THE IMPACT OF ANTENNAS ON WIRELESS IoT END-DEVICE CERTIFICATIONS

Antenna performance is critical to achieving wireless IoT device product certification. Gain insights into the complexity of multi-level certifications and how to design or select an antenna to meet the requirements for a successful launch to market.

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Introduction

The development of wireless technology has enabled the rapid explosion of the Internet of Things (IoT). Millions of IoT devices are interconnected on wireless networks gathering and sending data, impacting all aspects of society and life. Before an IoT end-product is permitted to be launched into the market, it needs to successfully navigate multiple levels of complex certification approval processes to certify the product is in compliance with government regulations and industry standards; safe to use; and interoperable with other devices on the network. Certification approval processes can be time consuming and costly, and failure to pass may lead to longer product development time, higher cost, and launch delay.

Antennas are an essential part of a wireless IoT device and the antenna's performance is critical to product certification approval. Having a thorough understanding of the certification approval tests on the radiation performance of the wireless device helps in selecting or custom designing the right antenna to meet the required radiation performance and, ultimately, the success of product certification.

This paper provides an overview of the complexity of the multiple levels of product certifications with an emphasis on how antenna performance requirements are decided by the regulatory restrictions and industry standards. Throughout, examples are used to demonstrate how to design or select an antenna to meet the restrictions and requirements for certification and a successful launch to market.

Overview of the Three Levels of Certification

A wireless device needs to go through several levels of certification before the product can be brought to market. These certification processes are to ensure the product meets government regulations and industry standards, and to verify the product's interoperability to the subscribed mobile network operator's (MNO) cellular network (if used). This section provides an overview of each level of certification, highlighting the complexity of the processes and the differences between the certifications for wireless module products and end-device products. These differences explain why it is important to utilize the module certifications toward the certifications of end-devices to help reduce cost and bring them to market faster.

	Level 1: Regulatory Approval	**Level 2: Industry Standard Certification**	**Level 3: Carrier Certification (only for cellular technology)**
Certification Description	Regulate RF devices to comply with government regulations and restrictions on the transmitted signal's characteristics, output power level, and its effect on human tissue to help protect public safety and prevent system interference	Check the device's functionality and compliance to the industry standards for network interoperability, application-specific protocols and security to ensure it can operate on the networks and interoperate with other certified devices	Verify the cellular device's interoperability specific to the MNO's cellular network configuration and parameter settings to obtain permission to operate on the their networks
Examples	• FCC (USA) • CE (Europe and EFTA) • CCC (China) • ISED (Canada) • IFT (Mexico) • UKCA (UK)	• GCF (Europe and Global) • PTCRB (NA) • Wi-Fi • Bluetooth • NFC • LoRaWAN	• Vodafone • Deutsche Telekom • Telefónica • Verizon • T-Mobile • AT&T • Rogers • TELUS • SoftBank • NTT • SKT
Complexity	Medium complexity	High complexity	Medium complexity
Typical Time and Cost	Average 5 weeks, $10K	Average 8 weeks, $30K	Average 6 weeks, $20K

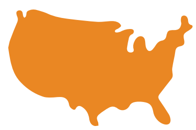
Note: Required certifications vary regionally. Some certifications are mandatory in select regions, but not required in others. Information provided in this white paper is based on the author's industry experience. The readers shall refer to the standard organizations and authorized test labs for accurate information.

Level 1: Regulatory Approval

Regulates RF devices that are capable of emitting energy by radiation and conduction and have the potential to cause interference to radio service operations.

RF devices are required to be compliant with government regulations and restrictions on the transmitted wireless signal's characteristics, output power level, and its effect on human tissue to help protect public safety and prevent system interference. Therefore, regulatory approvals are country-specific and mandatory for offering devices legally on the market in a country.

In Europe, CE Marking is a self-written Declaration of Conformity (DoC) from the device manufacturer with proof that the product passes all required tests defined in the applicable CE Directives, affirming conformity with CE standards.



