Cellular Antennas

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Introduction

This Tech Note discusses common issues regarding cellular (GSM/CDMA/UMTS/HSPA/LTE) antennas for modems such as those used in the Proxicast LAN-Cell and PocketPORT routers. The best solution for each installation depends on many factors such as operating frequency band, signal strength from the carrier, interference sources, and mounting considerations. This Tech Note is intended as a resource to help end-users understand the proper selection and installation of antennas and their options for using external antennas with Proxicast products.

Proxicast offers a variety of cellular antennas, extension cables, connectors, amplifiers and related accessories. Please visit our online store at http://shop.proxicast.com or contact sales@proxicast.com for more information.

The antennas sold by Proxicast are intended to meet the needs of the majority of users operating in a location with good wireless carrier signal coverage. We suggest attempting to use one of these antennas before investigating third-party solutions. Proxicast has only tested and certified the specific antennas and accessories sold via our web site. Proxicast is unable to provide technical support for any other third-party antennas and accessory equipment. The user is also responsible for ensuring that the combination of the modem and any third-party accessories meets FCC (or other local regulatory agency) regulations and wireless carrier standards.

Cellular Data Networks

Mobile network operators around the world deliver wireless data services using a variety of different standards, air interfaces and protocols such as CDMA, GSM, UMTS, HSPA and LTE among others. Collectively these are referred to as “cellular data networks”. Operators also use the terms 2G, 3G and 4G to refer to the relative speed of data transmission on their networks.

Each type of wireless data service can operate in one or more radio frequency bands (see table below). The proper antenna for a wireless network operator must include the frequency bands used by the services that the operator offers. Contact your cellular network operator for information on the frequencies in use at your location; for example, Europe and Asia tend to operate on different frequency bands than North America.

Many antennas have been designed to operate in more than one of the commonly used frequency bands, although as more bands are included, both the size and cost of the antenna typically increase.

Antennas from other types of wireless equipment such as 802.11 Wi-Fi products or portable telephones cannot be used because they are tuned for bands outside of the cellular data network frequencies.

Operator	Protocol	Class	Frequency Bands
AT&T Wireless	UMTS/HSPA	3G	850 MHz & 1900 MHz
	LTE	4G	700 MHz & 1700/2100 MHz
Sprint	CDMA/1xRTT	3G	800 MHz & 1900 MHz
	EV-DO Rev.0 & A	3G	1900 MHz
	LTE	4G	800 MHz & 1900 MHz
	WiMAX (Clearwire)	4G	2500 MHz
	LTE (Clearwire)	4G	2500 MHz
Verizon Wireless	1xRTT/EV-DO/eHRPD	3G	850 MHz & 1900 MHz
	LTE	4G	700 MHz & 1700/2100 MHz
Bell Mobility	HSPA	3G	850 MHz & 1900 MHz
	LTE	4G	1700/2100 MHz & 2600 MHz
Rogers	HSPA	3G	850 MHz & 1900 MHz
	LTE	4G	1700/2100 MHz & 2600 MHz
Telus	HSPA	3G	850 MHz & 1900 MHz
	LTE	4G	1700/2100 MHz

Antenna Gain

The term "gain" (or "power") is used to indicate how effectively the antenna converts radio waves into electrical signals (and vice-versa). Higher gain antennas are able to detect weaker cellular radio signals and consequently transmit signals to more distant cellular towers.

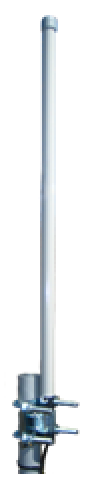
Antenna gain is often quoted in *decibels* either dBd (dipole) or dBi (isotropic) which are different reference systems for measuring the performance of a specific antenna versus a theoretically "loss-less" antenna[1]. Decibel is a logarithmic (base 10) measuring scale; hence an antenna with a 3 dBi gain has only 2 times the gain of a 1 dBi antenna, but a 10 dBi gain antenna has 10 times the gain of a 1 dBi antenna.

