Inverse Modeling/Transmit Power Levels

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Overview

- At October 2016 Workshop, the following relationship was derived between adjacent band transmitter tolerable effective isotropic radiated power (EIRP) and ITM. At a particular center frequency, and for the case of a single transmitter this relationship is:

$$EIRP_{Tol}(\vec{r}_T,\vec{r}) = \frac{PL(\vec{r}_T,\vec{r})}{g_T\big(\theta(\vec{r}-\vec{r}_T)\big).\, g_R\,\big(\theta(\vec{r}_T-\vec{r})\big)}.ITM$$

propagation loss

normalized transmitter and GNSS receiver gains, respectively, with respect to linear polarization

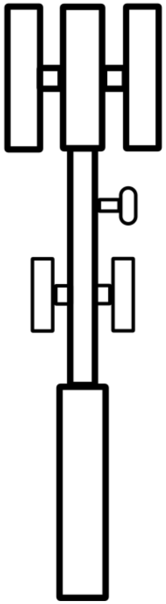
- This presentation:
  - Provides models for adjacent band transmitters (base stations and handsets), and GNSS receiver antenna patterns
  - Provides C/A results for: (1) impacted regions for adjacent band transmitters of various types, (2) maximum EIRPs as a function of "standoff" distances

Adjacent Band Transmitter Models

Base Station Modeling

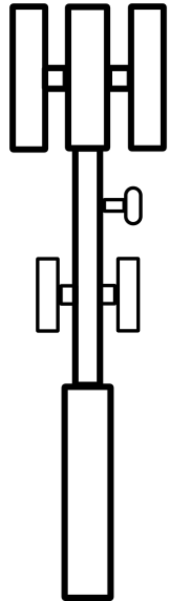
- Models from International Telecommunication Union Radiocommunication Sector (ITU-R) utilized:
  - Report ITU-R M.2292 – provides characteristics of 4G networks
  - Recommendation ITU-R F.1336 – invoked in M.2292; provides base station antenna gain pattern models
- M.2292 addresses five network deployment types for 1-3 GHz:
  1. Macro rural
  2. Macro suburban
  3. Macro urban
  4. Small cell outdoor/Micro urban
  5. Small cell indoor/Indoor urban
- Following charts provide a summary of their base station characteristics

ITU-R M.2292 Macro Base Stations



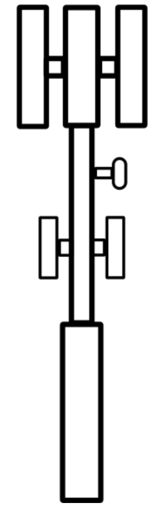
Macro Rural

- 18 dBi antenna gain
- +/-45° polarization
- 3 sectors
- EIRP: 58/61/61 dBm
- 30 m height
- 3 deg downtilt
- > 3 km cell radius



Macro Suburban

- 16 dBi antenna gain
- +/-45° polarization
- 3 sectors
- EIRP: 56/59/59 dBm
- 30 m height
- 6 deg downtilt
- 0.5 – 3 km cell radius



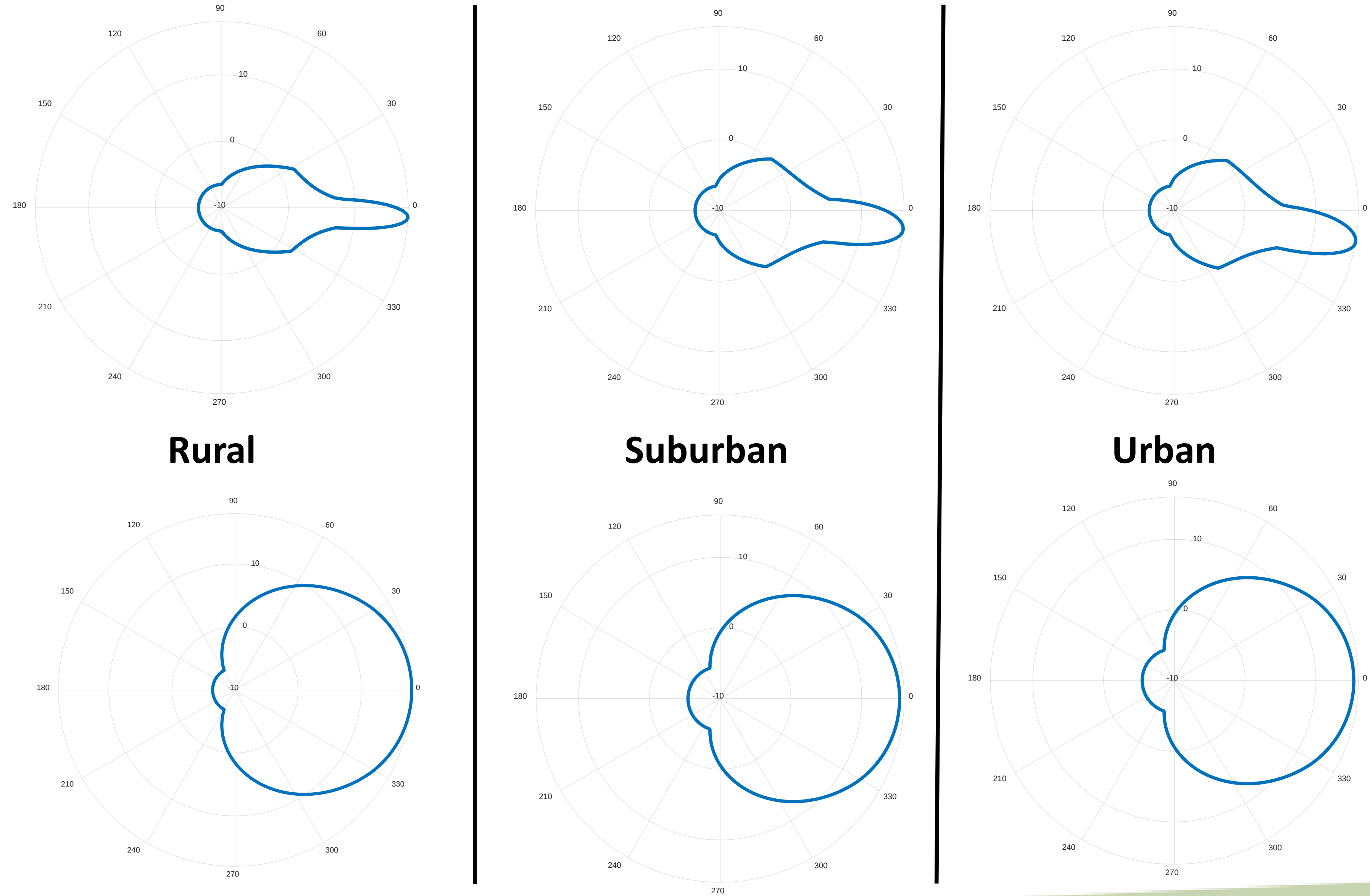
Macro Urban

- 16 dBi antenna gain
- +/-45° polarization
- 3 sectors
- EIRP: 56/59/59 dBm
- 25 m height
- 10 deg downtilt
- 0.25 – 1 km cell radius

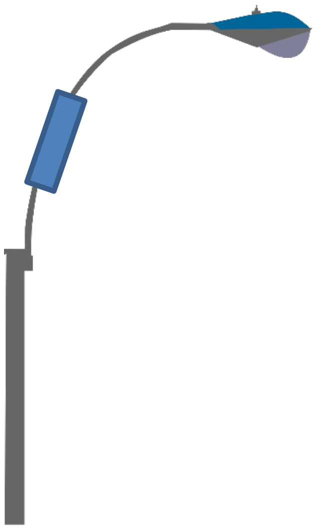
Macro Base Station Antenna Gain Patterns

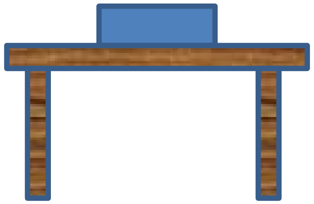
ELEVATION

AZIMUTH



ITU-R M.2292 Small Cell Base Stations





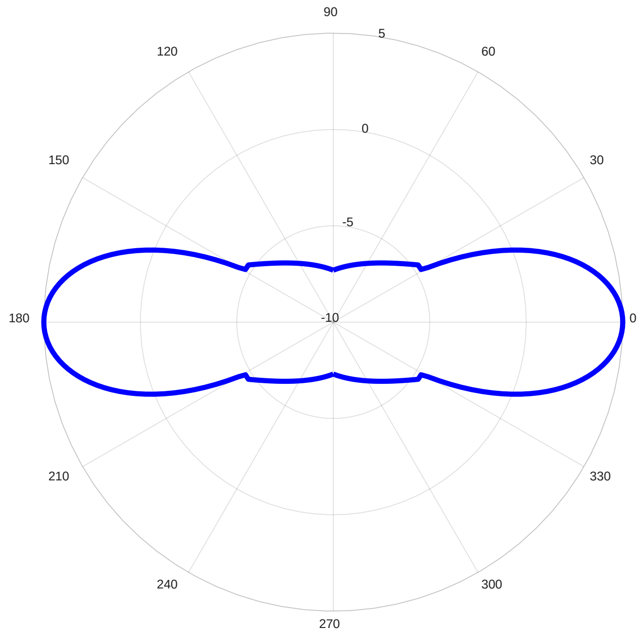
Small cell outdoor/ Micro urban

- 5 dBi antenna gain
- Linear polarization
- Single sector
- No downtilt
- EIRP: 40 dBm
- 6 m height
- 1 – 3 per Urban macro cell

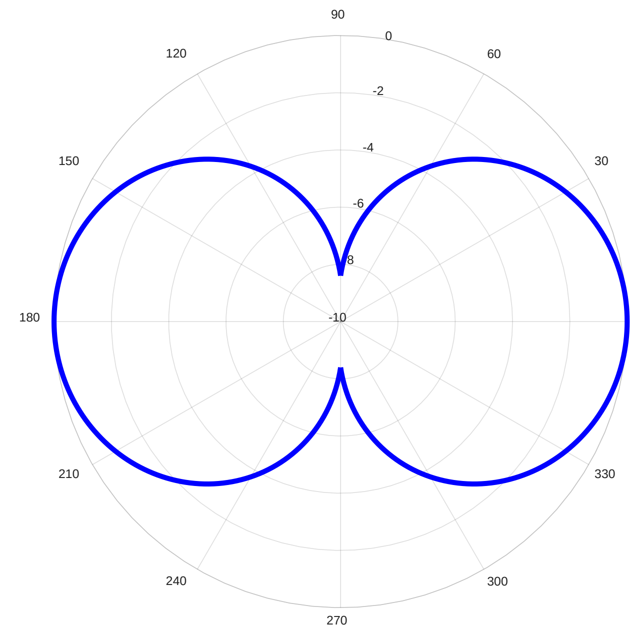
Small cell indoor/ Indoor urban

- 0 dBi antenna gain
- Linear polarization
- Single sector
- No downtilt
- EIRP: 24 dBm
- 3 m height

Small Cell Antenna Gain Patterns



Small cell outdoor/Micro urban



Small cell indoor/Indoor urban

Both patterns are omnidirectional. Plots above are elevation cuts.

Handset/Mobile Device Modeling

- 23 dBm EIRP
- Isotropic transmit antenna gain
- Vertical polarization
- Assumed to be at 2 m height above ground

GNSS Receiver Antenna Models

GNSS Receiver Antenna Pattern Models

- GLN, GAV, HPR, TIM
  - Measured horizontal and vertical (HPOL/VPOL) antenna patterns from 14 antennas were grouped by category of receivers and averaged
  - A second order parametric fit:

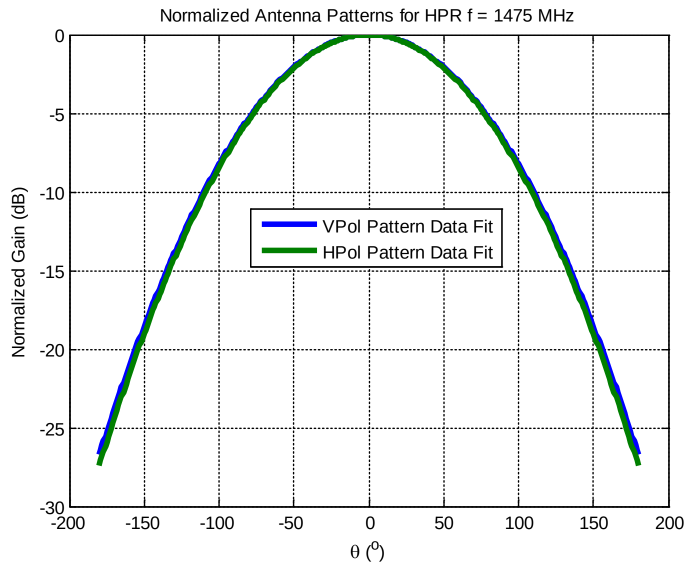
Function of receiver category, frequency, V/H

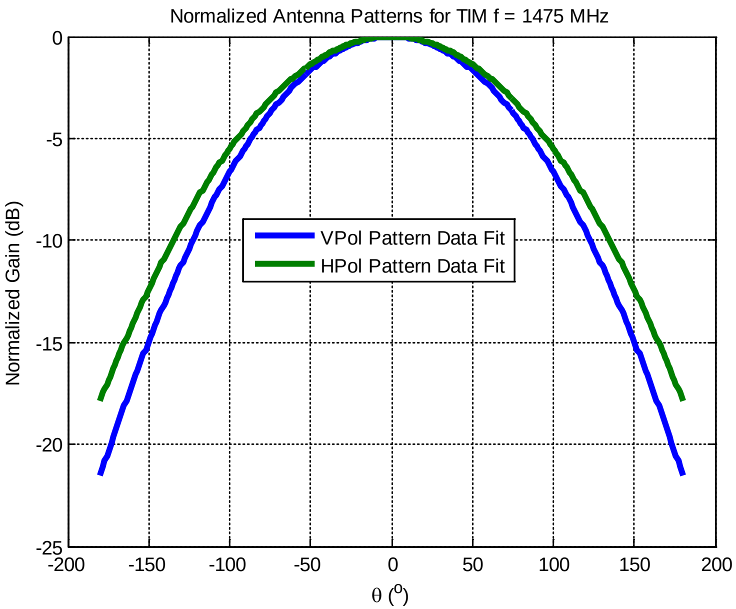
$$(\textit{normalized gain}) = -\alpha \times (\textit{off-boresight angle})^2$$

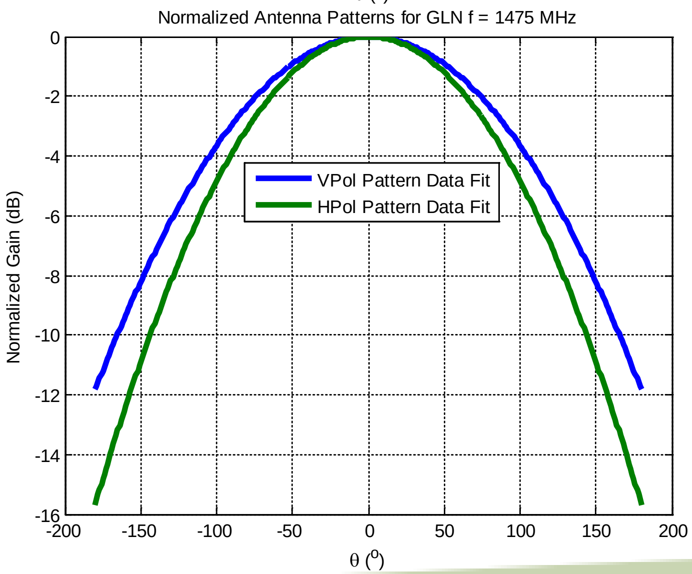
to the average pattern within each category was performed to capture the frequency dependent patterns for each of the H and V polarizations in the analysis

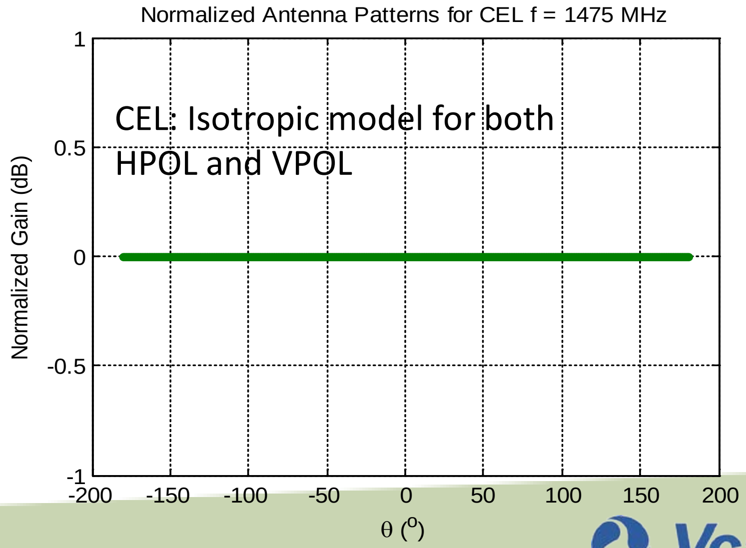
- CEL
  - Normalized pattern modeled as isotropic with equal HPOL/VPOL

Example of VPOL and HPOL Patterns

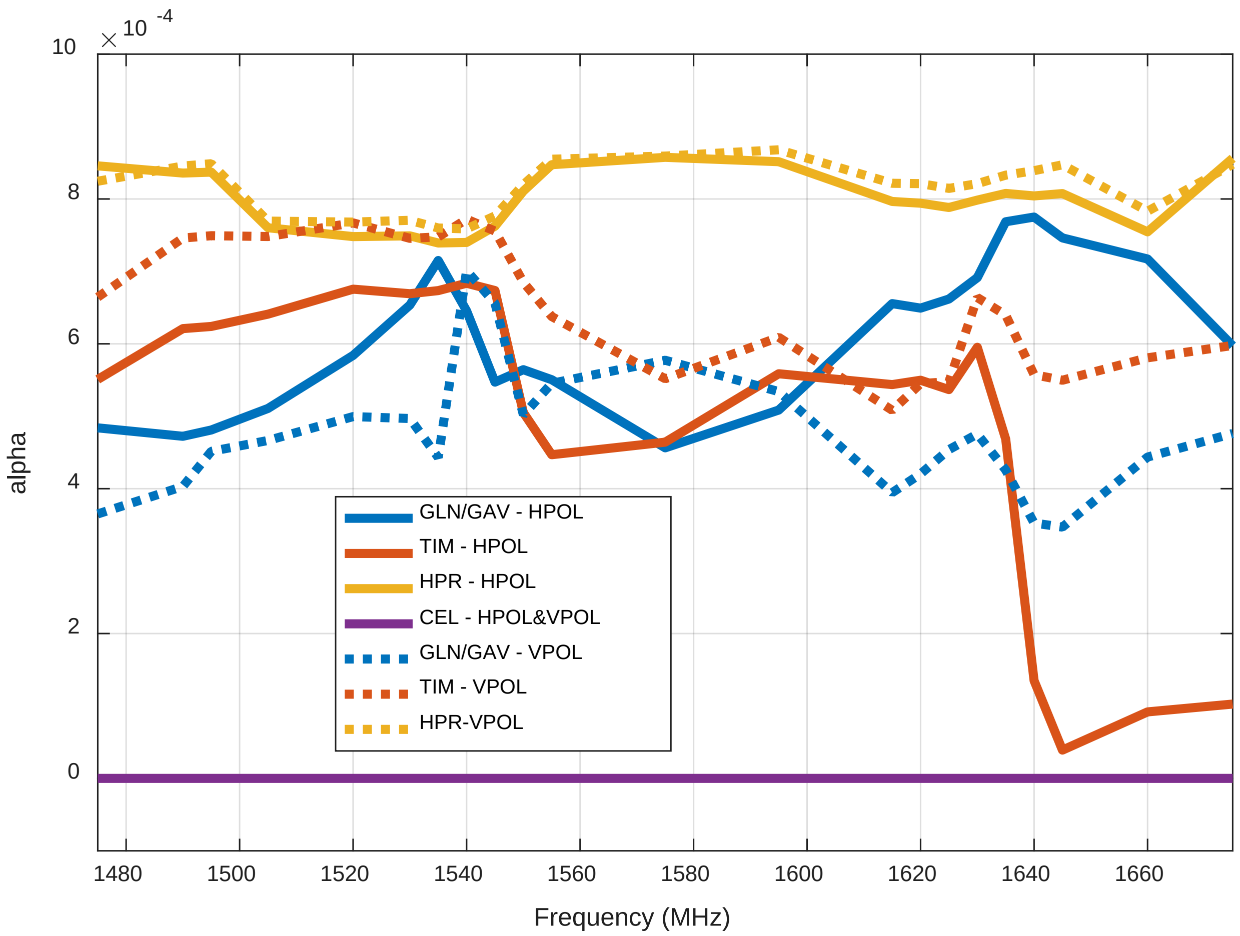








Parametric Fit Parameters



- Normalized gain, $G = -\alpha\theta^2$ where θ is off-boresight angle (deg)
- Higher α means gain falls off faster with decreasing elevation angle
- Note that HPR antennas had most rapid gain fall-off and retained RHCP at low elevation angles
- GLN/GAV antennas exhibited faster fall-off of HPOL gain with decreasing elevation angle (as expected)

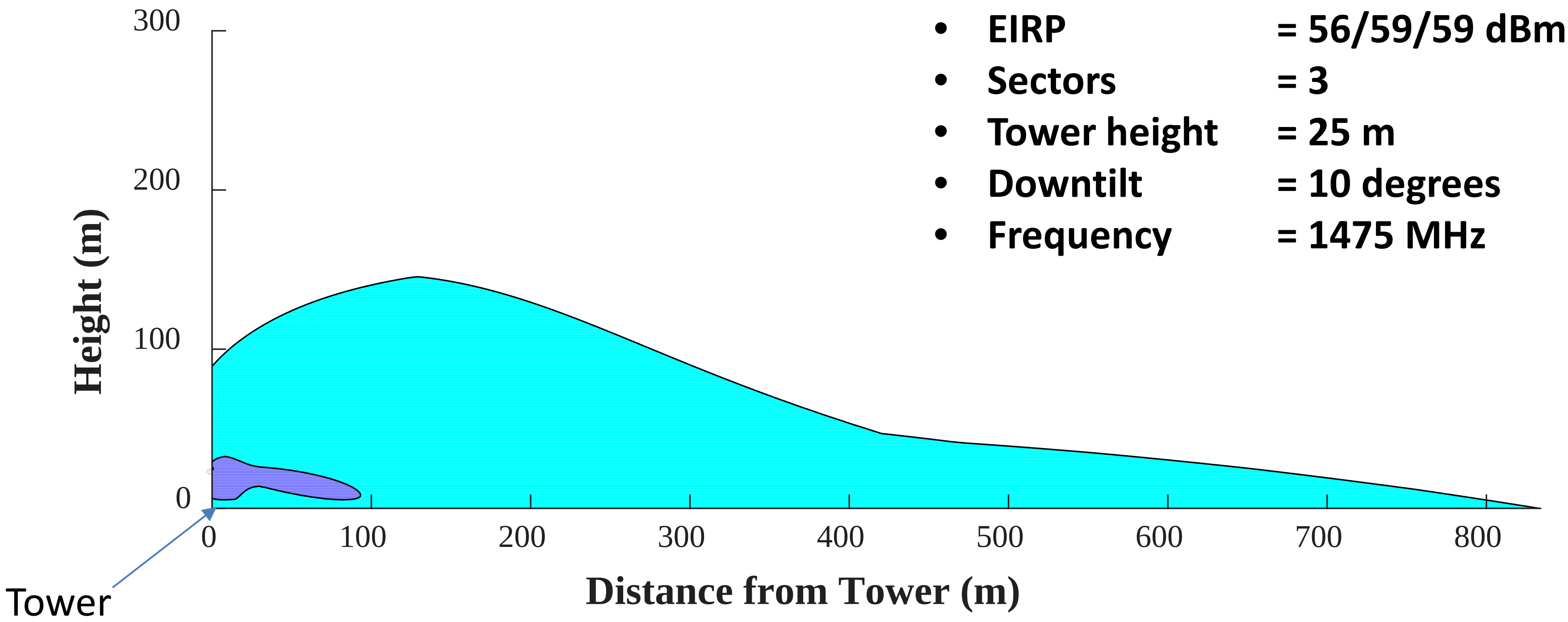
Propagation Loss Models

Propagation Loss Modeling

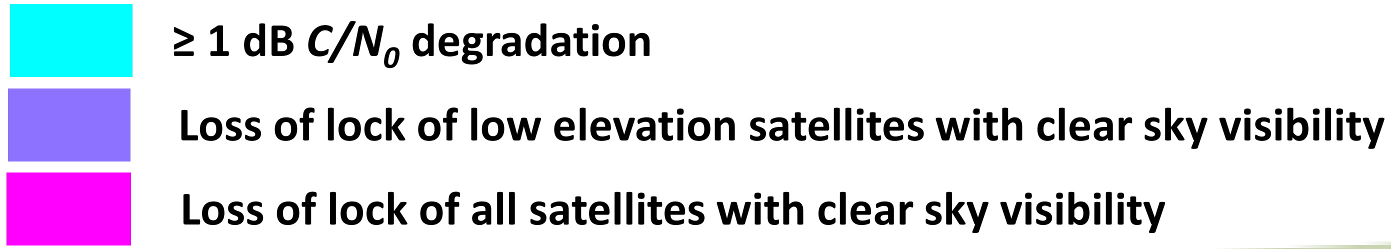
- The primary propagation model used in this presentation is the free-space path loss
- Two-ray path loss model is expected to show larger impact regions (A GLN use case is discussed later in this brief)
- Irregular Terrain Model (an improved version of the Longley-Rice Model) will be considered in the final report

Impacted Area Results:
Single Macro-Urban Base Station

Macro Urban, GLN, 1475 MHz

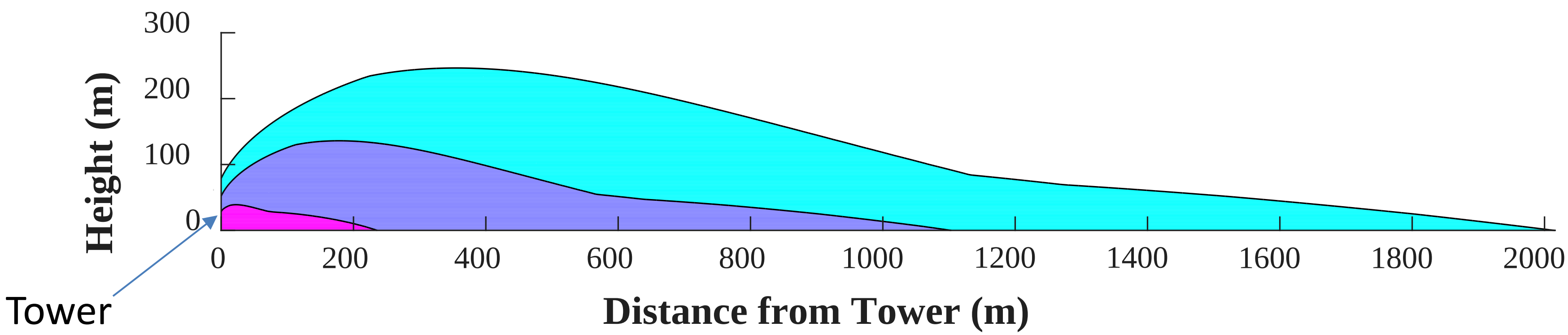


- EIRP = 56/59/59 dBm
- Sectors = 3
- Tower height = 25 m
- Downtilt = 10 degrees
- Frequency = 1475 MHz



Macro Urban, HPR, 1475 MHz

- EIRP = 56/59/59 dBm
- Sectors = 3
- Tower height = 25 m
- Downtilt = 10 degrees
- Frequency = 1475 MHz

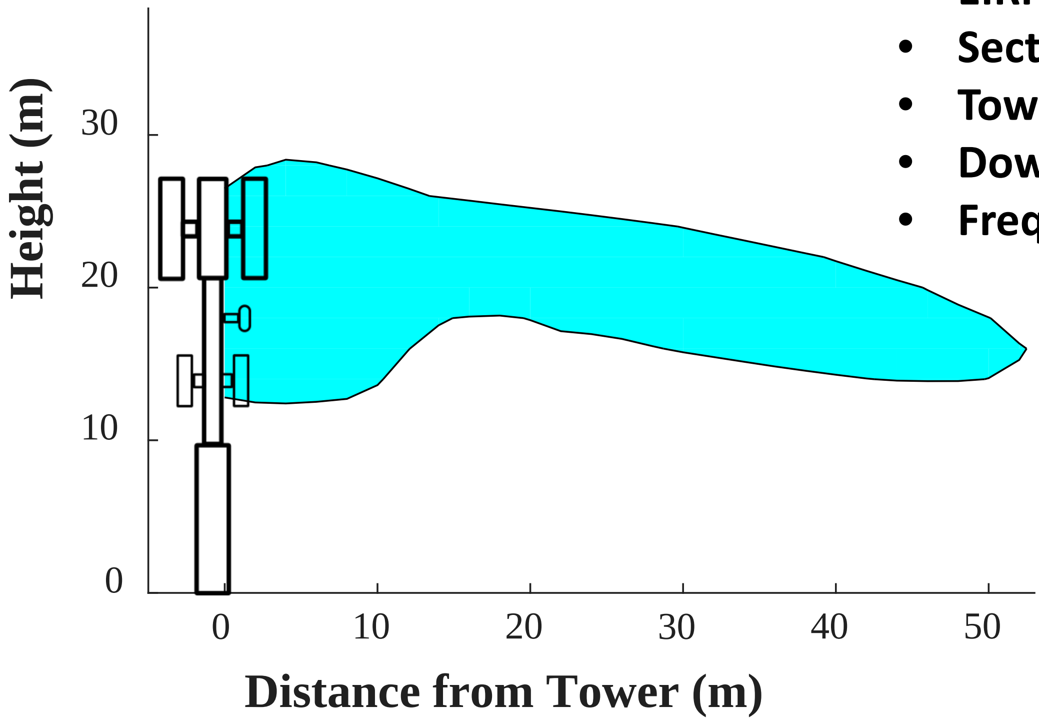


≥ 1 dB C/N_0 degradation

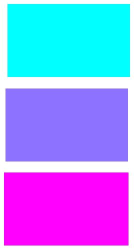
Loss of lock of low elevation satellites with clear sky visibility

Loss of lock of all satellites with clear sky visibility

Macro Urban, TIM, 1475 MHz



- EIRP = 56/59/59 dBm
- Sectors = 3
- Tower height = 25 m
- Downtilt = 10 degrees
- Frequency = 1475 MHz



≥ 1 dB C/N_0 degradation

Loss of lock of low elevation satellites with clear sky visibility

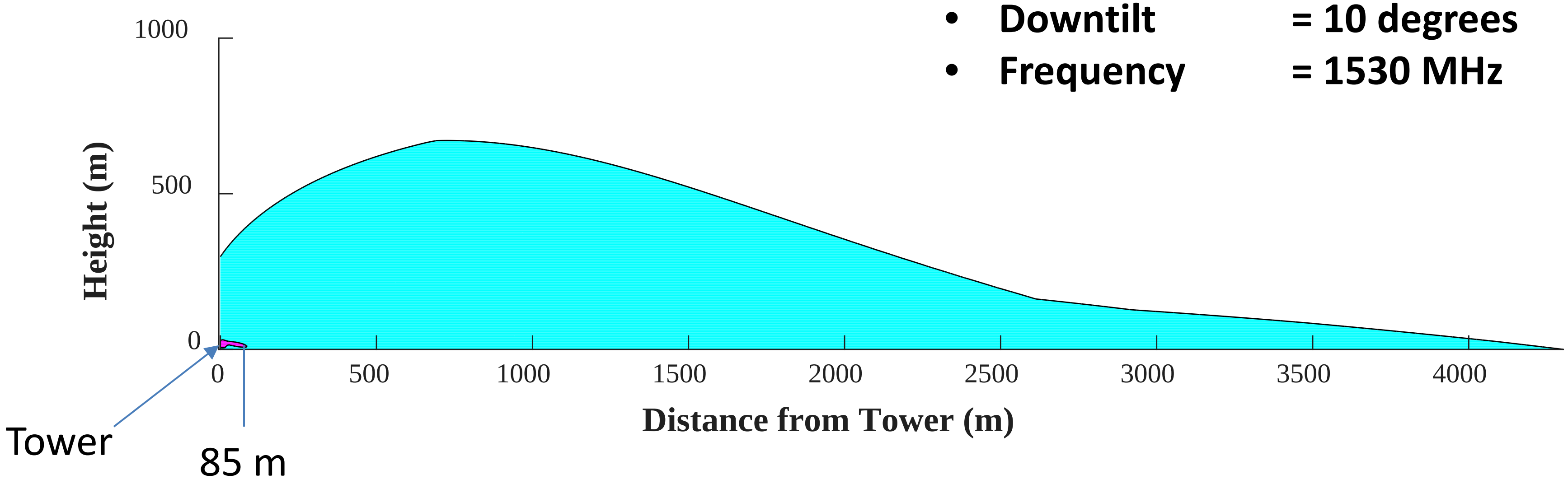
Loss of lock of all satellites with clear sky visibility

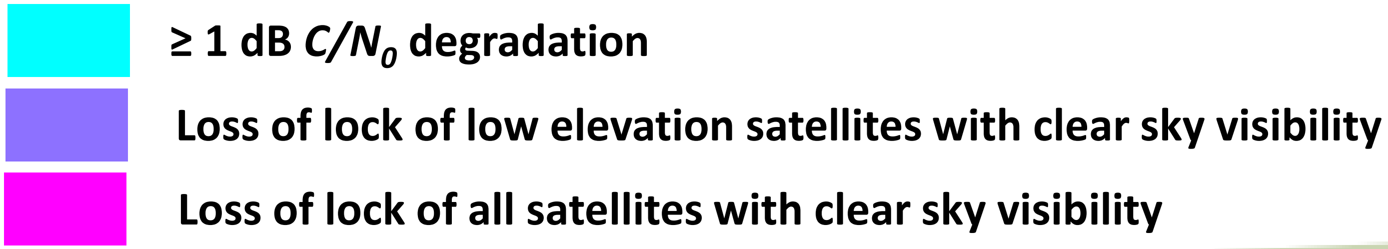
Macro Urban, CEL, 1475 MHz

No impact up to maximum power tested at WSMR.

Macro Urban, GLN, 1530 MHz

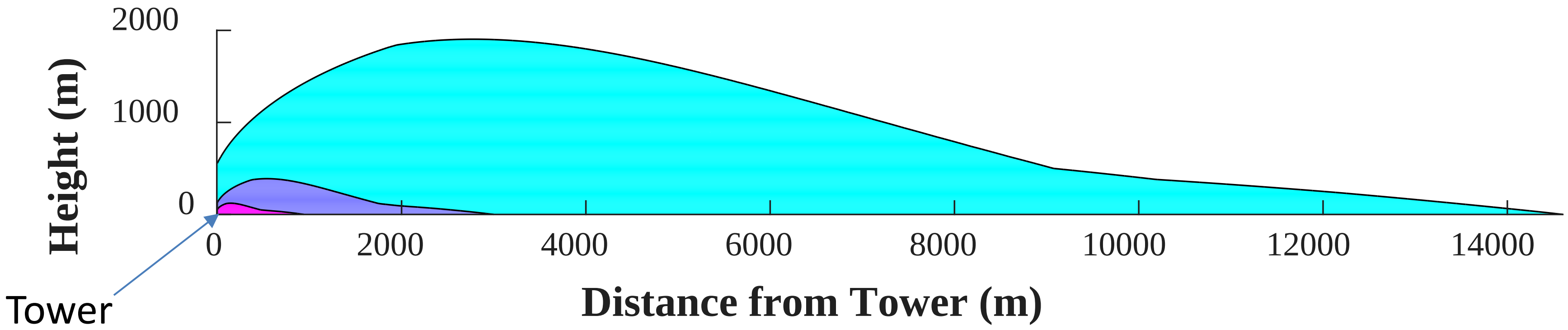
- EIRP = 56/59/59 dBm
- Sectors = 3
- Tower height = 25 m
- Downtilt = 10 degrees
- Frequency = 1530 MHz





Macro Urban, HPR, 1530 MHz

- EIRP = 56/59/59 dBm
- Sectors = 3
- Tower height = 25 m (82’)
- Downtilt = 10 degrees
- Frequency = 1530 MHz



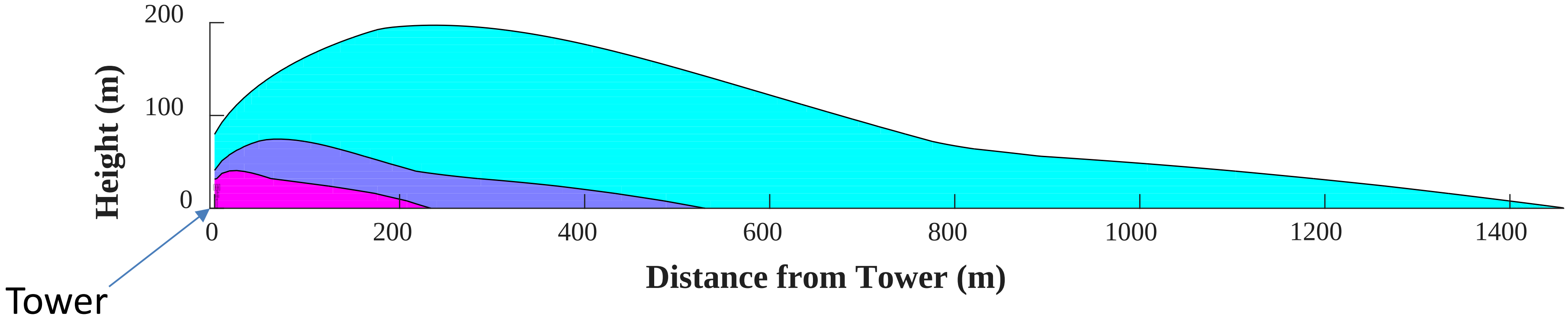
≥ 1 dB C/N_0 degradation

Loss of lock of low elevation satellites with clear sky visibility

Loss of lock of all satellites with clear sky visibility

Macro Urban, TIM, 1530 MHz

- EIRP = 56/59/59 dBm
- Sectors = 3
- Tower height = 25 m (82’)
- Downtilt = 10 degrees
- Frequency = 1530 MHz

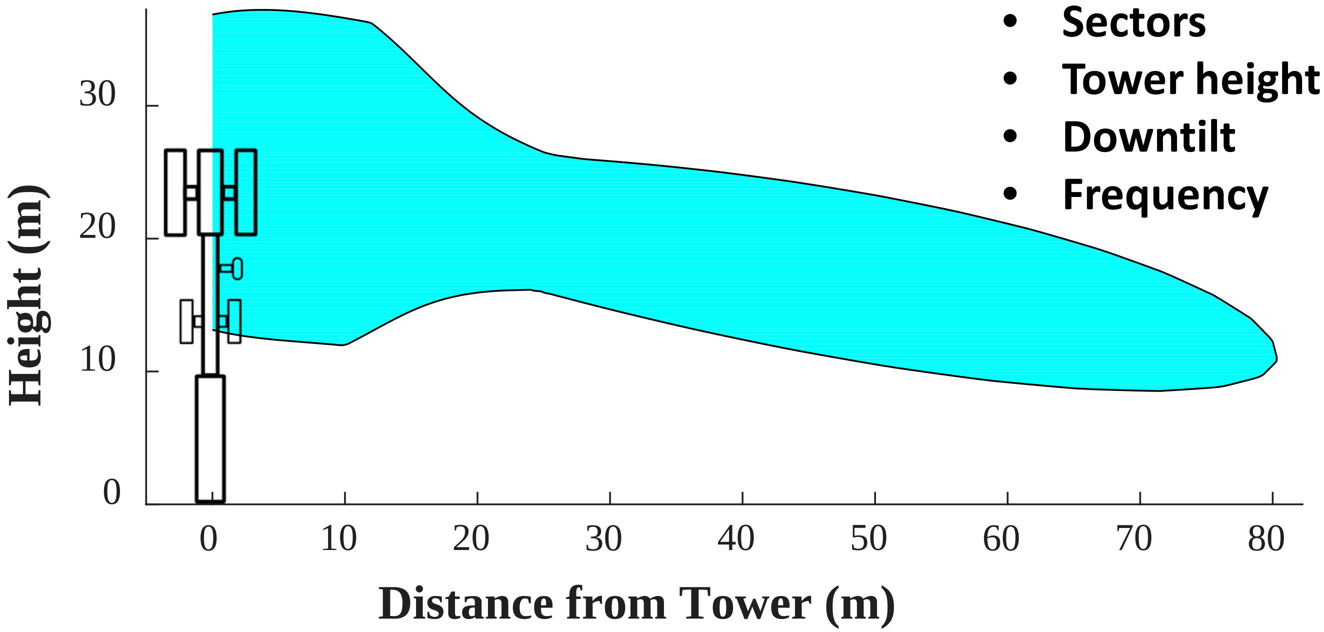


≥ 1 dB C/N_0 degradation

Loss of lock of low elevation satellites with clear sky visibility

Loss of lock of all satellites with clear sky visibility

Macro Urban, CEL, 1530 MHz



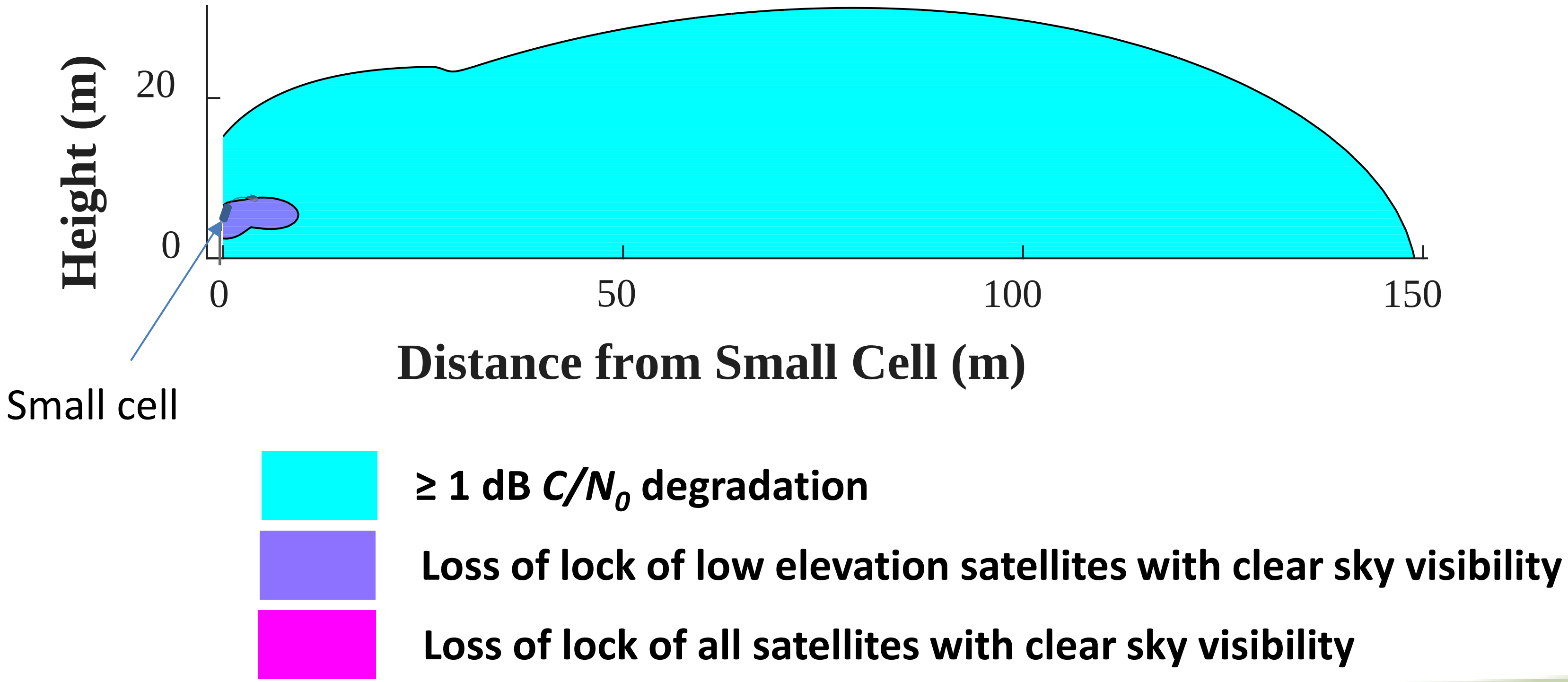
- EIRP = 56/59/59 dBm
- Sectors = 3
- Tower height = 25 m (82’)
- Downtilt = 10 degrees
- Frequency = 1530 MHz

(cyan)	≥ 1 dB C/N_0 degradation
(purple)	Loss of lock of low elevation satellites with clear sky visibility
(magenta)	Loss of lock of all satellites with clear sky visibility

Impacted Area Results: Single Small Cell Outdoor

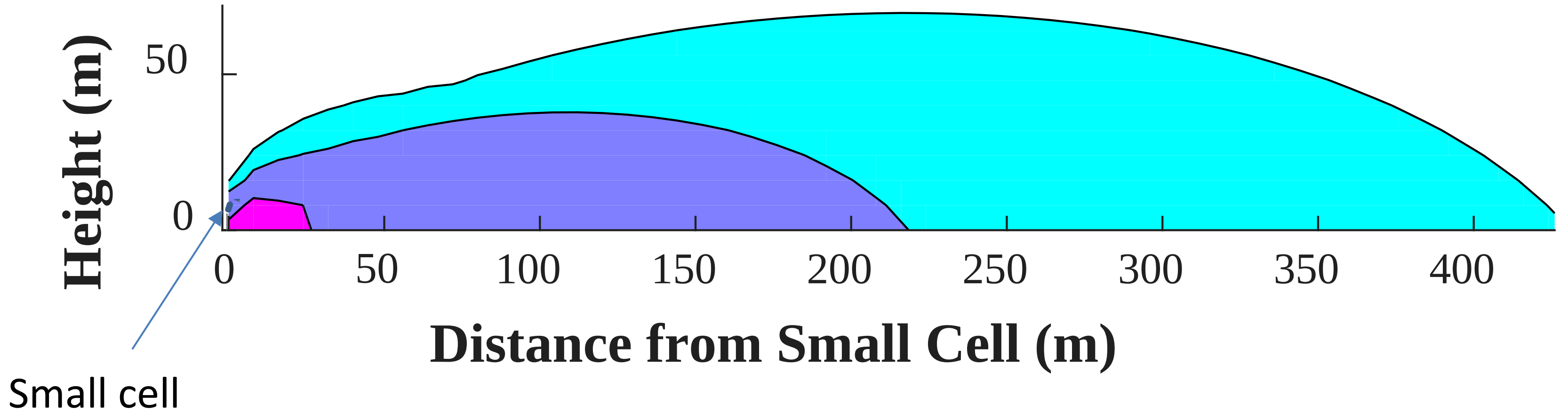
Small Cell Outdoor, GLN, 1475 MHz

- EIRP = 40 dBm
- Sectors = 1
- Antenna height = 6 m
- Frequency = 1475 MHz



Small Cell Outdoor, HPR, 1475 MHz

- EIRP = 40 dBm
- Sectors = 1
- Antenna height = 6 m
- Frequency = 1475 MHz

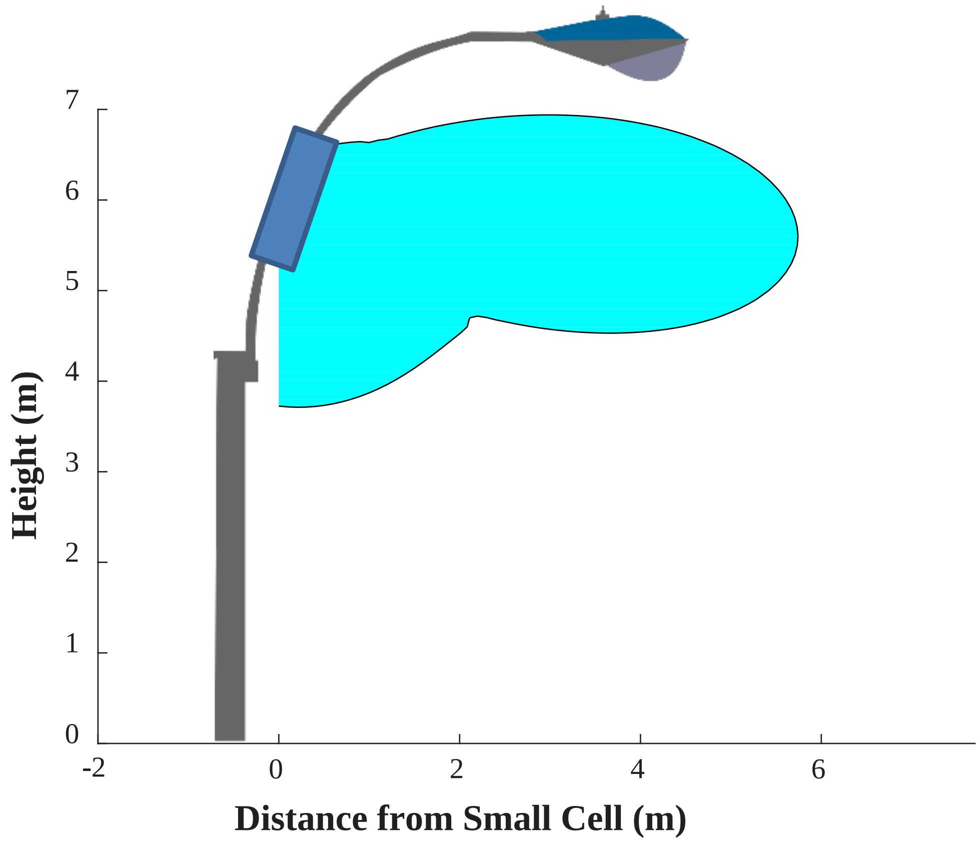


≥ 1 dB C/N_0 degradation

Loss of lock of low elevation satellites with clear sky visibility

Loss of lock of all satellites with clear sky visibility

Small Cell Outdoor, TIM, 1475 MHz



EIRP = 40 dBm
Sectors = 1
Antenna height = 6 m
Frequency = 1475 MHz

≥ 1 dB C/N_0 degradation

Loss of lock of low elevation satellites with clear sky visibility

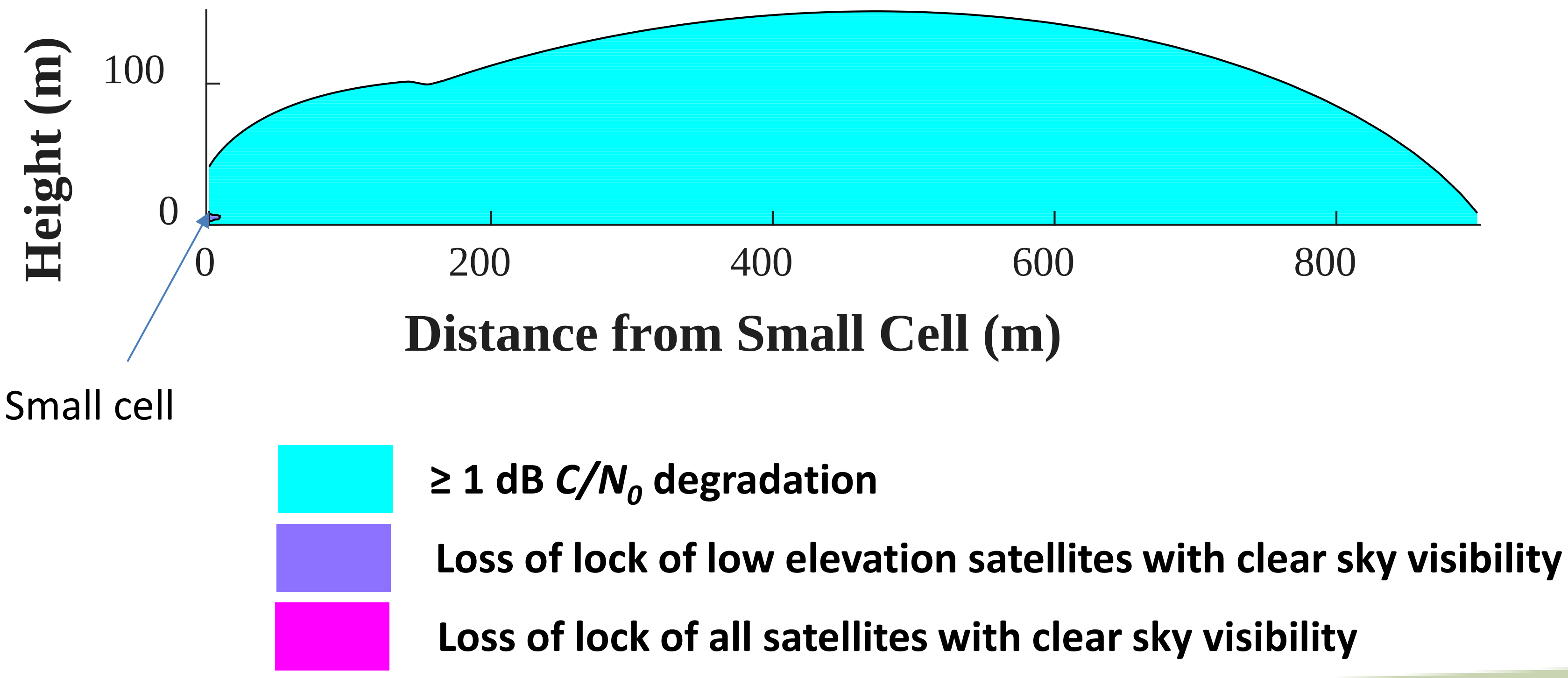
Loss of lock of all satellites with clear sky visibility

Small Cell Outdoor, CEL, 1475 MHz

No impact up to maximum power tested at WSMR.

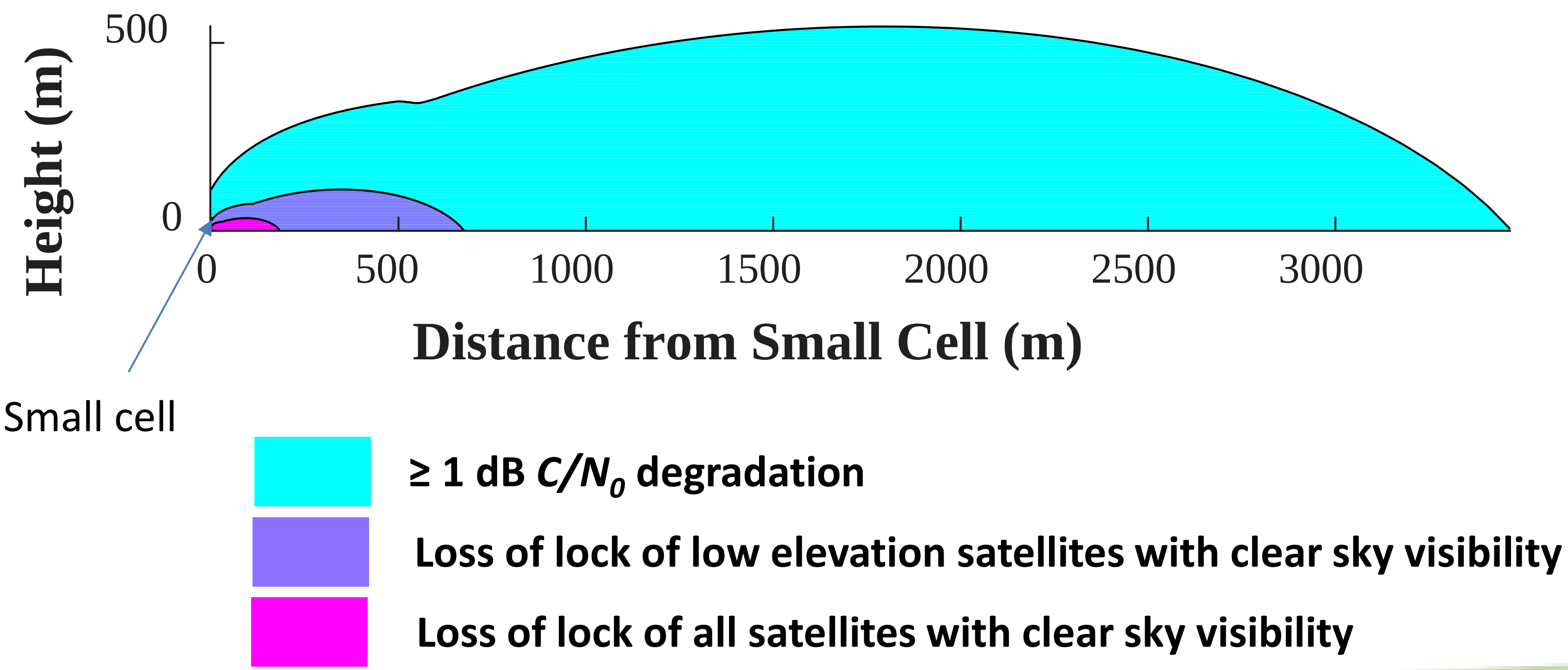
Small Cell Outdoor, GLN, 1530 MHz

- EIRP = 40 dBm
- Sectors = 1
- Antenna height = 6 m
- Frequency = 1530 MHz



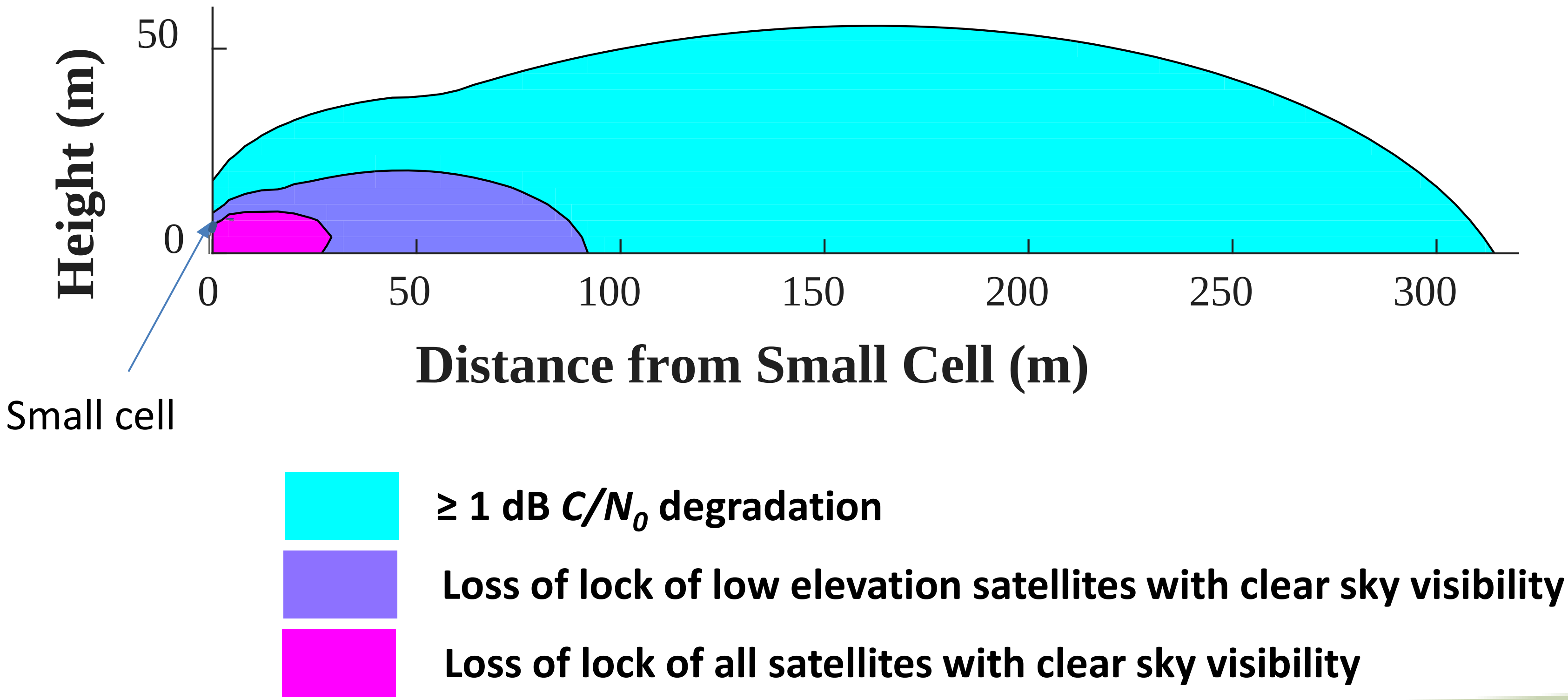
Small Cell Outdoor, HPR, 1530 MHz

- EIRP = 40 dBm
- Sectors = 1
- Antenna height = 6 m
- Frequency = 1530 MHz

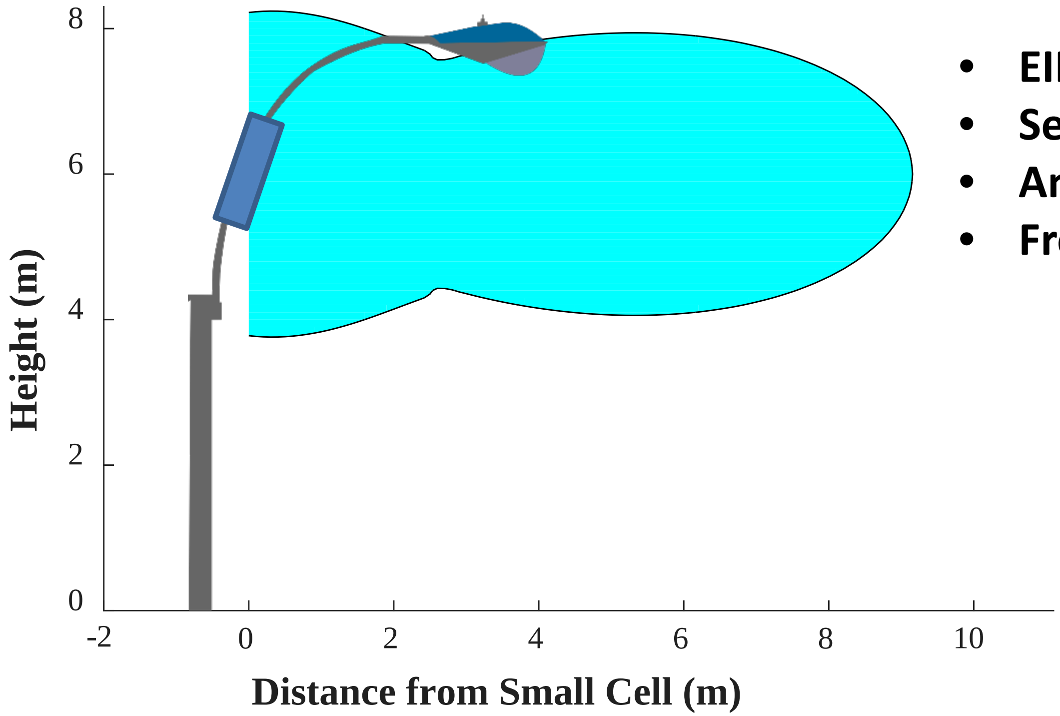


Small Cell Outdoor, TIM, 1530 MHz

- **EIRP = 40 dBm**
- **Sectors = 1**
- **Antenna height = 6 m**
- **Frequency = 1530 MHz**



Small Cell Outdoor, CEL, 1530 MHz



- EIRP = 40 dBm
- Sectors = 1
- Antenna height = 6 m
- Frequency = 1475 MHz

≥ 1 dB C/N_0 degradation

Loss of lock of low elevation satellites with clear sky visibility

Loss of lock of all satellites with clear sky visibility

Impacted Area Results: Single Mobile Device

Mobile Transmitter Analysis

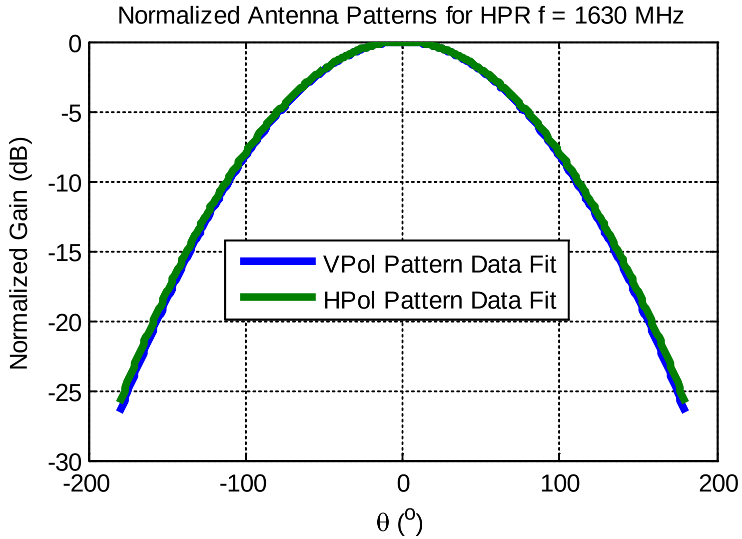
- The next analysis considers the impact of 23 dBm mobile transmitter

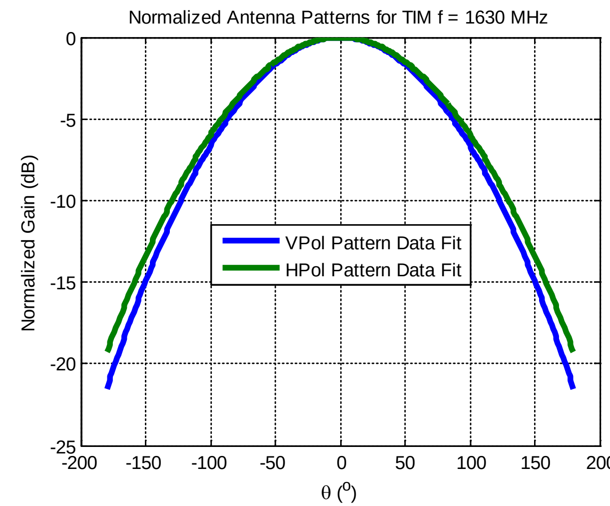
- Analysis performed for the 1630 MHz frequency

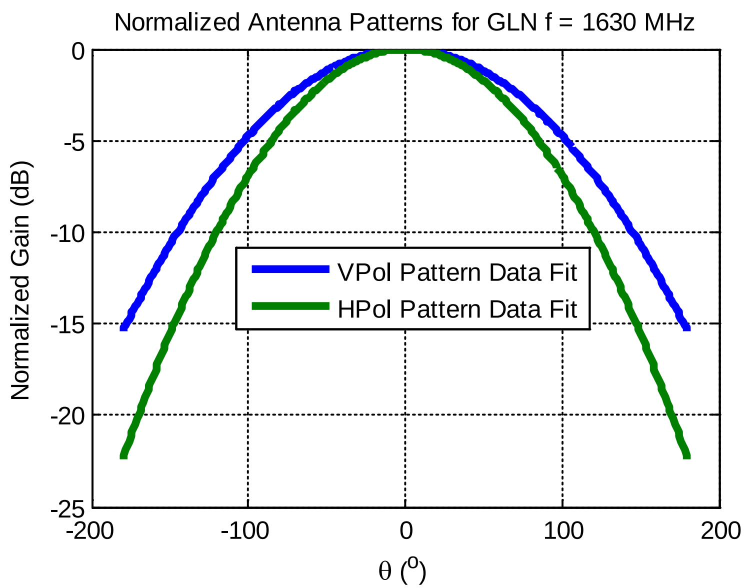
- Mobile transmitter assumed to have an antenna with vertical polarization and isotropic pattern

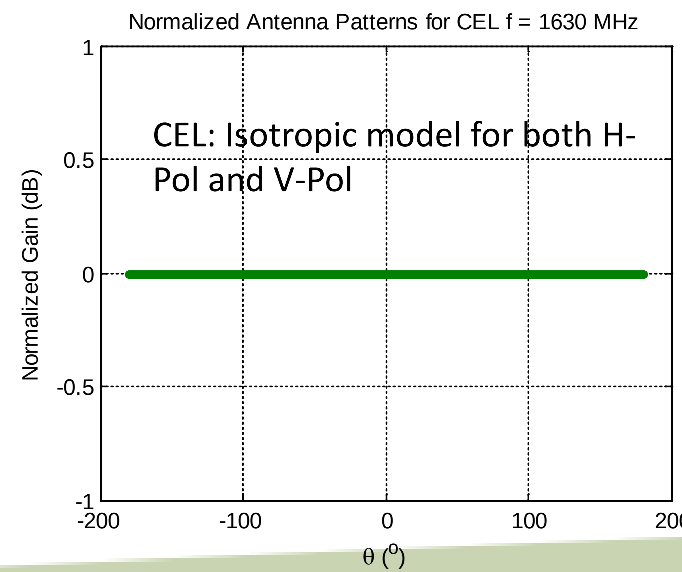
- Mobile device is at a height of 2 m above local ground

1630 MHz, V-Pol and H-Pol Patterns

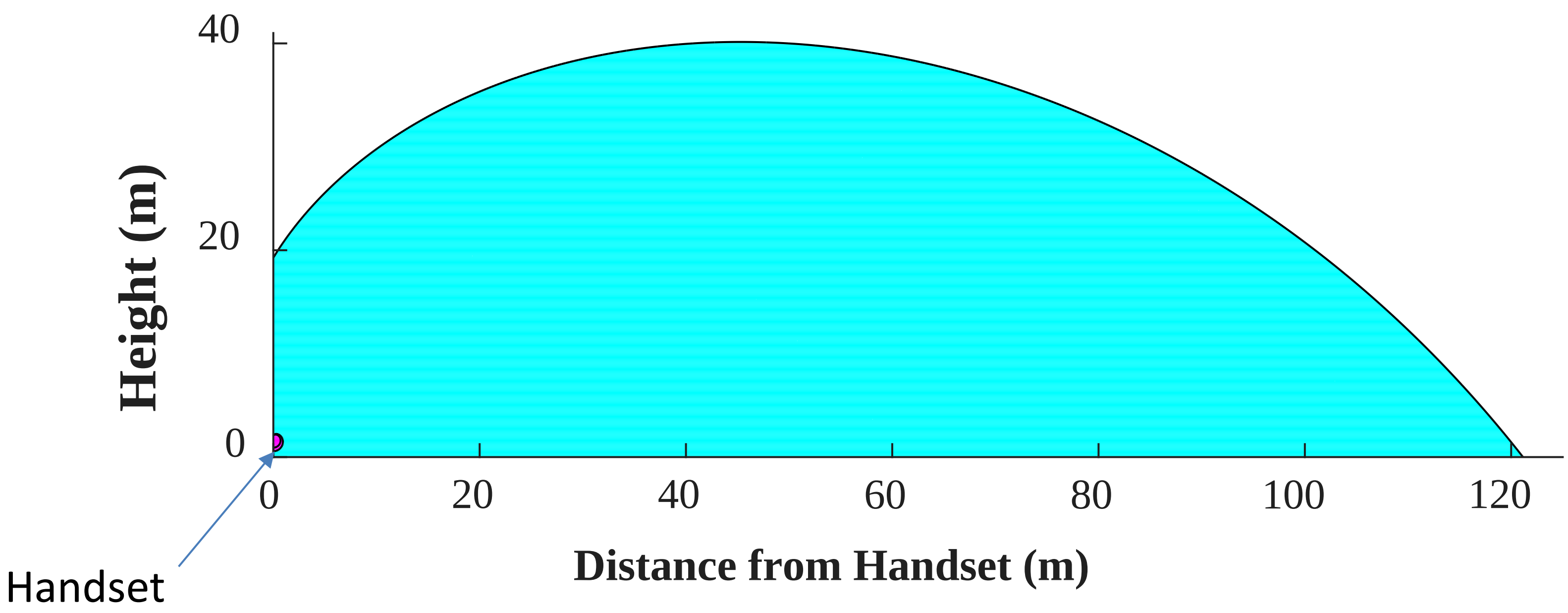








Mobile Transmitter: GLN, 1630

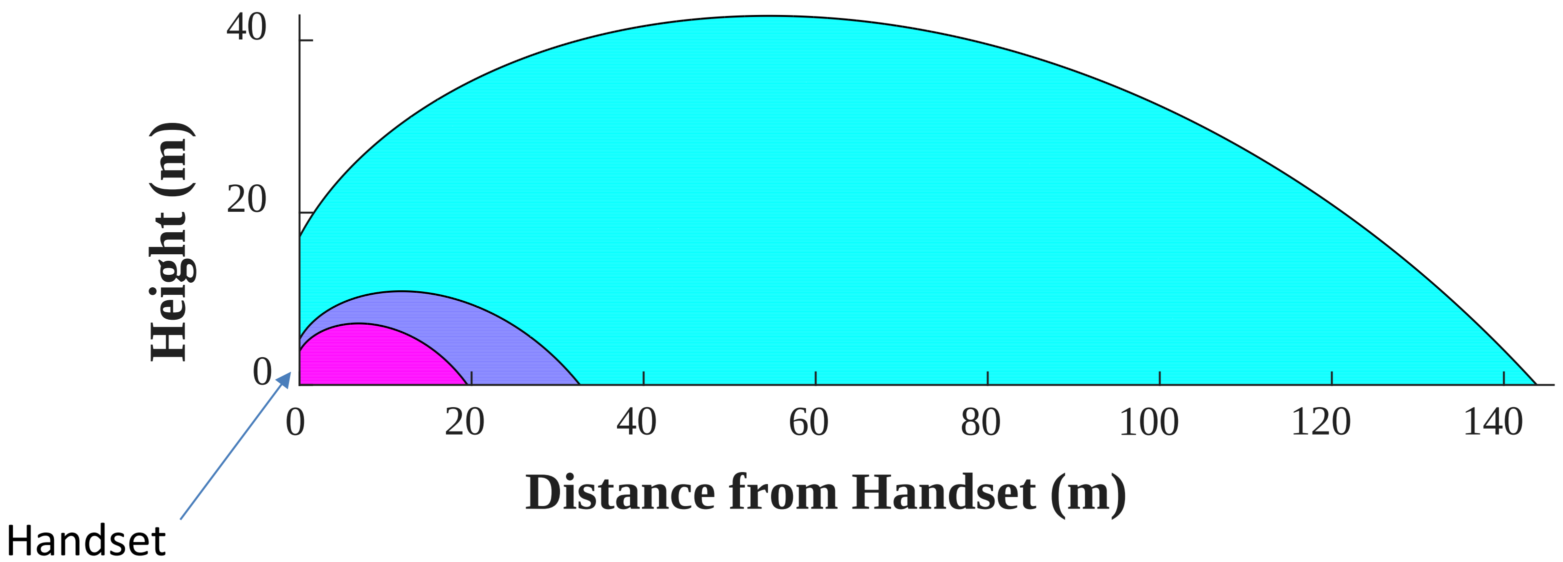


≥ 1 dB C/N_0 degradation

Loss of lock of satellites with 10 dB attenuation

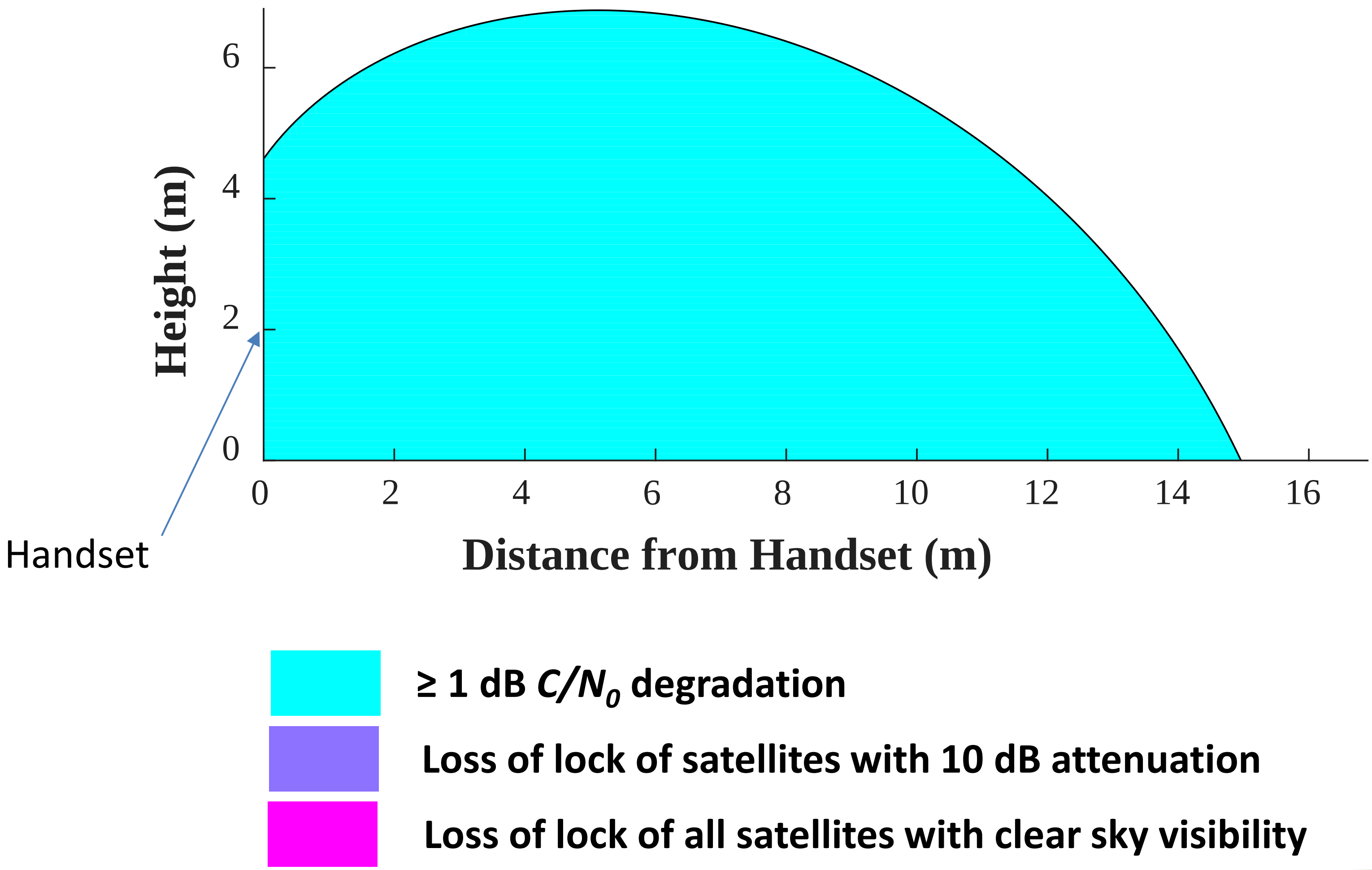
Loss of lock of all satellites with clear sky visibility

Mobile Transmitter: HPR, 1630

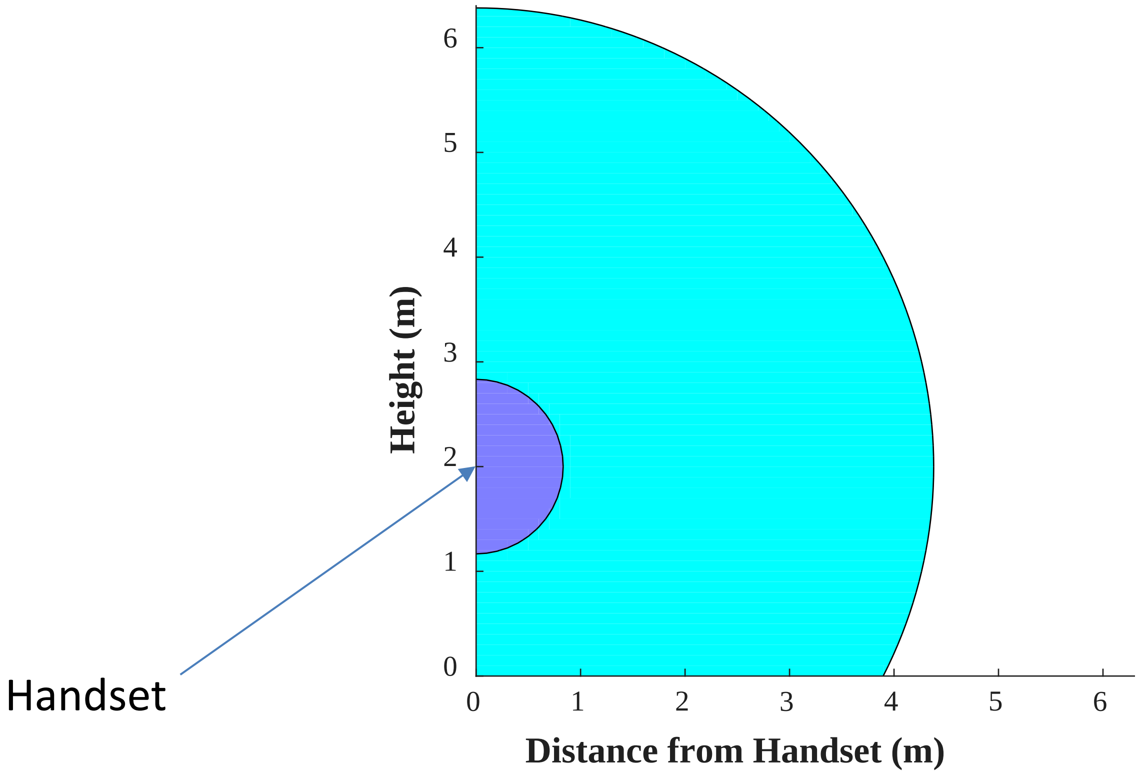


- $\geq$ 1 dB C/N_0 degradation
- Loss of lock of satellites with 10 dB attenuation
- Loss of lock of all satellites with clear sky visibility

Mobile Transmitter: TIM, 1630



Mobile Transmitter: CEL, 1630



≥ 1 dB C/N_0 degradation

Loss of lock of satellites with 10 dB attenuation

Loss of lock of all satellites with clear sky visibility

Inverse Modeling Results:
Single Macro-Urban Base Station

Inverse Modeling Analysis

- The inverse modeling analysis calculates the maximum tolerable EIRP levels as a function of standoff distance

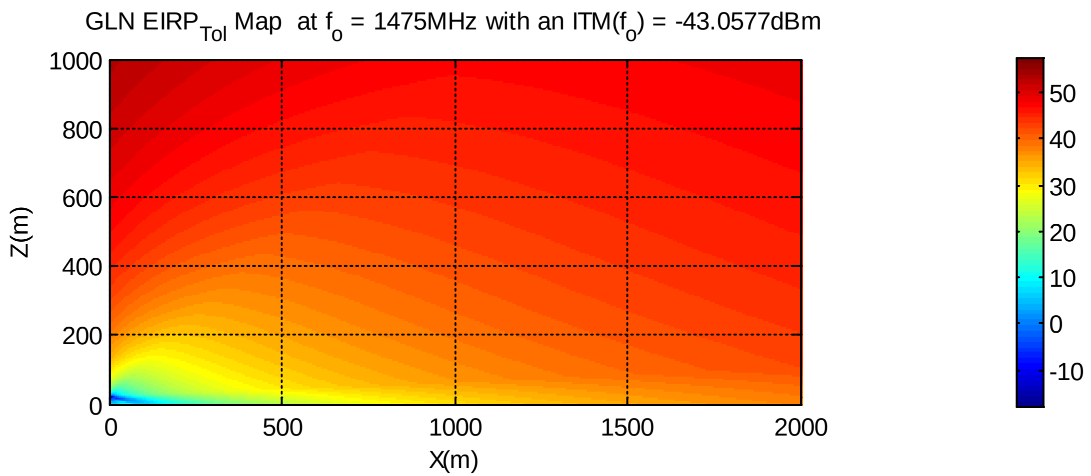
- Inverse modeling is a design tool to determine the maximum EIRP value that can be tolerated for the case of either single transmitter or a network transmitters

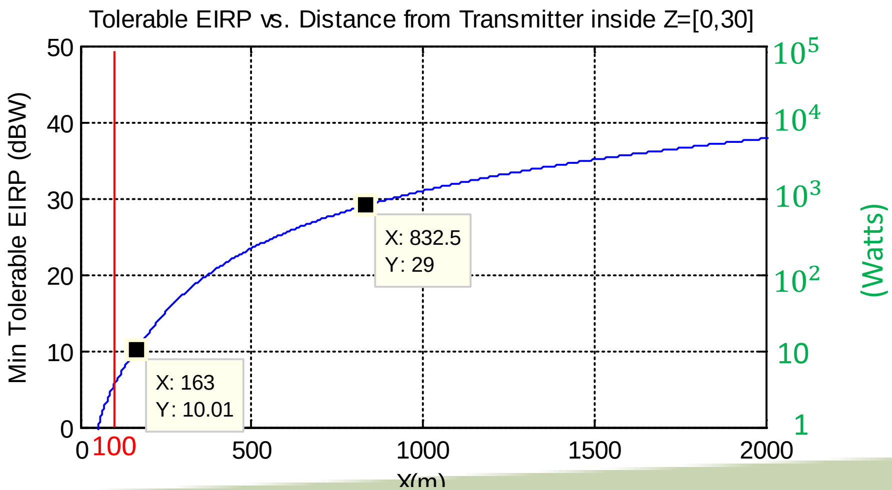
Inverse Modeling: CEL, 1475 MHz

- No detectable impact up to -10 dBm receive power => No inverse EIRP calculated

Inverse Modeling: GLN, 1475 MHz

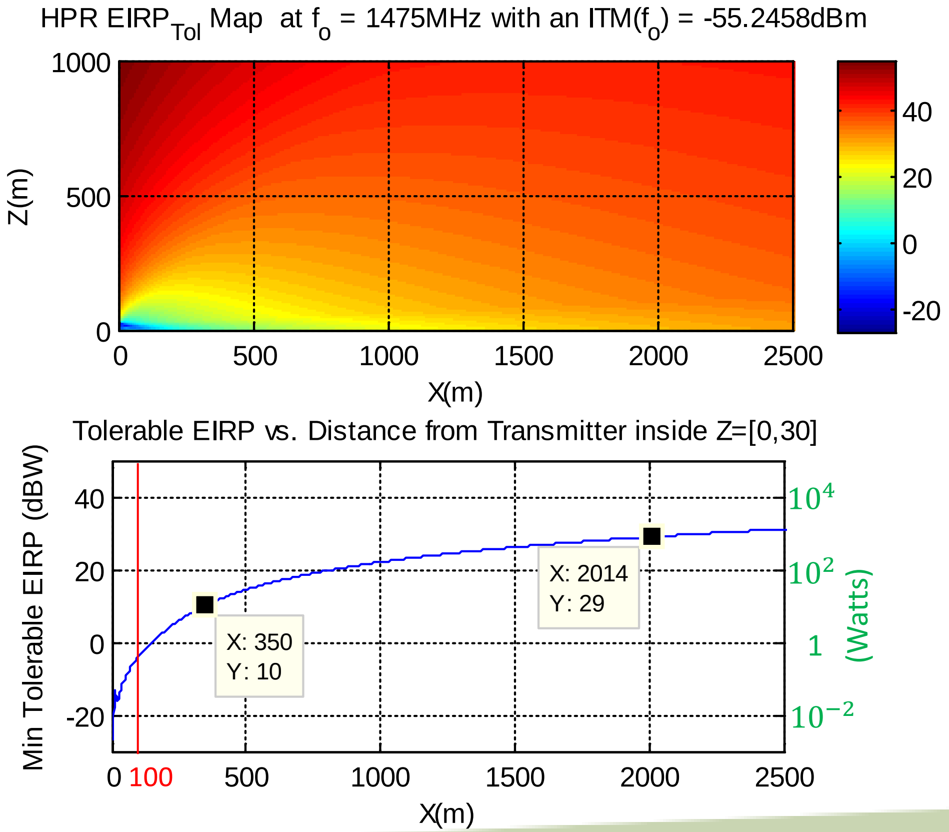
- Extent of the impact region: 800 to 850 m from transmitter for EIRP of 29 dBW
  160 to 165 m for EIRP of 10 dBW





Inverse Modeling: HPR, 1475 MHz

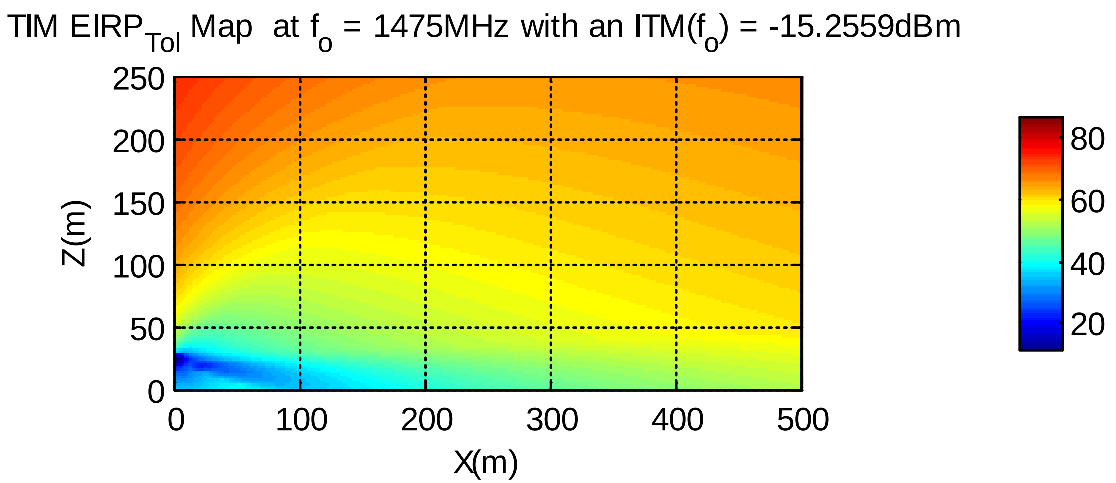
- Extent of the impact region: 2 km from transmitter for EIRP of 29 dBW
  350m for EIRP of 10 dBW

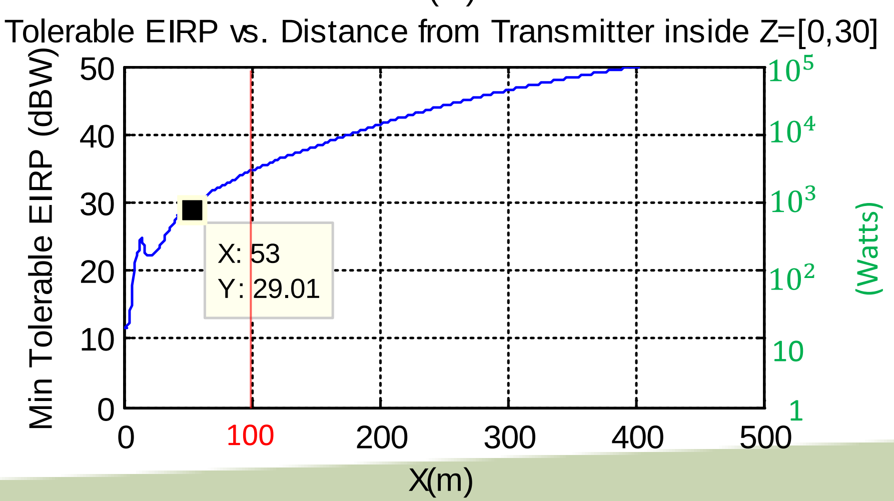


Inverse Modeling: TIM, 1475 MHz

- Extent of the impact region: 50 to 60 m from transmitter for EIRP of 29 dBW

  No detectable impact for EIRP of 10 dBW

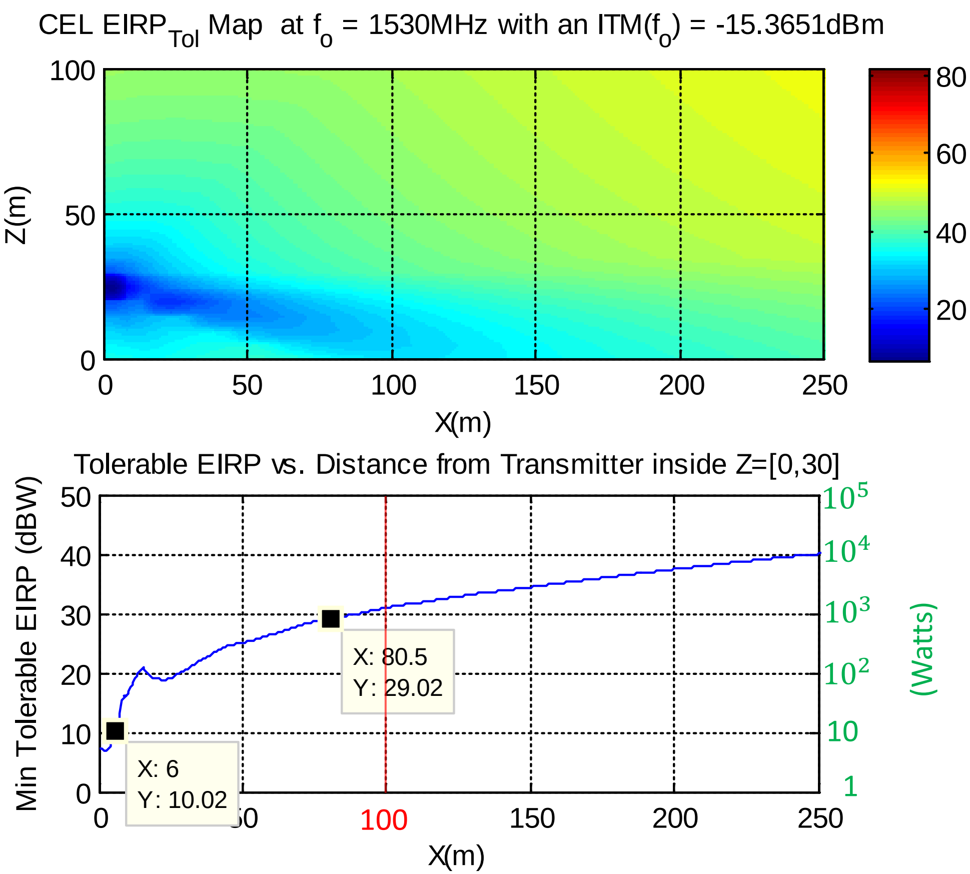




Inverse Modeling: CEL, 1530 MHz

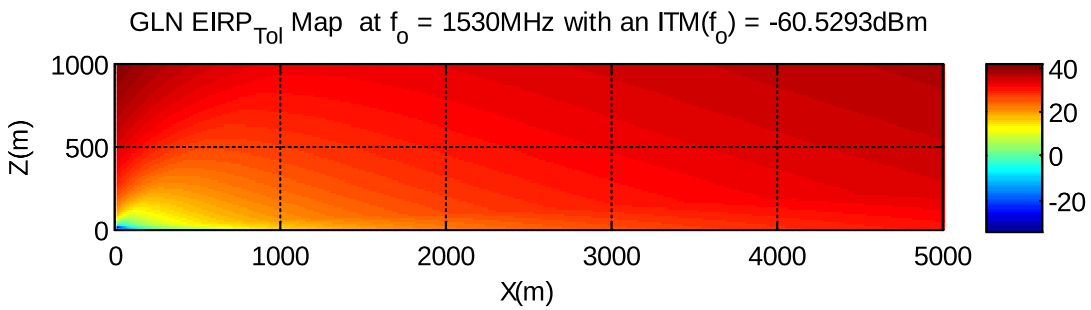
- Extent of the impact region: 80 m from Transmitter for EIRP of 29 dBW

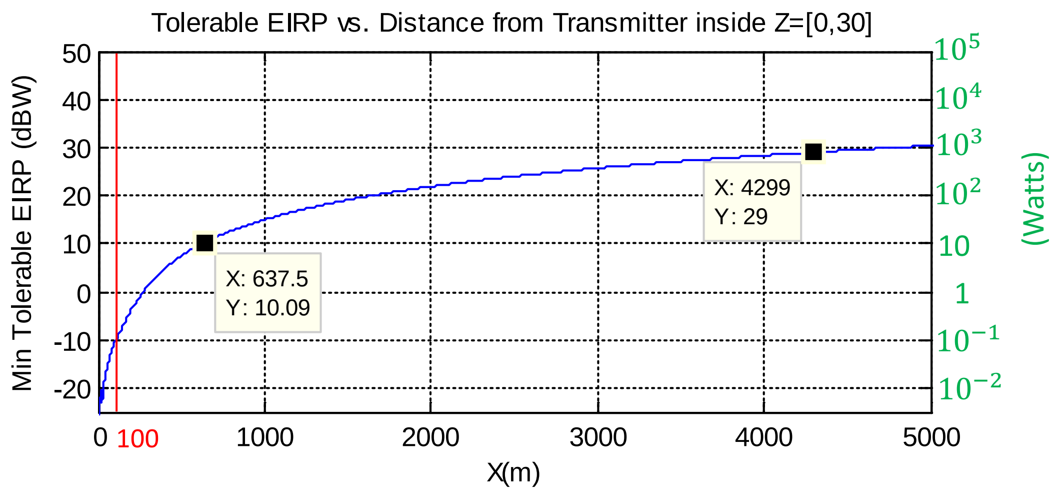
  6 m for EIRP of 10 dBW



Inverse Modeling: GLN, 1530 MHz

- Extent of the impact region: 4 to 4.5 km from Transmitter for EIRP of 29 dBW
  600 to 650 m for EIRP of 10 dBW

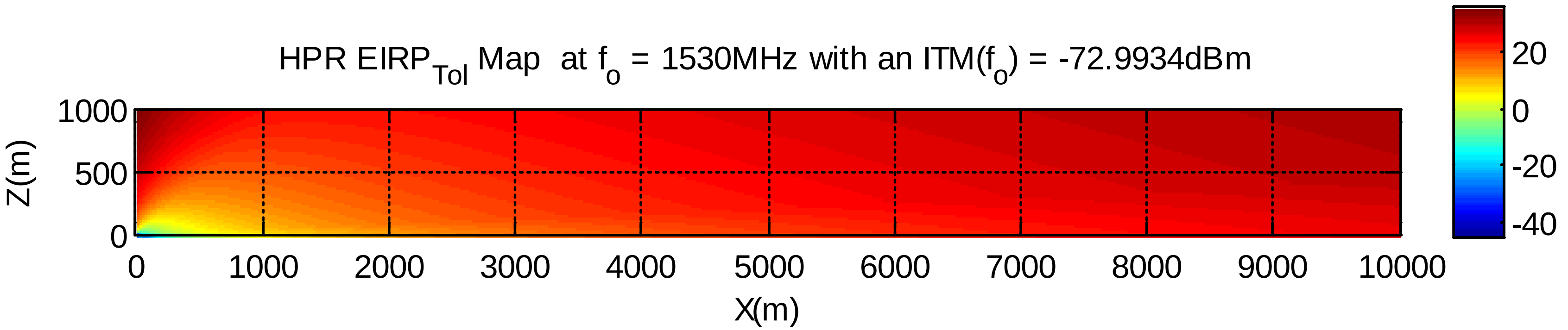


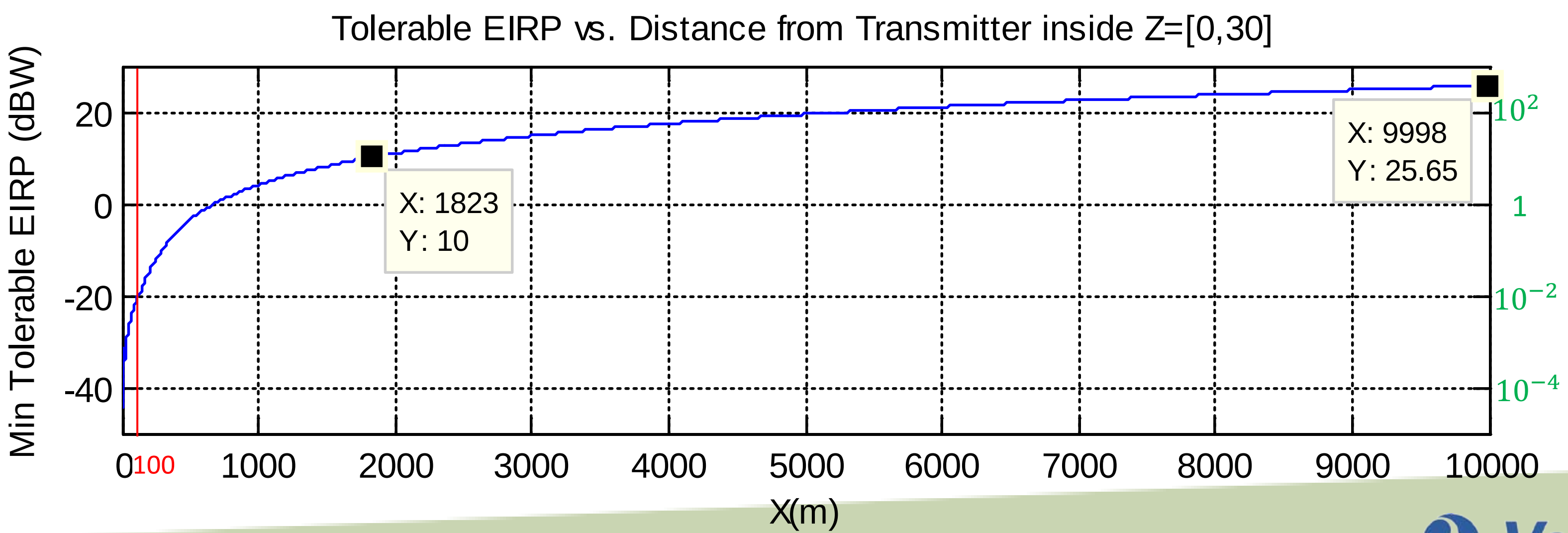


Inverse Modeling: HPR, 1530 MHz

- Extent of the impact region: >10 km from Transmitter for EIRP of 29 dBW

  1.5 to 2 km for EIRP of 10 dBW

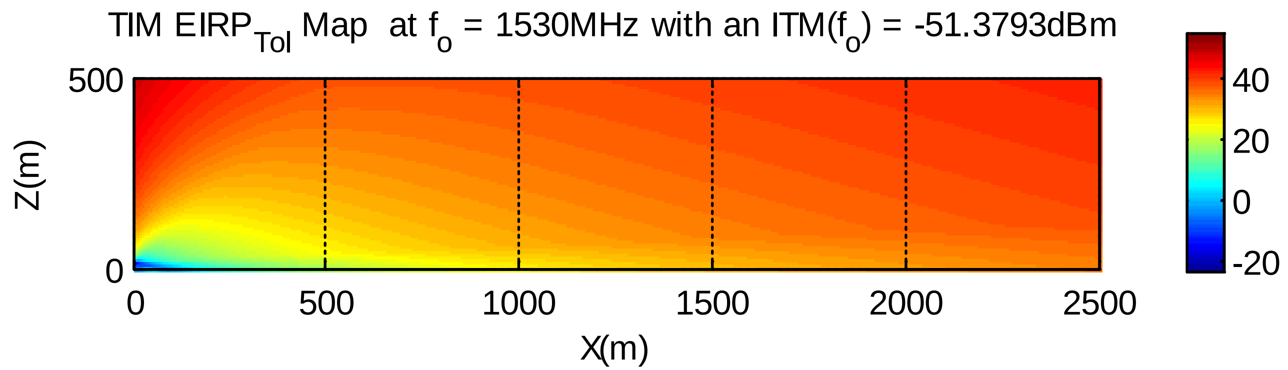


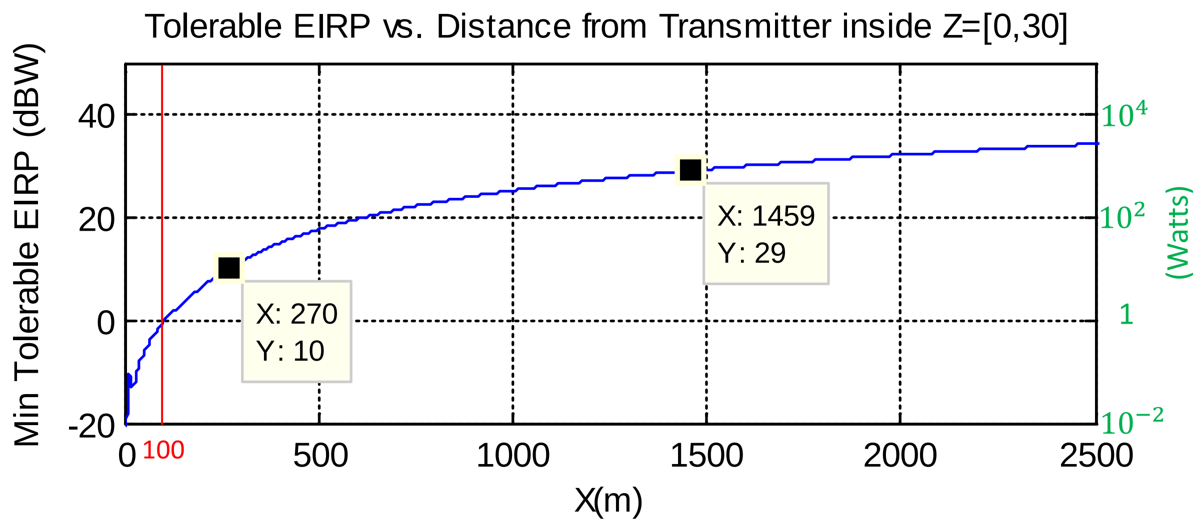


Inverse Modeling: TIM, 1530 MHz

- Extent of the impact region: 1.5 km from transmitter for EIRP of 29 dBW

  270 m for EIRP of 10 dBW





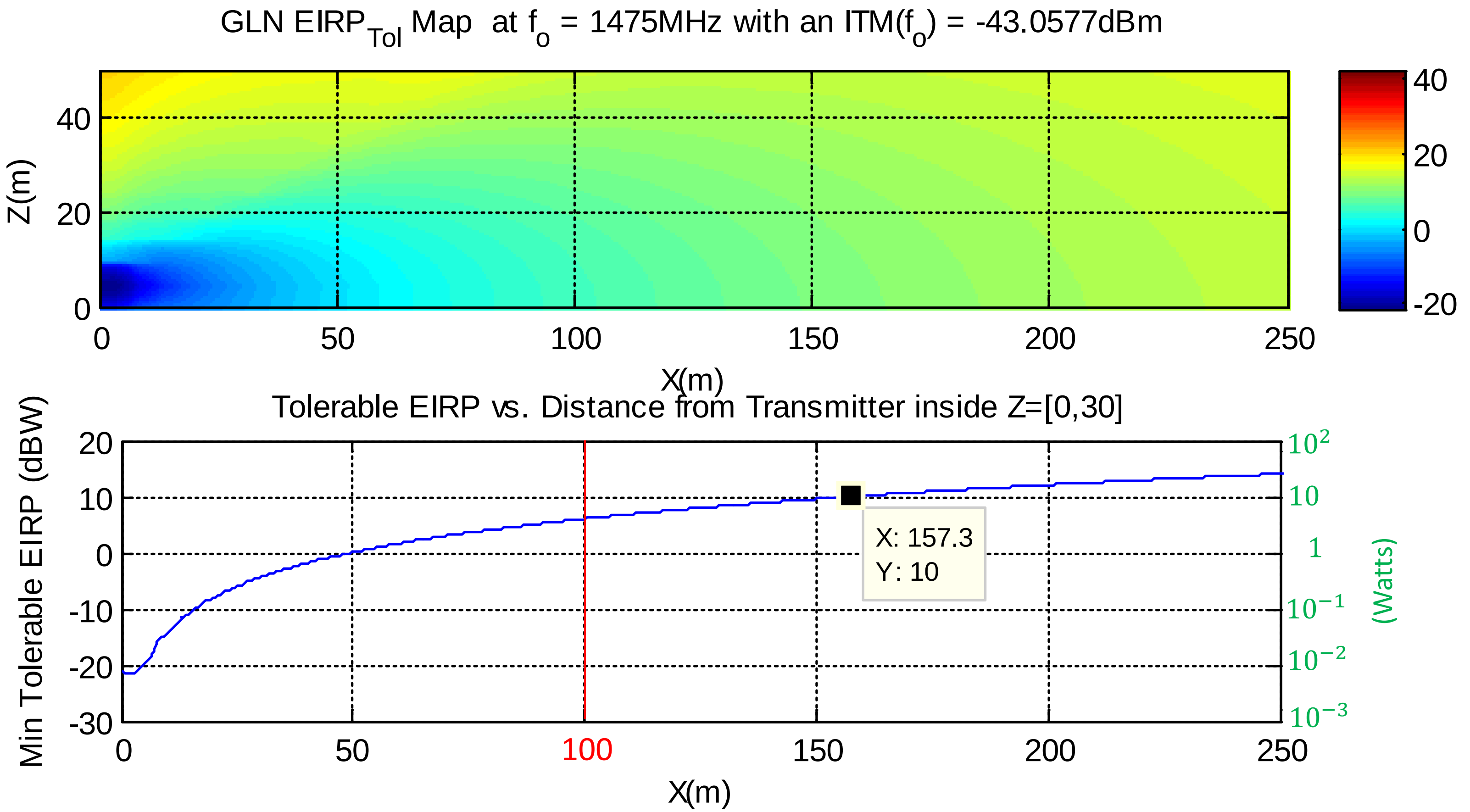
Inverse Modeling Results:
Single Micro-Urban Base Station

Inverse Modeling: CEL, 1475 MHz

- No detectable impact up to -10 dBm receive power => No inverse EIRP calculated

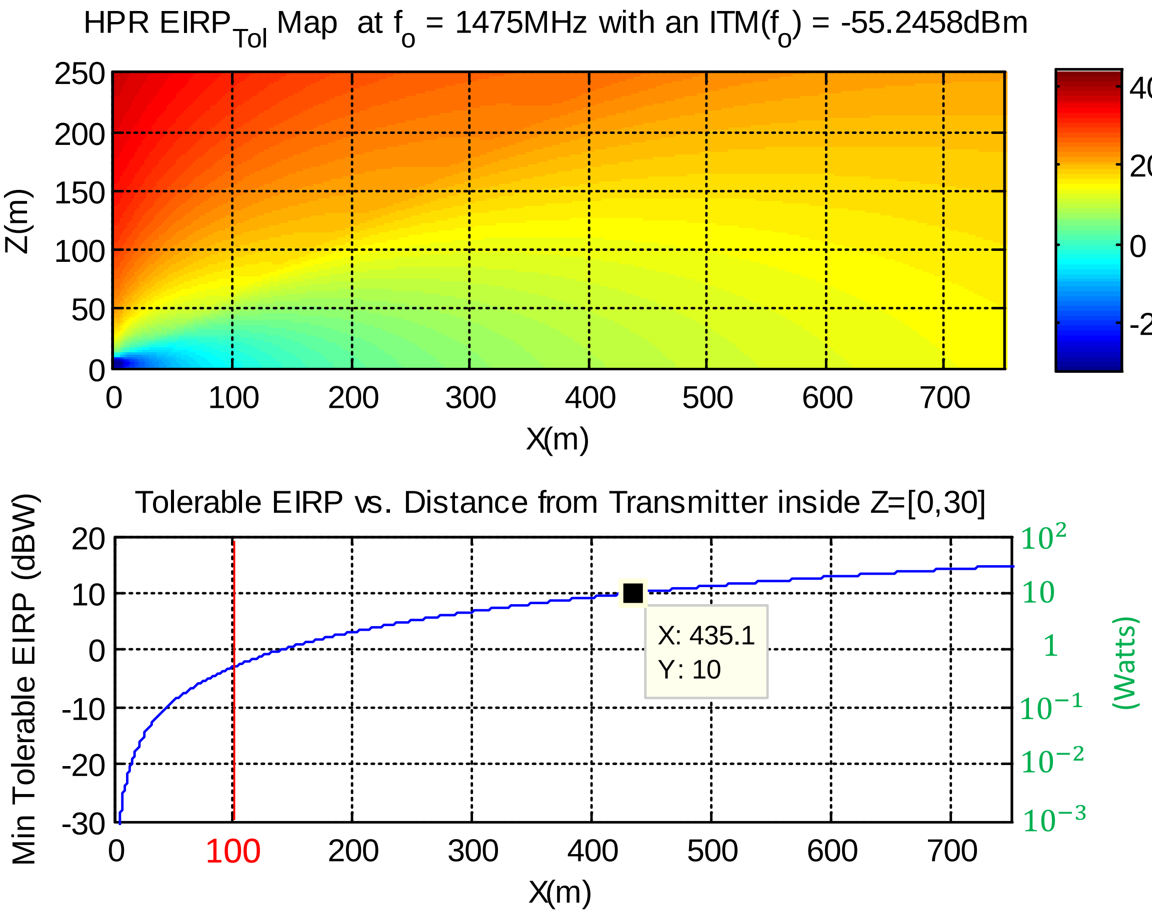
Inverse Modeling: GLN, 1475 MHz

- Extent of the impact region: 150 to 160 m from transmitter for EIRP of 10 dBW



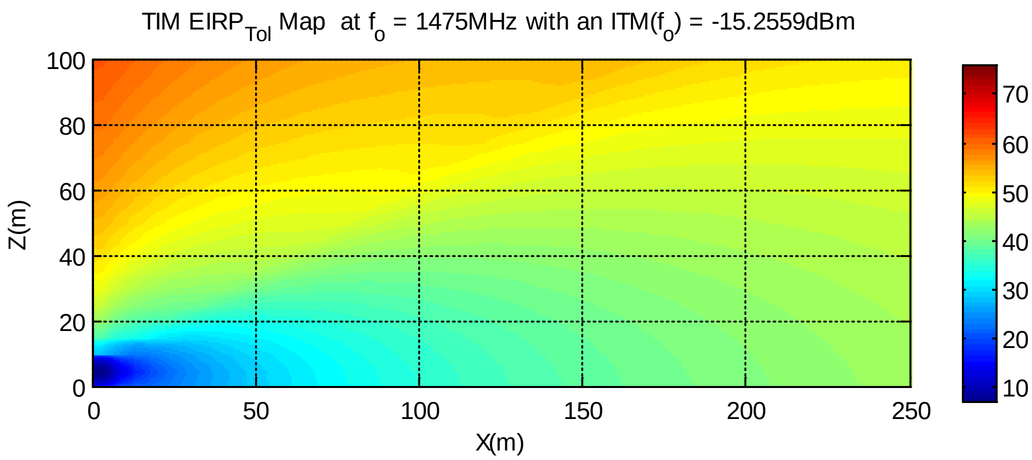
Inverse Modeling: HPR, 1475 MHz

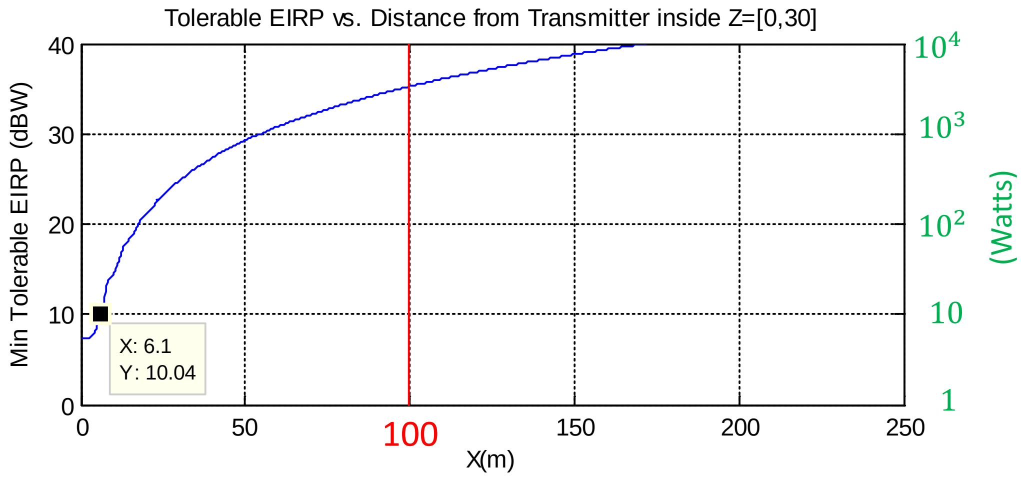
- Extent of the impact region: 400 to 450 m from transmitter for EIRP of 10 dBW



Inverse Modeling: TIM, 1475 MHz

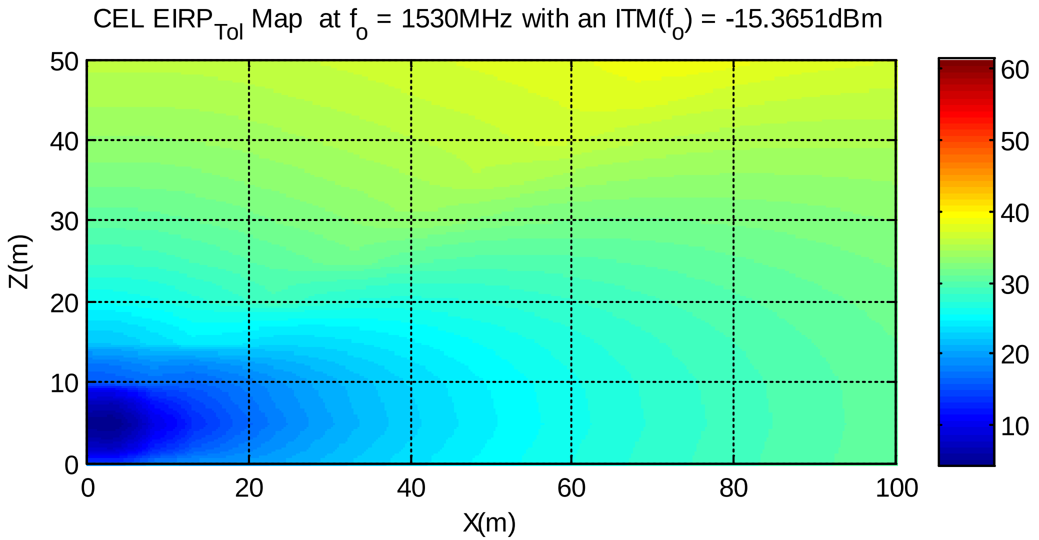
- Extent of the impact region: < 10 m from transmitter for EIRP of 10 dBW

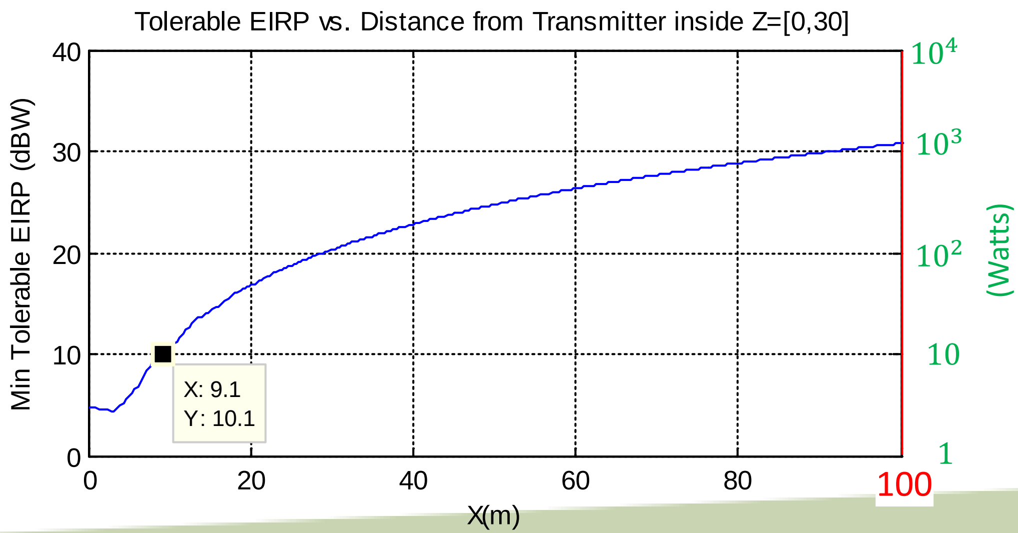




Inverse Modeling: CEL, 1530 MHz

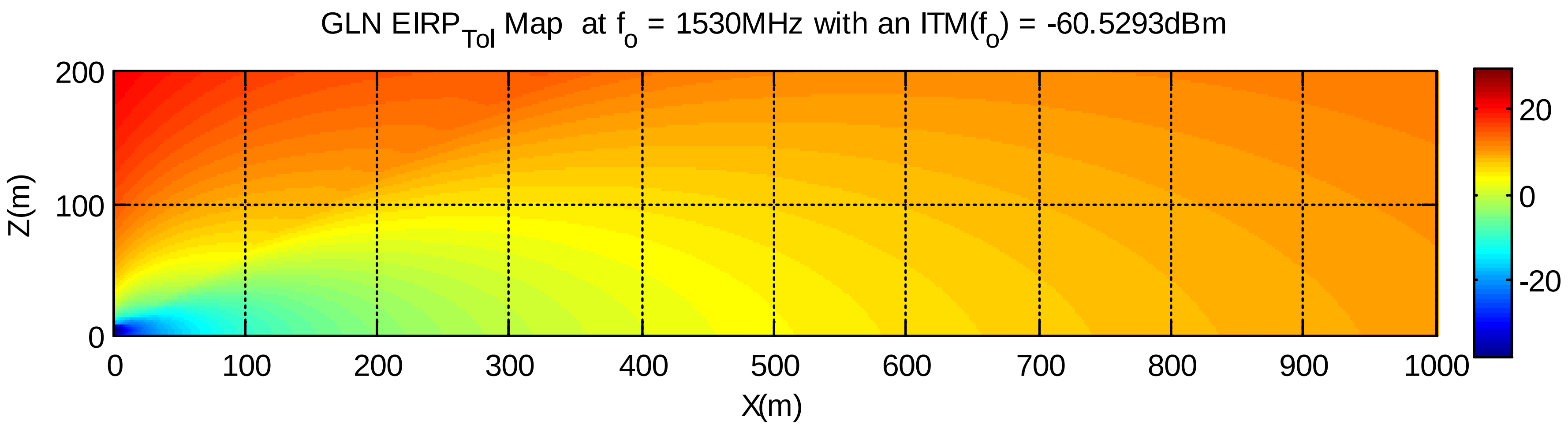
- Extent of the impact region: < 10 m from transmitter for EIRP of 10 dBW

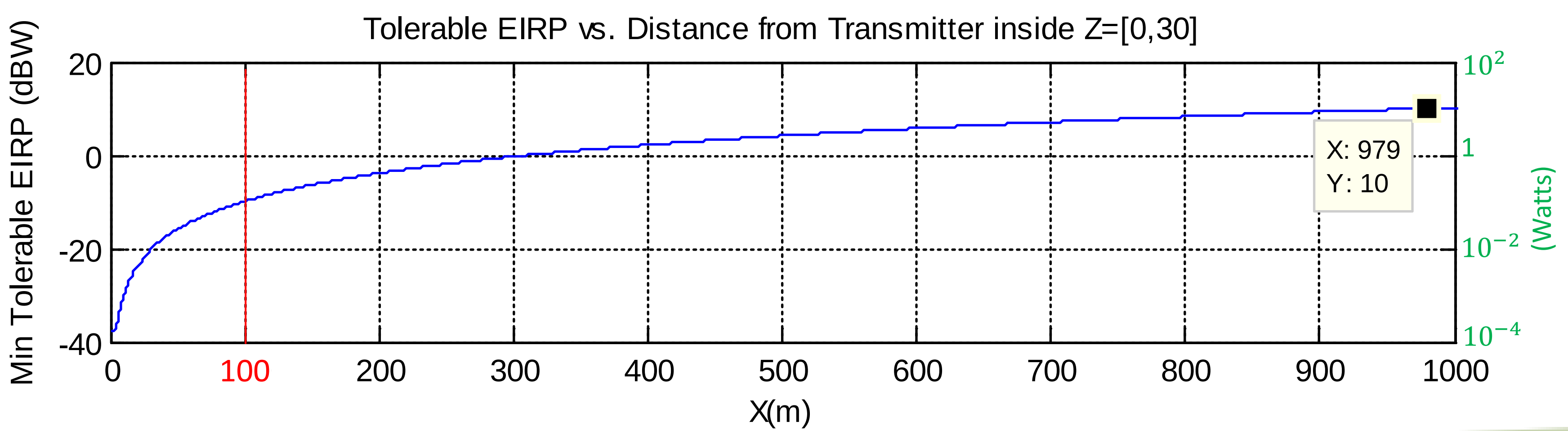




Inverse Modeling: GLN, 1530 MHz

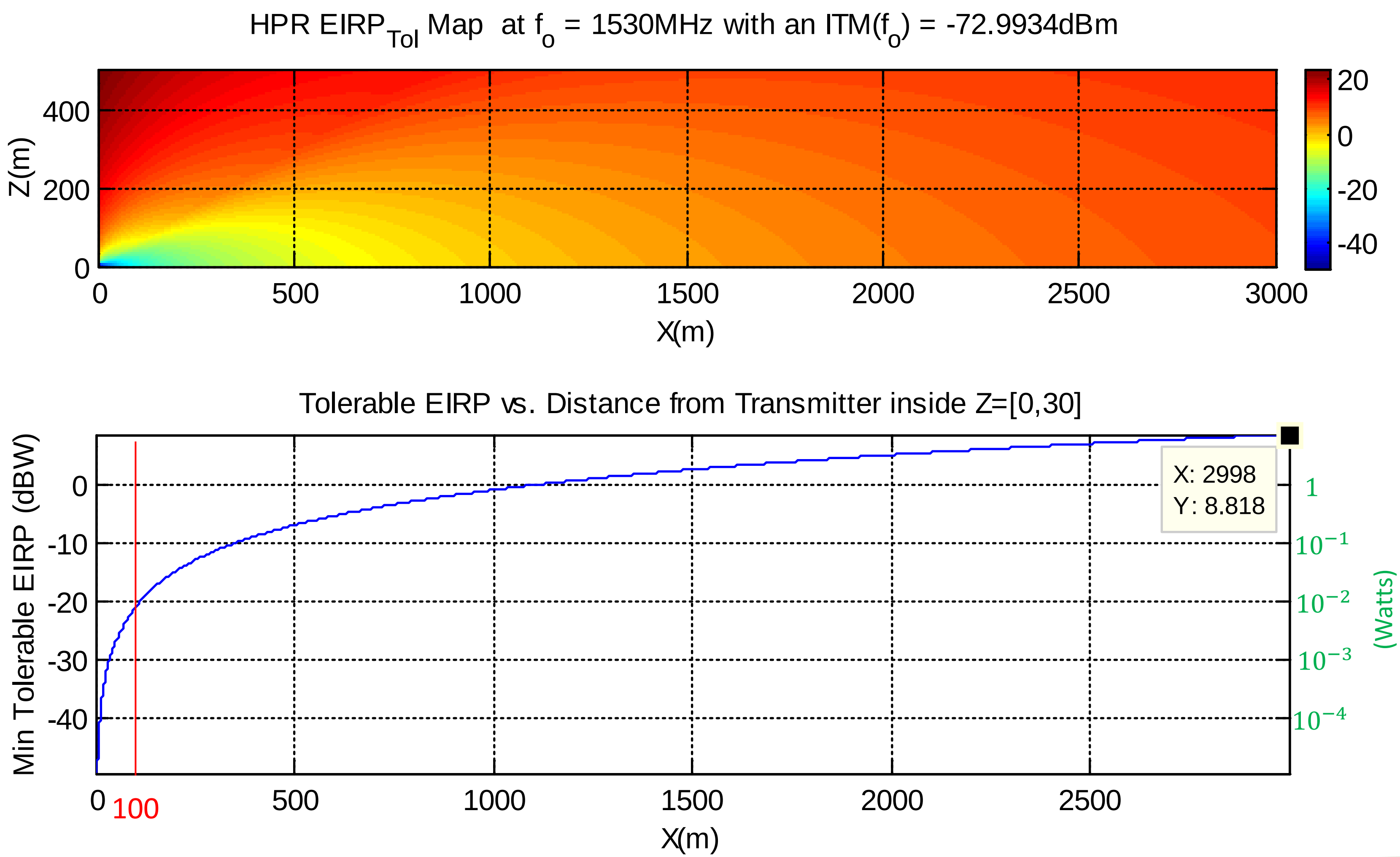
- Extent of the impact region: 900m to 1 km from transmitter for EIRP of 10 dBW





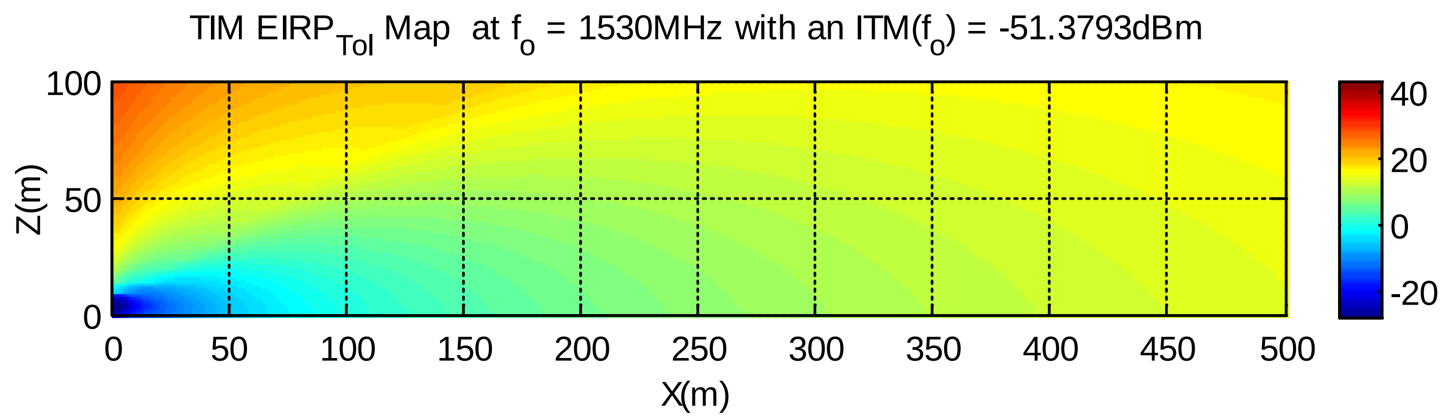
Inverse Modeling: HPR, 1530 MHz

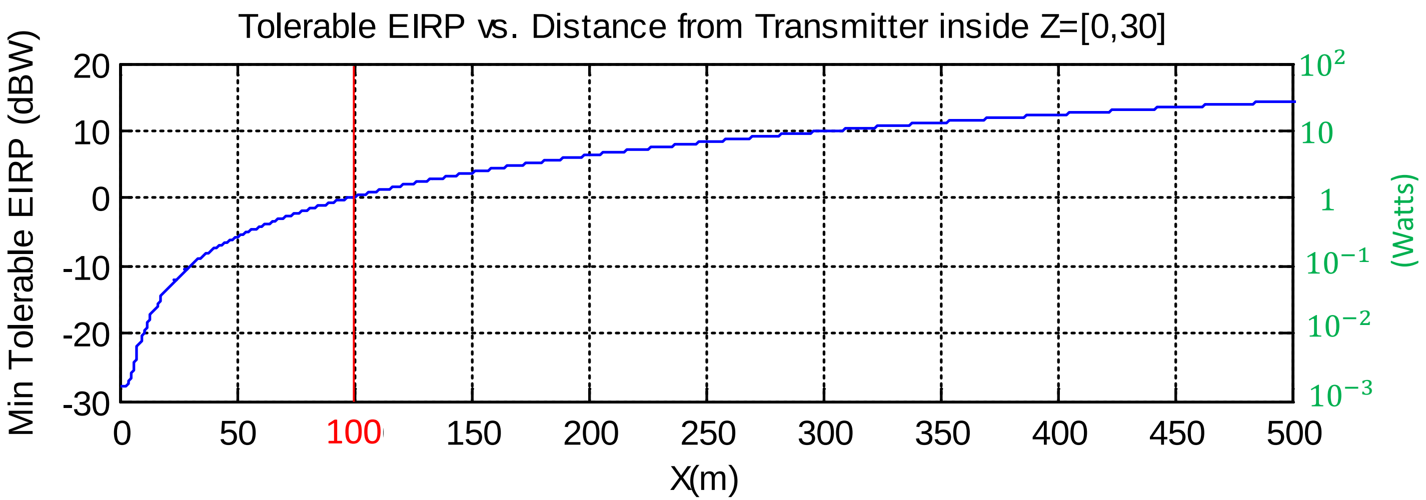
- Extent of the impact region: > 3km from Transmitter for EIRP of 10 dBW



Inverse Modeling: TIM, 1530 MHz

- Extent of the impact region: 300 m from Transmitter for EIRP of 10 dBW





Summary Inverse Modeling Results (Single Base Station) in dBW

1475 MHz

Deployment	Stand off distance (m)	Max Tolerable EIRP (dBW)			
		GLN	HPR	TIM	CEL
Macro Urban	10	-14.4	-24.0	14.6	N/A*
	100	5.6	-4.0	34.6	N/A*
Micro Urban	10	-13.5	-23.0	14.8	N/A*
	100	6.5	-3.0	34.8	N/A*

1530 MHz

Deployment	Stand off distance (m)	Max Tolerable EIRP (dBW)			
		GLN	HPR	TIM	CEL
Macro Urban	10	-31.0	-41.9	-20.6	10.9
	100	-11.0	-21.9	-0.6	31
Micro Urban	10	-29.8	-41.2	-20.1	10.7
	100	-9.8	-21.1	-0.1	30.8

*N/A = not applicable; no degradation at maximum power at WSMR.

Summary Inverse Modeling Results (Single Base Station) in Linear Form

1475 MHz

Deployment	Stand off distance (m)	Max Tolerable EIRP			
		GLN	HPR	TIM	CEL
Macro Urban	10	36.3 mW	4 mW	28.8 W	N/A*
	100	3.6 W	0.4 W	2.9 kW	N/A*
Micro Urban	10	44.7 mW	5 mW	30.2 W	N/A*
	100	4.5 W	0.5 W	3 kW	N/A*

1530 MHz

Deployment	Stand off distance (m)	Max Tolerable EIRP			
		GLN	HPR	TIM	CEL
Macro Urban	10	0.8 mW	64 μW	8.7 mW	12.3 W
	100	79.4 mW	6.5 mW	0.9 W	1.26 kW
Micro Urban	10	1 mW	76 μW	9.8 mW	11.7 W
	100	104 mW	7.8 mW	1 W	1.2 kW

*N/A = not applicable; no degradation at maximum power at WSMR.

Inverse Modeling Results:
Base Station Network

Aggregation Effect

- The analysis so far considered the impact of a single transmitter on the degradation of the L1 C/A signal received by GNSS receivers

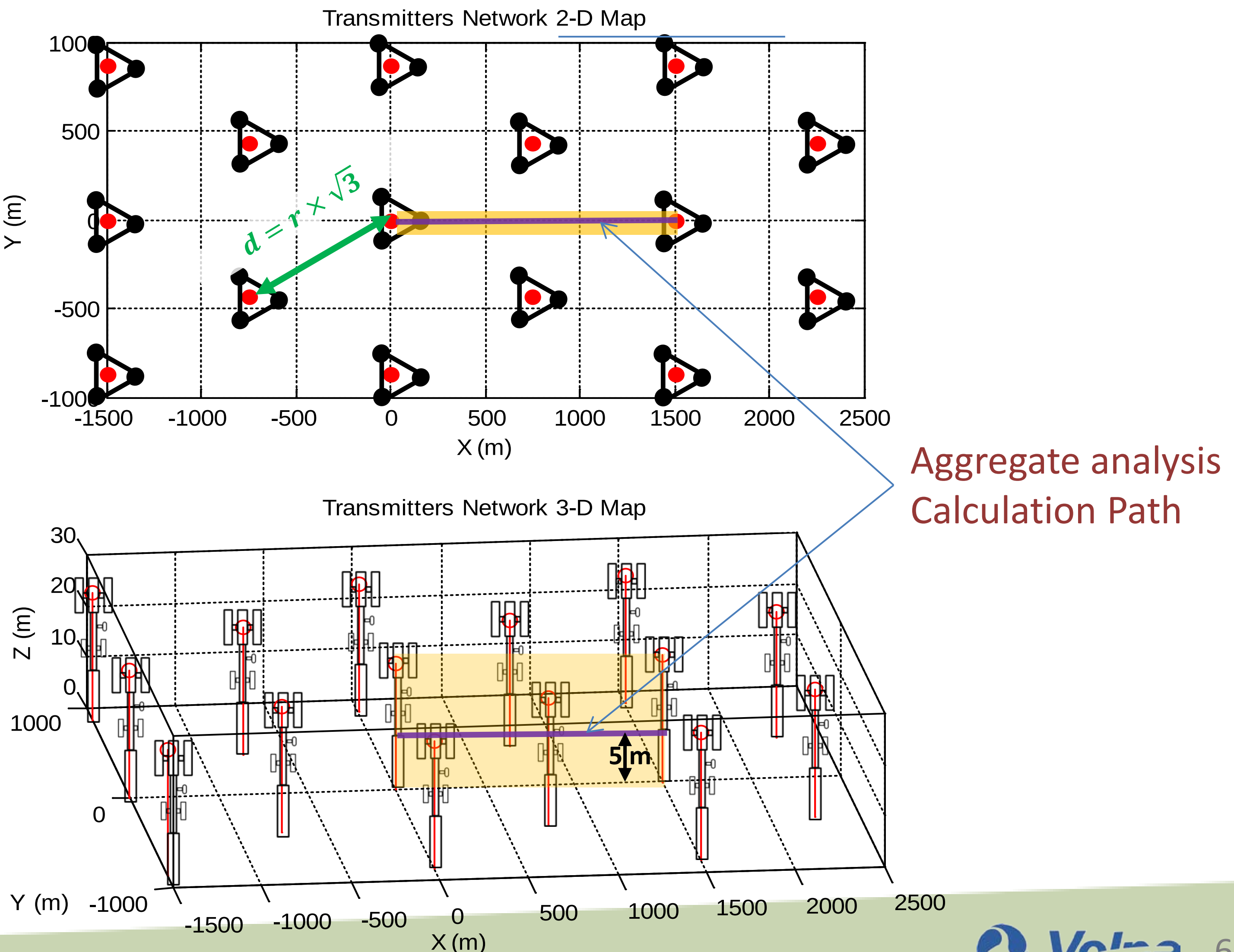
- The following analysis will look at the aggregate effect of a macro urban IMT network deployment with a transmitter at the center of each cell by receiver category
  - Performed for a user at 5 m above ground level (20 m below the base station transmitter)
  - Network parameters are: Cell radius $A = 2.r = 500m^{*}$, resulting in an tower interspacing distance of $\mathrm{d} = \sqrt{3}.r = \sqrt{3} \times 250 = 433\ m$

