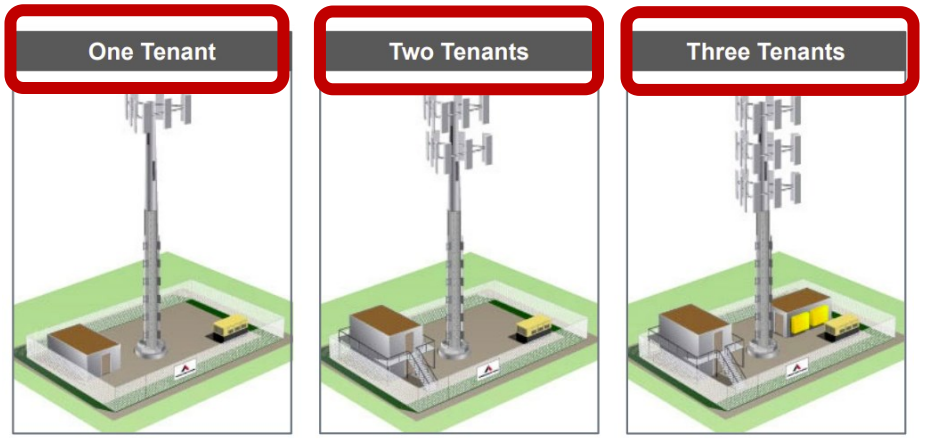
"Techno-economical study of the antenna system weight, wind load and space occupancy in view of the mobile network transition to the 5G era and beyond"

Dimitris Kolokotronis

FASMETRICS SA

Hosting Multiple Tenants (Colocations) Produce Profits! But…

- *The amount of Active equipment that a Tower accommodates defines the Revenue Peak & consequently the Returns on Investment (RoI) for the Tower owner shareholders (max hosting annual income per Tower).*
- *RoI for increased Tower tenancy ratios (x2, x3) is maximum when assuming that both Tower construction and upgrade costs are minimum AND tenant lease rates are maximum.*
- *Tower construction and upgrade costs depend on Tower capacity (in terms of static, space and EMF adequacy) meaning that when Tower capacity nulls… revenues peak or further investments needed!*



	One Tenant	Two Tenants(2)	Three Tenants(2)
Construction / Upgrade Costs ($ in USD)	$275,000	—	—
Tenant Revenue	$20,000	$50,000	$80,000
Operating Expenses (including ground rent, utility, monitor)	$12,000	$13,000	$14,000
Gross Margin	$8,000	$37,000	$66,000
Gross Margin (%)	40%	74%	83%
Gross Margin Conversion Rate (%)	–	97%	97%
Return on Investment (3)	**3%**	**13%**	**24%**

Introduction to the Tower Industry and American Tower
https://www.amminvest.com/wp-content/uploads/2020/11/AMT-American-Tower-Investor-Presentations-08.06.20.pdf

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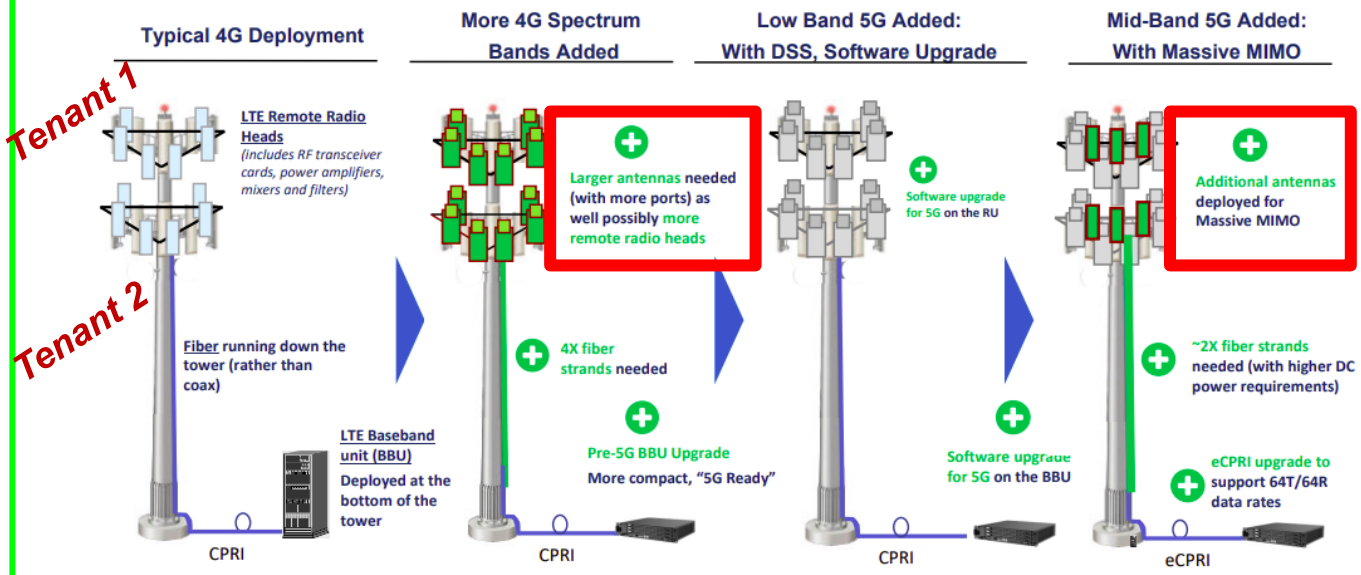
Networks Continue to Evolve as We Drive Toward 5G

Equipment configuration is progressing, with additional antennas, fiber and software upgrades



The Trend is *More* Equipment Being Placed on Towers

Notes: CPRI = Common Public Radio Interface, eCPRI = Enhanced Common Public Radio Interface

Source: American Tower Research and Altman Solon Research & Analysis

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Tower Tenants tend to add more Weight, Wind Load & EMF on the Tower

Does the Tower have the capacity to withstand the additional loading?

Could a 3rd Tenant be hosted and skyrocket RoI?

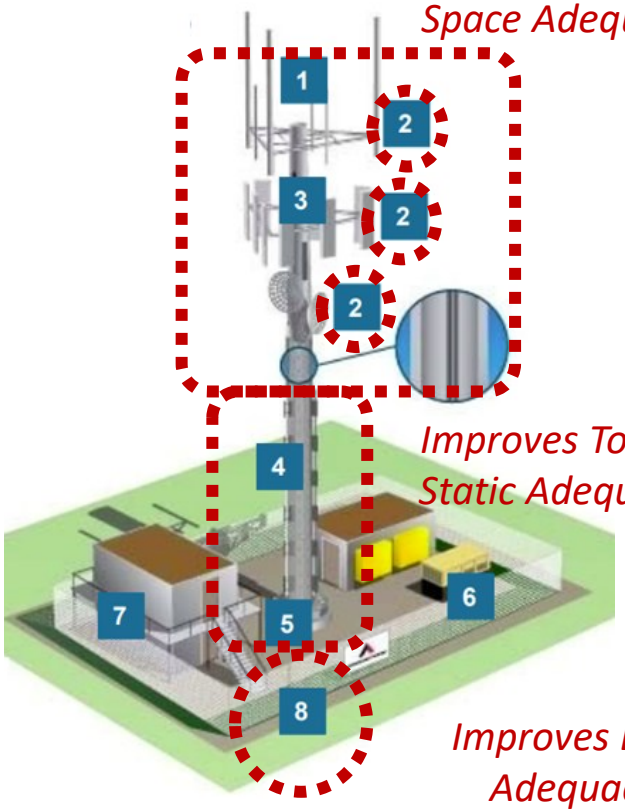
Accommodating More Tenants on Tower:

When towers reach their capacity, there are multiple options to accommodate future tenants

Redevelopment CAPEX Examples

1. **Height Extension**
   - Allows for more equipment and more tenants
2. **Multiple Antenna Mounting Scenarios**
   - Options include whips, panels, microwaves and various combinations determined by internal RF engineering
3. **Port Hole Additions**
   - Additional entry and exit port designs accommodate additional coaxial cables
4. **Tower Reinforcements**
   - Adds structural strength to accommodate additional tenants
5. **Strengthened Foundation**
   - Increases load capacity of the tower
6. **Backup Power Generator**
   - Provided by American Tower, maximizes compound space
7. **Stacked Shelters**
   - Shelter stacked atop an existing shelter using a steel platform
8. **Extended Ground Space**
   - Where space allows, expanded to accommodate more equipment

Improves Tower Space Adequacy



Improves Tower Static Adequacy

Improves EMF Adequacy

Introduction to the Tower Industry and American Tower
https://www.amminvest.com/wp-content/uploads/2020/11/AMT-American-Tower-Investor-Presentations-08.06.20.pdf

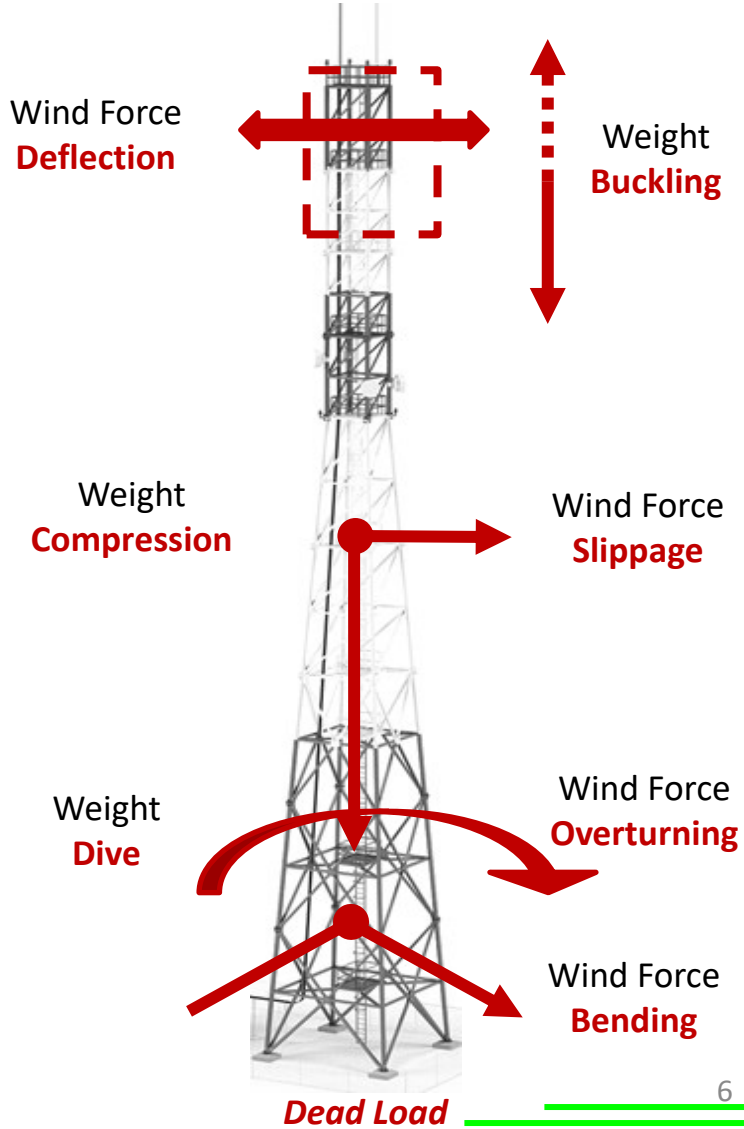
Tower Static Adequacy Limit

Briefly

Tower Static Adequacy Limit (Hosting beyond Standard Configuration)

Tower Company peaks hosting revenues from a Tower vertical space when Tower static adequacy nulls.

Tower Companies need to ensure (by specialized studies[1]) that when adding equipment on Tower, the structure is within its static capacity limit. Tower static adequacy depends on weight and wind load of equipment (antennas & RRUs) and their actual position (height) on Tower.