Antenna Types

The most common type of antenna is an *omni-directional*. Omni-directional antennas radiate and receive signals in a 360 degree pattern and are a good general purpose choice, especially in areas of strong cellular signal coverage or where the location of the cell tower is unknown or for mobile applications. Omni-directional antennas can be placed almost anywhere with little regard to orientation (although higher locations are usually preferred).

In some instances, an antenna with more sensitivity (gain) may be required in order to achieve adequate performance. *Directional* antennas offer higher gain by focusing their energy patterns into a smaller area. Directional antennas range from panels with approximately 180 – 270 degree beam widths, to sector antennas with 30 – 120 degree beam widths, to very high gain Yagi antennas with beam widths as small as 10 degrees. Directional antennas must be oriented so that their primary beam points in the direction of the carrier's tower. This requires knowledge of the carrier's antenna placement and some trial-and-error with the equipment.

Also, certain antennas require the use of a separate external ground-plane. This is a flat, horizontal conducting metal structure that works with the antenna to reflect and/or concentrate radio signals onto the antenna's primary elements. Be certain to check if an antenna requires an external ground-plane for proper operation.

		
Omni-Directional	**Directional**	**Yagi**

Common Antenna Types

[1] Antenna gain is defined as gain in dBi (dB referenced to an isotropic radiator) minus cabling loss.
Antenna gain in dBi (isotropic) = antenna gain in dBd + 2.15 (dipole)

Antenna Mounting

Cellular modems incorporate internal “patch” antennas that typically provide between 0 dBi and 2 dBi of gain. These are designed to work in a typical office environment where the modem is not obstructed by metal enclosures or other signal limitations. Most cellular modems also include one or more jacks to which external antennas can be connected.

If the cellular modem will be placed inside of a non-radio permeable enclosure such the LAN-Cell Card-Guard, Mode-SAFE base, a metal control cabinet or NEMA enclosure, an external antenna will likely be required for adequate signal strength to ensure good performance.

Low gain omni-directional antennas (< 3 dBi) are intended to replicate the internal antennas of the modem while allowing the antenna to be placed in a more advantageous location with better cellular signal coverage.

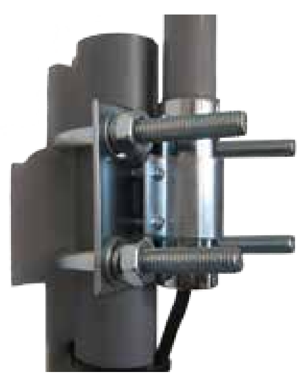
Medium gain (3 – 8 dBi) antennas are designed for situations where signal strength is weak or a long (10 - 20 ft) cable run between the modem and antenna is required (see below).

High gain (9+ dBi) antennas are typically outdoor fixed-mount antennas (sometimes directional in design) that are used where signal strength is very low or cable runs are very long (25+ ft).

Low and medium gain antennas with SMA Male connectors can be mounted directly onto “pigtail” adapters available for cellular modems. On the LAN-Cell, these can be mounted directly onto the unit’s base if adequate cellular signal is available. Otherwise, use a coaxial extension cable to locate the antenna for better signal coverage.

Many cellular antennas designed for desktop, mobile, or vehicle use can be mounted on a magnetic mount base. Higher gain and directional antennas often used for fixed location applications can be pole (mast), through-hole or wall mounted.

For outdoor fixed antenna installations, lightning protection, proper grounding and other safety measures may be required to meet local codes. Please consult with the antenna manufacturer or a qualified antenna installation contractor regarding requirements for proper mounting to masts, towers, buildings, walls or other surfaces.

