Milwaukee Train Station GPS

Setup and power link budget

Project: **SubWAVE**

Customer: **Canadian Pacific Railway**

Syntony reference: ING-CPR20210618

Version: 1.0

Date of this version: 2021-06-18

Page number: 17

DOCUMENT HISTORY

Version	Release Date	Modifications summary
1.0	18-06-2021	First release

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LIST OF FIGURES

APPLICABLE DOCUMENTS

ID	Title	Reference
[AD01]	Applicable document title	Applicable document reference

REFERENCE DOCUMENTS

ID	Title	Reference
[RD01]	TX antenna datasheet, PCPI GPS – AMPHENOL PROCOM	PCPI GPS (amphenolprocom.com) (Last visited June, 17th 2021)
[RD02]	U-Blox: NEO-M8, u-blox M8 concurrent GNSS modules, Data Sheet	From: https://www.u-blox.com/sites/default/files/NEO-M8_DataSheet_%28UBX-13003366%29.pdf (Last accessed date June, 17th 2021)
[RD03]	ICD GPS (Interface Contrôle Document)	https://www.gps.gov/technical/icwg/ (last visited : June, 17th 2021)

LIST OF ACRONYMS

Acronym	Description
C/A	Coarse acquisition
CPR	Canadian Pacific Railway
FRA	Federal Rail Administration
GPS	Global positioning System
ICD	Interface Control Document
PTC	Positive Train Control

1 Introduction

1.1 Scope of the document

This document details the **SubWAVE installation** at the Milwaukee train station for Canadian Pacific Railway, where **standard antenna** are to be used, underground for **GPS repetition**.

Are included in this document the list of equipment required, the details of the setup and the link budget.

Syntony’s SubWAVE solutions expands the GPS/GNSS coverage to underground areas enabling GPS position to be received by standard GPS/GNSS receivers such as those already in smartphones, navigation systems in cars and other road and rail vehicles, and increasingly in communications devices used by emergency services and other critical industries for operations and safety.

SubWAVE operates by broadcasting a replicated GPS L1C/A @ 1575,42Mhz signal through one or more antennas in deep underground environments: it is exactly equivalent to a GPS repeater equipment, in term of generated electromagnetic environment, ephemeris, and synchronization with outside.

1.2 Structure

The document is organized as follows. The section 2 presents the SubWAVE system in the context of GNSS repeaters. An overview of the Milwaukee installation is presented in section 3. The sub-section 3.1, describes the context of the Milwaukee installation, and the sub-section 3.2 introduces the SubWAVE setup including emitting antenna location. The power link budget is detailed in the sub-section 3.3.

2 Regulatory framework

2.1 Repeaters

The RNSS (Radio Navigation Satellites Services, also known as the Global Navigation Satellite System, or GNSS) is a system of satellites, which together with supporting infrastructure, provide accurate positioning, velocity and timing data. The most well-known RNSS is the Global Positioning System (GPS).

RNSS repeaters are radiocommunications devices that receive and re-transmit RNSS signals. Some repeater systems re-broadcast an adjusted signal that incorporates the receiver's location with a spatial correction. These types of devices are intended to be used in areas where there is no reception of RNSS signals, such as in an underground environment where RNSS signals do not reach.

RNSS repeaters use a simple set of radio equipment that includes receiving and transmitting antennas. For tunnel applications, external antennas in view of RNSS satellites receive RNSS signals for a tunnel. The signal is processed in order to adjust the signal to reflect an in-tunnel position. Antennas are deployed at required intervals throughout the tunnel, with each one transmitting a corrected in-tunnel position.

Where RNSS repeater systems are deployed, devices that contain RNSS receivers for position, velocity and timing applications can receive the RNSS signals radiated by the system.

The introduction of RNSS signal availability in tunnels would not deny any competing uses of spectrum, since there are currently no RNSS signals successfully being provided in those environments.

A repeating GNSS system, such as SubWave, must ensure that it does not cause degradation of the accuracy of other position location devices, and has no effect on genuine GNSS signals.

2.2 Subwave as a repeater

Connected to an external GPS signal, the SubWAVE rack replicates the entire constellation on a place covered by an antenna in underground where no GPS services is accessible.

