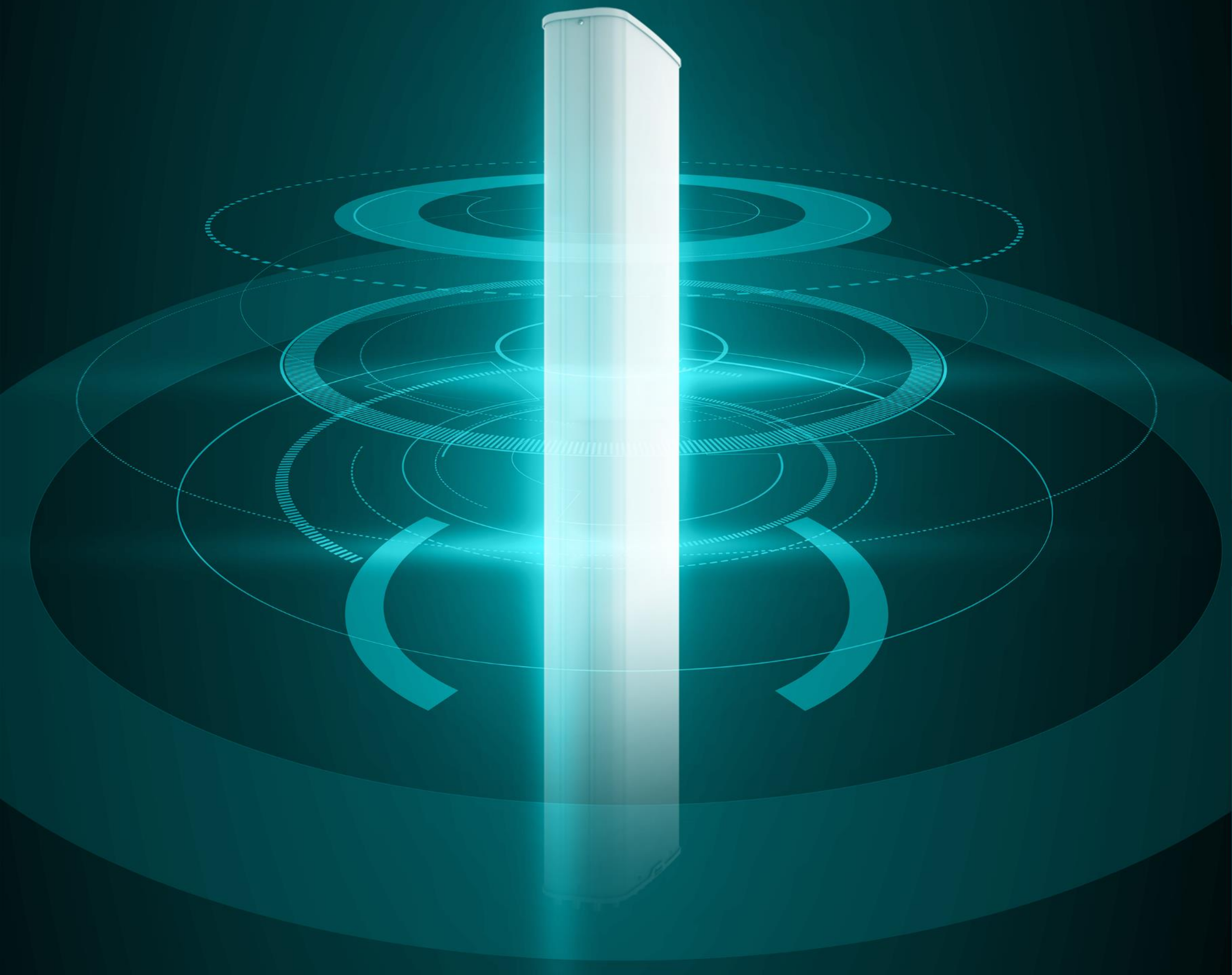


Generalized Antenna Efficiency White Paper

HUAWEI

Content

01 Abstract

After more than 30 years of development as a key element of mobile communications technologies, base station antennas have evolved significantly in form factors and capabilities. The development at each network stage comes with new and enhanced key capability requirements, which adds up to the continued innovation and advancement of antenna technologies while driving the evolution of antenna performance evaluation metrics.

As sustainability has become a focus topic of mobile networks, boosting network energy efficiency is a top priority for both operators and equipment vendors. Achieving a higher energy efficiency needs end-to-end synergy between equipment, meaning all equipment must run with maximized energy efficiency.

Antennas are essentially energy converters between signal transmitting and receiving devices. They convert the energy of high-frequency currents from transmitters into radio waves that are projected towards the areas with mobile users. Conversely, they receive radio signals from air and convert them into the energy of high-frequency currents flowing to the receivers. The energy conversion and projection efficiency are fundamental to network performance and network-level energy efficiency.

Enhancing the performance evaluation metrics of base station antennas based on efficiency will enable manufacturers to improve antennas and also help operators select antennas that allow for the highest possible network energy efficienc. It is necessary that the antenna industry quickly draws consensus from the discussions around antenna efficiency to further the development of antenna evaluation metrics.

This white paper provides a complete overview of antenna efficiency as a reference for the industry researchers. In this document, the term 'generalized antenna efficiency' collectively refers to the energy conversion efficiency of antenna circuits and the energy projection over air interfaces, in contrast to the term 'radio frequency (RF) efficiency' of antenna circuits.

02 Importance of Research on Generalized Antenna Efficiency

Generalized antenna efficiency analyzes antenna capabilities from the angle of energy processing results. It is a threefold concept that incorporates RF, coverage, and beamforming efficiencies, with the first involved in energy conversion and the latter two related to energy projection.

- RF efficiency refers to the proportion of RF energy an antenna converts into radio waves from the conducted RF energy input.
- Coverage efficiency refers to the proportion of radio waves that an antenna projects to a target area based on geographical coverage.
- Beamforming efficiency refers to the proportion of radio wave energy that an antenna projects to an area with target users based on beamforming.

This chapter qualitatively analyzes how the generalized antenna efficiency affects base station energy efficiency and how it is related to antenna performance indicators, for the purpose of highlighting both the necessity and importance of analyzing generalized antenna efficiency. Detailed definition, calculation, and testing methods will be provided in chapters 3 and 4.