[1] *Tower static capacity limits are calculated for Tower failure scenarios (such as overturning, slipping, diving, bending and buckling, among others). Any tower structure bears its dead load plus additional loads (such as active equipment loads, mounting loads, cable loads, cable tray loads and generally any load that does not contribute as a structural part of the Tower). Tower static studies verify the ability of a tower structure to bear the additional loads without failing under extreme environmental conditions (such as earthquakes and wind forces). Obviously, tower static capacity is limited to a certain amount of additional loading.*

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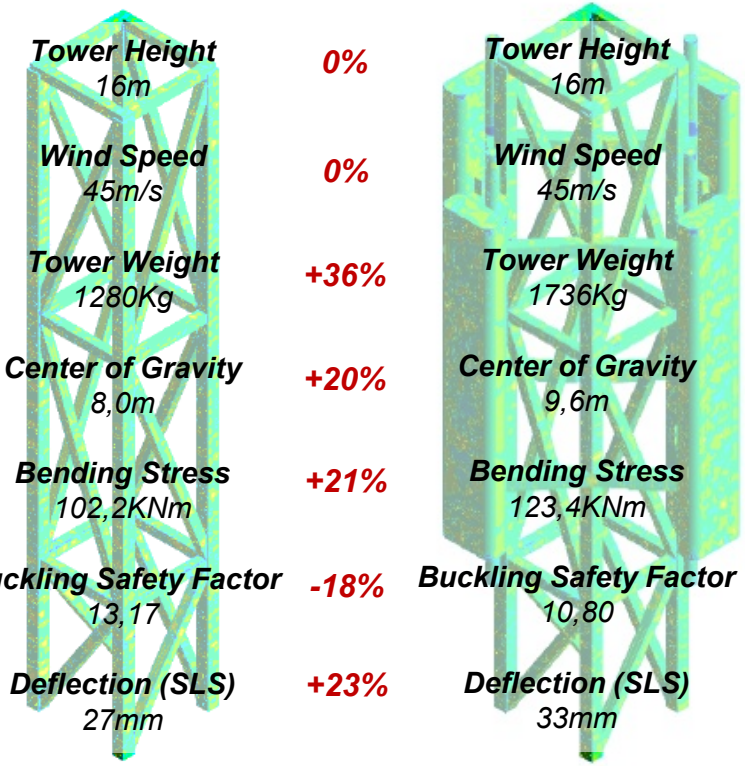
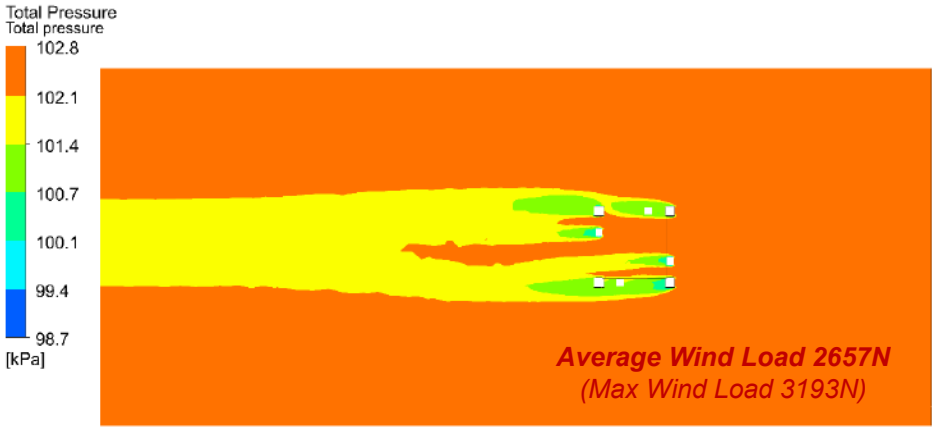
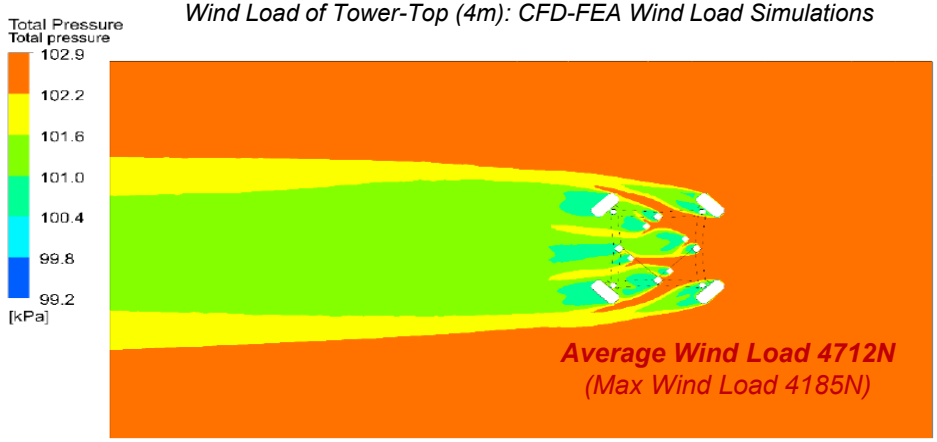
Active Equipment Buckling, Bending & SLS Stress Contribution on Tower



Tower Height 16m	0%	**Tower Height** 16m
Wind Speed 45m/s	0%	**Wind Speed** 45m/s
Tower Weight 1280Kg	+36%	**Tower Weight** 1736Kg
Center of Gravity 8,0m	+20%	**Center of Gravity** 9,6m
Bending Stress 102,2KNm	+21%	**Bending Stress** 123,4KNm
Buckling Safety Factor 13,17	-18%	**Buckling Safety Factor** 10,80
Deflection (SLS) 27mm	+23%	**Deflection (SLS)** 33mm



Wind Load of Tower-Top (4m): CFD-FEA Wind Load Simulations



If the tower's designed Safety Margin supports the additional loading, the tower is static adequate!

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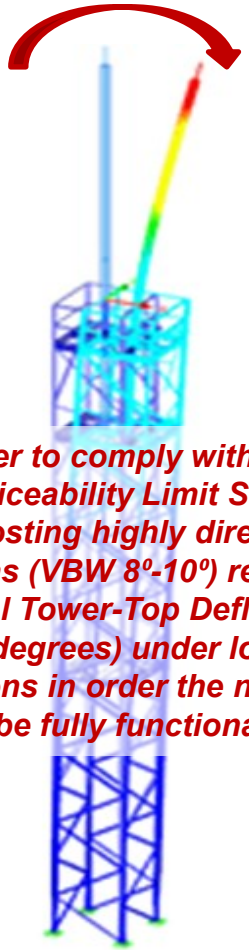
Examples of Buckling, Bending and Deflection (the most common) failures…

Buckling

(weight and/or wind load exceeded the Tower's Safety Margin)

Bending

(weight and/or wind load exceeded the Tower's Safety Margin)



Tower's
SLS

A tower to comply with SLS (Serviceability Limit State) when hosting highly directional antennas (VBW 8º-10º) requires minimal Tower-Top Deflection (a few degrees) under loading conditions in order the network to be fully functional!

Deflection

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Tower Reinforcement: *An option to increase the Tower Static Limit*

Tower Space Adequacy

Briefly

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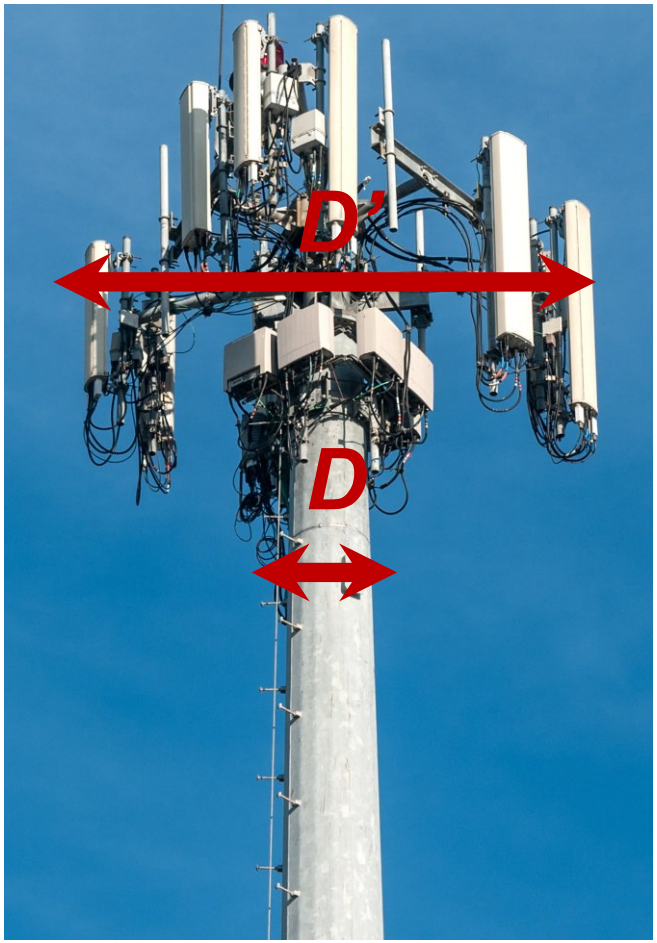
Tower-Top Perimeter Extension: *An option to increase the Tower Space Limit*