In the U.S., FCC Certification is for RF devices to get authorization prior to selling in the U.S. market.

Globally, most of the regulatory bodies in different regions use a self-declared DoC like CE (Australia and New Zealand, etc.), or a certification approval like FCC (Canada, Mexico, Japan, Korea, Taiwan, Brazil, etc.).

Some countries (Russia, China, etc.) have a restrictive market and require in-country testing. Certifications are only granted to companies residing in the country.

CE Marking

If a product is sold in EU and EFTA countries, CE marking is mandatory to indicate the product is compliant with the EU health, safety, and environmental protection standards. CE is not a certification like FCC approval. CE is a self-declaration from the device manufacturer affirming the product's conformity with the standards, bearing proof that the manufacturer has passed all required tests defined in the applicable CE Directives. Manufacturers can use the CE Mark based on the self-written Declaration of Conformity (DoC)*.

As of 2022, there are about 24 CE marking Directives. Each Directive describes the technical and regulatory requirements of a certain product scope. Normally, a product can be covered by several directives simultaneously. To affix the CE Mark, the product must be tested and meet the requirements of the applicable Directives. For example, a wireless device is covered by a minimum of three directives: Electromagnetic Compatibility Directive (EMC), Radio Equipment Directive (RED), and Low Voltage Directive (LVD).

* Medical and industrial devices are exceptions and often required to be assessed by a notified body to use the CE Mark.

FCC Certification

Any RF device being marketed into the United States is required to be authorized by the Federal Communications Commission (FCC). An RF device must be tested by accredited test labs to prove it is in compliance with regulations before it can be granted an FCC certification by a Telecommunication Certification Body. Three categories of RF tests are required, as shown in the following table.

Radiated emission testing – Intentional and unintentional radiation from the device can cause interference to the licensed radio services. An FCC accredited test lab measures the electromagnetic field strength of the in-band emissions and out-of-band emissions generated by the device when it is operating under the possible configurations of normal operation in the frequency range from 30 MHz to the 5th harmonic of the highest fundamental frequency or to 40 GHz, whichever is lower. The measured radiated emission is verified to ensure it is within the limits for radiated emissions set by FCC.

Conducted emission testing – A portion of the electromagnetic energy generated by a device can be conducted to the power supply. The conducted emission is tested in the frequency range from 150 kHz to 30 MHz to verify if it is in compliance with the FCC allowed limit.

RF exposure testing – when the device is used in the proximity of human bodies, Specific Absorption Rate (SAR) is tested to evaluate if the human RF exposure is under the allowed FCC limit.

An IoT end-device typically integrates one or multiple wireless modules with other functions such as antennas, processor and software, application-specific sensors, power supply and power management, hardware interface, etc. Wireless modules in the U.S. market are FCC approved. In many cases, about 85% of the FCC approval tests are already done in the module level when the modules are certified, and only about 15% of the tests may need to be done on the end-device level. As an example, the FCC test items of the TE Connectivity (TE) LEMBAS LTE/GNSS USB modem are listed below. The LEMBAS modem uses a certified LTE/GNSS module available on the market and its FCC test items are also listed for comparison.

FCC Test Item - Module Used in the LEMBAS modem	FCC Test Item – LEMBAS End-Device
Conducted RF Output Power	SAR [1]
EIRP/ERP/Maximum Antenna Gain Permitted	Conducted Emission
Conducted Spurious Emissions	Radiated Emission
Radiates Spurious Emission	-
Peak-to-Average Power Ratio	-
Occupied Bandwidth	-
Conducted Band Edge	-
Frequency Stability	-

TE Connectivity (TE) LEMBAS LTE/ GNSS USB modem for LTE CAT4 network and GPS tracking

(1) If the end-device is a portable device operating within proximity to human bodies, SAR will be tested. This applies to the LEMBAS modem.