				
Screw On	**Magnetic Mount**	**Through-Hole**	**Pole/Wall Mount**	**Pigtail**

Common Antenna Mount Types

Antenna Placement Tips

- Place the antenna a minimum of 20 cm (7.87 inches) from any person.
- Place the antenna outside if possible, or near a window.
- Place the antenna away from sources of interference such as computer equipment, CRTs, televisions, lights, telephones, appliances and other radio equipment.
- Elevate the antenna as high as possible so that it has a clearer path to the cell site.
- Most cell sites have vertically polarized antennas. Mount the antenna vertically for the best performance.
- Do not place the antenna inside of metal structures (e.g. computer equipment racks/closets/cabinets, ATM machines, or NEMA enclosures).
- Keep all antenna cables as short as possible. Extending the antenna cable to achieve better placement is a trade-off between the improved signal reception and the RF loss due to the longer cable (see below).
- Check the connector type used on the antenna. Proxicast provides SMA Female "pigtail" adapters to connect from cellular modems to external antennas. Minimize the number of connectors between the modem and the antenna.
- Know the location of the closest cell sites. The cellular carrier can provide the appropriate location information. There are also online tower databases and tower locating smartphone applications.
- Man-made and natural obstacles such as buildings, water towers, mountains, hills and trees can cause the cellular signal to deteriorate or even block the signal. Raising the antenna, relocating the antenna, or choosing a higher gain antenna may improve reception.

Antenna Cables

Antennas are connected to the cellular modem via coaxial cable specifically designed for RF applications. All coax cables result in some loss of RF signal (line-loss) as the length of cable increases. The loss rate (expressed as dB loss/ft) depends on the specifications of the coax cable and the operating frequencies of the modem. The most commonly used RF cable thicknesses include:

Size (diameter)	Loss (dB) per 100 ft @ 1000 MHz	Recommended Max Length
100 series (0.100 in)	24.16	10 ft
195 series (0.195 in)	11.75	20 ft
240 series (0.240 in)	7.99	40 ft
400 series (0.400 in)	4.13	75 ft

When selecting coax extension cables, keep these factors in mind:

- In general, thicker coax results in less RF loss per foot (measured in dB), but thicker cable is heavier and more difficult to install, especially if tight bends are required.
- Keep the antenna cable as short as possible.
- Use 50 ohm "low-loss" coax only. Cable TV and other forms of coax are typically 75 ohm and will not work properly with cellular equipment.

- Purchase pre-made extension cables with the correct connectors already attached or have an antenna professional crimp the connectors with the proper tools. Bad connections between the connector and the coax are the cause of many antenna/signal issues.
- The thickness of the cable indicates how much signal is lost, not its maximum signal carrying capacity. It is OK to terminate a long 400 series cable run into a short 100 series pigtail.
- Coax cable cannot be “spliced”. If necessary, cut the cable and use connectors to rejoin the pieces.
- Do not place sharp bends in the coax as this will crack the dielectric and/or jacket.
- Ensure that the cable has the correct connectors on each end.
- Factor in the total cable and connector RF loss when calculating EIRP for your installation (see below).

Antenna Connectors

Cellular data modems use a variety of different connector types to provide connections for external antennas. These are typically miniature connectors that are delicate and prone to disconnection when moved. For this reason, Proxicast offers a variety of short “pigtail” coax cables to convert the modem’s antenna connector into the more widely used SMA Female jack. External antennas can then be connected to the SMA jack.

Many antennas, especially fixed mount types, use other antenna connectors such as FME, N or TNC attached to their lead wire (coax). Use either an “inter-series adapter” to convert between the SMA connector and the type on the external antenna or use a coax extension cable with and SMA Male connector on one end and the necessary connector on the other end.

Each antenna connector between the modem and its antenna introduces a loss of RF signal (insertion-loss). The exact loss depends upon the properties of the connector and the operating frequencies. Consult the connector specifications when calculating RF loss due to connectors and cables in for EIRP calculations. A reasonable estimate is 0.2 dB insertion-loss per connector. Each “mating” represents 2 connectors. The line-loss from the short pigtail can be safely ignored, but include the 2 pigtail connectors in the insertion-loss calculation.

If any connectors will be located outdoors, the connectors must be protected from moisture to prevent water from shorting out the cable or being absorbed by the inner insulating materials and degrading performance. Multiple layers of special waterproof tape and/or liquid rubber sealing compounds are commonly. Dot use electrical or duct tape to seal connectors!

Female			
Male			
	SMA	**N**	**FME**

Common Antenna Connector Types

NOTE: Some connectors (esp. SMA) are available in “reverse polarity (RP)” form where the pin is on the externally threaded connector. RP connectors are typically used for Wi-Fi and not cellular cabling. Be certain to specify the correct connector polarity when ordering cables.