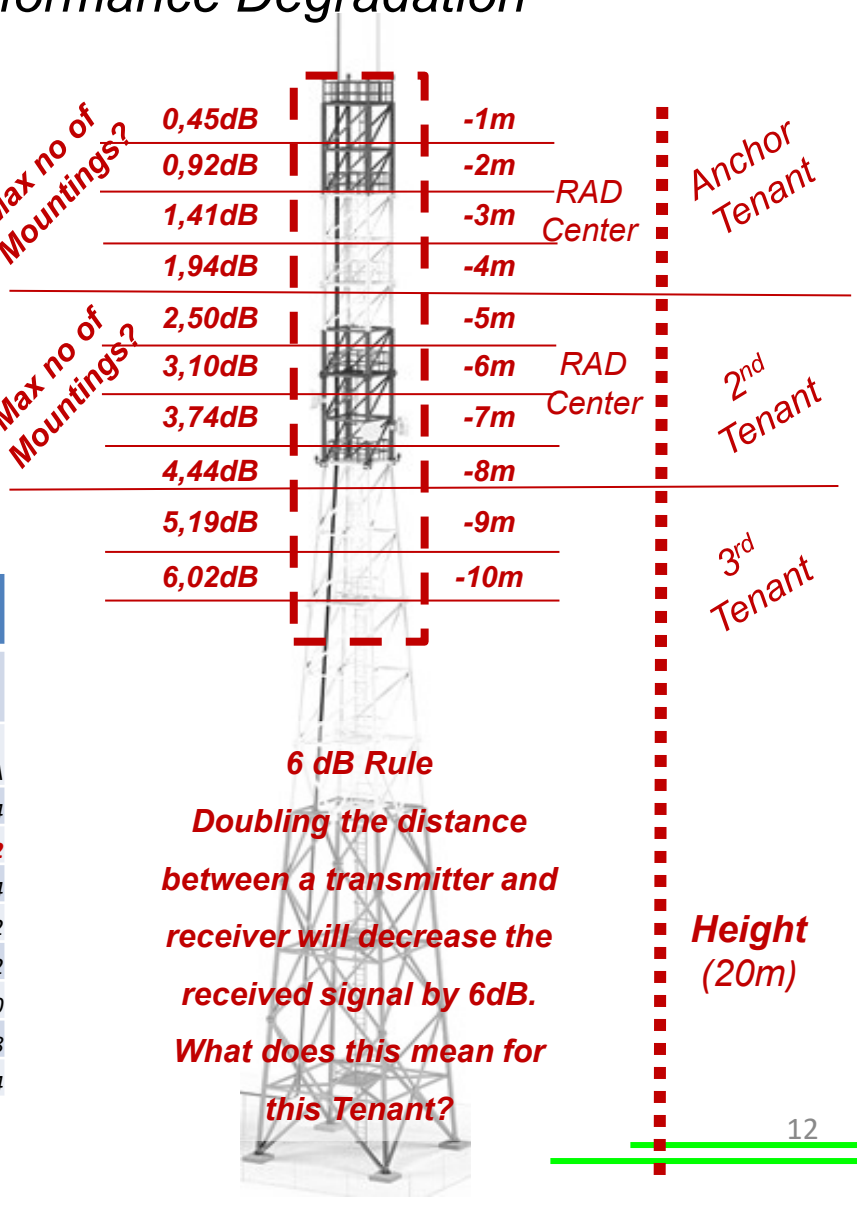


Tower-Top Perimeter Limit: *Performance Degradation due to Positioning!*

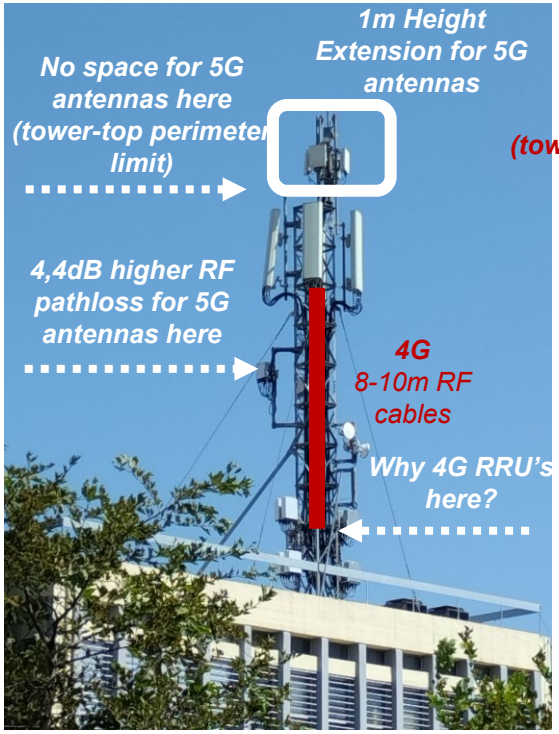
Tower-Top perimeter limitation at a designated tower height is defined by the number of mounting poles / antennas (1:1) can be installed around it. Site sectorization, heading towards the target coverage area while keeping the antenna's main radiation bore free of obstacles are the main site configuration tenant requests that limit the tower-top from equipment upgrades (space capacity limitation).

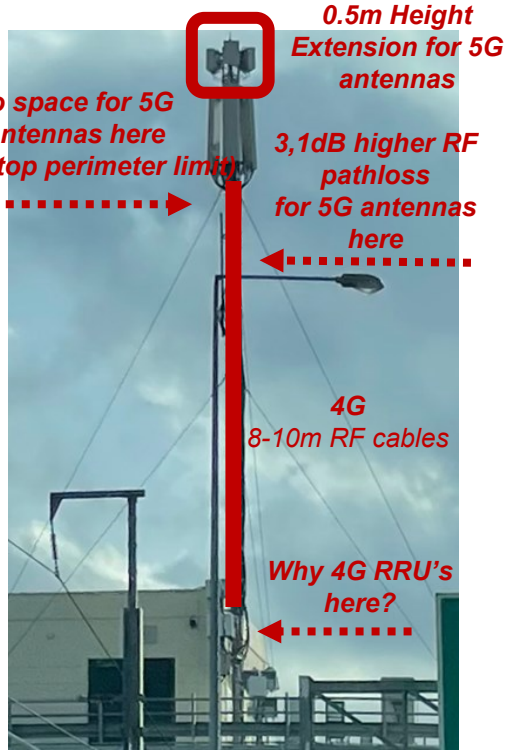
$$\Delta PL(dB) = -20\log\left(1 + \frac{\Delta h_b}{h_b}\right)$$

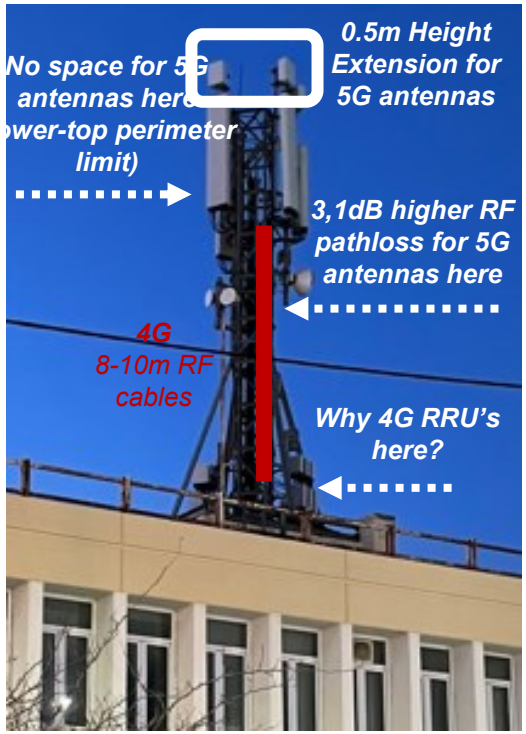
RF Pathloss (dB)	Antenna Height Reduction (m):									
Tower Height (m):	1	2	3	4	5	6	7	8	9	10
10	0,92	1,94	3,10	4,44	6,02	7,96	10,46	13,98	20,00	N/A
15	0,60	1,24	1,94	2,69	3,52	4,44	5,46	6,62	7,96	9,54
20	**0,45**	**0,92**	**1,41**	**1,94**	**2,50**	**3,10**	**3,74**	**4,44**	**5,19**	**6,02**
25	0,35	0,72	1,11	1,51	1,94	2,38	2,85	3,35	3,88	4,44
30	0,29	0,60	0,92	1,24	1,58	1,94	2,31	2,69	3,10	3,52
35	0,25	0,51	0,78	1,05	1,34	1,63	1,94	2,25	2,58	2,92
40	0,22	0,45	0,68	0,92	1,16	1,41	1,67	1,94	2,21	2,50
45	0,20	0,39	0,60	0,81	1,02	1,24	1,47	1,70	1,94	2,18
50	0,18	0,35	0,54	0,72	0,92	1,11	1,31	1,51	1,72	1,94



Tower Height Extension: *An option to increase the Tower Space Limit*





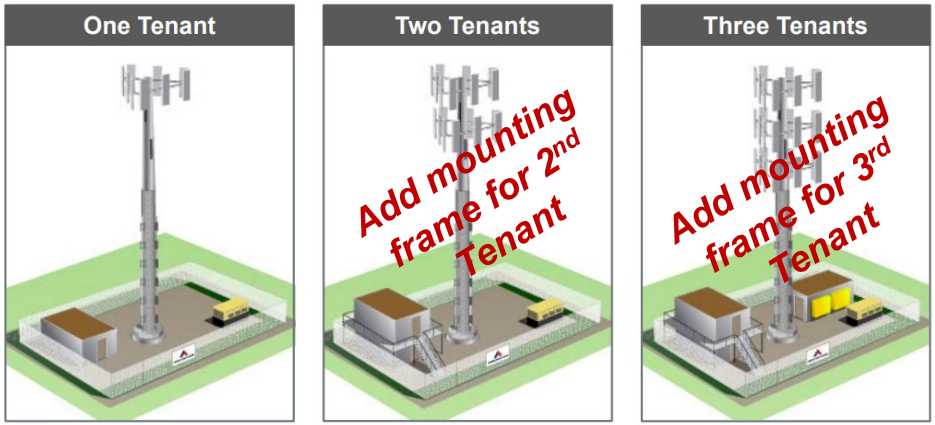


Obviously, tower capacity is limited to a certain amount of additional loading (weight or wind)...

Adding active equipment on Tower is not a free ride!

Too optimistic… *when true, the upgrade costs are the mounting frames*

6 dB Rule



	One Tenant	Two Tenants[2]	Three Tenants[2]
Construction / Upgrade Costs ($ in USD)	$275,000	≠0€	?
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Operating Expenses (including ground rent, utility, monitor)	$12,000	$13,000	$14,000
Gross Margin	$8,000	$37,000	$66,000
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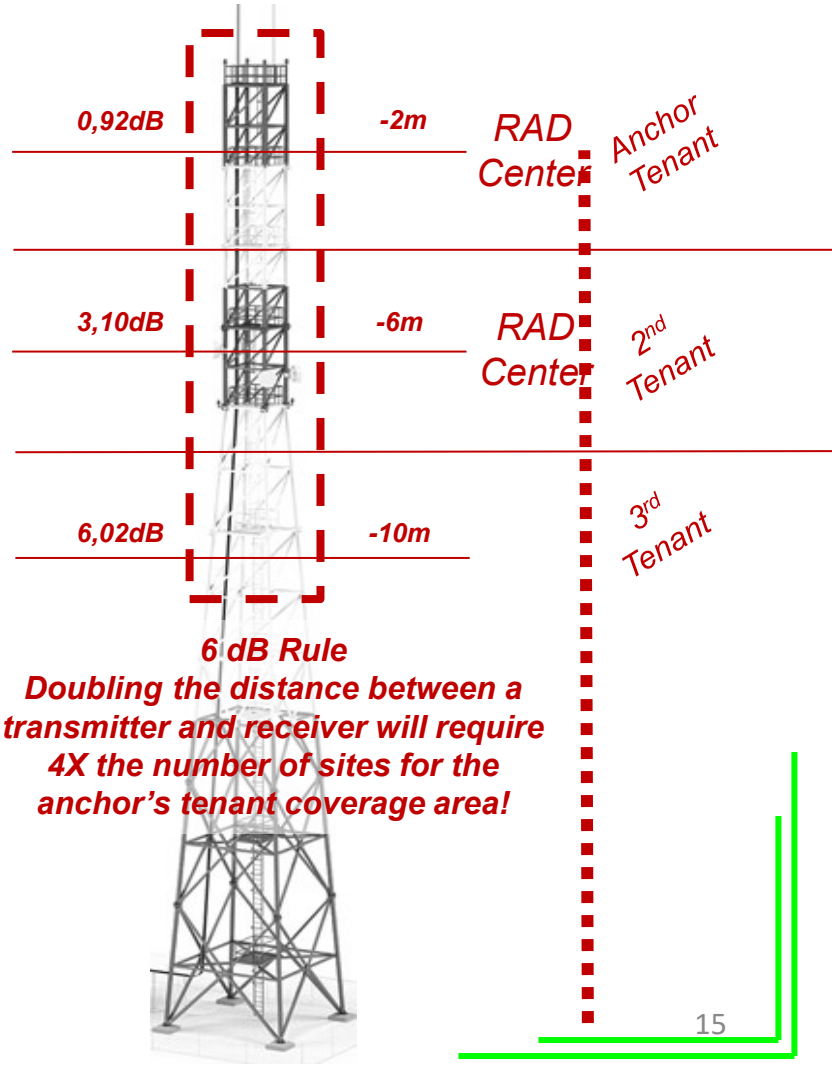

6 dB Rule
Doubling the distance between a transmitter and receiver will require 4X the number of sites for the anchor's tenant coverage area!

Commscope's Antenna Mounting Frame (12 & 18 Pipes) Monopole Price

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CommScope

14'6" Monopole Platform w/ (12) 2-3/8" x 96" Pipes

GSA TESSCO SKU: 552731 UPC: 552731 QTY/UOM: 1/each MFG PART #: MC-HP14L-12-96

ⓘ Sign In or Register for preferred pricing!