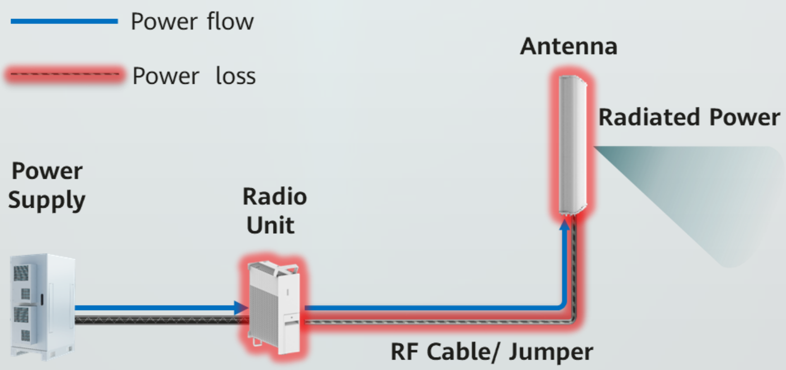
2.1 Impact of Generalized Antenna Efficiency on Energy Saving

With a certain fraction of energy lost inside the antenna for a variety of reasons, an antenna does not convert 100% of the energy input into radio waves. Likewise, an antenna does not project all converted radio waves to target areas, as a certain share is projected towards areas not used by the network (such as the sky) or as interference to other cells.

The generalized antenna efficiency affects base station energy efficiency during both energy conversion and projection.

2.1.1 Energy Conversion

Energy conversion measures how much energy fed to an antenna is converted into radio waves. The conversion efficiency is mainly affected by the loss arising from the antenna's internal RF circuits, so it is called RF efficiency.



A radio unit provides a certain amount of transmit power to ensure communication services for a sector. As illustrated above, one portion of the energy is lost inside the antenna, and the other portion radiates from the antenna in the form of radio waves for communications service. Although feeders or jumpers also have a small energy loss, this does not affect the analysis of antenna efficiency, and this loss is not considered in this document. The power radiated from an antenna can be expressed in the formula below:

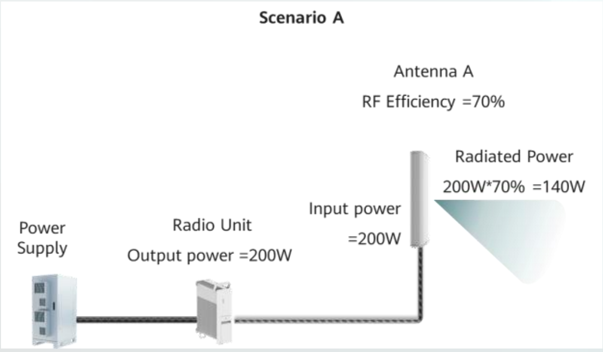
Antenna radiated power = antenna input power x RF efficiency

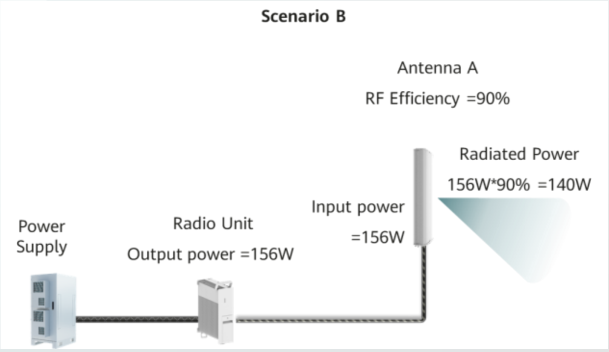
If two antennas designed with the same directivity radiate the same amount of power, they deliver the same quality of coverage. Based on this, by using an antenna with a higher RF efficiency with low internal loss, the radio unit needs a lower transmit power to achieve a given quality of coverage. This indicates that an antenna with a higher RF efficiency will help reduce the power provided by the radio unit, enabling the base station to consume less energy.

Here is an example.

In scenario A, the radio unit's total transmit power is 200 W and antenna A has an RF efficiency of 70%. The power radiated from the antenna is 140 W (200 W x 70%).

In scenario B, the same radio unit is used and antenna B has an RF efficiency of 90%. The radio unit just needs 156 W of transmit power to ensure the same quality of coverage (156 W x 90% = 140 W). Compared with scenario A, the transmit power from the radio unit is reduced by 22%, amounting to less energy consumed at the base station.





The RF efficiency indicates how efficiently an antenna converts the RF energy into radio waves, intuitively reflecting the impact on the base station's overall energy efficiency. This capability cannot be easily indicated by using common indicators such as gain and beamwidth. Therefore, RF efficiency provides a good supplement to existing antenna capability indicators.

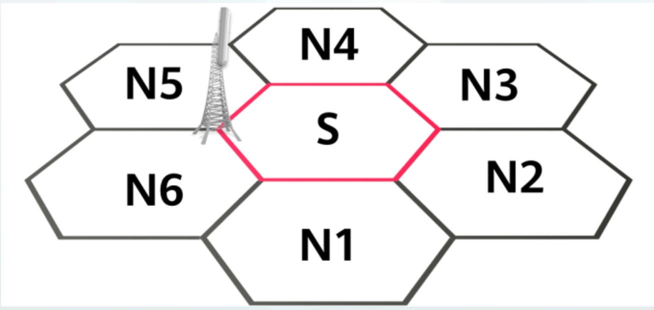
2.1.2 Energy Projection

Energy projection measures the performance of an antenna projecting the energy of radio waves to a target area. In reality, antennas transmit radio waves in all directions, and this means that only a portion of the energy can be projected to the target area. The ratio of the energy projected to the target area to the total energy of radio waves indicates how effectively the energy is utilized, and it determines not only the signal quality available for users in the target areas but also interference for users in other areas. Depending on the scopes of target areas and the types of antenna beams, the energy projection efficiency may come with diverse scenarios.

In this document, the scenarios are divided into two groups: static beams and dynamic beams. With static beams, coverage is provided based on fixed target geographical areas, and the ratio of energy projected to a target area is called 'coverage efficiency'. With dynamic beams, user-specific beams are formed through beamforming in response to user channel conditions, and the ratio of the energy projected to the target area is called 'beamforming efficiency'.

