amplitude, and delay of signals change after they are transmitted through different channels. Such changes can be calculated based on changes in the phase, amplitude, and delay of known calibration signals after they are transmitted through different channels. Then, compensation is applied to the channels.

Figure 8 Calibration network diagram




### ◆ Chapter summary

The advantages of 8T8R multi-antenna technology lie in capacity and coverage improvement. The preceding three types of beams and indicators can be used to comprehensively define the performance of 8T8R antennas.

In FDD, all traffic beams and space division multiplexing beam groups are defined in 3GPP specifications. Therefore, the performance of traffic beams can be evaluated based on the traffic beams defined in 3GPP specifications.

On the other side, to ensure that the weight of a beam reaching an antenna port is consistent with the weight in 3GPP specifications, and that the weight of a broadcast beam reaching the antenna port is consistent with the planned weight, the channel calibration capability needs to be specified in antenna design.

# 03 New Indicators of FDD 8T8R Antennas

The traffic beam weights of FDD 8T8R antennas are defined in 3GPP TS 38.214 and are referred to as precoding matrix indication (PMI) codebooks. 8T8R antenna traffic beams based on PMI codebooks are critical to network performance, Based on the PMI codebook, we use the relationship between traffic beams to define the performance of 8T8R antennas.

## 3.1 Characteristics of FDD 8T8R Traffic Beams

3GPP Release 15 defines the NR-based codebook. The codebook whose antenna layout is H4V1 (N1 = 4, N2 = 1) is based on 16 discrete Fourier transform (DFT) weights. The 16 DFT weights are as follows (the amplitudes are the same, only the phase is displayed, and P1 to P4 indicate the numbers of a co-polarized antenna array):

Table Codebook defined in 3GPP TS 38.214 5.2.2.2.1 (N1 = 4, N2 = 1)

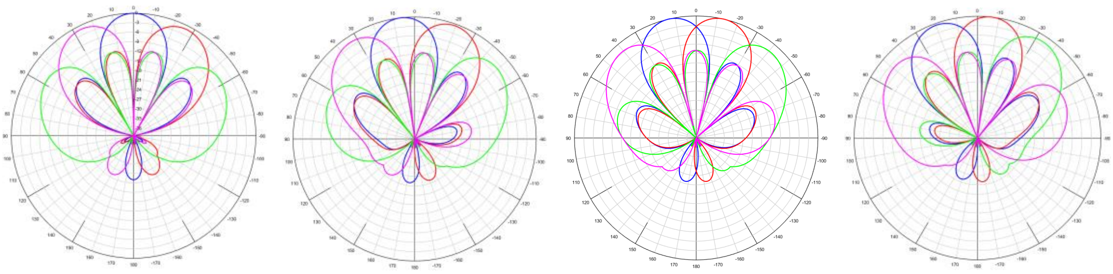
| Rank1 PMI No. | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 22.5 | 45 | 67.5 |
| 8 | 0 | 45 | 90 | 135 |
| 12 | 0 | 67.5 | 135 | 202.5 |
| 16 | 0 | 90 | 180 | 270 |
| 20 | 0 | 112.5 | 225 | 337.5 |
| 24 | 0 | 135 | 270 | 405 |
| 28 | 0 | 157.5 | 315 | 472.5 |
| 32 | 0 | 180 | 360 | 540 |
| 36 | 0 | 202.5 | 405 | 607.5 |
| 40 | 0 | 225 | 450 | 675 |
| 44 | 0 | 247.5 | 495 | 742.5 |
| 48 | 0 | 270 | 540 | 810 |
| 52 | 0 | 292.5 | 585 | 877.5 |
| 56 | 0 | 315 | 630 | 945 |
| 60 | 0 | 337.5 | 675 | 1012.5 |

The 16 groups of basic weights can be further divided into four orthogonal groups. No. 0/16/32/48 form an orthogonal group, No. 4/20/36/52 form an orthogonal group, No. 8/24/40/56 form an orthogonal group, and No. 12/28/44/60 form an orthogonal group. As described in section 0, MU-MIMO and SU-MIMO multi-stream transmission trigger multiple beams on the same time-frequency resource. All beam combinations that can be triggered correspond to some weights in the same orthogonal group.