$17,726.19

– 1 +

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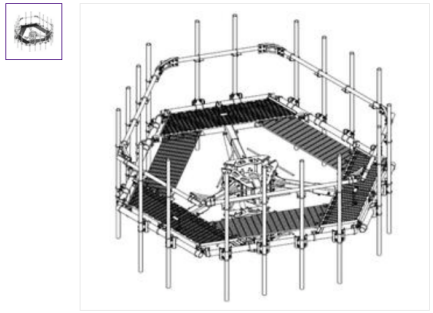


CommScope

6-Sector Monopole Co-location Platform kit

NCNR TESSCO SKU: 260442 UPC: 260442 QTY/UOM: 1/each MFG PART #: MTC3984

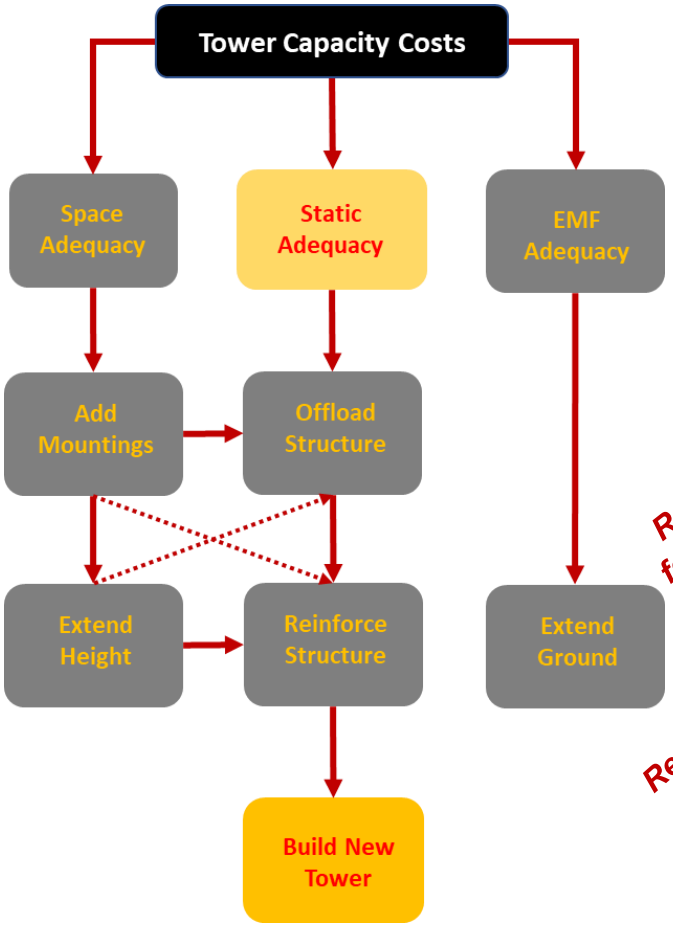
ⓘ Sign In or Register for preferred pricing!

$21,442.32

– 1 + Add To Cart

COMMSCOPE's MTC3984 six-sector monopole co-location platform kit, 12 in – 50 in OD, three (3) 8 ft faces, three (3) 6 ft faces, and includes eighteen (18) 96 in pipes.

An attempt to structure additional equipment Upgrade Costs…



5 main cost elements to increase tenancy ratio if tower capacity nulls:

1. ***Mounting additions (2.000€ - 20.000€)***
   - *I. Mounting Frames (high height towers)*
   - *II. Mounting Brackets (low height towers)*

2. ***Height extensions (1.000€ - 10.000€)***
   - *I. Mounting addition above max tower height*

3. ***Tower Offloading (1 or 2 + Tenant Costs)***
   - *I. Mounting addition above or below max tower height*
     - *I. Active equipment mis-positioning*
       - *I. Power consumption*
       - *II. Network performance*
       - *III. Other Costs*

Revenue Loss for Tower Tenant X€/year

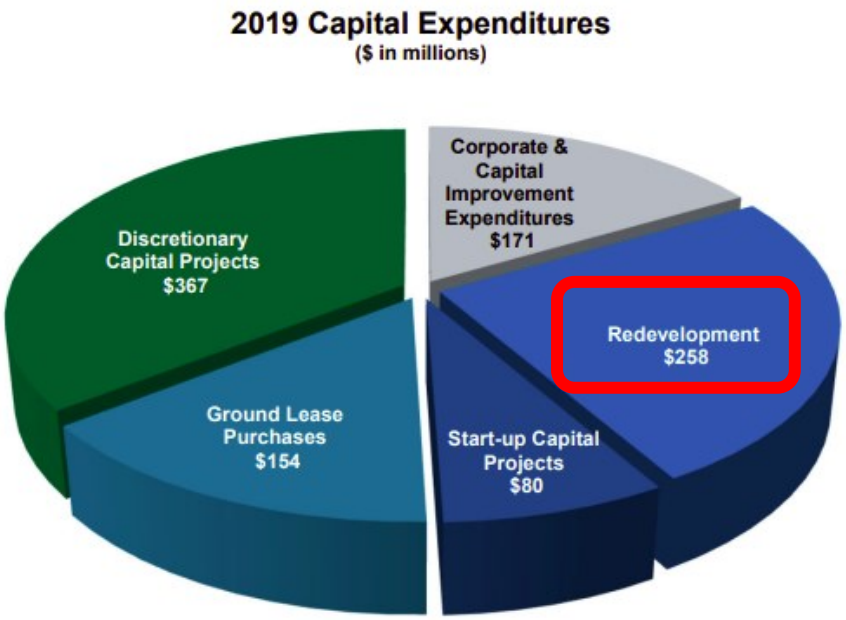
Avoid reinforcement or new tower build

4. ***Tower reinforcement (10.000€ - 70.000€)***

Revenue Loss for Tower Company 30.000€/year

5. ***New tower build (275.000€)***

Tower Upgrade Costs? *American Towers Redevelopment CAPEX 2019*



22% of Annual CAPEX

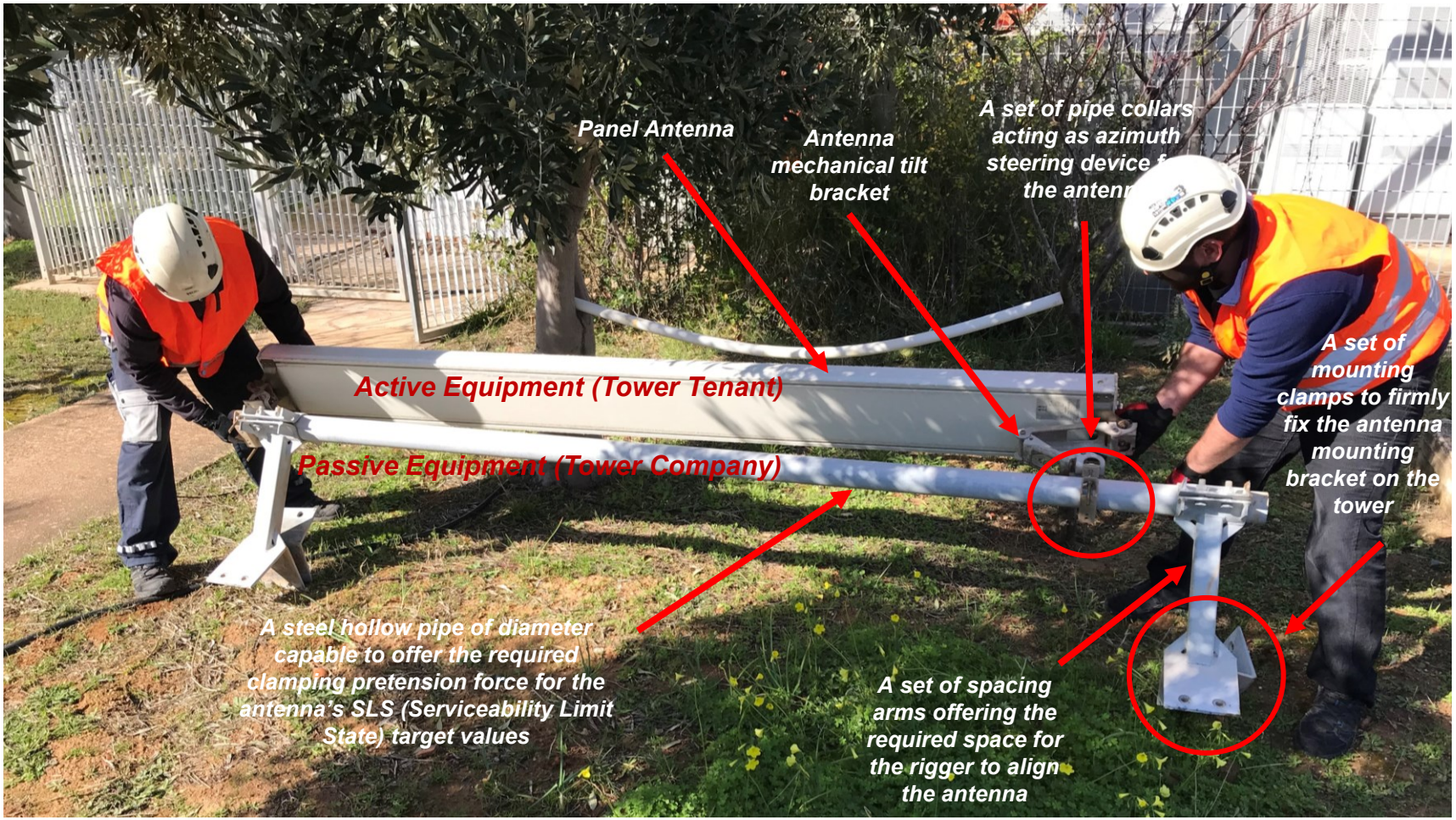
How Tower Companies can reduce costs on tower upgrades when increasing tower static adequacy and space capacity by drastically reducing (or eliminating):

1. *The need for height extensions*
2. *The need for tower reinforcements*
3. *The need for additional mountings*

…while at the same time satisfy their Tenants operational efficiency and reducing the related active equipment operational and capital expenses by:

1. *Minimizing power consumption*
2. *Improving network performance*
3. *Avoiding unnecessary costs (i.e. cabling)*

Exemplary Antenna System (Antenna + Mounting) on the Tower-Top



Please note that antenna mounting bracket mechanical specifications (pole, spacer arms and tower clamps) are defined by the antenna dimensions and weight it intends to carry. Antenna SLS (Serviceability Limit State) under wind loading conditions need to be ensured by both the Tower structure and the mounting brackets.