◆ Coverage Efficiency

The following figure uses standard three-sector cellular networking as an example. The target area covered by the antenna is a hexagonal sector. The radio waves radiated by the antenna are projected to the target area (region S) as effective energy, to its neighboring cells (ground regions N1 to N6 and beyond) as interference, and to the air as useless energy.



As such, the higher the proportion of the energy projected to the region S, the better the coverage in the sector. Given that an antenna C can radiate 100 W of radio wave energy and 60% of it is projected to the sector, the total radiated power to the sector is 60 W (100 W x 60%).

If we use antenna B that can project 75% of the energy into the sector instead, 80 W of radio wave energy needs to be radiated to achieve an equivalent coverage in the sector (80 W x 75% = 60 W).

Based on the antenna energy conversion efficiency described in the previous section, the following formula can be obtained:

Radiated power to the target area = antenna input power x RF efficiency x coverage efficiency

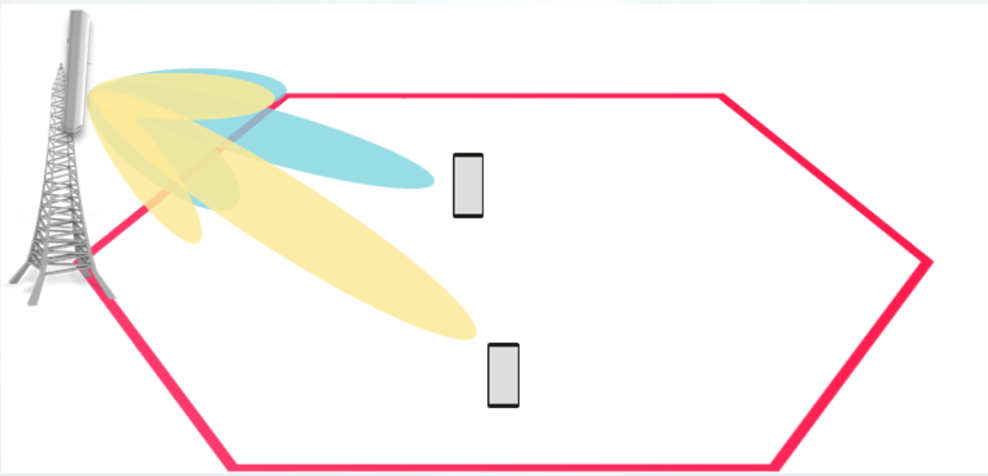
When the RF efficiency is fixed, using antennas with higher coverage efficiency can reduce the transmit power of radio units to achieve base station energy saving while ensuring the same coverage.

Therefore, the RF efficiency x Coverage efficiency can comprehensively reflect the antenna energy utilization, and demonstrate how antennas affect the overall energy efficiency of base stations that need to meet a certain coverage target.

◆ Beamforming efficiency

For user-level dynamic beams, antennas not only project radio wave energy to the desired sectors, but also use beamforming to form shaped beams pointing to users, so that more radio wave energy can be projected to the area where the user is located. The proportion of energy projected to the area of the user location refers to beamforming efficiency.

Dynamic beams project energy to a target area based on user status, but the area is not fixed geographically (see the following figure). The concept of beamforming efficiency is similar to that of coverage efficiency.



With reference to the description of coverage efficiency, higher beamforming efficiency enables higher signal strength towards target users. Alternatively, for a given signal strength, the transmit power of radio units can also be reduced, allowing for energy saving of base stations.

More importantly, higher beamforming efficiency allows target users to obtain stronger signal strength. This improves SINR and enables faster user-perceived rates. In addition, higher beamforming efficiency means smaller side lobe energy of user-level beams, and therefore less interference to other users in the same sector. For Massive MIMO systems, this can boost the MU-MIMO pairing success rate, increasing cell-wide capacity. For antennas, this is also an important indicator that weighs beamforming performance.

2.1.3 Overall Impact on Base Station Power Consumption

Based on descriptions in previous sections, higher generalized antenna efficiency is of great significance to reduce the power consumption of base stations.

The efficiency of conventional antennas is limited due to architectures and materials. For example, common 2L4H six-band antennas have an average RF efficiency and coverage efficiency of about 70%. Through innovation in architectures and materials, their overall efficiency can be significantly improved.

RF efficiency and coverage efficiency can be used to evaluate the overall energy utilization of an antenna. See the following table.

	RF Efficiency	Coverage Efficiency	Energy Utilization
Legacy antenna	70%	70%	49%
Theoretical goal	90%	85%	76.5%

Take a typical site configuration as an example: The low-band (800 MHz/900 MHz) and mid-band (1.8 GHz + 2.1 GHz) radio units are configured with transmit power of 4x80 W, and the 2.6 GHz radio unit is configured with transmit power of 4x40 W. The RF transmit power of the entire base station is 800 W. To achieve the same coverage, that is, the same effective coverage power, the transmit power of radio units required by conventional antennas and high efficiency antennas is compared in the following table.

	RF Transmit Power	Antenna Energy Utilization	Effective Coverage Power
Conventional antenna	800 W	49%	392 W
High efficiency antenna	512 W	76.5%	392 W
Difference	288 W (36%)		

The preceding table shows that, to achieve the same coverage, using high efficiency antennas can considerably reduce the transmit power of base stations. For a base station with typical configurations, the transmit power can be reduced by 36%, that is, 288 W. For a base station with medium traffic, this means that the power consumption of the entire site can be reduced by up to 25% (the specific power consumption reduction depends on factors such as radio unit models, network load, and ambient temperature etc.).

Therefore, improving the generalized antenna efficiency can enable remarkable base station energy consumption savings. This also brings direct economic benefits and supports environmental sustainability development of operator networks.

2.2 Efficiency Is Key to Weighing Antenna Performance

Base station antennas need a certain directivity when providing specific coverage, for which a series of performance indicators are necessary. The legacy antenna performance metrics are roughly depicted based on the characteristics of certain points in radiation patterns. As network complexity increases, networks need to be planned and constructed more precisely, and accordingly antenna performance needs to be described more accurately. The generalized antenna efficiency indicators are good supplements to existing antenna performance metrics. Here is an example.