In typical installations, a single outdoor GPS antenna is routed to each rack via optic fiber or a coax cable. The GPS signal needs to be precisely synchronized (<100 nanoseconds precise) with the outside satellites system, but also, in terms of ephemeris (all satellites should be generated exactly at the same place as the real ones, constantly), to provide a seamless transition between the outside and the inside, where the Subwave system is installed.

Similarly, to standard GPS repeaters, SubWAVE generates a totally identical and synchronized GPS L1C/A electromagnetic environment to what can be received outside at the very same place and time: as such, it can be received by any GPS receivers, as if it were the real outdoor GPS signal.

SubWAVE repeater has been designed specifically for deep indoor environment like underground metro or railway and tunnel that distribute radio waves (for telecommunication) via underground antennas networks.

During installation, the SubWAVE equipment is programmed to be connected to a specific external GPS antenna, associated with a precise position. After parameter set, the system will not emit any GPS signal anymore, if it is moved and connected to another antenna, in order to prevent being used as a spoofer.

3 SubWAVE installation at the Milwaukee Train Station

This section introduces the context of the project and the SubWAVE installation. In addition, this section presents a predicted power link budget for signals emitted from each emitting antenna.

3.1 Context

Current operation **does not allow Amtrak Hiawatha** trains to select track and be PTC active inside the depot **due to no GPS signal under the covered train station.** This station is located under a large United States Postal Services facility built in concrete.

This requires the locomotive occupy main track in a non-enforceable PTC state and is not currently FRA compliant.

The Figure 1 is an example of train position measured by a GNSS receiver at the Milwaukee Train Station. On this Figure, we observe an area without GPS positioning. This area contains initialization points allowing to initiate train location in accordance with PTC state.

Figure 1: no GPS signal area in the station

Traditional GPS repeaters cannot be set-up in the station, by lack of access to a relevant place where an antenna with clear sky view could be placed.

Using the Subwave solution, Syntony proposed an GPS extension coverage for trains evolving within the Milwaukee station. The Subwave solution covers two small areas of synchronization around the center of the covered area.

As described in Figure 2, locomotive will stop at a posted initialization point under the depot canopy and receive a GPS signal for this location via a GPS repeater to be able to select track and be PTC active inside the depot.

Figure 2: Projected setup (two mini-zone setup)

The Figure 3. presents the two different positions of antenna's receiver on locomotive. The goal being to provide a true GPS environment where the locomotive stops to initialize its GPS receiver. Each mini-zone of the SubWave solution will be configured to cover of 7ft.

This will allow the solution to work with both types of locomotive (when the GPS receiver is mounted at the nose and also when it is on the roof of the locomotive). It considers a 2 feet accuracy for stopping position (ensured by the train control protocol). The solution is engineered only cover the 2 mini-zones, to not interfere in between mini-zones, and obviously not to leak outside.

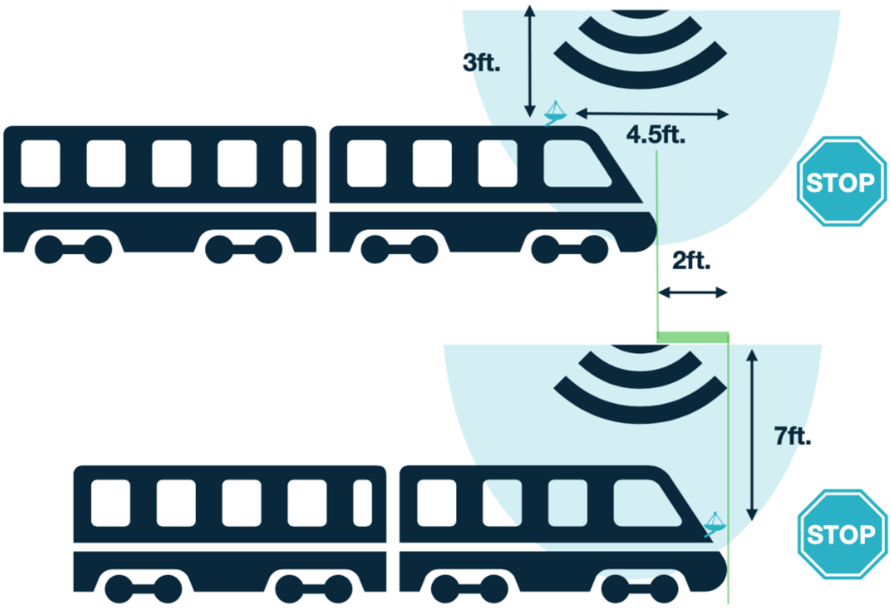


Figure 3: possible positions of GPS antenna's receiver on locomotive

In order to simplify the maintenance of the equipment, the antennas will be placed on a structure ensuring ~7ft. distance in between the receiver (worst case, receiver at the nose) and the active emitting antenna.