[1] SLS criteria are defined on TIA222 standard among others

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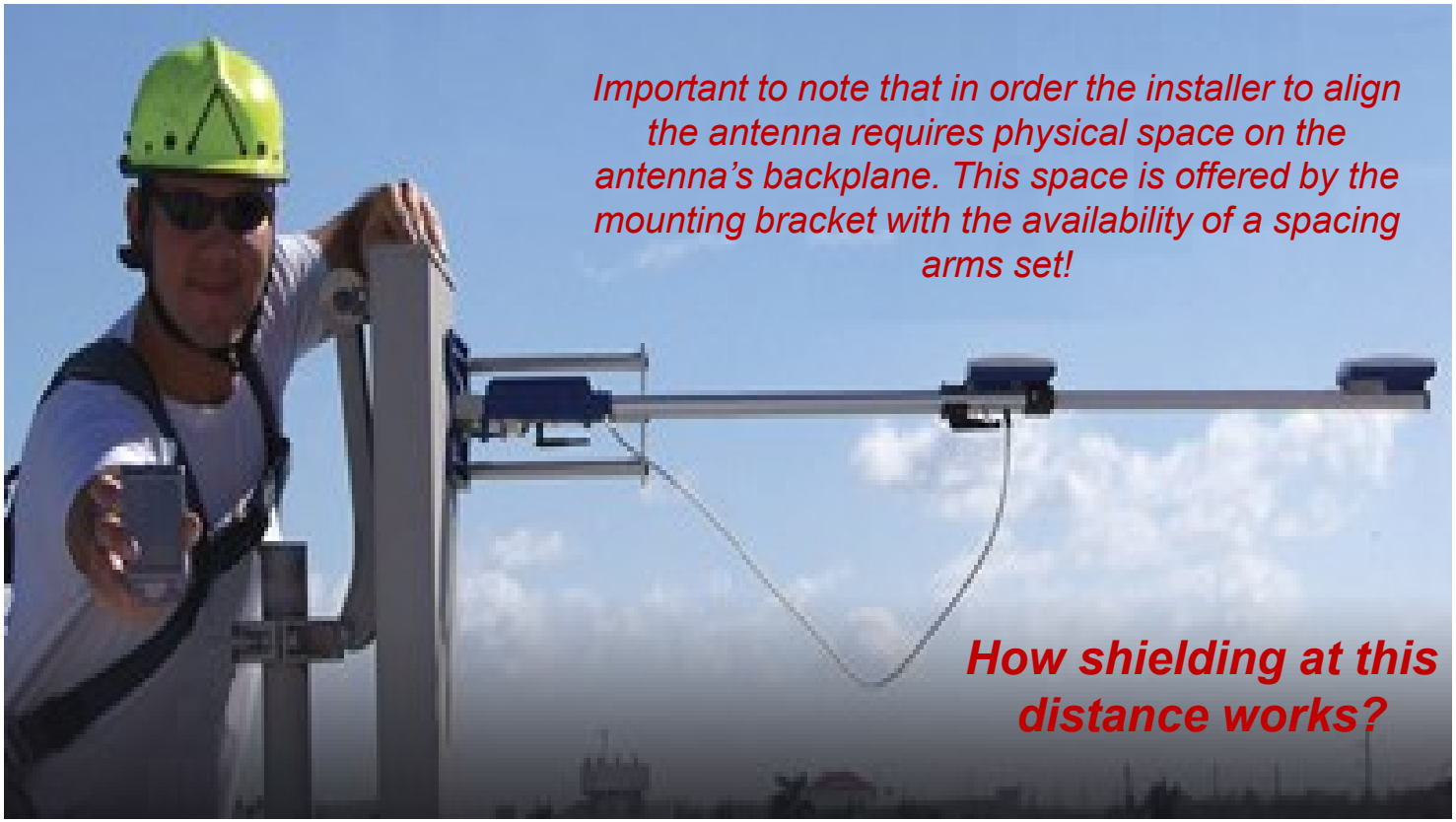
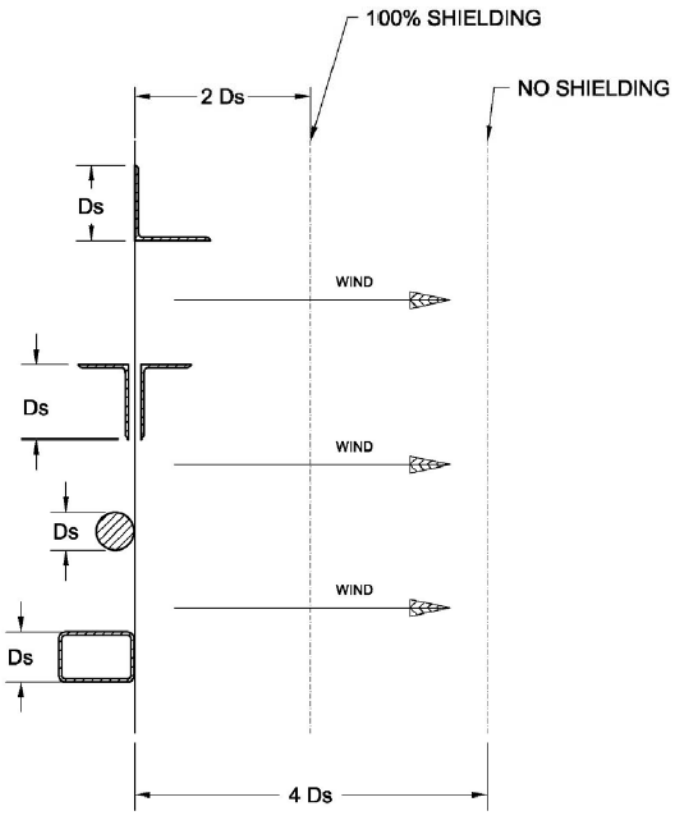
Antenna Alignment: *Targeting Directional Antennas on the Azimuth Plane*



Please note that spacing arms set on an antenna mounting bracket are usually provide a 500mm offset from the Tower structure. Such offset allow the antenna riggers to align and fix in position the antennas using appropriate alignment tools.

[1] Dual GPS alignment tools offer ≤±2° measurement uncertainty

Importance of Shielding on Tower! *– acc. to TIA 222-G (§2.6.9.4)*



Full shielding may be considered when the clear distance between the elements in the wind direction under consideration for determining effective projected areas (EPA) is less than or equal to 2.0 times the smallest projected dimension of the element in the wind direction under consideration.

No shielding shall be considered for clear distance ratios greater than 4.0. Linear interpolation shall be allowed for ratios between 2.0 and 4.0. Refer to Figure on the left. Shielding from an appurtenance shall not be considered when a value of Ka less than 1.0 per 2.6.9.2 is used to determine the design wind force on the appurtenance.

Note: Shielding considerations will vary with wind direction.

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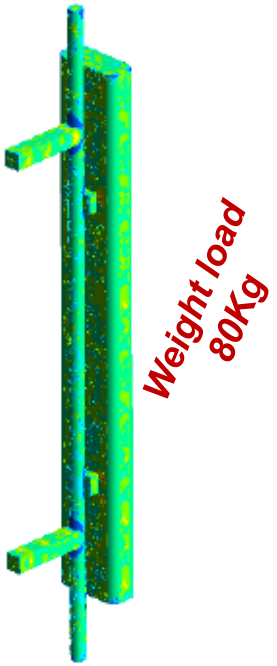
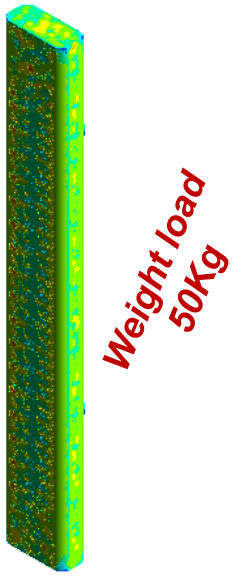
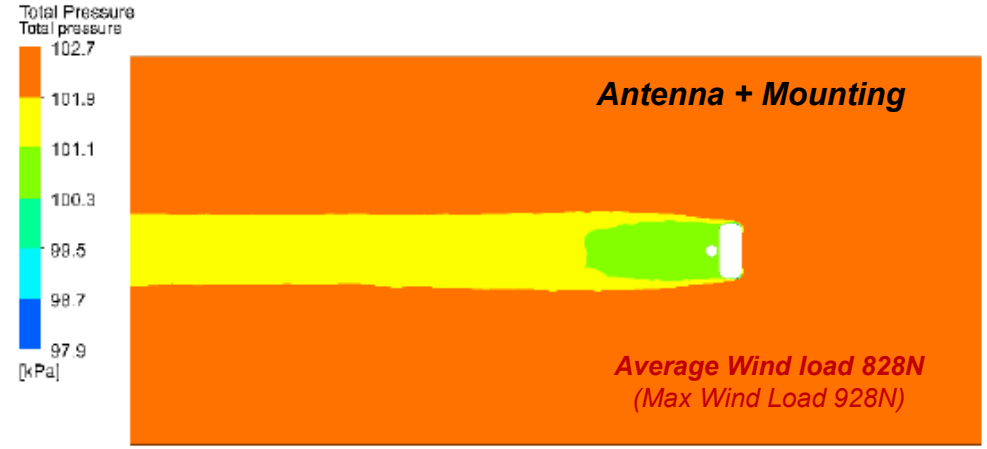
Remove non-structural weight & wind loads *(i.e. the mounting brackets)*

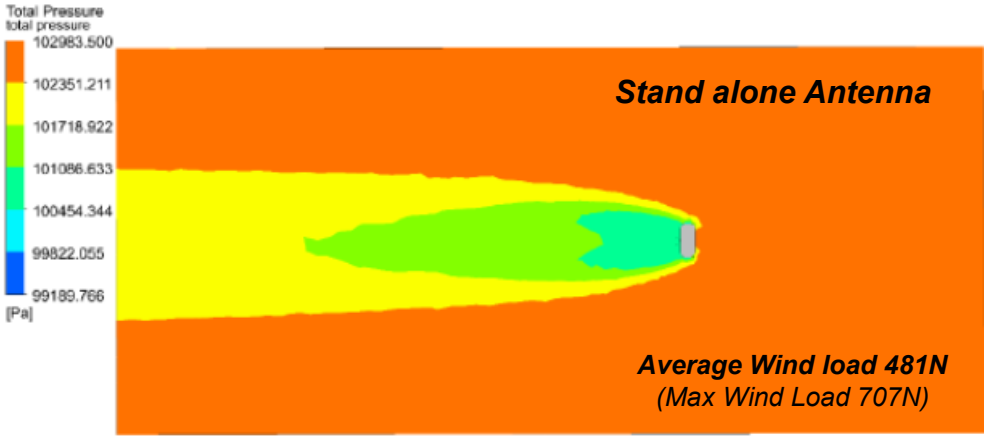


Antenna + Mounting Type 1



Standalone Antenna





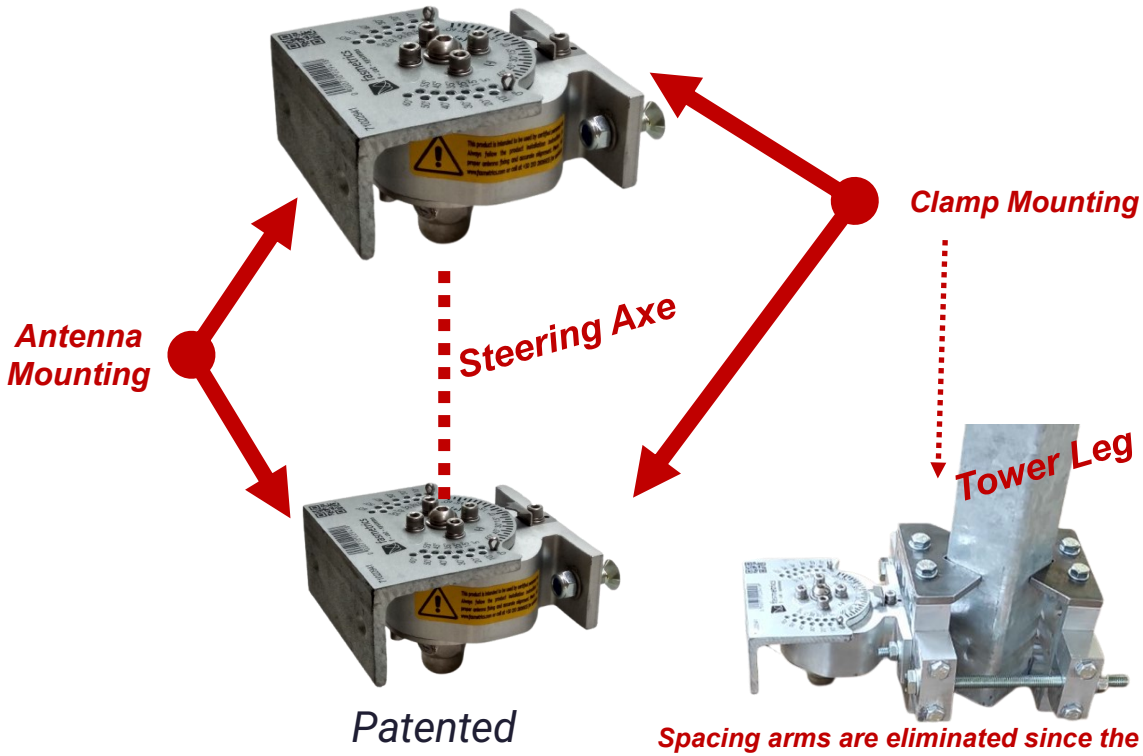
[1]Average Wind load is derived acc to TIA222 standard by calculating the mean value of frontal (0º) and lateral (90º) wind loads