Because a module isn't an end-device and doesn't have antennas and other device level hardware/software integrated, its FCC certification is limited with restrictions. One typical example of the restriction is the maximum allowed antenna gain derived from the transmitter's output power and the FCC limits on EIRP and RF exposure. When the module is integrated into an IoT end-device, if these restrictions are followed, the module's certifications can be fully utilized toward the end-device's FCC certification. Utilizing the module's certification can help reduce the end-device's product execution risk, lower its certification cost, and increase its speed to market. In the case of the LEMBAS modem, its LTE antenna is embedded inside the enclosure of the device and the antenna's gain is lower than the maximum allowed antenna gain specified by the certified module, so the module's FCC certification is fully utilized to simplify the LEMBAS modem's end-device certification process.

Note: Unlike FCC, CE is not a certification so a module with the CE Mark has no pre-certification. Therefore, a manufacturer who uses a module with the CE Mark is required to test the end-device according to all applicable directives and is solely responsible for the end-device meeting all the essential requirements in order to affix the CE Mark.

Level 2: Industry Standard Certification

Verifies products meet industry standards for network interoperability, application specific protocols and security to ensure the device can operate on the networks and interoperate with other certified devices.

To obtain Industry Standard Certifications, a wireless product is often required to be tested in a variety of ways to validate that the industry standards are met for the device to operate on the network and interoperate with other certified devices. Multiple certifications for different technologies and different industries are shown below as an example.

Wireless Cellular Networks	PTCRB; GCF
Wireless Local Networks	Wi-Fi Certified; LoRaWAN Alliance Certification; Sigfox Ready; Zigbee Alliance Certification
Vehicle Usage	EU EMC (72/245/EEC, 2009/19/EC); ISO7637-2 (EMC); SAE J1455 (Environmental)
Rail Usage	EN50155/EN45545; NFPA-130

Among the certifications listed above, PTCRB and GCF for use on cellular networks are mandatory in North American and European markets. PTCRB/GCF certification focuses on testing the following aspects of the device: conformance to the 3GPP Standards; interoperability with the network server and/or other devices; over-the-air (OTA) performance; and field trial performance driven through a number of networks used by different infrastructure vendors (required by GCF only).

Examples of Typical End-Device PTCRB Tests

- RF Interface – RSE Spot Check And Possible RF Conducted Test
- Power Interface
- SIM And eSIM Interface Testing
- Audio Interface Testing
- OTA Antenna Testing
- Field (Required By GCF Only)

Cellular modules available on the market are typically fully tested and pre-certified by following the PTCRB/GCF certification processes. GCF and PTCRB pre-certified modules are listed in [1] and [2]. Unlike end-devices, these pre-certified modules cannot be run on an operator network by themselves. End-devices integrate the modules with the needed network interfaces such as SIM, antennas, and power controlling circuitries to operate on the networks. The end-device certification test process can be significantly simplified if a pre-certified module is used, since most GCF/PTCRB tests are completed with a pre-certified module), and if the integration of the module does not change the RF characteristics (e.g. RF layout and RF shielding) of the module and follows the maximum allowed antenna gain restriction. Often, only required spot-checkup tests can be sufficient. Therefore, the time and cost to certify a cellular IoT device can be notably reduced if a pre-approved module is used.

Level 3: Carrier Certification

Verifies the cellular device's interoperability specific to the MNO's cellular network configuration and parameter settings to obtain permission to operate on their networks.

After receiving regulatory approvals and industry standard certifications, a cellular device still needs to undergo additional interoperability testing specific to the cellular network to obtain carrier certification to operate on the network. These interoperability tests are based on the network configuration and parameter settings, so the carrier certification process can be very different from one carrier to another.

Certifications Key Takeaways

In summary, before an IoT end-device product is sold on the market, different levels of end-device certifications on the product are required. The process to get the device certified can be lengthy and costly. To speed up this process, the wireless module industry provides pre-certified modules with specified integration restrictions. By strictly following these restrictions when the module is integrated into the end-device, the end-device certification process can be simplified with notably reduced time and cost to bring the end-device product to the market.