Every two of the four groups of weights in the same orthogonal group are orthogonal to each other. In addition, in a 4-dimensional linear space, the four groups of weights in one orthogonal group are complete orthogonal weights, that is, any weight in the space can be linearly represented by the four groups of weights in one orthogonal group. Therefore, beams corresponding to four groups of orthogonal weights in an orthogonal group can be randomly selected to evaluate the antenna. Other beams can be weighted based on these four beams.

As Four groups of weights in orthogonal beam group 3 are combined into two symmetric narrow beams to facilitate the definition of beam indicators, so we select orthogonal beam group 3 formed by No. 8/24/40/56 to evaluate the antenna.

Figure 9 Four orthogonal beam groups in an 8T8R cell



No. 0/16/32/48
Orthogonal beam group 1

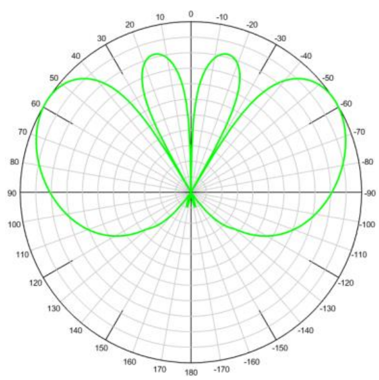
No. 4/20/36/52
Orthogonal beam group 2

No. 8/24/40/56
Orthogonal beam group 3

No. 12/28/44/60
Orthogonal beam group 4

It should be noted that orthogonal beam group 1 formed by four beams numbered 0/16/32/48 in Figure 10 is also symmetric, but green beams in orthogonal beam group 1 have two lobes with significant difference in directions and a same maximum radiation lobes. The main lobe and the maximum side lobe on the horizontal plane are indeterminate. Therefore, orthogonal beam group 1 is not selected for defining traffic beam indicators.

Figure 10 Green beams in orthogonal beam group 1

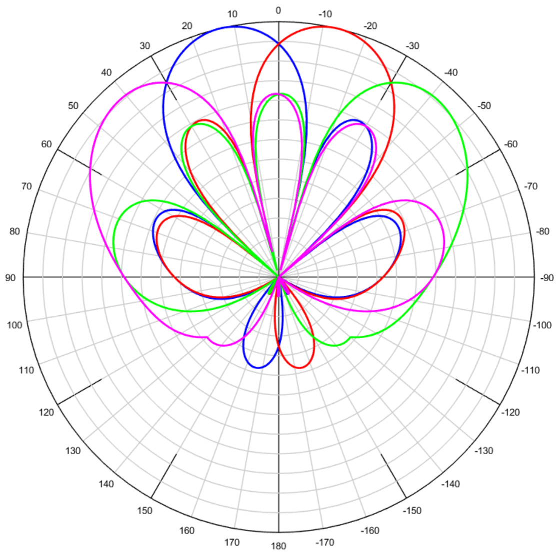


## 3.2 PMI Orthogonal Beam Group and Indicator Definitions

### 3.2.1 PMI Orthogonal Beam Group

As described in section 3.1, beams corresponding to the orthogonal group of No. 8/24/40/56 are selected as the PMI orthogonal beam group, as shown in Figure 11.

Figure 11 PMI orthogonal beam group diagram




The following table shows the weights of the PMI orthogonal beam group (equal amplitude and only the phase is displayed). P1 to P4 are the number of a polarized port of the antenna.

| PMI Orthogonal Beam Group No. | P1 | P2 | P3 | P4 |
|---|---|---|---|---|
| 1 | 0 | 45 | 90 | 135 |
| 2 | 0 | 135 | 270 | 405 |
| 3 | 0 | 225 | 450 | 675 |
| 4 | 0 | 315 | 630 | 945 |

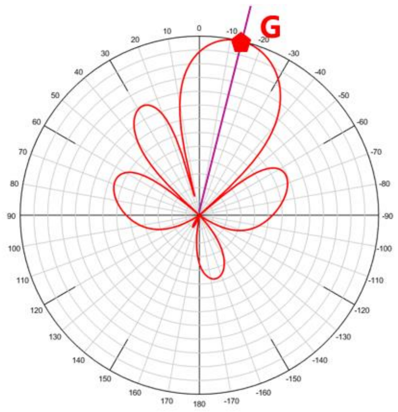
From the perspective of network performance, the indicators related to PMI orthogonal beam groups are defined as following section.