3.2 Setup at the Milwaukee Station

The Figure 4 details the station's dimensions and Figure 5 displays the interior of the train station. This covered train station in Milwaukee is 385 ft by 1015 ft with very low (thick concrete, no opening and no window) ceiling at 22ft. The extended GPS covered area is located 100ft. from the concrete wall (north of the station) and 250ft. from the limit of concrete pillars dividing the inside/outside train station. The two-initialization point, called A and B, are showed in the Figure 4. The distance between these two points is 65 ft.

Figure 4: Milwaukee station and installation site (dimensions)
The 2 pins represent the 2 points of emission, each one covering a 7ft. mini-zone

Figure 5: Milwaukee station inside (train platform) and at the end, the limit of the inside/outside (south).

The solution is composed of a 2 mini-zones setup emitting local SubWAVE GPS signals. As described in 6.a, the deployed equipment is composed of a SubWAVE unit, 2 outdoor (for redundancy) GPS antennae receiving GPS signals. All the other components such as the antenna (all are active antenna) will be connected and power supplied via coaxial cables.

The Subwave equipment (excluding antennae) will be located in an existing bungalow. The SubWAVE antennae will be mounted on a 21ft. structure at an estimated distance of 7ft. from the receiver on the side of the tracks. They will be oriented at a 45 degrees angle downward and facing the concrete wall located 110ft. and 150Ft. away (north).

The Figure 6.b details the SubWAVE installation. We note:

- The SubWAVE units
    - Located at the bungalow (green cross)
    - contains redundant SubWAVE system
- RX location #3:
    - 2 reference GPS antennae at a tilt tower
    - receiving genuine GPS signals
    - connected with the SubWAVE system by a 165 ft coaxial cable
- TX Location #1 (zone A):
    - Emitting GPS antenna [RD01] (see Appendix A)
        - Emitting GPS L1 C/A signals, coordinate:
            - Lat: 43.0340622282°
            - Lon: -87.9148213469°
    - connected from SubWAVE unit by a 315 ft coaxial cable
- TX Location #2 (zone B):
    - Emitting GPS antenna [RD01] (see Appendix A)
        - Emitting GPS L1 C/A signals, coordinate:
            - Lat: 43.0339008592°
            - Lon: -87.9149379390°
    - connected from the SubWAVE unit by a 325 ft coaxial cable