An IoT end-device integrates the wireless module with other needed network interfaces such as SIM, antenna, and power controlling circuitry to operate on the network. Among these interfaces, the antenna is the most important RF hardware which directly impacts the IoT device's radiation performance. To successfully certify a wireless product, it is critical to understand which regulatory restrictions and industry technical standards will define the requirements on the antenna's performance. It is also essential to know which certification test results will be impacted by the antenna's performance and lead to the success or failure of the certification application. Additionally, it is important to understand why the module's pre-certification typically has restrictions on the antennas, and how to follow these restrictions to fully utilize the module's pre-certification.

End-device Certification Requirements on Antennas

Antennas are the essential parts of wireless devices and convert energy from RF circuitry into the form of electromagnetic waves so information can be radiated and transmitted through the air. How much energy can be radiated depends on the efficiency of the antenna, and how strong the radiated energy in certain spatial direction depends on the gain of the antenna in that direction. We want all the energy from the RF transmitter to be radiated towards the intended directions, so the antenna efficiency needs to be as high as unity and the antenna gain as high as possible towards the intended directions. At the same time, to reduce potential harmful interference to other RF devices, we need to regulate the energy radiated by the antenna in any given direction, so the gain of the antenna needs to be limited as well.

In this section, we explain how the EIRP and RF exposure regulatory requirements limit the permitted maximum antenna gain and how to estimate the needed antenna efficiency so the industry standard OTA requirements can be met. Several TE antenna products are shown as examples to demonstrate how we improve the antenna design to meet challenging requirements so end-device products can successfully achieve all levels of certifications and be brought to market smoothly.

Maximum Allowed Antenna Gain Decided by EIRP and RF Exposure Limits

To help prevent potential radio interference and reduce human exposure to RF radiation, the government regulatory has limits on EIRP and RF exposure of an RF device. The Maximum Allowed Antenna Gain for the device to use is defined based on these limits.

A cellular module's FCC test data is used below as an example of how the Maximum Allowed Antenna Gain is defined. Since it is for demonstration, only the data in a few frequency bands are listed. The first step is to calculate the allowable antenna gain based on the FCC EIRP limit and on the module's Tx conducted output power level. The second step is to calculate the allowable antenna gain based on the RF exposure power density limit, and again on the module's Tx conducted output power level. Finally, the Maximum Allowed Antenna Gain is the minimum value of the above two to ensure both FCC limits are met.

LTE Band	Tx Freq. (MHz)	Max. Tx Conducted Output Power (dBm)	EIRP Limit (dBm)	Max. Antenna Gain to Comply with EIRP Limit* (dBi)	Power Density Limit (dBm)	Max. Antenna Gain to Comply with Power Density Limit** (dBi)	Max. Allowed Antenna Gain (dBi)
12	699 - 716	25.0	36.9	11.9	33.7	8.7	8.7
5	814-849	25.0	40.6	15.6	34.4	9.4	9.4
4	1710 - 1755	25.0	30.0	5.0	37.0	12.0	5.0
2	1850 - 1910	25.0	33.0	8.0	37.0	12.0	8.0
30	2305 - 2315	22.0	23.9†	1.9	37.0	15.0	1.9
41	2496-2690	25.0	33.0	8.0	37.0	12.0	8.0
42	3550 - 3650	22.0	23.0††	1.0	37.0	15.0	1.0
48	3550 - 3700	22.0	23.0††	1.0	37.0	15.0	1.0