Amplifiers/Boosters

In certain situations, an amplifier (signal booster) may be necessary to provide sufficient RF signal strength between the modem and the wireless carrier's cell site. Like antennas, amplifiers are tuned to one or more frequencies; the amplifier selected must match the frequencies used by the cellular network operator. The combination of radio (modem), amplifier, and antenna is subject to the FCC limits for EIRP in the frequencies of operation.

Amplifiers increase the noise level by the same factor that they increase the signal. If you have low signal due to high noise, you may need an RF filter instead of (or in addition to) the amplifier.

Regulatory Information

Applicable Regulations

The Federal Communications Commission (FCC) is the agency of the Federal Government that oversees all non-governmental radio frequency transmitters that operate within the United States. Intentional radiators operating as a PCS-1900 radio transmitter are regulated under 47 CFR Part 24, Subpart E—Broadband PCS of the FCC Rules and Regulations. Intentional radiators operating as a cellular (800 MHz) radio transmitter are regulated under 47 CFR Part 22 – Subpart H: Cellular Radiotelephone Service. Intentional radiators operating as a cellular (700 MHz, 1700/2100 MHz) radio transmitter are regulated under 47 CFR Part 27 – Subpart C: Miscellaneous Wireless Communications Services.

Use of third-party accessories such as antennas and/or amplifiers must comply with the FCC regulations for maximum radiated power (see below). Exceeding the allowable radiated power output requires additional FCC licensing and is the responsibility of the end-user.

Radio emission regulations differ by country. Please consult your local telecommunications authority for more information on how their rules correspond to the FCC regulations.

Specific wireless operators may impose additional limitations on acceptable radio emissions. Please consult with your carrier regarding your specific installation requirements if you will be using any third-party antenna or amplifier equipment with the LAN-Cell or PocketPORT.

Definitions

Effective Radiated Power (ERP) is the power supplied to an antenna multiplied by the antenna gain.

Effective isotropically-radiated power (EIRP) is the amount of power that would have to be emitted by an isotropic antenna (that evenly distributes power in all directions) to produce the peak power density observed in the direction of maximum antenna gain. EIRP takes into account the losses in transmission line and connectors and the gain of the antenna.

EIRP(dBm) = (power of transmitter (dBm)) – (losses in transmission line (dBi)) + (antenna gain(dBi))

EIRP (watts) = 1.64 X ERP (watts) assuming a lossless transmission line between the transmitter and antenna

Maximum Allowable Power Output / Antenna Gain

FCC limits on the maximum allowable output power from a transmitter depend upon the frequency range of operation and the type of antenna installation (mobile or fixed).

	FCC Max EIRP		**Approx. Maximum Antenna Gain (dBi) @ Modem***	
Band	**Mobile**	**Fixed**	**Mobile**	**Fixed**
700 MHz	5 W (37 dBm)	5 W (37 dBm)	14	14
800-900 MHz	2.5 W (34 dBm)	11.5 W (40.6 dBm)	11	17.6
1800-1900 MHz	2 W (33 dBm)	5 W (37 dBm)	10	14
1700/2100 MHz	1W (30 dBm)	1W (30 dBm)	7	7

*Note: The LAN-Cell and PocketPORT use removable modems. The specific power output of each modem at various frequencies will vary from modem model to model. Please consult the technical specifications for your specific modem regarding maximum power output and maximum antenna gain. The values shown are for a typical USB cellular modem with an output of 200 mW (23 dBm)[2].

Antenna gain is often quoted in dBd (dipole) or just dB. Convert this value to dBi (add 2.15) then subtract the RF loss from the feed cable and connectors when determining the total EIRP for your installation. Add the net gain from your antenna system to the maximum nominal power output (in dBm) of the radio in the frequency band of operation and compare this against the FCC limits.