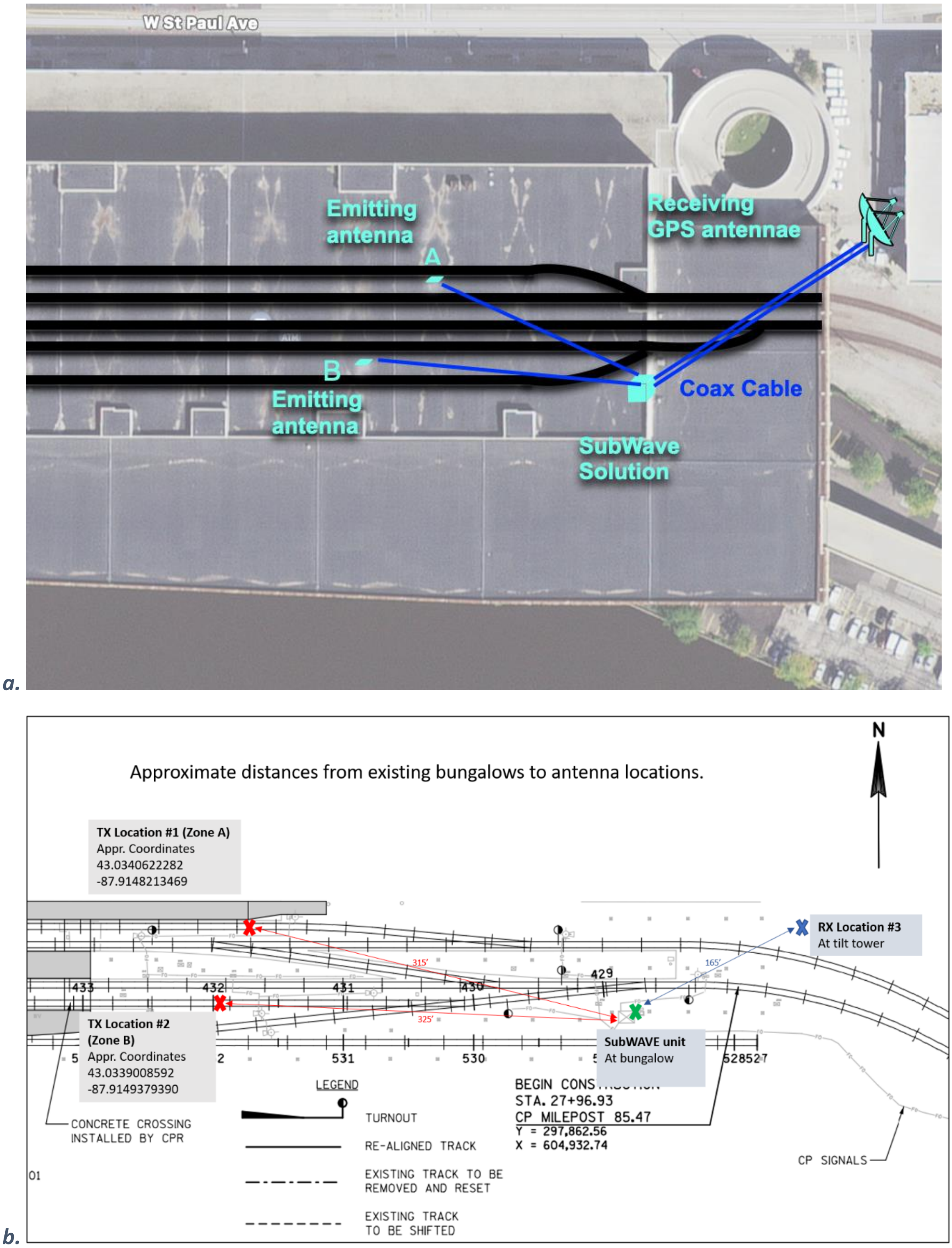


Figure 6: SubWAVE setup: deployed equipment (a) with distances and coordinates (b)

3.3 Power link budget

The power link budget is made considering the fact that the SubWave solution will be configured to cover a mini-zone of 7ft in order to initialize locomotive's GPS receiver.

We make two assumptions on the calibrated SubWAVE installation:

- We assume that a commercial GNSS receiver has an acquisition threshold of 25 dB-Hz in "cold start" acquisition and a loss of lock threshold of 7 dB-Hz for "Tracking&Navigation" mode (see [RD02]). "Hot Start" condition corresponds to approximately 16 dB-Hz (see [RD02]).
- We assume a 2dB Noise Factor of the receiver's RF front end, noted F. The effective noise power density expressed in dB-Hz can be defined by $N0eff$=N0+F= −204+2≈ −202 dB/Hz.

Consequently, we conclude that the emitted signal must be received at least -177 dBW (=25-202), or -147 dBm in order to allow a commercial receiver to perform a successful "Cold-Start" acquisition.

At setup time, SubWAVE system for Milwaukee Train Station will be calibrated 7 ft. away from emitting antenna (or 25 dB-Hz at 7 ft).

In addition, this is approximately 20 dB lower than the minimum guaranteed power of a genuine GPS L1 C/A signal, according to the GPS ICD ([RD03]).

We note that with "classical" emitting antennas, the standard relation for Free-space path loss is defined by:

$$\mathrm{Loss}_{\mathrm{dB}} = 20\log_{10}\left(\frac{4\pi\, r}{\lambda}\right) \tag{1}$$

where λ is the wavelength of the emitted signal. In this study, only the central frequency corresponding to GPS signal is considered (typically $\lambda = C/F_{L1}$, with $F_{L1} = 1575.42\ MHz$).

Considering that, in the case of that project, the emitting antennae are directive with 5dB gain (see Appendix A), the Figure 7 shows the power of the emitted SubWAVE signal in function of the distance.

We observe that the power of the signal is under the "Hot start Acquisition" threshold at 25 ft and the power of emitted GPS signal is close to 10 dB-Hz at 60 ft (or approximatively -160 dBm, less than 20 dB lower than the minimum guaranteed power of a genuine GPS L1 C/A signal).