The antenna coverage capability is usually evaluated by indicators such as the gain, vertical beamwidth, and horizontal beamwidth. The gain reflects the coverage capability to the farthest point and is related to the beamwidth. When an antenna's RF efficiency cannot be improved, a higher antenna gain is needed for a greater coverage distance, which results in the use of a narrow beamwidth which will deteriorate coverage uniformity.

However, as excessively narrowing the beamwidth is not recommended in most scenarios, the optimal method is to reduce internal antenna loss and optimize beam directivity to improve overall coverage while avoiding the deterioration of coverage uniformity.

The RF efficiency and coverage efficiency discussed above exactly reflect the internal antenna loss and beam directivity, allowing for comprehensive evaluation of the antenna coverage capability.

Likewise, indicators related to antenna interference suppression can also be more complete if coverage efficiency is used, which is not described in detail in this white paper.

03 The Definition and Calculation Method of Generalized Antenna Efficiency

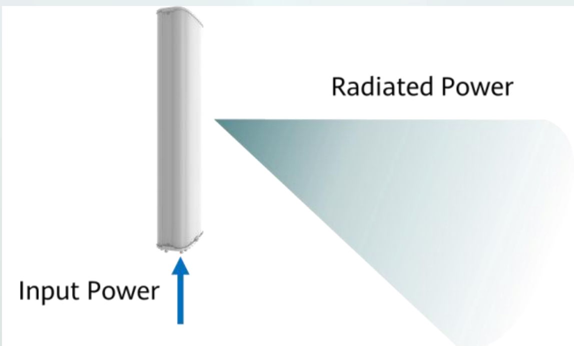
The relationship between generalized antenna efficiency, network energy efficiency and antenna performance is described qualitatively in the previous sections. Nowadays, there is an increasingly strong demand for green development. The communication industry pays much attention to improvement of antenna efficiency, to increase the energy efficiency of the entire network. Therefore, it is necessary for the base station antenna industry to form a unified and quantitative standard for antenna efficiency indicators to promote industry innovation and provide operators with high-quality products and solutions. This chapter describes the RF efficiency, coverage efficiency, and beamforming efficiency of the generalized antenna efficiency, and introduces their definitions and quantitative impacts on network energy efficiency and performance.

3.1 RF Efficiency

RF efficiency is defined as "efficiency" in the NGMN P-BASTA project white paper Recommendation on Standards for Passive Base Station Antenna Systems V12.0. In this document, "RF efficiency" is used to distinguish it from other efficiency concepts. It is consistent with the description in P-BASTA in terms of definition method, calculation method, and test method described in the following sections.

3.1.1 Definition of RF Efficiency

The RF efficiency describes the conversion efficiency of an antenna serving as a conversion apparatus, that is, a ratio of antenna radiated power (namely the power that is effectively converted into radio waves) to antenna input power. The RF efficiency reflects the capability of antennas to effectively transmit RF signals. Because RF efficiency is the ratio of radiated power to input power, it naturally associates the directivity with the gain. That is, RF efficiency can also be defined as the ratio of antenna gain to the directivity.



According to the foregoing definition, RF efficiency can be calculated by following formula.

RF efficiency (%) = antenna radiated power/antenna input power

Or

RF efficiency (%) = Antenna gain/Antenna directivity

3.1.2 Calculation Method of RF Efficiency

The antenna efficiency can be calculated by measuring the antenna input power and antenna radiated power based on the parameter definitions.

$$RF\ efficiency\ (\%)\ =\frac{P_{rad}}{P_{in}}$$

P_{rad} is the antenna radiated power and P_{in} is the antenna input power. The symbol % is used in the preceding formula and the symbol dB can also be used. In the case of dB, the formula is as follows:

$$RF\ efficiency\ (dB)\ =\ 10\cdot\log\left(\frac{P_{rad}}{P_{in}}\right)$$

The %- and dB-based formulas are the same in essence. The relationship between % and dB is as follows:

$$RF\ efficiency\ (\%)\ =10^{RF\ efficiency\ (dB)/10}\cdot 100\%$$

The RF efficiency, antenna gain, and directivity meet the following formula:

$$RF\ efficiency\ (\%)\ =\frac{G}{D}$$

In the formula, G indicates the gain (linear value) at the maximum radiation angle of the antenna and D indicates the antenna directivity (linear value).

The directivity can be calculated based on the 3D far-field radiation pattern and its maximum value:

$$\frac{4\pi\ P_n\ (\varphi_m,\theta_m)}{\oiint P_n\ (\varphi,\theta)\ \sin(\theta+90)d\varphi d\theta}$$

In the formula, D indicates the directivity, P_n indicates the 3D far-field radiation pattern, and $P_n\ (\varphi_m,\theta_m)$ indicates the gain at the maximum radiation angle, which is the same as that of G.

In the case of dB, based on the maximum gain G (dBi) and directivity D (dB), the efficiency can be calculated using the following formula.

RF efficiency(dB) = G(dBi) - D(db)

In addition, according to the relationship between antenna loss and antenna gain/directivity, the RF efficiency can also be calculated using the following equation:

$$RF\ efficiency(dB) = -a_{antenna}$$

In the ideal situation where the antenna has no loss (that is, 100% of the input power is radiated), the RF efficiency is equal to 0 dB. In practice, RF efficiency is always negative.

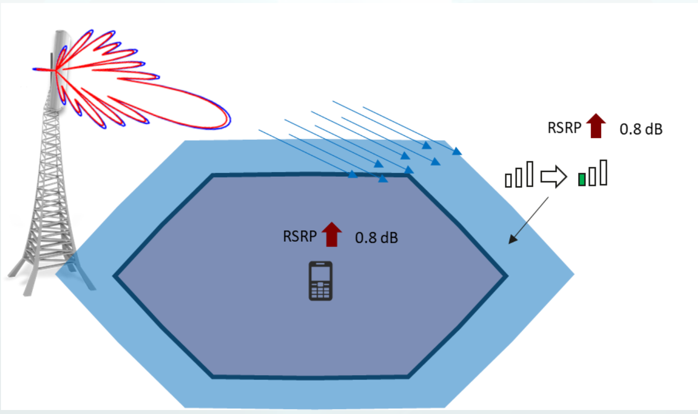
3.1.3 Significance of RF Efficiency

From the perspective of network performance, antennas with high RF efficiency can be used to improve the cell coverage (maintaining the same input power). From the perspective of energy saving, antennas with high RF efficiency can be used to reduce the power consumption of the base station by reducing the transmit power of the radio unit while maintaining the same coverage quality. The following describes the details from the two perspectives.