### 3.2.2 PMI Orthogonal Beam Group Indicator Definitions

◆ **Gain**

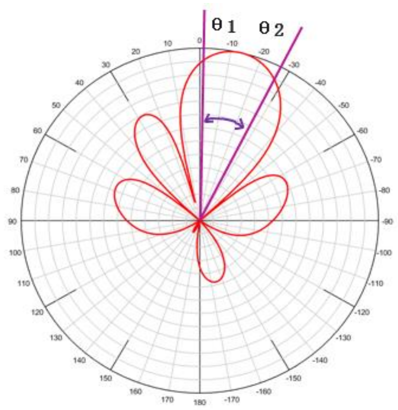
The antenna gain is the ratio of radiation power flux-density in a certain direction to the radiation power flux-density of a reference antenna when input power is fixed. Generally, the antenna gain refers to the gain in the direction with the maximum radiation. As shown in Figure 12, Gain = G.

Figure 12 Gain definition




◆**Horizontal half-power beamwidth (HBW)** HBW refers to the angle between two points where the power flux density in the horizontal direction decreases to half of the maximum radiation direction (or less than the maximum value 3 dB). As shown in Figure 13, HBW = |θ2 – θ1|.

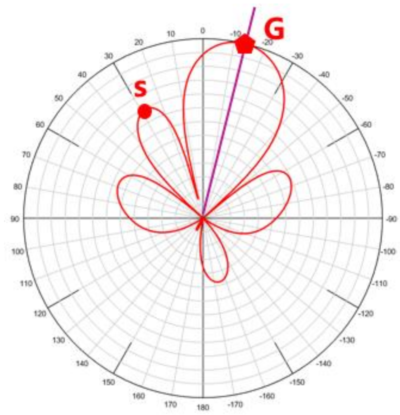
Figure 13 Horizontal half-power beamwidth



◆ **Horizontal side lobe suppression (SS) (unit: dB)**

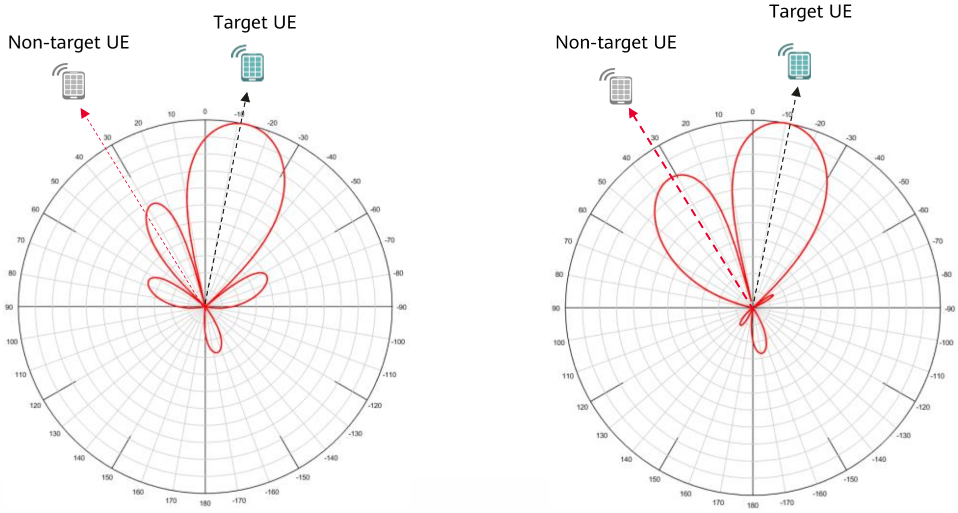
Definition: Side lobe suppression refers to the ratio of the power of the main lobe in the horizontal direction to the peak power of the maximum side lobe within ±60° . As shown in Figure 14, SS (dB) = G – s (max).