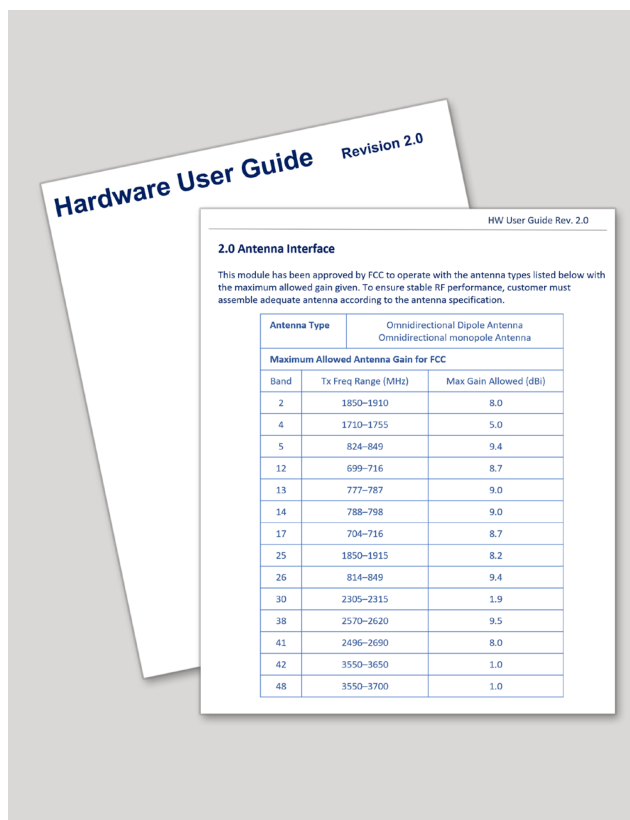
†† Band 42 and Band 48 EIRP restrictions are to prevent unlicensed CBRS band interferes with licensed incumbents.
* Max Antenna Gain (including cable loss) to Comply with EIRP Limit = EIRP Limit - Max Tx Output Power
** Max Antenna Gain (including cable loss) to Comply with RF Exposure Limit = Power Density Limit - Max Tx Output Power
† Band 30 EIRP restriction is to mitigate outdoor cellular antenna's interference to Sirius XM in North America.

Note: EIRP and RF exposure limits are especially strict for portable devices. A portable device must not have antenna gain exceeding the limit defined in the certification of the RF module. EIRP requirements on fixed devices, such as CPEs, are often more relaxed, so the antenna gains can be higher.

The maximum allowed antenna gain is a restriction from the wireless module's FCC certification. To have the appropriate antennas used at the end-device level, this restriction is specified in the module's user manual (or hardware selection guide), and so are the types of antennas used in the module's FCC certification tests. Furthermore, some module suppliers will provide a list of approved antennas for the end-device integrators to choose from.

With the antenna requirement information provided by the module suppliers (example shown on the right), the choice of antenna in the end-device integration will directly impact the complexity of the end-device's FCC certification process and associated cost.

- If the same antenna type with equal or lower gain as described in the module's specification is used, the module's certification can be reused when the FCC ID is applied for the end-device with reduced lab testing or even without additional testing.
- If a different type of antenna is used, and/or with a different antenna gain, it may fall into so-called Class II Permissive Change (C2PC). The radiated emission tests must be performed again to obtain a new FCC ID for the end-device. The EIRP and RF Exposure of the end-device with the new antenna must meet FCC compliance requirements.
- If a device is certified as an end-device but is supplied without integrated antennas or specific external antennas, the antennas to be used with the device must comply with regulatory requirements defined in the government regulatory approval (e.g., FCC, CE, ISED, etc.). In other words, the antennas must be of the same types of authorized by the device's government regulatory certification and have similar in-band and out-of-band radiation characteristics. As a result, the device manufacturer would need to supply a list of acceptable antennas to customers.


Hardware User Guide Revision 2.0

HW User Guide Rev. 2.0

2.0 Antenna Interface

This module has been approved by FCC to operate with the antenna types listed below with the maximum allowed gain given. To ensure stable RF performance, customer must assemble adequate antenna according to the antenna specification.