Putting those numbers in perspective with the dimension of the Milwaukee station showed in Figure 4, we can conclude that:

- the solution is engineered to only cover the mini-zones defined,
- will not interfere in between zones
- will not affect genuine GNSS signals (outside).

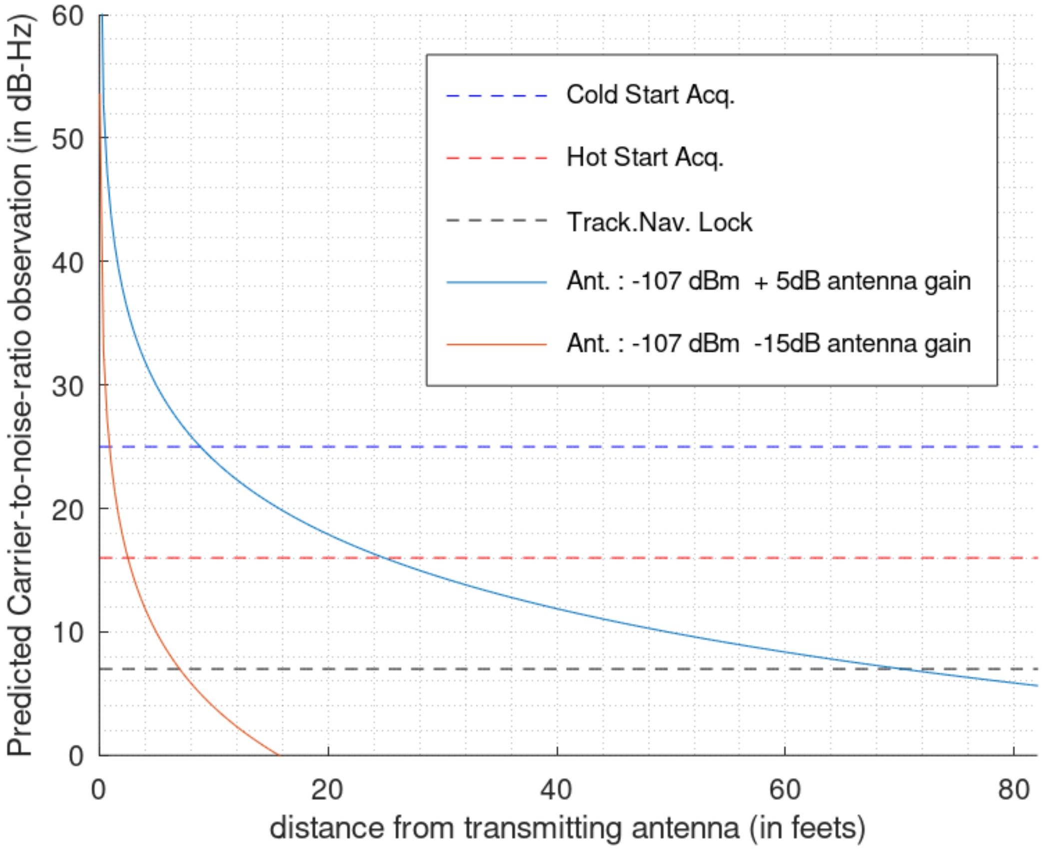


Figure 7: Emitted power (in signal noise ratio) in function of the distance, from emitting SubWAVE antenna. (blue line is toward the northern wall, red is south from both emission points)

Present the associated link power budget:

- Signal out of the SubWAVE solution, after the coaxial cable, entering the antenna: -107 dBm
- Signal received by a locomotive receiver located 7ft. away from the directive antenna: -147dBm
- Signal 20 ft. behind the emitting antenna (there is still more than 200 ft. of covered area behind and aside each emitting antennae): 0dB-Hz
- Signal at the wall 110Ft. in front of the antenna: less than 5dB-Hz

4 Conclusion

The SubWAVE setup will emit very low power to cover a small area (7 ft.) from a short distance (7 ft.) using directive antennas. This signal will be used by locomotives for the initialization of their navigation systems.

This solution will ensure:

- the possibility of GPS receivers to cold start within 7-feet in front of the emitting antenna (in front).

- no signal affect to the outside.

- no interference in between the mini-zones and away from each mini-zone.