◆ Impact of RF Efficiency on Network Performance

From a network performance perspective, the benefits of high efficiency antennas are obvious.

For a given shape of the antenna radiation pattern, coverage in all directions is improved as antenna loss is reduced. As shown in the following figure, assuming that the insertion loss decreases by 0.8 dB, the coverage level at any position in the sector will increase by 0.8 dB. The reference signal received power (RSRP) in the original coverage area increases by 0.8 dB, improving user experience. Under the demodulation threshold of UEs, some areas that cannot be covered originally become coverage areas after the RSRP increases by 0.8 dB. In this way, the antenna coverage radius is increased.



◆ Impact of RF Efficiency on Energy Saving

From the perspective of energy saving, higher efficiency antennas can be used to reduce the base station power consumption by reducing the transmit power of the radio unit, without degrading the coverage.

The following uses the test data of a commercial site as an example to show the energy saving effect by using high RF efficiency antennas.

The site uses three-sector networking and deploys two frequency bands: 900 MHz and 1800 MHz. The coverage area is mainly commercial plazas and residential areas. The test adopts two kinds of configuration, maximum transmit power with baseline antenna and reduced transmit power with high efficiency antenna, and collects statistics on network KPIs and base station power consumption for comparison.

The RF efficiency of the two antennas on different frequency bands is as follows.

	Baseline Antenna	High Efficiency Antenna
900 MHz	69%(-1.6dB)	86%(-0.65dB)
1800 MHz	61%(-2.15dB)	83%(-0.8dB)

The transmit power configuration of each frequency band corresponding to the two antennas is as follows:

Frequency Band	TRX	Configured Power		Power Reduced (%)
		Baseline Antenna	High Efficiency Antenna	
900 MHz	2T2R	2x80 W	2x64 W	20%
1800 MHz	4T4R	4x40 W	4x30 W	25%

Statistics on KPIs for seven consecutive days for each configuration are collected. The result shows the network KPI keeps stable.

	900M		1800M		Total		
	Baseline Antenna	High Efficiency Antenna	Baseline Antenna	High Efficiency Antenna	Baseline Antenna	High Efficiency Antenna	Comparison
Total DL Traffic (GB)	433.7	446.8	1949.9	2097.8	2383.6	2452.6	Improved
Average DL User Throughput (Mbps)	5.2	5	8.4	8.6	6.8	6.8	Stable
DL PRB Usage(%)	32.1	30.7	40.9	41.5	36.5	36.1	Stable
Average User Number	20.1	19.5	64.4	66.3	42.3	42.9	Stable
ERAB Success Rate(%)	99.98	99.99	100	99.99	99.99	99.99	Stable
Call Drop Rate(%)	0.14	0.12	0.01	0.01	0.08	0.07	Stable

The following table lists the power consumption of radio units working at each frequency band and power saving estimation. The unit is KWh.

Average Per Day Per Sector	Baseline Antenna	High Efficiency Antenna	Power Saving	Saving Ratio	Power Saving Per Site Per Year
900M	7.14	6.06	1.08	15.09%	1180
1800M	7.84	6.35	1.49	19.02%	1633
Total	14.98	12.41	2.57	17.15%	2813

The test results show that the RF power consumption is reduced by 17.15% by using high RF efficiency antennas. It can be learned that improving antenna RF efficiency is of great significance to energy efficiency of a base station

3.2 Coverage Efficiency

As the description in chapter 2, the coverage efficiency of an antenna is the ratio of the power projected to the target area to the antenna radiated power. In the description, “Antenna radiated energy" equals “Antenna input power" x "RF efficiency".

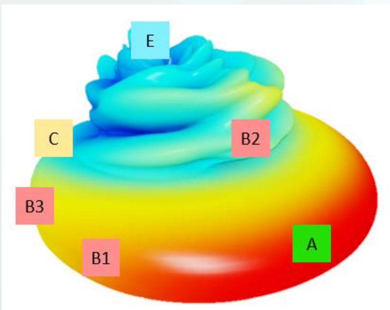
The “the power projected to the target area” needs to be analyzed from the perspective of network coverage. The target area varies according to the networking mode and scenario. This document describes only the most common three-sector networking scenario. For other scenarios, such as omnidirectional coverage and six-sector network sites, the target area should be defined based on the corresponding scenario.

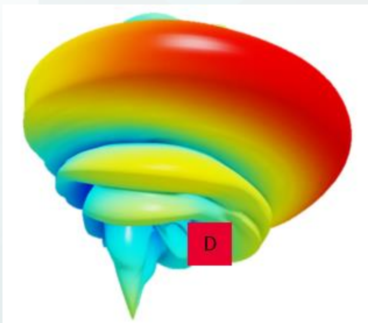
3.2.1 Definition of Coverage Efficiency

As described in Chapter 2, coverage efficiency reflects the ability of an antenna to project energy into a target area. In the standard three-sector network scenario, the target area refers to the hexagonal sector covered by the antenna. The coverage efficiency can be defined as follows.

Coverage efficiency(%) = power radiated into target sector/antenna radiated power

The coverage efficiency can be specifically defined by mapping the target sector covered to a 3D far-field power pattern of the antenna, as shown in the 3D pattern below.





The energy in area A is projected to the target sector, which is effective energy.