Figure 14 Horizontal side lobe suppression




Horizontal side lobe suppression plays an important role in reducing interference between multiple beams during space division multiplexing. As shown in Figure 15, in a complex channel environment, side lobes may cause interference to non-target UEs, affecting user experience.

Figure 15 Performance of different side lobes




Lower side lobe,
smaller interference to no-target UE

Higher side lobe,
higher interference to no-target UE

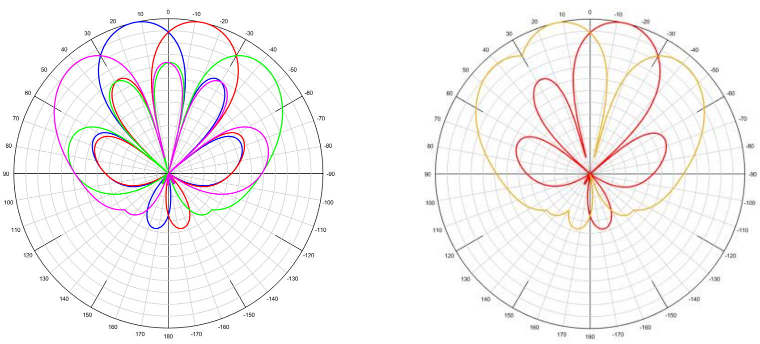
◆ **Beam isolation (BI) (unit: dB)**

In a PMI orthogonal beam group, the maximum ratio of the power of a beam to the outer envelope power of the other three beams within ±60° on the horizontal plane is the BI value of this PMI beam.

A BI value may be represented in dB, that is, beam isolation BIn (dB) = max(Gn(θ) – Gn_others(θ)). Where n = 1 to 4. Gn is the radiation pattern of the beam to be calculated. Gn_others is the outer envelope radiation pattern of the other three beams except n. Gn(θ) and Gn_others(θ) are the radiated power (represented by dBi) at different θ angles.

As shown in Figure 16, taking the calculation of a BI of a red beam as an example. In Figure 16.b, G1(θ) is the radiation pattern of the red beam, and G1_others (θ) is an outer envelope of beams 2, 3, and 4. Values of G1_others (θ) and G1_others (θ) vary with θ.

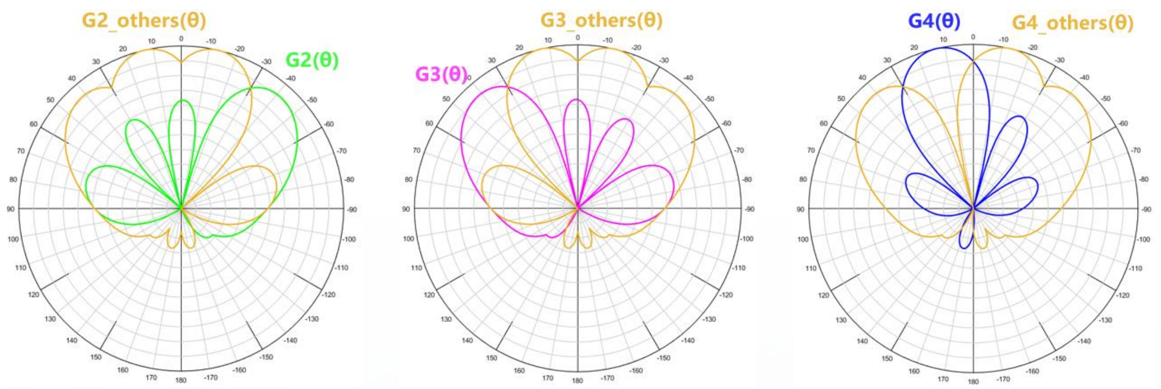
Figure 16 Beam isolation calculation example