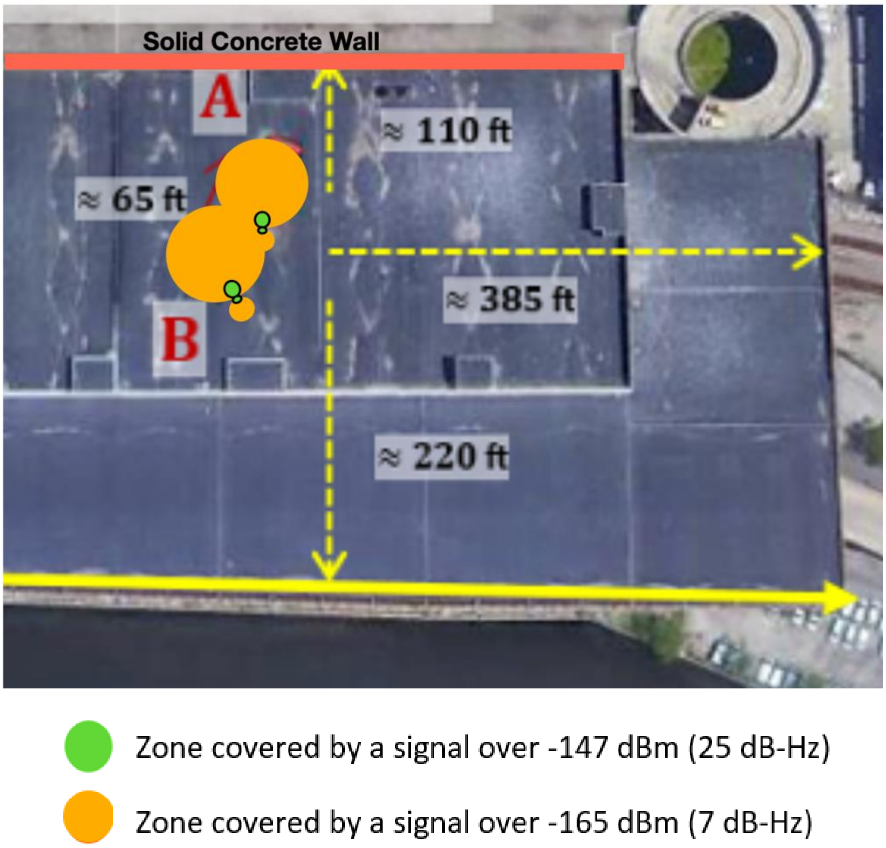
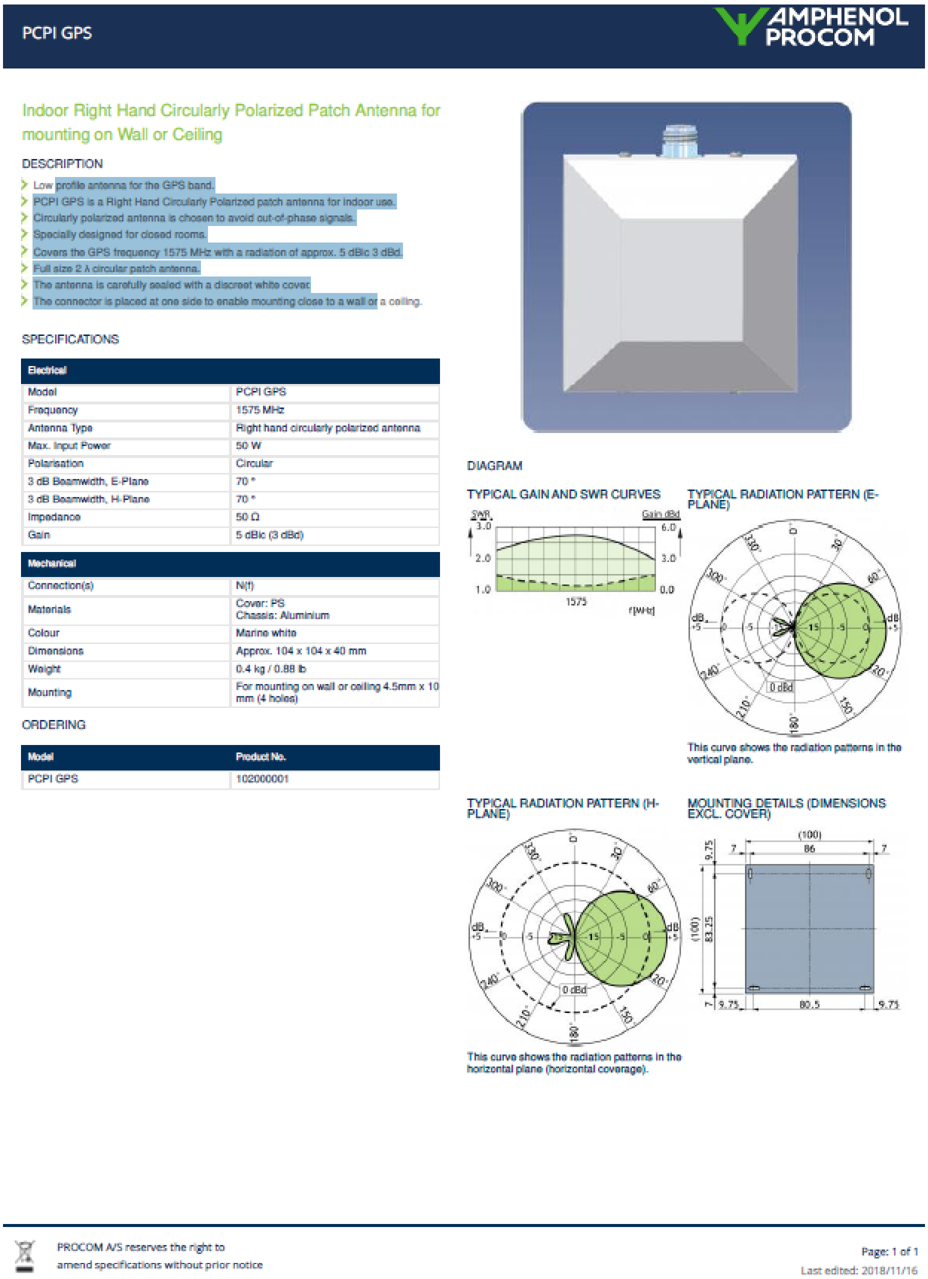