(Max EIRP) – (Modem Output Power) + (Line Loss) + (Insertion Loss) = Max Antenna Gain

Examples

For a 200 mW (23 dBm) modem in the 700 MHz LTE band with 25 ft of LMR240 cable and 4 connectors:

37 dBm – 23 dBm + 1.7 dB + 0.8 dB = 16.5 dBi (or 14.35 dBd)

For a 400 mW (26 dBm) modem in the 1900 MHz band with 10 ft of LMR100 cable and 6 connectors in a mobile deployment:

33 dBm – 26 dBm + 1.6 dB + 1.2 dB = 9.8 dBi (or 7.65 dBd)

[2] To convert Power (P) in Watts to dBm: $P_{dBm} = 10 \times \log10(P_W) + 30$

Antenna Selection Checklist

The following questions will help guide the selection of the appropriate antenna for your application.

ÿ What is the signal strength without an external antenna?

ÿ What frequencies does the antenna need to cover?

- o AT&T 3G: 850 MHz & 1900 MHz
- o AT&G 4G/LTE: 700 MHz & 1700/2100 MHz
- o Sprint 3G: 1900 MHz
- o Sprint 4G/LTE: 800 MHz & 1900 MHz
- o Verizon 3G: 850 MHz & 1900 MHz
- o Verizon 4G/LTE: 700 MHz & 1700/2100 MHz

ÿ What is the transmit power of the modem?

ÿ Will the modem be stationary or mobile?

ÿ Where will the antenna be mounted (inside/outside, to the router, to an enclosure, etc.)?

ÿ How will the antenna be mounted (screw, hole, pole, wall, magnet)?

ÿ Are any installation accessories such as ground planes, lightning arrestors, masts/brackets or waterproofing required?

ÿ How long is the cable run between the modem and the antenna?

- o < 10 ft use 100 series coax
- o 10 – 20 ft use 195 series coax
- o 20 – 40 ft use 240 series coax
- o 40 – 75 ft use 400 series coax

ÿ What is the correct pigtail required for the modem?

ÿ What connector type (and sex M/F) is on the antenna?

ÿ What connector types are needed on the coax extension cable?

ÿ Does the modem + antenna – cable_loss meet FCC regulations?

Frequently Asked Questions

Q: How do I know if I need an external antenna?

A: Check the signal strength displayed by the modem while the modem is in its final operating location and NOT in a data session with the carrier. If you have good to excellent signal strength (60+%), an external antenna may not be necessary.

Q: Why not just use the highest gain antenna on every installation?

A: High gain antennas are expensive and large. Outdoor and directional antennas are difficult to install. Modem and cell towers also communicate to negotiate the lowest possible output power by the modem in order to maintain a reliable connection. A high gain antenna would be a waste of money where the cellular signal is already strong.

Q: Why not use an amplifier everywhere?

A: Like USB modems, amplifiers dynamically adjust their output based on the radio conditions present. In strong signal areas, the amplifier may provide little or no improvement.

Q: Will an external antenna increase my speed?

A: It might. If you are in an area with coverage from more than one service in different frequency bands (e.g. CDMA and LTE), an external antenna may enable the modem to "lock on" to the higher speed service. Also, improved signal strength will reduce the number of packets retransmitted due to errors or interference.

Q: Why does my cellular modem have multiple external antenna ports?

A: Some modems can communicate on different frequencies bands (such as CDMA and LTE). Modem manufacturers may provide different antenna ports for each frequency. Some higher speed modems (HSPA+ & LTE) have incorporated MIMO (multiple input/multiple output) antenna systems to increase speeds. On MIMO systems, a single antenna can be used (make sure to use the primary port), but a second, identical antenna will often provide increased performance if it is positioned properly. Consult the modem's documentation for details on using MIMO antennas.

Q: I added an external antenna and it did not improve my signal strength. Why?

A: Low gain (< 3dBi) antennas are not intended to dramatically increase the signal to cellular modems. They are intended to allow the antenna to be positioned away from the modem. As noted above, in areas where a strong cellular signal is present, the cellular modem may decrease its output power, offsetting some or all of the gain added by the antenna.

Q: Do I have to electrically ground the "ground plane"?

A: No. A Ground Plane refers to the metal reflector used below some types of antennas to increase signal gathering. The term is not related to electrical or earth grounding which is required for outdoor antennas to provide lightning protection.

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