Antenna Type	Omnidirectional Dipole Antenna Omnidirectional monopole Antenna	
Maximum Allowed Antenna Gain for FCC		
Band	Tx Freq Range (MHz)	Max Gain Allowed (dBi)
2	1850–1910	8.0
4	1710–1755	5.0
5	824–849	9.4
12	699–716	8.7
13	777–787	9.0
14	788–798	9.0
17	704–716	8.7
25	1850–1915	8.2
26	814–849	9.4
30	2305–2315	1.9
38	2570–2620	9.5
41	2496–2690	8.0
42	3550–3650	1.0
48	3550–3700	1.0

When an IoT end-device integrates certified modules, fully utilizing the module's certifications toward the end-device's FCC certification by following antenna restrictions, this can reduce the end-device's product execution risk, lower its certification cost, and increase its speed to market.

In the FCC test data example used in this section, the EIRP limits in Band 30, 42 and 48 are about 10dB lower than the limits in other cellular bands, so the resulting antenna gains in these bands are required to be much lower than the gains in other bands as well. These special EIRP restrictions are compulsory in the North American market and bring challenges to the designs of RF transmitter and antenna products.

Special EIRP Restriction in Cellular Band 30

In North America, FCC and ISED have a stringent EIRP limit in Band 30 to prevent harmful interference to SDARS operations. For mobile and portable devices, the FCC EIRP in this band is limited to 23.9dBm so the antenna gain must be below 1.9dBi for a module with 22dBm output power, as per the example shown above. For fixed customer premises equipment (CPE) antennas, the FCC EIRP limit is 33dBm in band 30 so the antenna gain can be about 10dBi, but the CPE and its antenna shall be professionally installed in locations which are at least 20 meters from roadways.

Citations from FCC 47 C.F.R Part 27:

"For mobile and portable stations transmitting in the 2305-2315 MHz band or the 2350-2360 MHz band, the average EIRP must not exceed 50 milliwatts within any 1 megahertz of authorized bandwidth, except that for mobile and portable stations compliant with 3GPP LTE standards or another advanced mobile broadband protocol that avoids concentrating energy at the edge of the operating band the average EIRP must not exceed 250 milliwatts (23.9dBm) within any 5 megahertz of authorized bandwidth but may exceed 50 milliwatts within any 1 megahertz of authorized bandwidth."

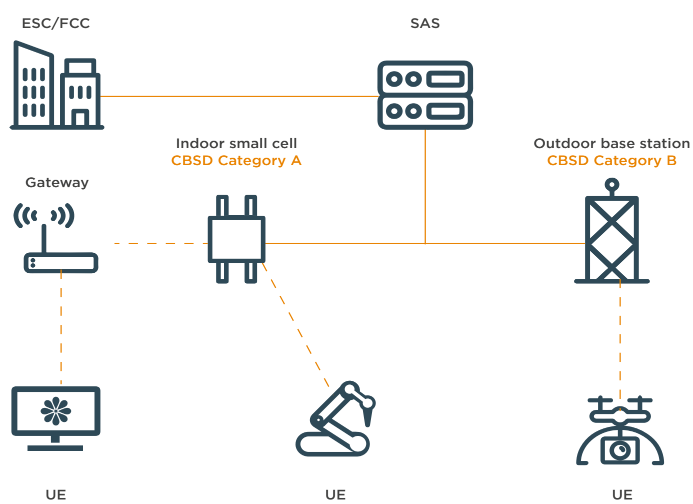
"**Automatic transmit power control.** Mobile and portable stations transmitting in the 2305-2315 MHz band or in the 2350-2360 MHz band must employ automatic transmit power control when operating, so the stations operate with the minimum power necessary for successful communications.

...

Prohibition on external vehicle-mounted antennas. The use of external vehicle-mounted antennas for mobile and portable stations transmitting in the 2305-2315 MHz band or the 2350-2360 MHz band is prohibited."