a b

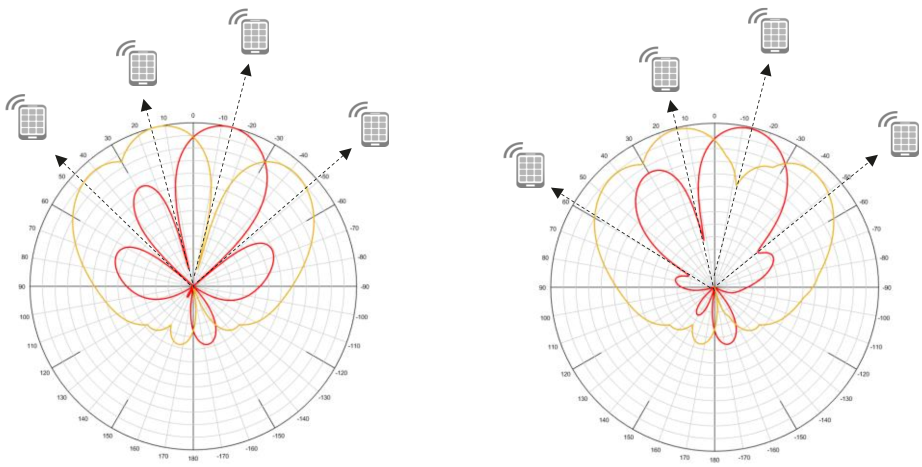
Similarly, the schematic diagram of BI calculation of the other three beams is as follows:

Figure 17 Beam isolation calculation example



Beam isolation is used to describe the relative relationship between beams in an orthogonal beam group. A larger beam isolation indicates lower interference between beams. As shown in the following figure, when the red beam is used for user data transmission, the higher the beam isolation, the lower the interference from other beams to the UE. In addition, low inter-beam interference results in a higher probability that SU-MIMO multi-stream and MU-MIMO takes effect. Therefore, a higher beam isolation can support higher throughput and higher network capacity.

Figure 18 Isolation performance of different beams



High beam isolation    Low beam isolation

Beam isolation is a new indicator of a base station antenna, and represents correlation between orthogonal beams. A larger beam isolation indicates lower beam correlation and better MIMO performance.

The following system simulation results can better show the impact of beam isolation on network capacity. As the beam isolation decreases, the cell capacity gradually decreases.

| Beam Isolation | 30 dB | 25 dB | 20 dB | 15 dB | 10 dB |
|---|---|---|---|---|---|
| Cell Capacity | Baseline | –0.20% | –2.20% | –11.70% | –15.50% |

## ◆ Chapter summary

This section describes the performance specifications of traffic beams of FDD 8T8R antennas based on the traffic beam weights defined in 3GPP specifications. The PMI orthogonal beam indicators defined in this section and the relationships between beams in orthogonal beam groups can be used to describe the traffic beam performance of FDD 8T8R antennas. The beam isolation and side lobe of PMI orthogonal beam groups reflect the correlation between traffic beams that can be triggered at the same time. The two factors directly affect user experience and cell capacity of FDD 8T8R networks. According to the network performance simulation results, beam isolation has a significant impact on network capacity. Beam isolation is an important indicator for measuring FDD 8T8R antennas.

# 04 Test Methods for FDD 8T8R Antenna Indicators

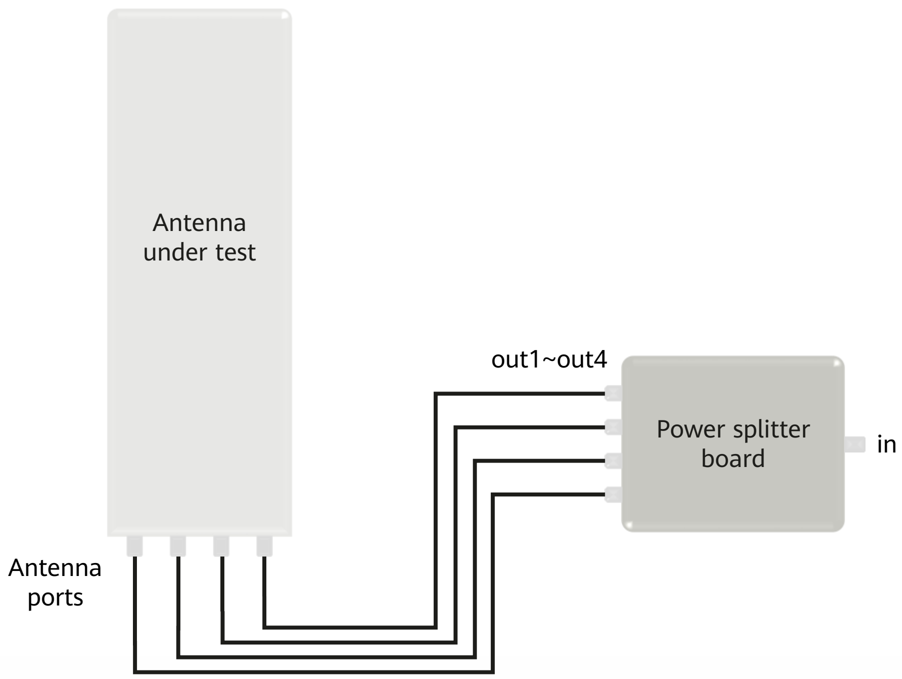
The method for testing FDD 8T8R single column beam specifications is the same as that for testing standard passive antennas and is not described in this document. The following describes how to test broadcast beam and PMI orthogonal beam groups. This section provides a possible test method. In actual tests, the designer can choose the test method according to his own conditions.