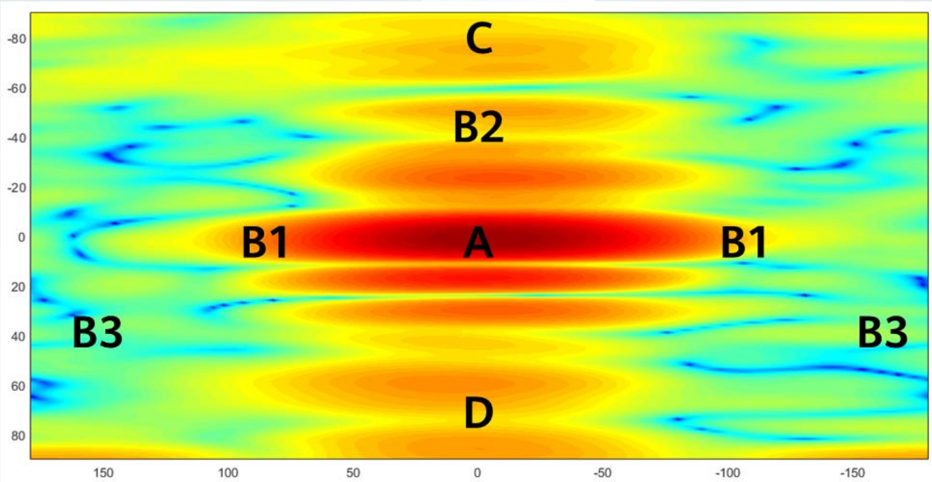
The energy in areas B1, B2, and B3 is projected to neighboring sectors, causing interference to neighboring sectors. This is interference energy.

The energy in area C is projected to the neighboring cell, which is useless energy.

Energy in area D is projected to the near area of the target sector, and EMF control needs to be considered. Area D may be referred to as an EMF area.

The energy in area E will be projected to the space over the target sector. Currently, the energy is mainly useless. In the future, it could be considered as low-altitude drone coverage.

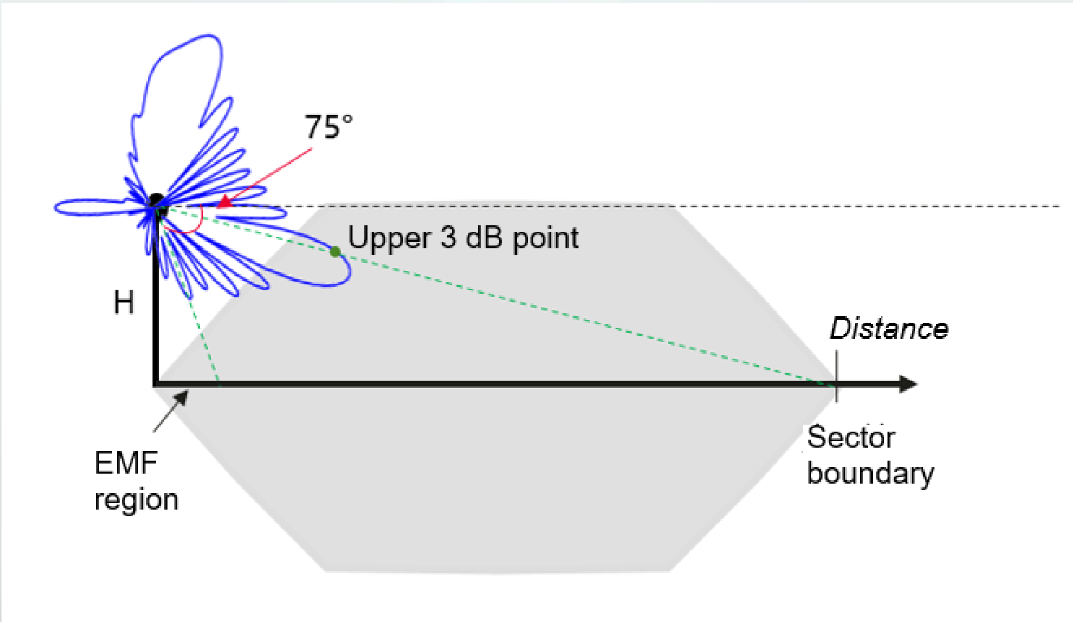
To quantify the range of each region more intuitively, the 3D far-field power pattern can be unfolded into a planar form as follows.



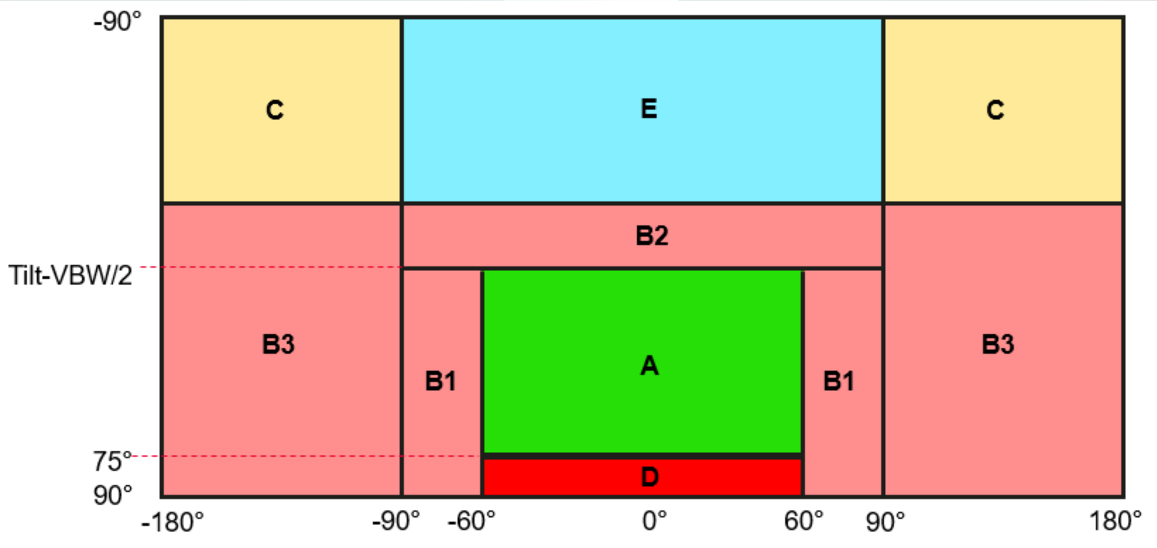
For coverage efficiency, the boundary of area A needs to be defined quantitatively.

For a regular hexagonal sector, the maximum angle to be covered by the horizontal plane is 120°. Reflecting in the pattern, the left and right boundaries of area A are -60° and +60°.

In the vertical plane, to achieve better coverage and to control interference, the upper 3 dB point of the antenna pattern is usually aligned with the cell edge, that is, Tilt-VBW/2 is used as the upper boundary of Area A. (Tilt indicates the electrical downtilt and VBW indicates the vertical beamwidth). In addition, to meet the requirements of EMF control at the near points of the base station, 75° is used as the boundary between area A and EMF. As shown in the following figure.