Figure 8: Representation of the signal power level at the setup location

Appendix A Antenna Datasheet

This appendix presents a screenshot from [RD01] of the antenna datasheet used in Milwaukee station (directive emitting antenna used to cover zone A and zone B). Those emitting antennae are semi-hemispheric with a circular polarization antenna gain of 5 dBic.



PCPI GPS

Indoor Right Hand Circularly Polarized Patch Antenna for mounting on Wall or Ceiling

DESCRIPTION

- Low profile antenna for the GPS band.
- PCPI GPS is a Right Hand Circularly Polarized patch antenna for indoor use.
- Circularly polarized antenna is chosen to avoid out-of-phase signals.
- Specially designed for closed rooms.
- Covers the GPS frequency 1575 MHz with a radiation of approx. 5 dBic 3 dBd.
- Full size 2 λ circular patch antenna.
- The antenna is carefully sealed with a discreet white cover.
- The connector is placed at one side to enable mounting close to a wall or a ceiling.

SPECIFICATIONS

Electrical	
Model	PCPI GPS
Frequency	1575 MHz
Antenna Type	Right hand circularly polarized antenna
Max. Input Power	50 W
Polarisation	Circular
3 dB Beamwidth, E-Plane	70 °
3 dB Beamwidth, H-Plane	70 °
Impedance	50 Ω
Gain	5 dBic (3 dBd)

Mechanical	
Connection(s)	N(f)
Materials	Cover: PS Chassis: Aluminium
Colour	Marine white
Dimensions	Approx. 104 x 104 x 40 mm
Weight	0.4 kg / 0.88 lb
Mounting	For mounting on wall or ceiling 4.5mm x 10 mm (4 holes)

ORDERING

Model	Product No.
PCPI GPS	102000001

DIAGRAM

TYPICAL GAIN AND SWR CURVES

TYPICAL RADIATION PATTERN (E-PLANE)

This curve shows the radiation patterns in the vertical plane.

TYPICAL RADIATION PATTERN (H-PLANE)

This curve shows the radiation patterns in the horizontal plane (horizontal coverage).

MOUNTING DETAILS (DIMENSIONS EXCL. COVER)

PROCOM A/S reserves the right to amend specifications without prior notice

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Last edited: 2018/11/16