## 4.1 Using the Power Splitter Board for Testing

There are two types of power splitter boards required for testing broadcast beams and traffic beams. For broadcast beams with self-designed weights, prepare power splitting boards based on the designed weights. For PMI orthogonal beam groups, four groups of power splitting boards with weights of orthogonal beam groups specified in section 3.2.1 need to be prepared. The test procedure is as follows:

- Step 1: Connect the antenna to the power splitter board. The 4 output ends of the power splitter board are respectively connected to the 4 ports of the antenna. The input end of the power splitter board is connected to the signal output cable of the antenna test field, as shown in Figure 19.

Figure 19 Connection between the antenna and the power splitter board



- Step 2: Place the connected antenna and power splitter board in the test field. For details, see the traditional antenna test method.
- Step 3: After the test conditions are set, test the antenna pattern of all tilts and frequencies of a power splitter.
- Step 4: After completing all the pattern tests corresponding to a power splitter board, replace the power splitter board and repeat steps 1 to 4 until the pattern test corresponding to all power divider boards is completed.
- After the radiation pattern test is complete, calculate the radiation pattern. Broadcast beam indicators include traditional antenna indicators. The radiation pattern indicator of the PMI orthogonal beam group is calculated according to the indicator definition in section 3.2.2.

## 4.2 Specifications of the Power Splitter Board

To minimize the test error of the broadcast beam and PMI orthogonal beam group, strict restrictions are imposed on the fluctuation range of the indicators of the power splitting board. The following table lists the indicator fluctuation ranges.

| Power Splitter Board Indicator | Requirement |
|---|---|
| Maximum deviation from target amplitude (dB) | ≤ 0.4 |
| Maximum deviation from the target phase (°) | ≤ 3 |
| VSWR of the port | ≤ 1.20 |

### ◆ Chapter summary

This section describes how to test broadcast beams and PMI orthogonal beam groups using power splitting boards. In actual tests, designers can select test methods based on actual conditions.

# 05 Conclusion

The key requirement of the FDD 8T8R solution for antennas is how to use 8T8R multi-antenna technologies to improve cell capacity, user experience, and coverage. To fully describe the performance of FDD 8T8R antennas, antenna indicators are defined based on three types of beams: single column beam, broadcast beam, and traffic beam. New indicators are defined for traffic beams, including beam isolation and horizontal side lobes. In addition, to ensure accuracy of antenna port weights, the antenna needs to cooperate with the system to perform channel calibration, therefore, the antenna needs to have a channel calibration capability.

# 06 Acronyms and Abbreviations

| Abbreviation | Full Name |
|---|---|
| NR | New Radio |
| UE | User Equipment |
| BF | Beamforming |
| MIMO | Multiple-Input Multiple-Output |
| SU-MIMO | Single-User MIMO |
| MU-MIMO | Multi-User MIMO |
| 3GPP | 3rd Generation Partnership Project |
| BBU | Baseband Unit |
| RRU | Remote Radio Unit |
| PMI | Precoding Matrix Indication |
| DFT | Discrete Fourier Transform |
| BI | Beam Isolation |

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