Based on the foregoing description, a region division diagram based on the planar 3D pattern can be drawn as followies.



To sum up, in the planar 3D pattern, area A is a rectangle. The horizontal boundaries are -60° and +60°, the upper boundary is Tilt-VBW/2, and the lower boundary is 75°.

3.2.2 Calculation Method of Coverage Efficiency

The coverage efficiency can be calculated by dividing the energy of area A defined in the previous section by the total energy corresponding to the entire pattern. Based on the 3D far-field power pattern, coverage can be expressed using the following formula.

$$Coverage\ efficiency = \frac{\int_{Tilt-VBW/2}^{75}\int_{-60}^{60} sin(\theta+90)*P_n\ (\varphi,\theta)d\varphi d\theta}{\int_{-90}^{90}\int_{-180}^{180} sin(\theta+90)*P_n\ (\varphi,\theta)d\varphi d\theta}$$

If necessary, the energy proportions of other areas can also be calculated based on the area boundary to analyze antenna performance.

3.2.3 Significance of Coverage Efficiency

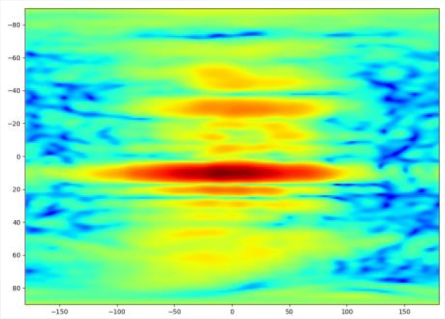
When the antenna radiated power is fixed, high coverage efficiency means that more power is projected to the target sector and less power is wasted in the air. If two antennas with the same RF efficiency are used, in terms of network performance, the antenna with higher coverage efficiency can improve the cell coverage quality while maintaining the same input power. And in terms of energy saving, antennas with higher coverage efficiency can reduce the power consumption of the base station by reducing the transmit power of the radio unit while maintaining the same coverage area.

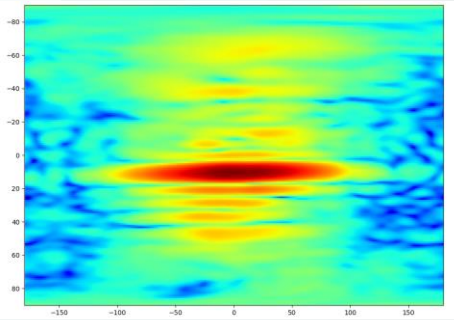
Coverage efficiency can be used to evaluate the difference in coverage capabilities of two antennas, which cannot be achieved by using traditional antenna indicators.

For example, the following lists two antennas. The indicators such as gain, vertical beamwidth, and horizontal beamwidth are similar. It is difficult to evaluate the coverage capability based on these indicators.

	Antenna 1	Antenna 2
Gain	17.3	17.5
VBW	6.3	6.5
HBW	62.4	68.9
RF efficiency	79.8	78.7
Coverage efficiency	69.5	79.6

The RF efficiency of the two antennas is similar, the coverage efficiency difference is around 10%. The following figure shows the planar 3D pattern.





Coverage simulation is performed for the two antennas under the following conditions: The inter-site distance is 500m, the site height is 25 m and the transmit power is 4*40 W . The coverage simulation results are as follows.

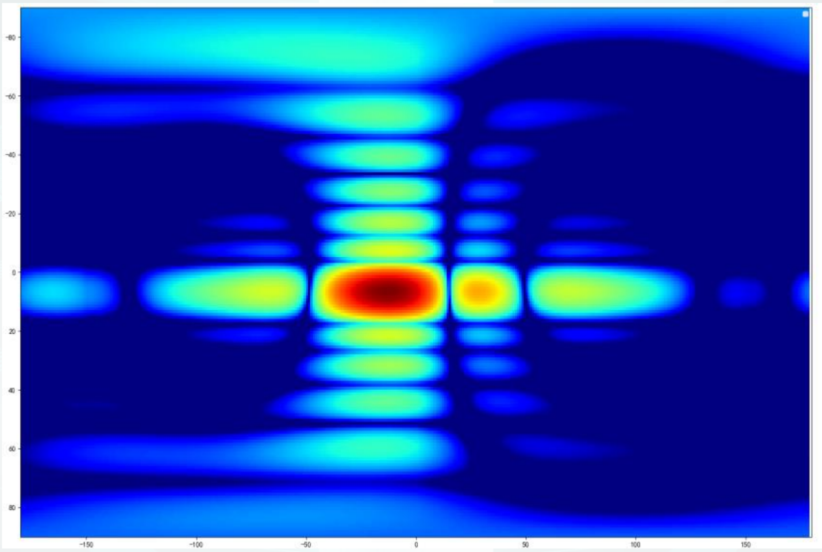
Antenna	Average RSRP(dBm)	Delta(dB)
Antenna 1	-108.74	Baseline
Antenna 2	-108.19	0.55

The simulation results show that under the condition of the same radiated power, using the antenna with higher coverage efficiency can improve the coverage quality. If the target coverage quality is specified, the radio transmit power can be reduced, thereby saving energy for the base station.

3.3 Beamforming Efficiency

Beamforming is one of the key technologies of 5G networks. It forms narrow beams to concentrate energy to target users, improving the SINR of received signals and reducing interference. Therefore, it is necessary to analyze the performance of beamforming from the perspective of energy distribution.

Beamforming efficiency is proposed to describe the capability of a beamforming antenna to project energy to a specified user, or the capability of a formed beam to concentrate energy.



Beamforming technology adaptively adjusts the antenna radiation pattern based on specific scenarios to form beams directed to target UEs. The scenarios are much more complex than static beam.

One possible definition of beamforming efficiency is the main lobe energy ratio. However, the better definition method, calculation method, and the quantitative impact of beamforming efficiency on network performance still need more in-depth research, more simulation and test results to verify.

This white paper only presents the concept of beam efficiency qualitatively, and more analysis will be supplemented in a new edition.

◆ Summary

This chapter describes the definition, calculation method, and significance of the RF efficiency and coverage efficiency. And more detailed beamforming efficiency analysis will be described in new edition.