FCAT 1st Innovation: Azimuth Steering Unit to Replace Mounting Pole

Azimuth Unit Specifications

Azimuth Unit Mounting Base Material	AL606350
Azimuth Unit Mounting Adaptor	S235
Azimuth Unit Self Weight	**1.55 Kgr**
Type of Azimuth Unit Tightening Bolts	70
M8 Tightening Bolts Torque	20 Nm
Type of Azimuth Steering Axe Locking Bolt	M16 class 8.8
M16 Locking Bolt Torque	52 Nm
Max Wind Rating	**250 Km/h**
Max Side Wind Loading (force due to wind)	**1,200 N**
Max Permissible Side EPA *for 1-Mounting Point Antenna*	0.294 m²
Max Permissible Side EPA *for 2-Mounting Point Antenna*	0.588 m²
Max Permissible Side EPA *for 3-Mounting Point Antenna*	0.882 m²
Max Vertical (Weight) Loading	**62 Kgr**
Max Permissible Weight *for 1-Mounting Point Antenna (1 Azimuth Unit)*	62 Kgr
Max Permissible Weight *for 2-Mounting Point Antenna (2 Azimuth Units)*	124 Kgr
Max Permissible Weight *for 3-Mounting Point Antenna (3 Azimuth Units)*	186 Kgr

Notes:
1. Max Side Wind Loading value assumes load distance from M16 locking Bolt @0,125m, and drag coefficient Cd=0.626 for panel antenna
2. Max permissible side EPA, represent average values for exposure category terrain B, C, D based on TIA222G §2.6.5.1 and §2.6.5.2 for Z=50m



Patented

Spacing arms are eliminated since the antenna is aligned on the ground!

…if re-alignment is needed, heading offsets are pre-calibrated on Azimuth Steering Unit…

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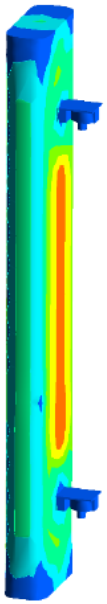
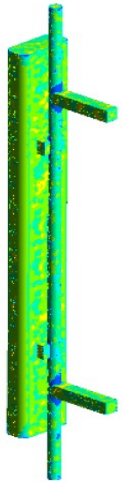
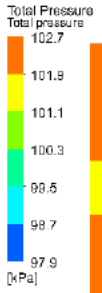


a) Antenna system with newly proposed mounting

Weight load 54Kg

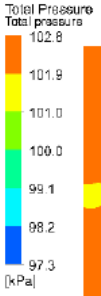




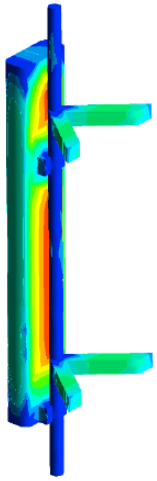
b) Antenna system with currently used mounting - Type 1

Max Wind load 928N
(Average Wind Load 828N)

Weight load 80Kg



Max Wind load 707N
(Average Wind Load 493N)



c) Antenna system with currently used mounting - Type 2

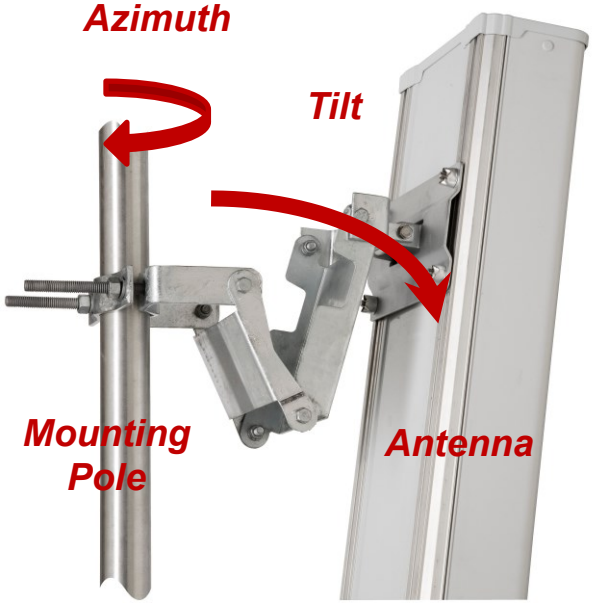
Max Wind load 969N
(Average Wind Load 864N)

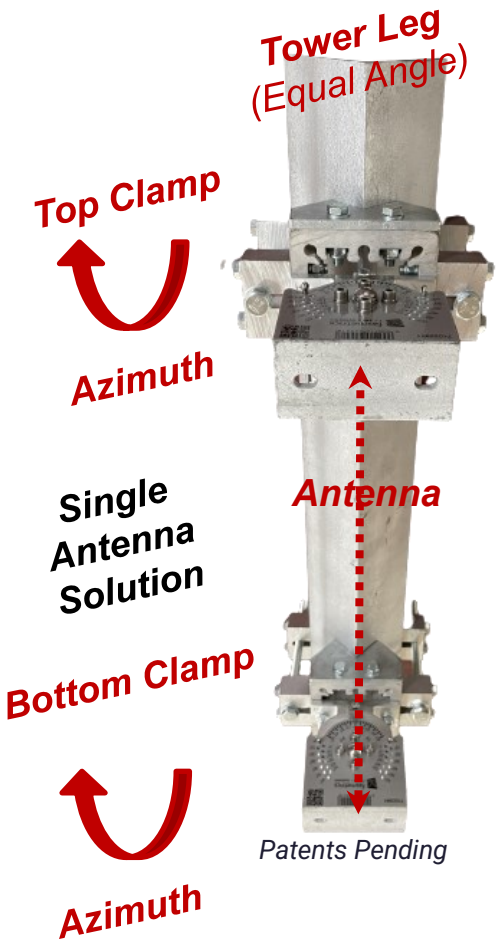
Weight load 97Kg

Wind Load of stand-alone antenna with Mounting: CFD-FEA Wind Load Simulations

fasmetrics

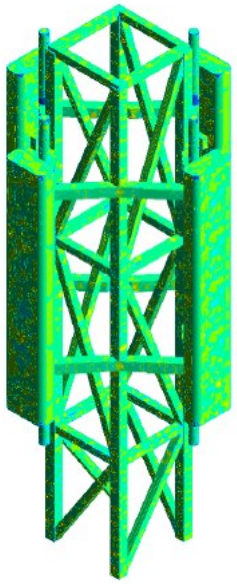
Newly proposed bracket to Replace the Mounting Pole/Bracket: *Static Capacity Gains*





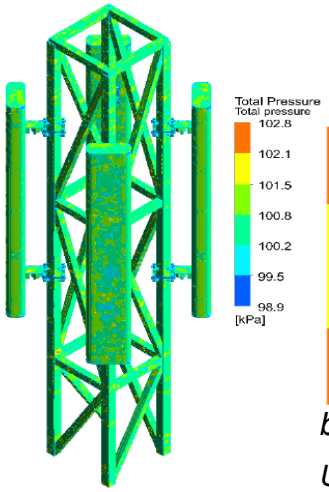
Static stress acting on Tower is not only due to the installed antennas but also due to the antenna mounting brackets. Since we have less loading on both weight and wind, the tower structural members are not fully utilized, thus we gain capacity for additional tenants.

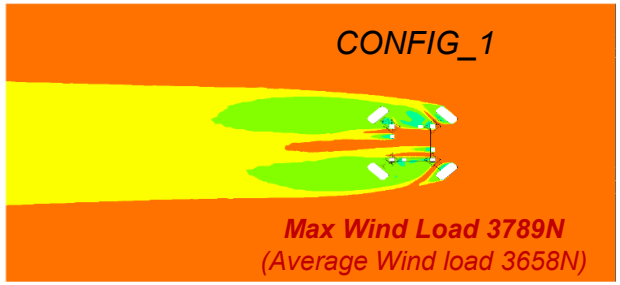
CFD-FEA proves that by replacing the antenna mounting with the newly proposed we remove a significant portion of the antenna wind load on the tower while weight tends to null. That basically means less static stress on the Tower for the same amount of installed active equipment.



a) REFtower CONFIGURATION:

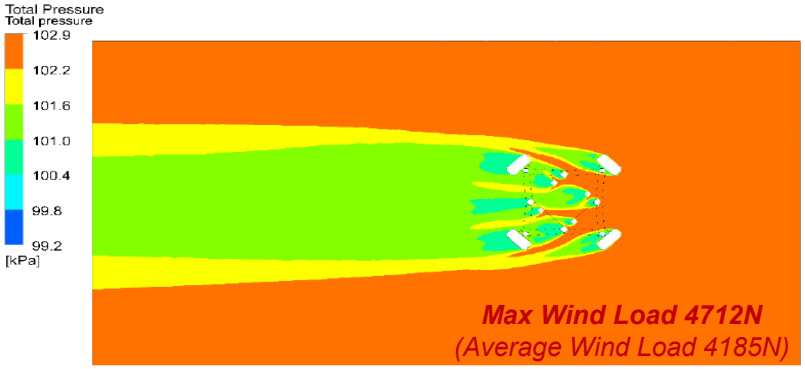
Unitary tower element
+4 antennas with mounting brackets – Type 2

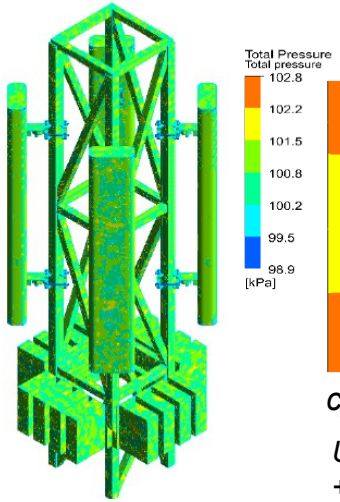


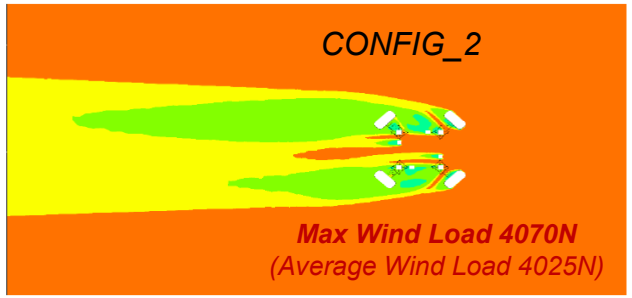


b) CONFIG_1:

Unitary tower
+ 4x antennas with newly proposed mounting brackets





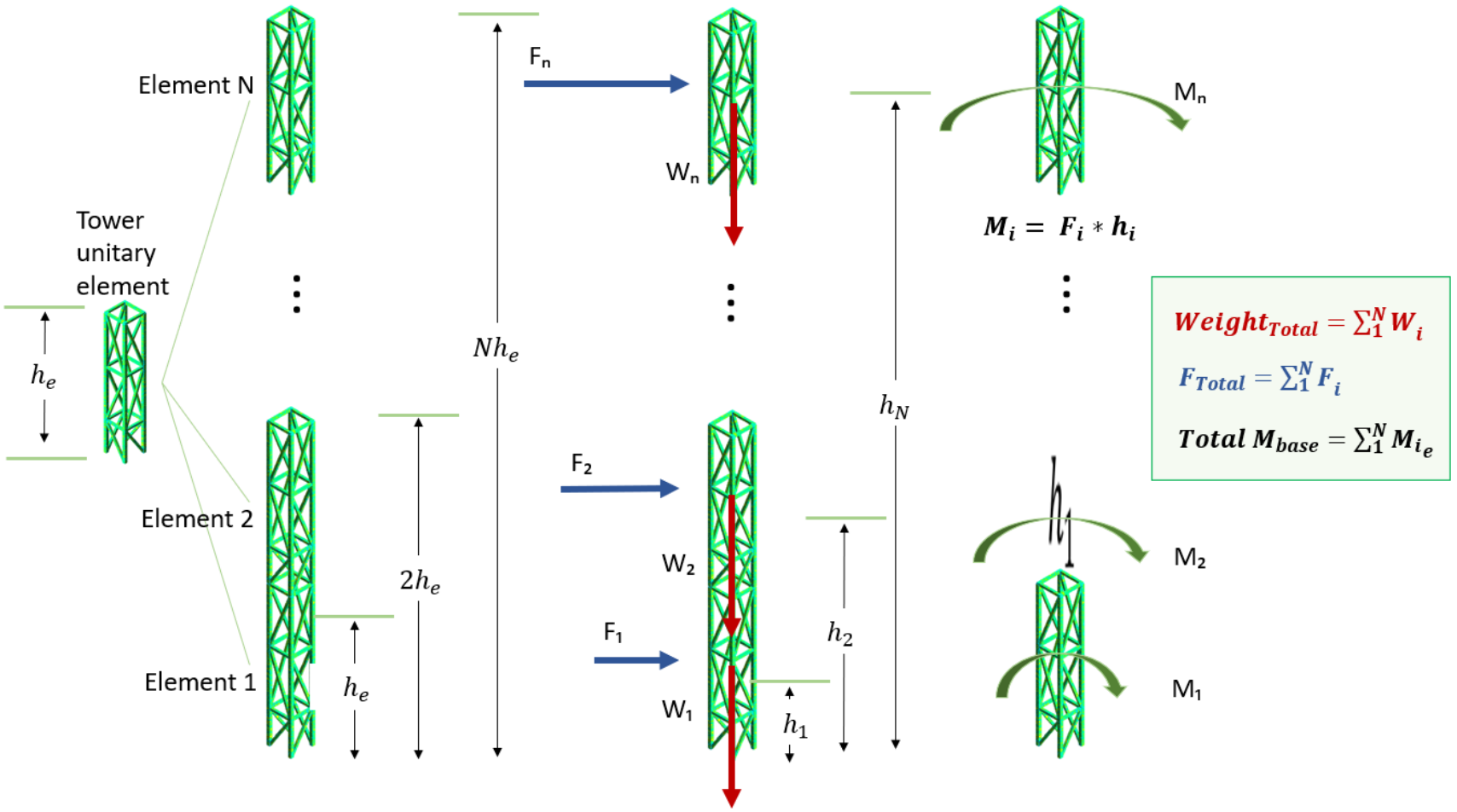


c) CONFIG_2:

Unitary tower element
+4 antennas with newly proposed mounting brackets
+ 4x RRUs per antenna (16 total)

Wind Load of Tower-Top (4m) with Mounting: CFD-FEA Wind Load Simulations

Tower Model

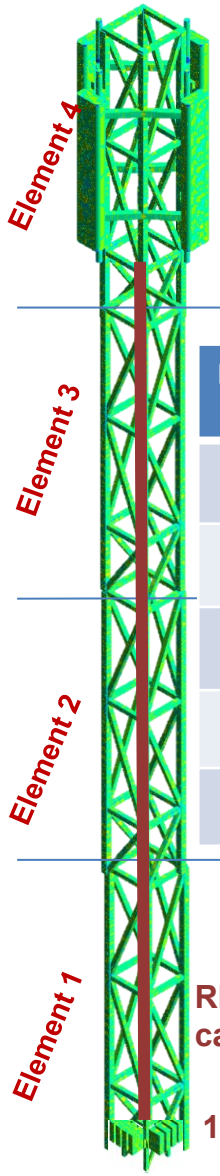


$$Weight_{Total} = \sum_1^N W_i$$

$$F_{Total} = \sum_1^N F_i$$

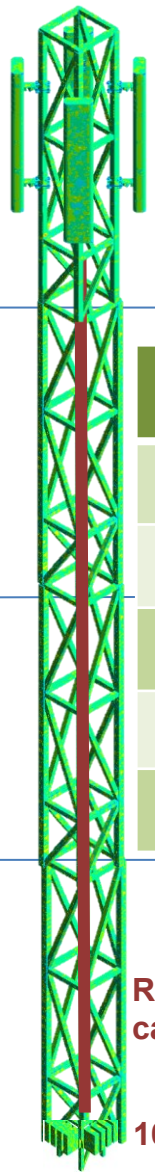
$$Total\ M_{base} = \sum_1^N M_{i_e}$$

16m (N=4 elements) Tower Case Comparison



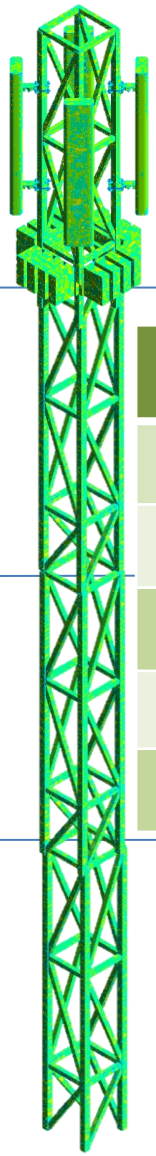
4xAnts with existing bracket type 2

Legacy 16m Tower case	
Tower Weight [Kgr]	1736
Center of mass [m]	9.6
Bending Moment [KNm]	123.4
Sf buckling	10.80
Deflection [mm]	33



4xAnts with new bracket

New bracket 16m Tower Config_1	
Tower Weight [Kgr]	1563 (-10%)
Center of mass [m]	9.1 (-5.1%)
Bending Moment [KNm]	110.5 (-10.5%)
Sf buckling	12.06 (+11.6%)
Deflection [mm]	30 (-11.3%)

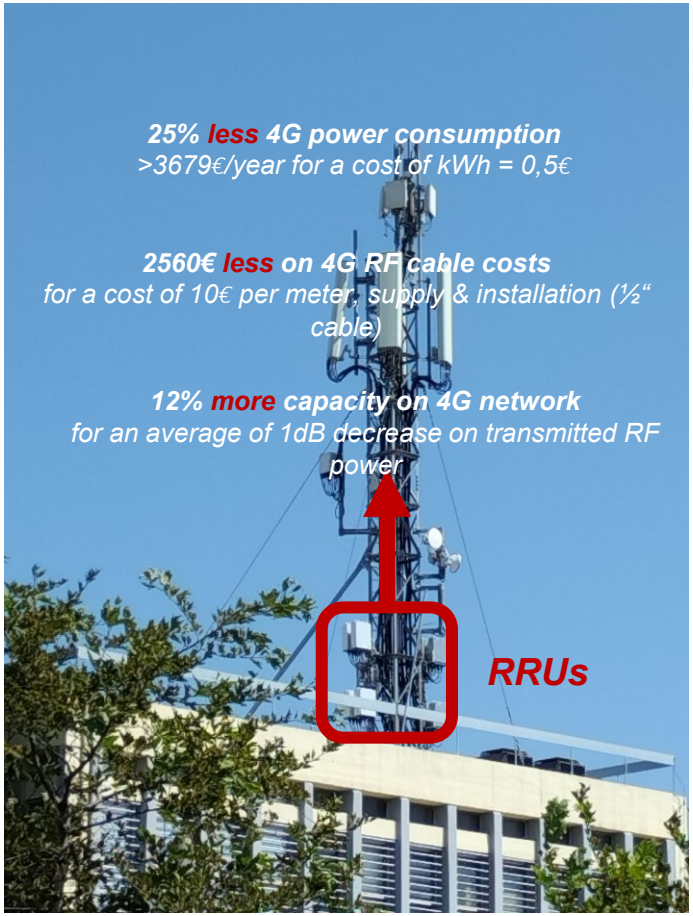


4xAnts with new bracket

16xRRUs (improved radio performance)

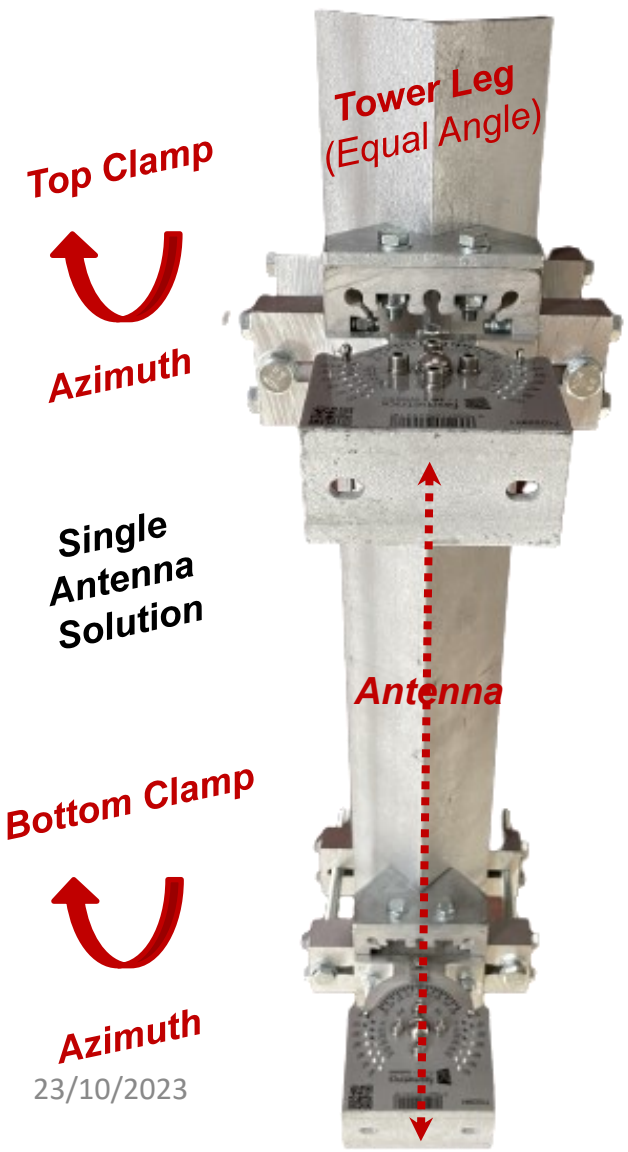
New bracket 16m Tower Config_2	
Tower Weight [Kgr]	1720 (-0.9%)
Center of mass [m]	9.5 (-0.4%)
Bending Moment [KNm]	114.5 (-7.3%)
Sf buckling	11.58 (+7.2%)
Deflection [mm]	31 (-7.9%)