Special EIRP Restriction in Cellular Band 48

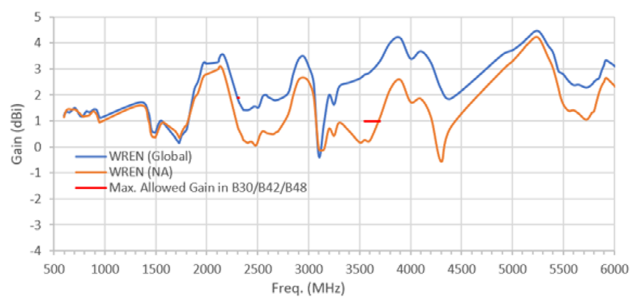
The FCC permits Citizen Broadband Radio Service (CBRS) Band 48 (3550-3700 MHz) for unlicensed general commercial usage by sharing the spectrum with incumbent military radars, fixed satellite stations and licensed priority users. To prevent radio interference to the incumbent and licensed users and to ensure their uninterrupted service, a Spectrum Access System (SAS) is used to maintain a database of all CBRS base stations. SAS dynamically coordinates the spectrum channel assignment to the CBRS base stations to avoid radio interference to the incumbent and licensed users. Besides using SAS to manage the spectrum usage priority, FCC classifies the CBRS equipment's EIRP limit into three categories. The EIRP limit for End User Device in CBRS band is 23dBm (about 10dB lower than the ones in many other cellular bands), thus the gain of the antenna in Band 48 needs to be lowered accordingly. In the example shown above, the maximum allowed antenna gain in band 48 is only 1 dBi for a module with 22dBm output power, while the antenna gain can be above 5dBi or even 8dBi in other bands (except band 30 in NA, and band 42 in Canada).



CBRS Equipment Power Category	EIRP Limit (dBm/10MHz)	PSD Limit (dBm/MHz)	Typical Equipment	Remark
End User Device	23	N/A	Indoor/outdoor gateway, router, CPE, edge devices	The device can transmit only after it receives authorization from an associated CBRS base station.
Category A	30	20	Indoor or low power outdoor small cells	The device can transmit only after it receives authorization from a SAS. Geo-location, antenna height is limited to 6 meters above average terrain if it is outdoors.
Category B	47	37	Outdoor operation, FWA	The device can transmit only after it receives authorization from a SAS. Information that needs to be provided: Geo-location, antenna height, antenna gain, antenna beamwidth, antenna azimuth, antenna down tilt angle.

Because of the compulsory EIRP restrictions in Band 30, 42 and 48 in the North American market, LTE/5G antennas would need to have low gains in these three frequency bands, but the gains (and efficiencies) in other cellular bands need to be higher to meet the performance requirements in those bands as well. This brings challenges to a high performing broadband LTE/5G antenna design. To meet these special FCC/ISED restrictions, TE uses an innovative solution to solve this technical challenge and provides two versions of 5G Swivel Blade Dipole Antennas for customers in North America and other global regions to meet their different needs. The North American version has the antenna gain specifically tuned down in these three bands, and the global version keeps the gain high in these bands for other regions.

WREN 5G Swivel Blade Dipole Blade



Band	Freq. (MHz)	WREN (Global)	WREN (NA)	Max. Allowed Gain (dBi)
B30	2305	1.9	0.8	1.9
B30	2310	1.8	0.7	1.9
B30	2315	1.7	0.7	1.9
B42 & B48	3550	2.8	0.3	1.0
B42 & B48	3600	2.9	0.2	1.0
B42 & B48	3700	3.3	1.1	1.0

Gain vs. Freq. of WREN Global Version and WREN North American Version

Wi-Fi 6E 6GHz Band EIRP Restriction

Wi-Fi 6E 6GHz band EIRP restriction is another FCC power restriction on a new unlicensed band to prevent interference with licensed incumbent services. FCC opened 5925-7125 MHz for Wi-Fi and other unlicensed users. This band has existing licensed incumbent users including satellite service, point-to-point public safety dispatch system to cell tower backhaul, and television broadcast service, etc. To avoid interference with these incumbent users, an Automatic Frequency Coordination (AFC) system is used on the Wi-Fi access point to get access to a database of all licensed users. Based on the access point's geo-location and antenna characteristics, the AFC coordinates the access point's power and frequency channels to avoid interference with the nearby incumbents. Additional to the use of AFC, the Wi-Fi 6 GHz power level is defined in four different classes:

Access Class	EIRP in 6 GHz band	Remark
Standard Power (Indoor/Outdoor)	36dBm	Standard Power Access Point must be coordinated through an AFC service to avoid interference with nearby incumbents. AFC is not required for other access classes.
Low Power (Indoor)	5dBm/MHz	
Clients (Indoor/Outdoor)	6dB less than AP's Max EIRP	
Very Low Power/Portable (Indoor/Outdoor)	-8dBm/MHz	

Antenna Efficiency Requirement Impacted by OTA Performance Requirements

Among all the end-device PTCRB/GCF tests, OTA testing is the direct measure of the antenna's radiation capability. OTA testing includes TIS and TRP, which quantify the device's downlink and uplink radiation performance respectively. They also provide a direct indication of the antenna's efficiency.

A practical method to estimate the required minimum antenna efficiency to meet a carrier's OTA performance requirement can be derived from the module's conducted transmit power/receive sensitivity and the carrier's TRP/TIS requirements. This antenna efficiency requirement derivation method is demonstrated using the LTE antenna specification of TE's wrist worn LTE location tracker demo as an example. The tracker demo uses an LTE module with 23dBm conducted transmit power and -104dBm receive sensitivity. AT&T, OTA, TRP and TIS performance requirements for wearable devices are applied. TE's LTE antenna design for this wrist-worn tracker demo product helps keep the device's antenna efficiency well above the minimum efficiency derived, therefore, allowing the demo device to pass the carrier's OTA tests comfortably.

TE wrist-worn LTE location tracker demo

LTE Band	Frequency (MHz)	Conducted Tx Power (dBm)	TRP (dBm)	Conducted Rx Sensitivity (dBm)	TIS (dBm)	Min. Antenna Eff. Derived* (dB)	Min. Antenna Eff. Derived (%)	TE Device Ant. Eff. Spec (%)
Band 12 Tx	699-716	23	>10	-	-	-13	5.0	14.0
Band 12 Rx	729-746	-	-	-104	<-83	-21	0.8	14.0
Band 2 Tx	1850-1910	23	>12	-	-	-11	7.9	15.0
Band 2 Rx	1930-1990	-	-	-104	<-83	-21	0.8	15.0
Band 4 Tx	1710-1785	23	>12	-	-	-11	7.9	10.0
Band 4 Rx	2110-2155	-	-	-104	<-83	-21	0.8	23.0

* Min. Antenna Eff. Derived (dB) = TRP (dBm) - Conducted Tx Power (dBm) or = Conducted Rx Sensitivity (dBm) - TIS (dBm)

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Jane holds a Ph.D. in the area of wireless and antenna technologies. She has published over 10 patents and more than 30 research papers.

Acronyms Legend

Acronym	Full Spelling
5G	5th Generation Mobile Network
AFC	Automatic Frequency Coordination
C2PC	Class II Permissive Change
CBRS	Citizen Broadband Radio Service
CPE	Customer Premises Equipment
DoC	Declaration of Conformity
Eff.	Efficiency
EFTA	European Free Trade Association
EIRP	Effective Isotropic Radiated Power
ERP	Effective Radiated Power
eSIM	Embedded SIM
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IoT	Internet of Things
LTE	Long-Term Evolution
MNO	Mobile Network Operator
NA	North America
OTA	over-the-air
RF	Radio Frequency
RSE	Radiated Spurious Emission
SAR	Specific Absorption Rate
SAS	Spectrum Access System
SIM	Subscriber Identity Module
TIS	Total Isotropic Sensitivity
TRP	Total Radiated Power
Tx	Transmit

Sources

[1] https://www.globalcertificationforum.org/services/3gpp-certifications/all-3gpp-certifications.html

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