The simulations and tests presented in this chapter reflect the impact of generalized antenna efficiency on base station energy consumption and network performance, and demonstrate the necessity and importance of generalized antenna efficiency as antenna capability evaluation indicator.

04 Measurement of Antenna Efficiency

The chapter 3 has described the calculation methods of RF efficiency and coverage efficiency included in the generalized efficiency.

It can be learned from these calculation formulas that RF efficiency and coverage efficiency can all be calculated by using a 3D far-field power pattern. This chapter will briefly introduce the measurement method for 3D pattern.

The near-field, far-field, and compact field are commonly used in the industry to measure the antenna pattern of a base station. The working principles of each test system are different, but the overall test process is similar.

4.1 Single Port Beam Pattern Measurement

The single-port beam pattern is the non-shaped beam pattern. Multi-probe spherical near-field system is widely used because of its advantage in 3D pattern measurement efficiency.

Using the near-field test method as an example, the test procedure is as follows.

- ◆ Using the calibration reference antenna for gain calibration.
- ◆ It is recommended that for the Antenna installation: The phase center of the antenna shall be aligned with the system laser positioning.
- ◆ Connect cables, adjust the downtilt of the antenna RET, and start the test.
- ◆ Rotate the antenna as many times as needed, in order to measure the near-field in all directions, then the near-field 3D pattern is obtained.
- ◆ The far-field 3D pattern is obtained through the NF to FF transformation

4.2 Synthetic Beam Pattern Measurement

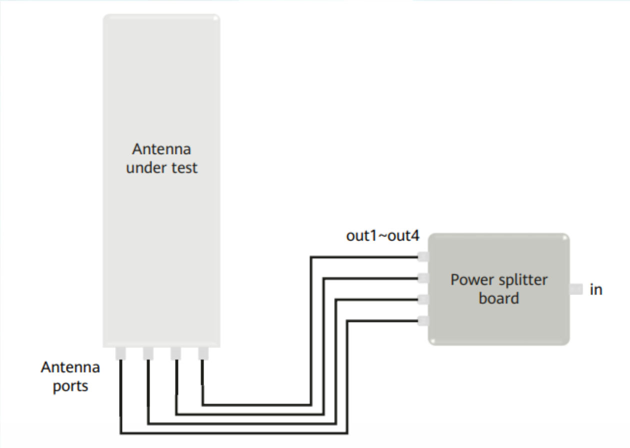
The synthetic beam is shaped beam formed by beamforming, includes service beam and NR broadcast SSB beam. The measurement process of synthetic beam pattern and single-port pattern is the same as that of the single-port pattern, except that multiple ports are required to be excited simultaneously.

Synthetic beam measurement requires to configure weight of each antenna port, which can be implemented by using the power splitter board. The following table uses an orthogonal beam group of an FDD 8T8R antenna with H4V1 architecture as an example. The weights (Same amplitude, different phases) of the power splitter board are listed in the following table. P1 to P4 indicate the number of a polarized antenna port.

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

The test procedure using the power splitter board 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 the following figure



- Step2: Place the connected antenna and power splitter board in the test field. For details, see the single-port radiation pattern test method.
- Step 3: After the test conditions are set, test the radiation pattern of all tilts and frequencies with a power splitter board.
- 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 splitter boards is completed.

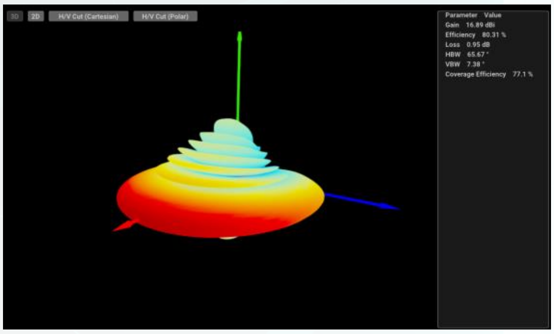
To minimize the test error, the fluctuation range of the indicators of the power splitter board must e strictly limited. The following table lists the indicator fluctuation ranges.

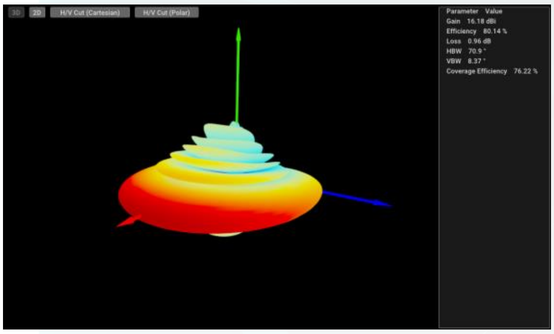
Power Splitter Board Indicator	Requirement
Maximum deviation from the target amplitude (dB)	≤ 0.4
Maximum deviation from the target phase (°)	≤ 3
VSWR of the port	≤ 1.20

4.3 Calculating Generalized Antenna Efficiency Based on 3D Patterns

The 3D pattern contains radiation characteristics of antennas in all directions, and contains a large amount of information. In order to calculate the generalized antenna efficiency efficiently, it is necessary to develop an automatic calculation tool based on the formula.

As shown in the following figure, the 3D pattern reading tool can graphically display the 3D pattern and automatically generalized efficiency indicators for operators or researchers to evaluate and compare antennas.





05 Acronyms and Abbreviations

Abbreviation	Full Name
RF	Radio Frequency
BF	Beamforming
UE	User Equipment
SNR	Signal-to-noise Ratio
SINR	Signal-to-interference-plus-noise Ratio
NGMN	Next Generation Mobile Networks
RSRP	Reference Signal Received Power
HBW	Horizontal Beamwidth
VBW	Vertical Beamwidth
RAT	Radio Access Technology
ISD	Inter-site Distance
RRU	Remote Radio Unit
OPEX	Operating Expense
KPI	Key Performance Indicator
EMF	Electromagnetic Field
NR	New Radio
SSB	Synchronization Signal And PBCH Block
3GPP	3rd Generation Partnership Project
UMa	Urban Macrocell
RMa	Rural Macrocell
PRB	Physical Resource Block
MIMO	Multiple Input Multiple Output
FDD	Frequency Division Duplex
PMI	Precoding Matrix Indication

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