[*] See ITU-R M.2292 TABLE-3 typical cell radius to be used in sharing studies

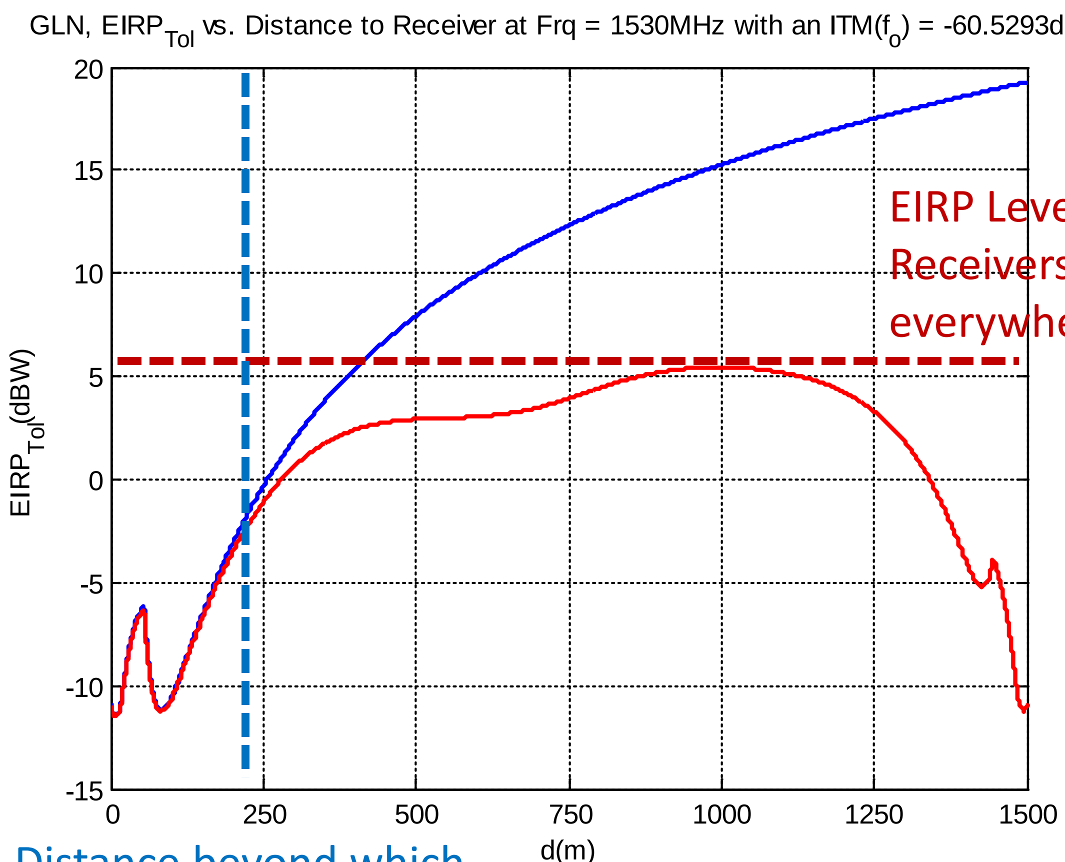
IMT Network Layout

Plan View

3D-View



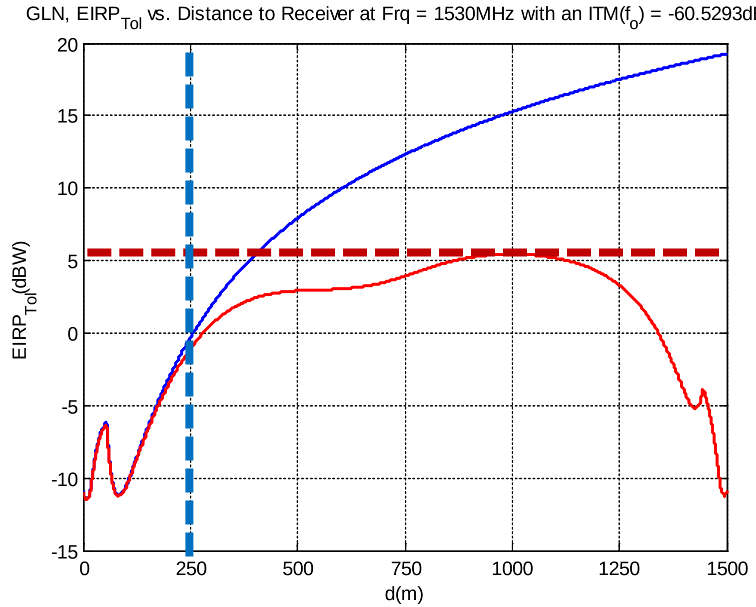
Single Transmitter vs. Network Results for GLN Category

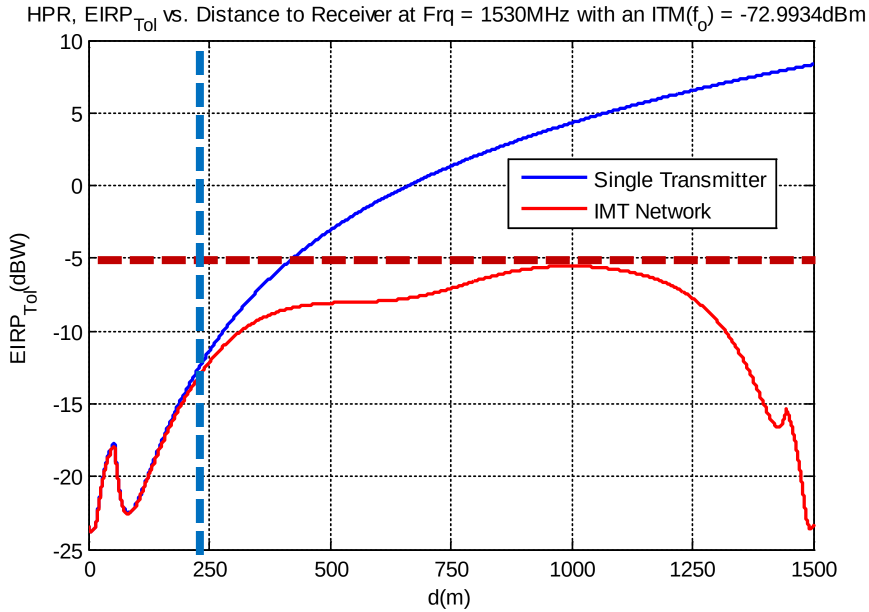


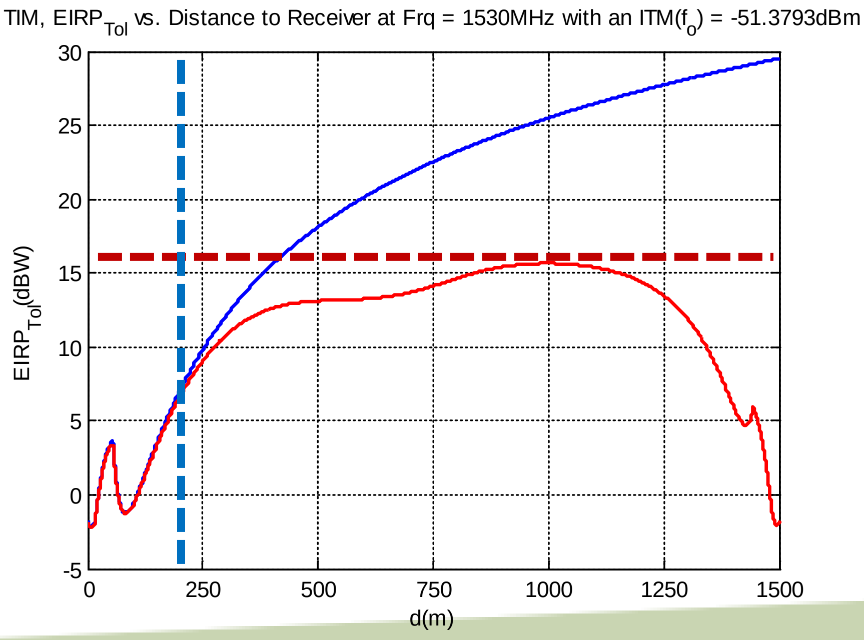
EIRP Level where GLN Receivers are impacted everywhere inside a network

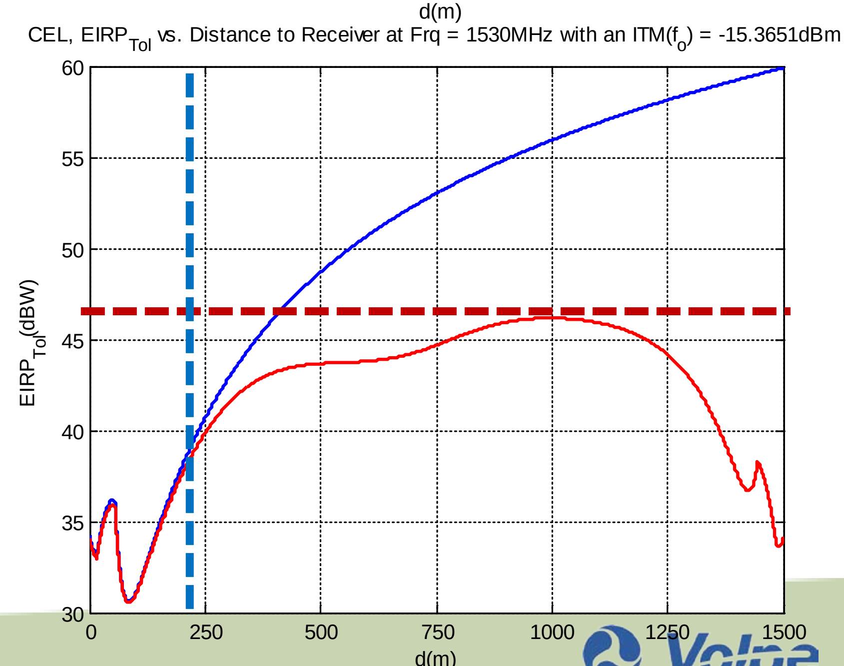
Distance beyond which Network Effects become significant

Single vs. Aggregate Modeling Results for 1530 MHz







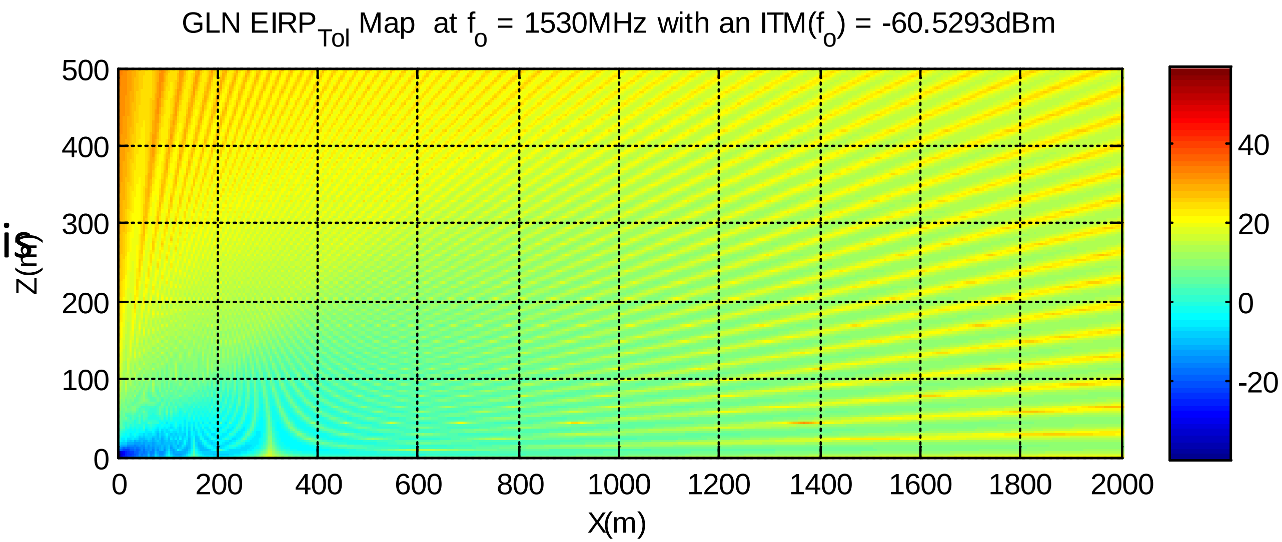


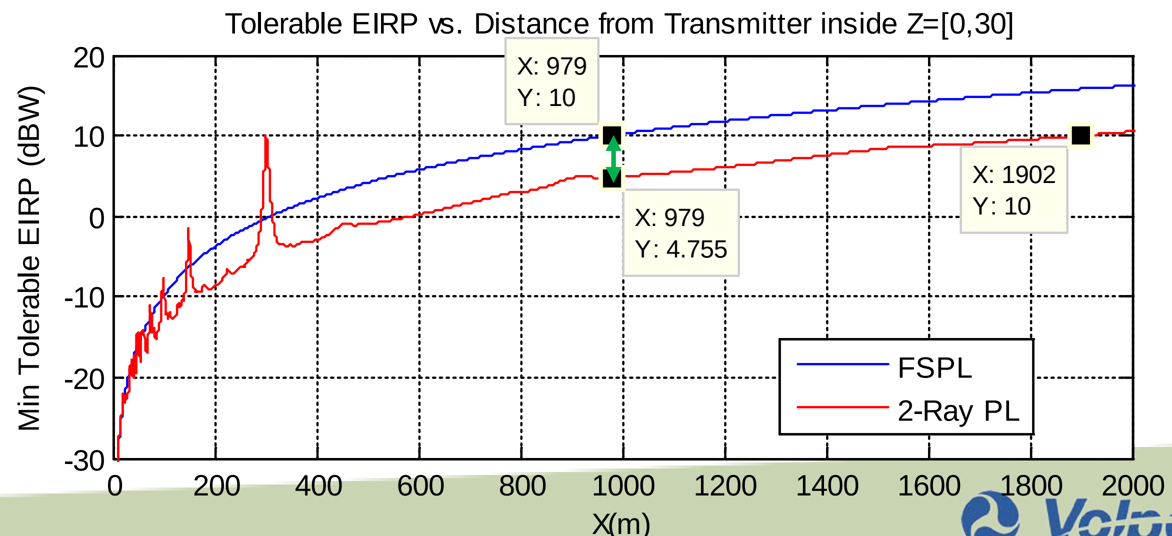
Sensitivity to Propagation Models

FSPL vs. 2-Ray PL

Sensitivity to Propagation models, GLN Case, Micro Urban

- 2-Ray PL reduces the maximum tolerable EIRP when protection is considered over a reasonable range of heights





Summary

- Models to determine tolerable transmit power levels have been developed
  - These models incorporate transmitter and polarization dependent receivers gain patterns
  - These models are capable of looking at different network characteristics and deployment types such as the ITU-R M.2292

- Results with two deployment types and using L1 C/A ITMs were presented
  - Single Macro Urban base station at 29 dBW resulted in standoff distances > 2 km for 1475 MHz and > 14 km for 1530 MHz
  - Single Micro Urban base station at 10 dBW resulted in standoff distances > 400 m for 1475 MHz and > 3 km for 1530 MHz
  - Single Handset at -7 dBW resulted in standoff distances > 140 m for 1630 MHz

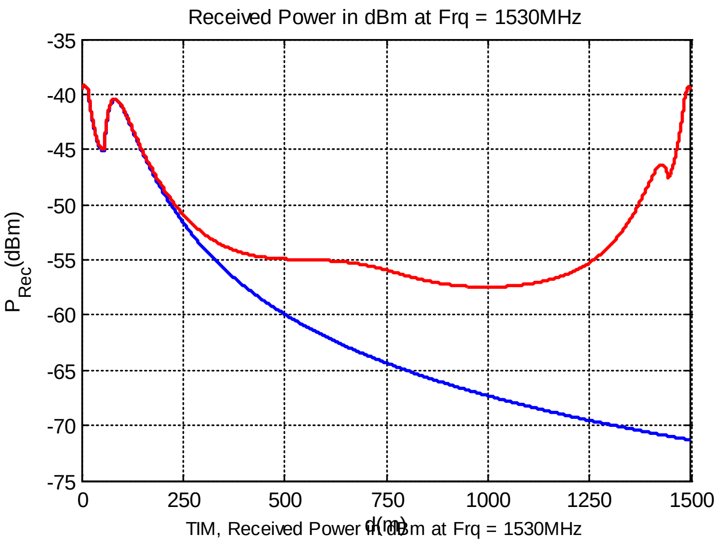
- Inverse modeling yields tolerable EIRP levels for given standoff distance. Key results are:
  - At 1475 MHz, the tolerable EIRP values for standoff distances of 10 m and 100 m are -24 dBW and -4 dBW respectively
  - At 1530 MHz, the tolerable EIRP values for standoff distances of 10 m and 100 m are -42 dBW and -22 dBW respectively
  - Results are similar for the single base station corresponding to either deployment type as expected

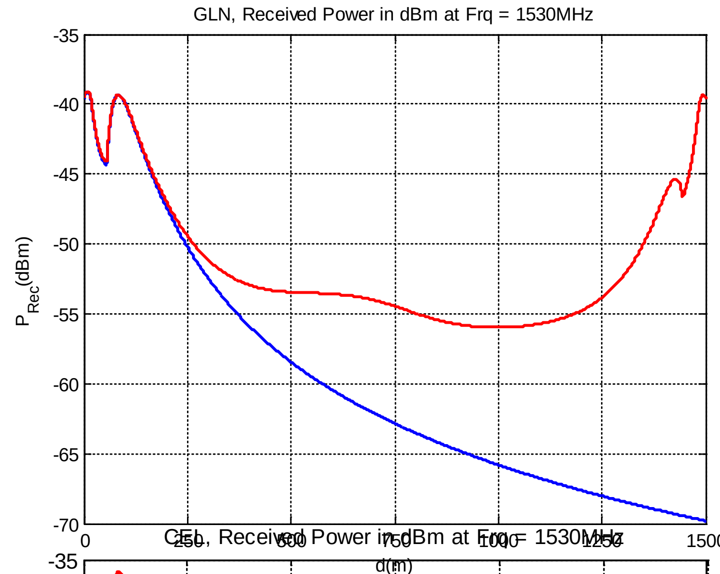
- Aggregation effects and 2-Ray propagation effects were shown to further reduce the tolerable EIRP levels

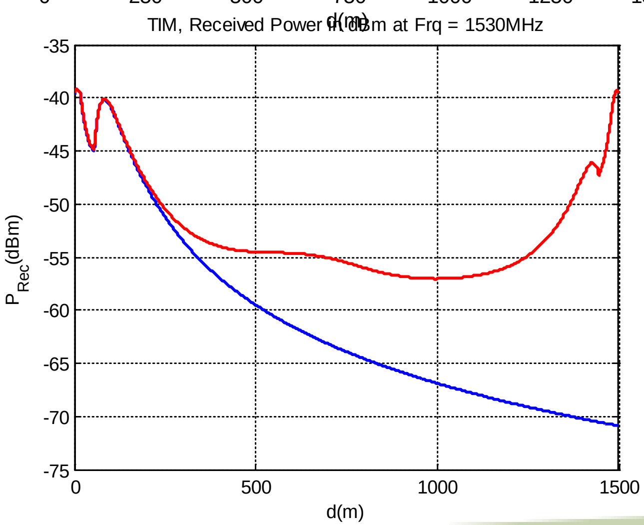
- This analysis will be applied to the remaining tested frequencies and the other GNSS signals with sensitivity analysis to additional propagation models (such as the Irregular Terrain Model)

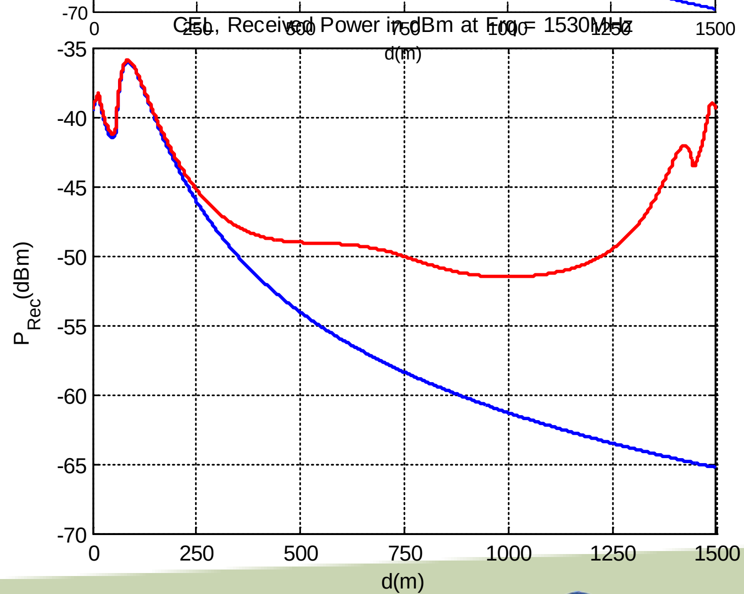
Backup Slides

Received Power: User Height 5 m, Macro Urban, EIRP = 10dBW









Volpe