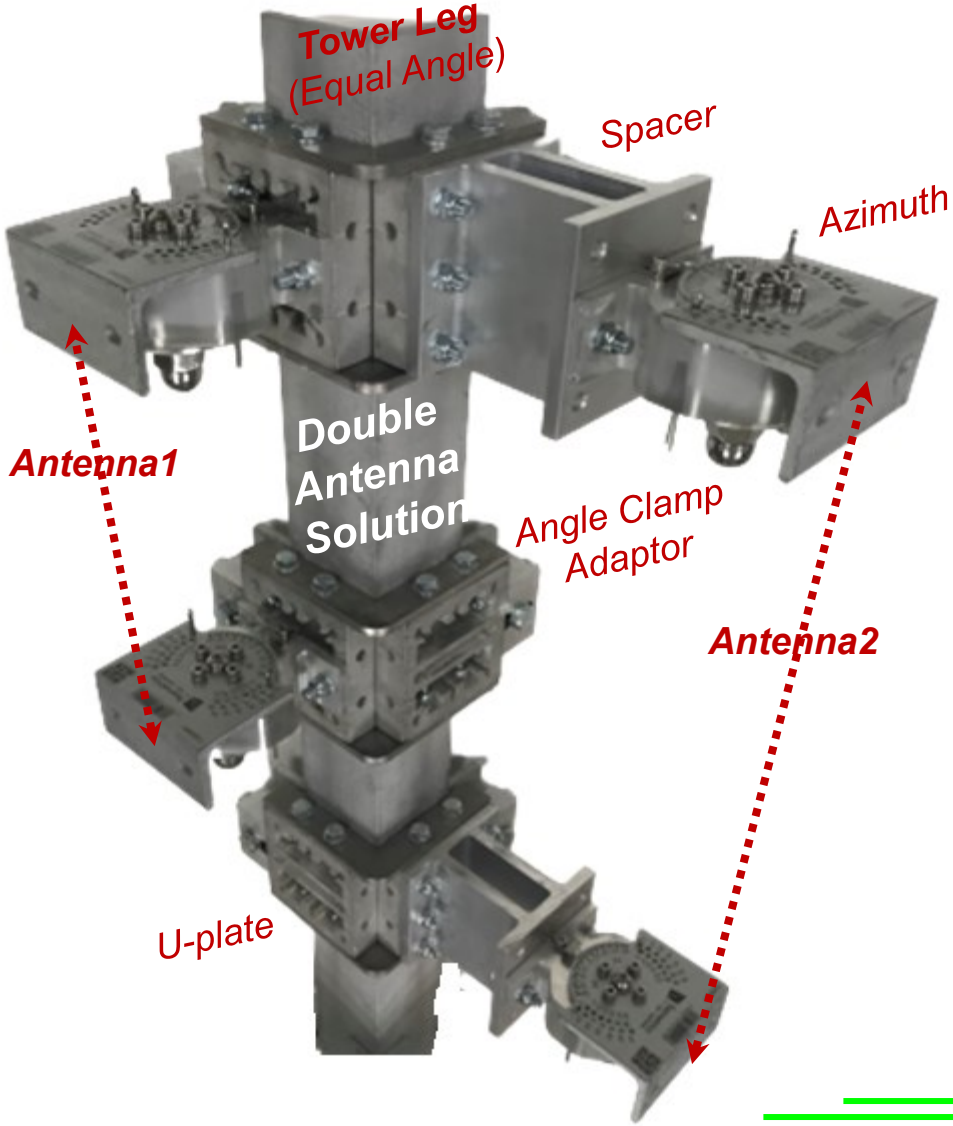
Exemplary Savings due to tower static relief from the mountings



fasmetrics

2nd **Innovation:** *Multiply the number of antennas on mounting*





Exemplary New Bracket Installation: *Improve Space Capacity on the Perimeter*

Avoid tower height extension…
- *Less tower upgrade hosting costs*

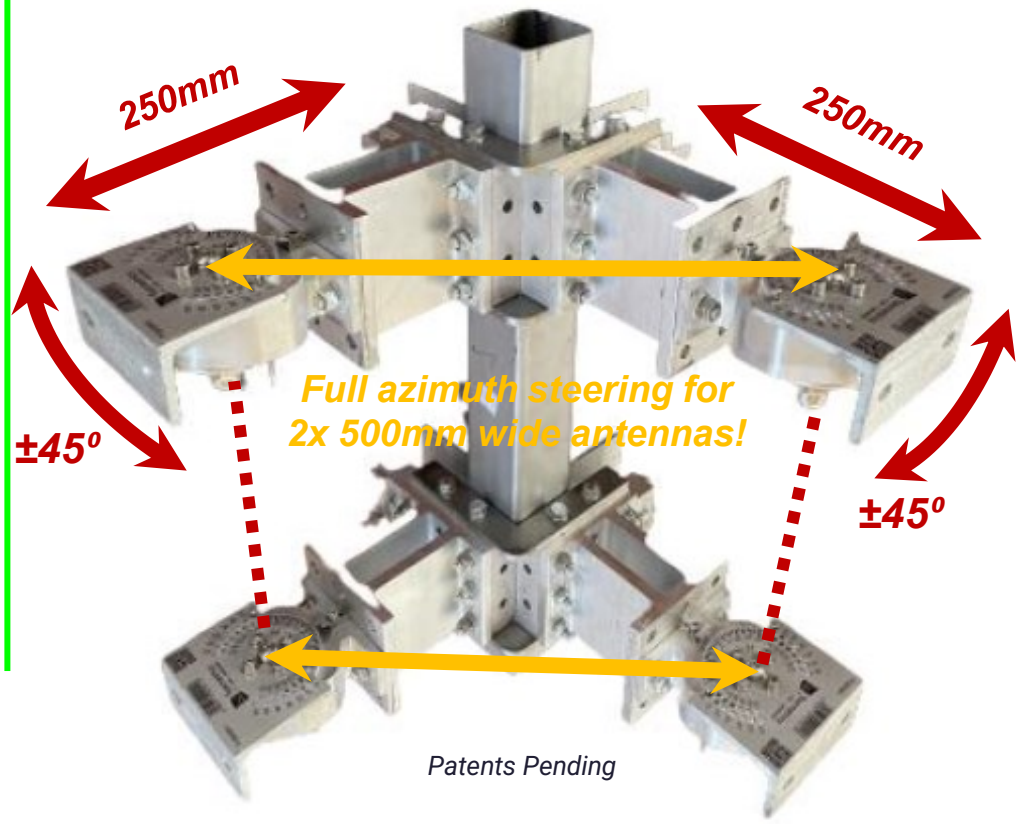
Reduce tower static stress!
- *Less tower reinforcement costs*

Make space for additional tenant!
- *More revenue opportunities*

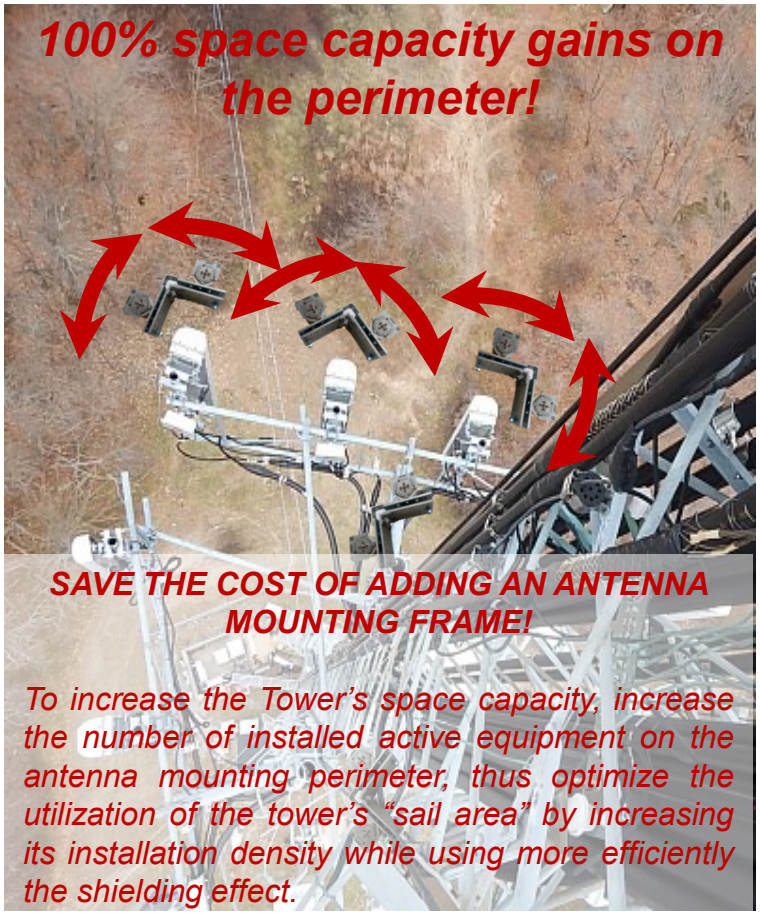
To increase the Tower's space capacity, increase the number of installed active equipment on the antenna mounting perimeter, thus optimize the utilization of the tower's "sail area" by increasing its installation density and using more efficiently the shielding effect.

Double the number of antennas on the existing mounting frames

Wide selection for mounting on any tower leg x-section!

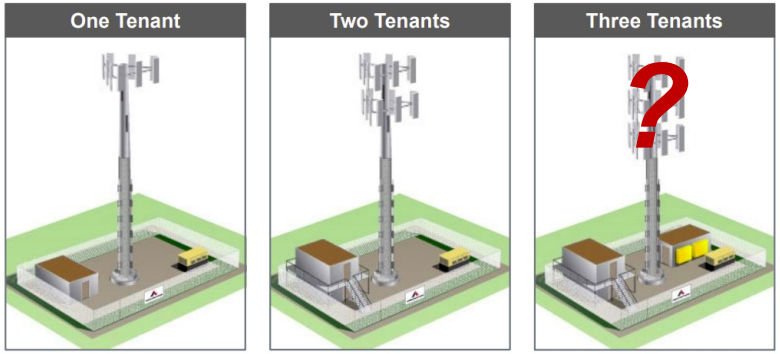


Antenna1 **Antenna2**

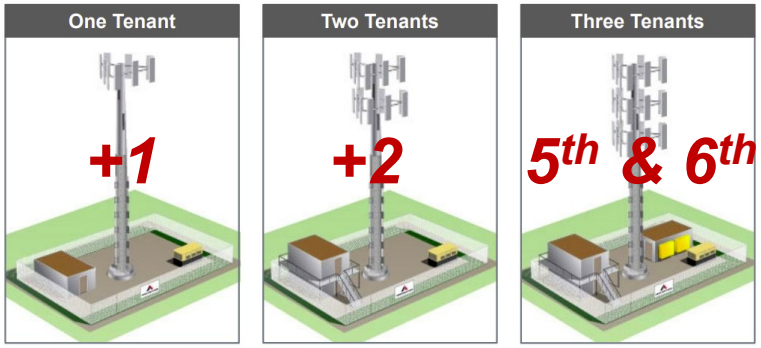


FCAT Financial Benefit for Tower Companies (& Tower Tenants…)

1. *Minimum upgrade costs (FCAT mounting) for the 2nd Tenant, while securing revenues for the 3rd Tenant!*
2. *Allow tower capacity for a 4th Tenant and further improve tenancy Revenues and Returns on Investment!*
3. *Avoid early reinforcement works (i.e. for the 2nd Tenant), while reducing such costs (i.e. for the 3rd & 4th Tenant)!*
4. *Boost the Tenant's operational performance, while optimizing its capital & operational expenses!*



	One Tenant	Two Tenants(2)	Three Tenants(2)
Construction / Upgrade Costs ($ in USD)	$275,000	+$20k	>$100k
Tenant Revenue	$20,000	$50,000	$80,000
Operating Expenses (including ground rent, utility, monitor)	$12,000	$13,000	$14,000
Gross Margin	$8,000	$37,000	$66,000
Gross Margin (%)	40%	74%	83%
Gross Margin Conversion Rate (%)	–	97%	97%
Return on Investment (3)	3%	13%	24%



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** Tower upgrade costs for 2nd Tenant (assumes costs for 1 antenna frame) and 3rd tenant (assumes costs for 1 antenna frame & the related required reinforcement works)*

Thank you for listening!

This research has been co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T2EDK-00581).

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Ταμείο Περιφερειακής Ανάπτυξης
ΕΠΑνΕΚ 2014-2020 ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ ΑΝΤΑΓΩΝΙΣΤΙΚΟΤΗΤΑ ΕΠΙΧΕΙΡΗΜΑΤΙΚΟΤΗΤΑ ΚΑΙΝΟΤΟΜΙΑ
ΕΣΠΑ 2014-2020
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης