Changing the Landscape of FM Broadcast Antenna Technology

Presented By:
Nicole Starrett

Dielectric®

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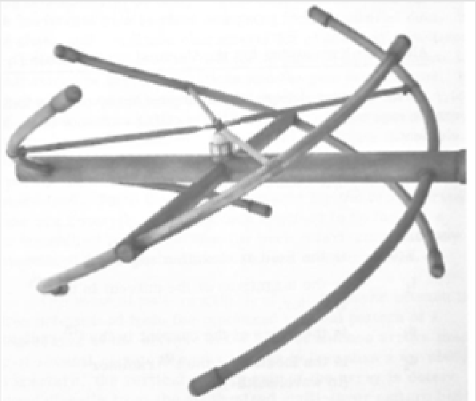
Todays Presentation

- New antenna design
  - Introducing pylon technology to FM broadcast antennas
  - What we have learned and improved since NAB
- FCC ruling on the use of simulation for FM pattern studies
  - June 2021 - Filed a PRM with the FCC to allow the use of computer simulation to verify performance of directional FM antennas
  - Where it stands
  - Developing a new Artificial Intelligence (AI) approach to pattern optimization

Introduction

It’s been many years since a game changing technology has been introduced into the FM broadcast antenna market



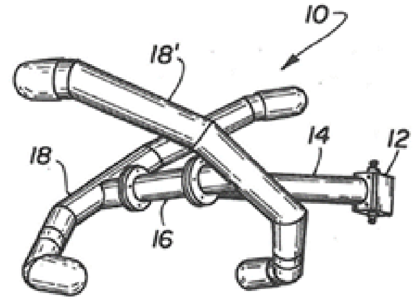
1967 – Matti Siukola – NAB paper “Dual Polarization FM Broadcasting From a Single Antenna” – BFC. Known today as the DCR-C

1978 – Don Hymas – IEEE paper “A New High Power Circularity Polarized FM Antenna” – BFM. Known today as the DCR-M

United States Patent [19] [11] **4,109,255**
Silliman [45] **Aug. 22, 1978**

[54] OMNIDIRECTIONAL BROADBAND CIRCULARLY POLARIZED ANTENNA

[56] References Cited
U.S. PATENT DOCUMENTS

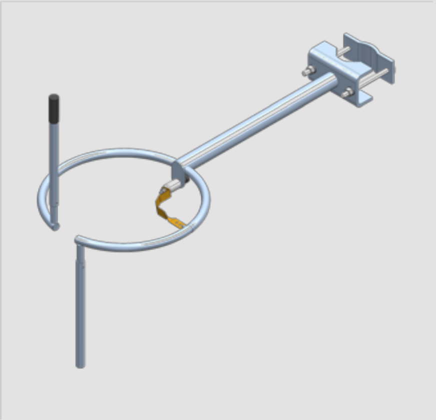


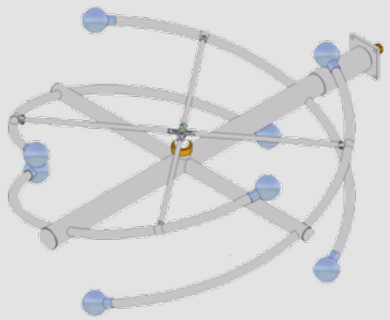
Rototiller

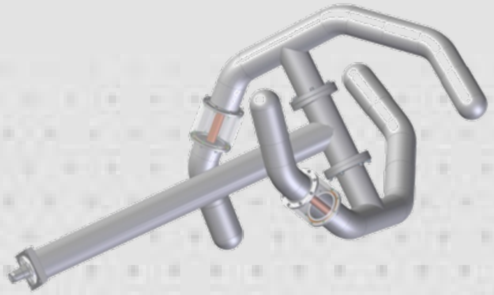
All are still popular choices in today’s market

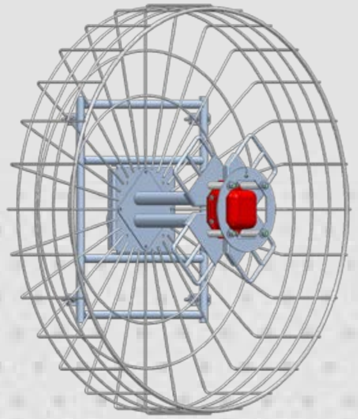
- FM broadcast antenna section available today
  - Rings
  - Tillers
  - Stub loops
  - Panels

Available Today

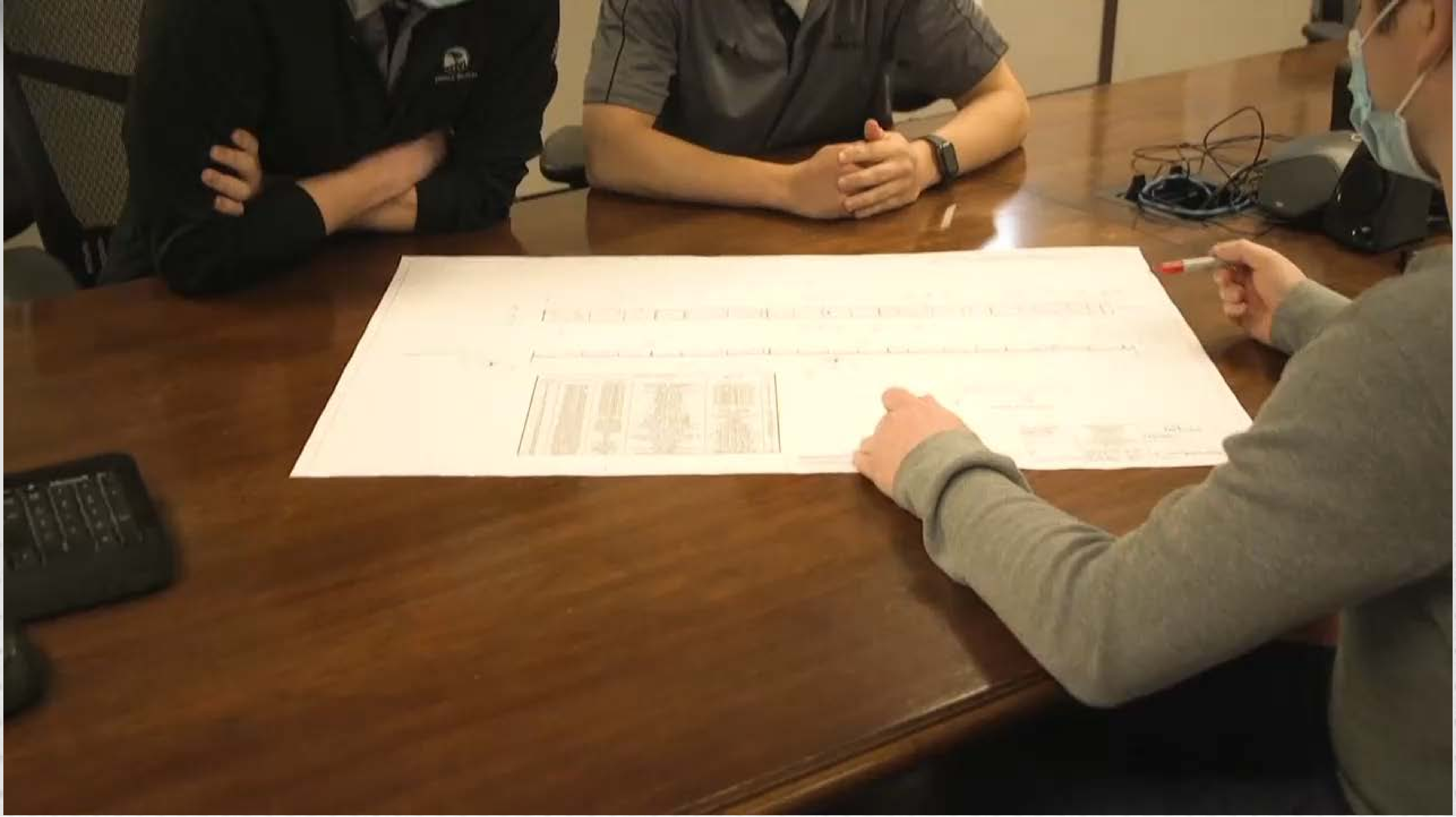








Selection is limited to individual elements with complex features and complex feed system



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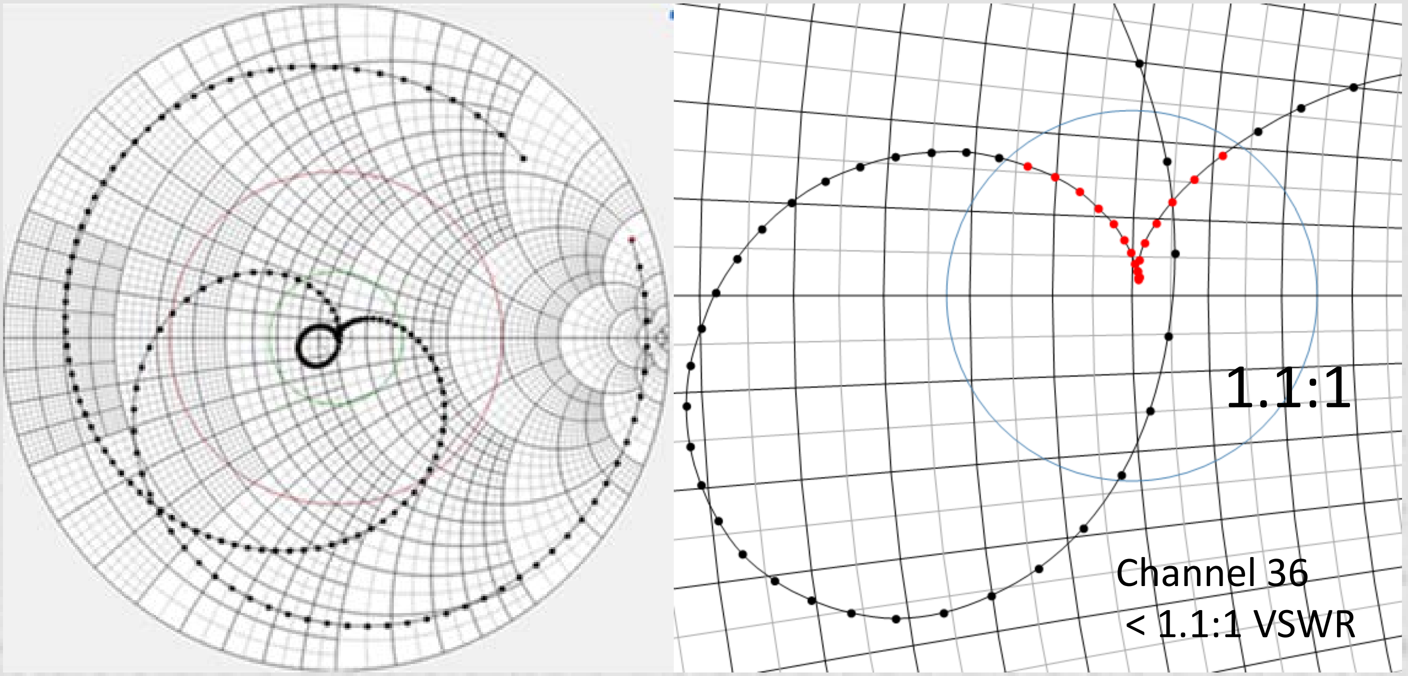
Pylon Antennas

- Pylon Antennas
  - Term coined by RCA
  - Top mounted slotted coaxial antenna
  - Long, thin, round structures
  - Much smaller size and less windload than other broadcast antennas
  - Simplicity
    - Very few parts and connections
      - High reliability
  - Vast majority of UHF (more recently VHF) broadcast antennas in the US are slotted coaxial "Pylon" designs

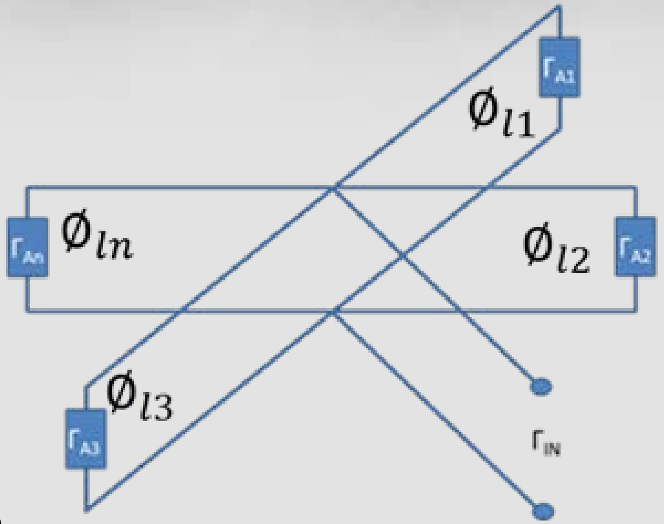
Pylon Technology - Disadvantage

- Inherently narrow bandwidth
- Most applications – usage is only considered for single channel operation
- The natural bandwidth – typically 1% at UHF for VSWR <1.1:1 (One channel)
- The % bandwidth is defined as: $\%bw = \frac{f_h - f_l}{f_0} x100$



Typical 100 MHz Pylon response at UHF

Increasing the Bandwidth

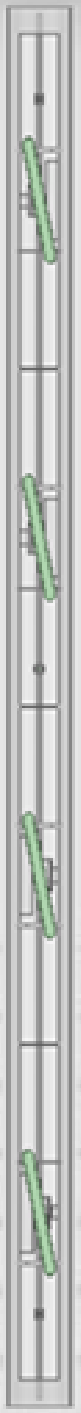


- Techniques classified into two categories
  - Those that lower the “Q”
  - Those that provide external phase cancellation in the feed system
- FM pylon basic building block is a 4-bay single section
- Focus is on lowering the Q.
- The expected bandwidth within an allowable VSWR specification is given by :

$$bw = \frac{\pi}{Q ln\left(\frac{VSWR+1}{VSWR-1}\right)}$$

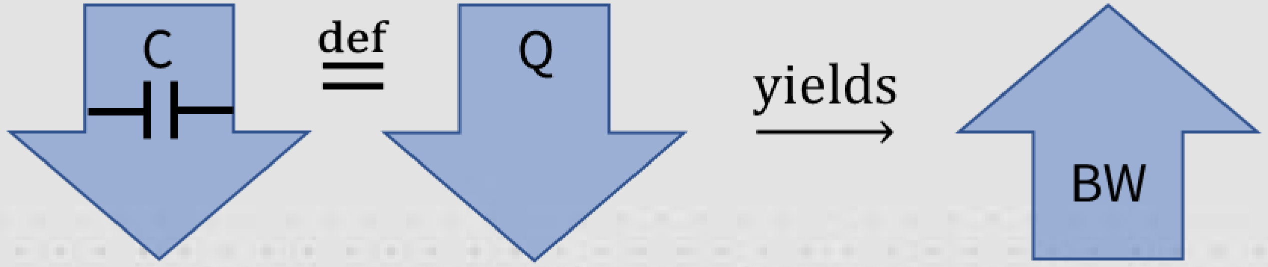
Q and bandwidth are inversely proportional

- Standard pylon Q≈ 30 to 40
- Need 19% bw for FM band
- Required new Q ≈ 5 to 10 for a max 1.2:1 VSWR



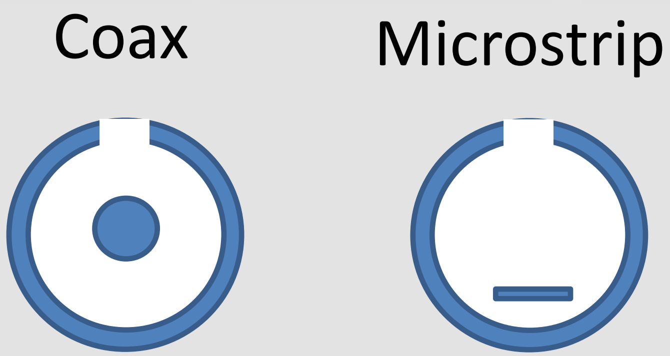
Increasing the Bandwidth - Techniques

- Reduce the capacitance
  - Q of a parallel resonant circuit : $Q = \omega_0 RC$
  - Q is directly proportional to capacitance



- The capacitance of the slot network can be greatly reduced by changing the coaxial inner to a microstrip

Using a microstrip fed slot cuts the Q in half – Doubles the bandwidth

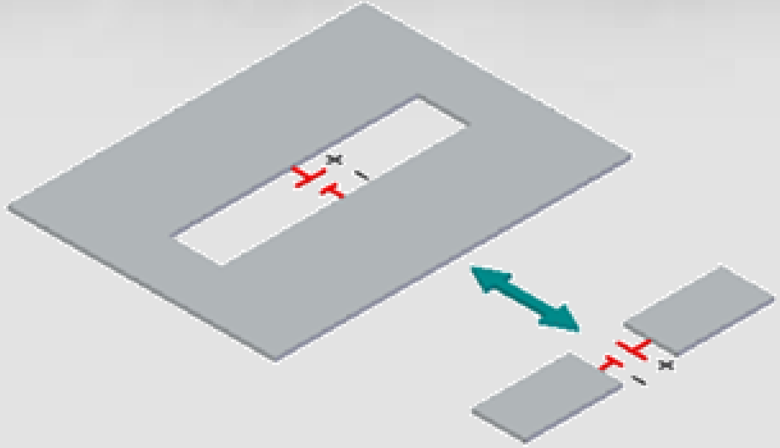


$$C_c = \frac{2\pi\epsilon_0\epsilon_r}{ln\left(\frac{D}{d}\right)}$$

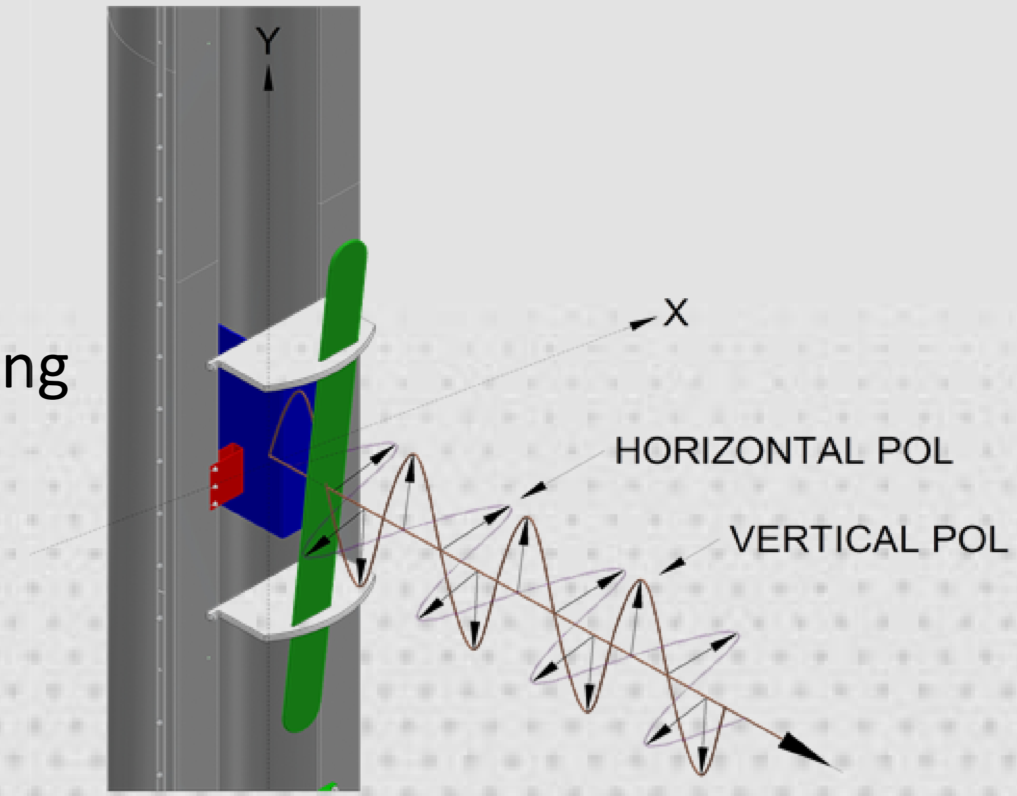
$$C_m = \frac{\epsilon_r L}{60v_0 ln\left[\frac{8h}{w} + \frac{w}{4h}\right]}$$

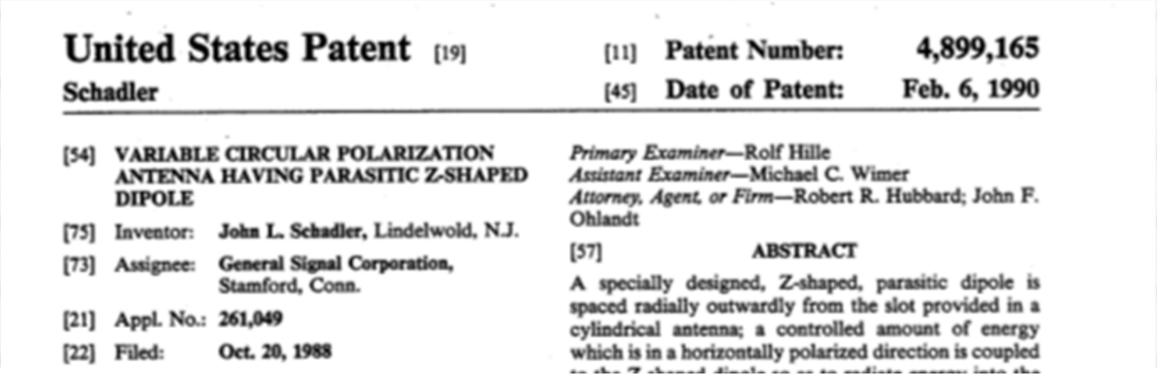
For same Zo $C_m \approx \frac{C_c}{2}$

Increasing the Bandwidth - Techniques



- Babinet's Principle – H.G Booker related the theory to antennas (1946)
- Slot is a complementary "dual" of a dipole
- Place a dipole and slot in the same circuit
  - Inverse response – Lowers the Q
  - **Tests have shown Q is cut in half**
  - Doubles the operating bandwidth
- **Technique also provides circular polarization**
  - Parasitic dipole couples the horizontally polarized energy emanating from the slot and re-radiates it into the vertical plane





United States Patent [19]
Schadler

[11] **Patent Number:** 4,899,165
[45] **Date of Patent:** Feb. 6, 1990

[54] VARIABLE CIRCULAR POLARIZATION ANTENNA HAVING PARASITIC Z-SHAPED DIPOLE

[75] Inventor: John L. Schadler, Lindelwold, N.J.

[73] Assignee: General Signal Corporation, Stamford, Conn.

[21] Appl. No.: 261,049

[22] Filed: Oct. 20, 1988

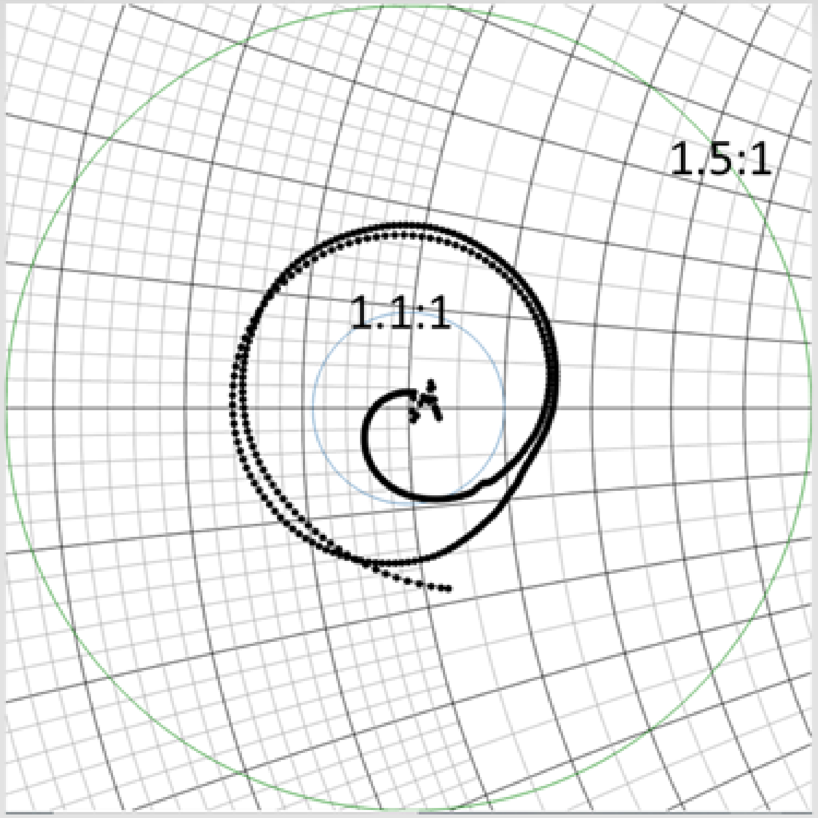
Primary Examiner—Rolf Hille
Assistant Examiner—Michael C. Wimer
Attorney, Agent, or Firm—Robert R. Hubbard; John F. Ohlandt

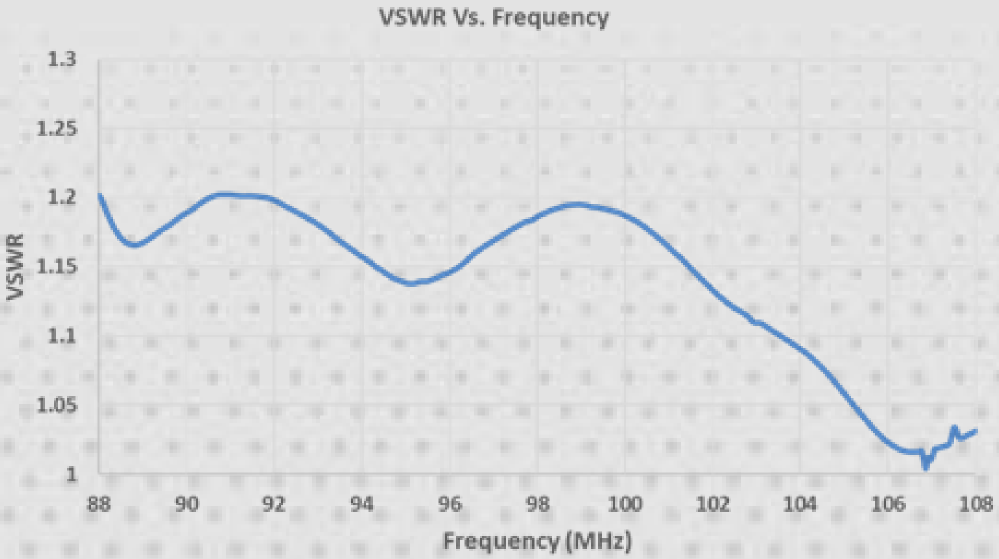
[57] ABSTRACT

A specially designed, Z-shaped, parasitic dipole is spaced radially outwardly from the slot provided in a cylindrical antenna; a controlled amount of energy which is in a horizontally polarized direction is coupled

FM Pylon Single Section VSWR

- Testing confirms - Using these Q reducing techniques allows VSWR performance < 1.2:1 across the FM band in a single 4 bay section
- Antenna tested on 25’ trestle





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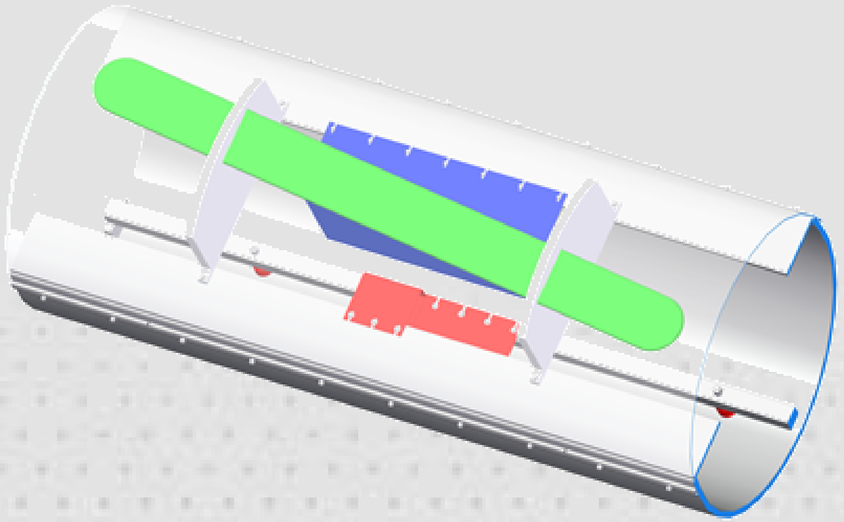
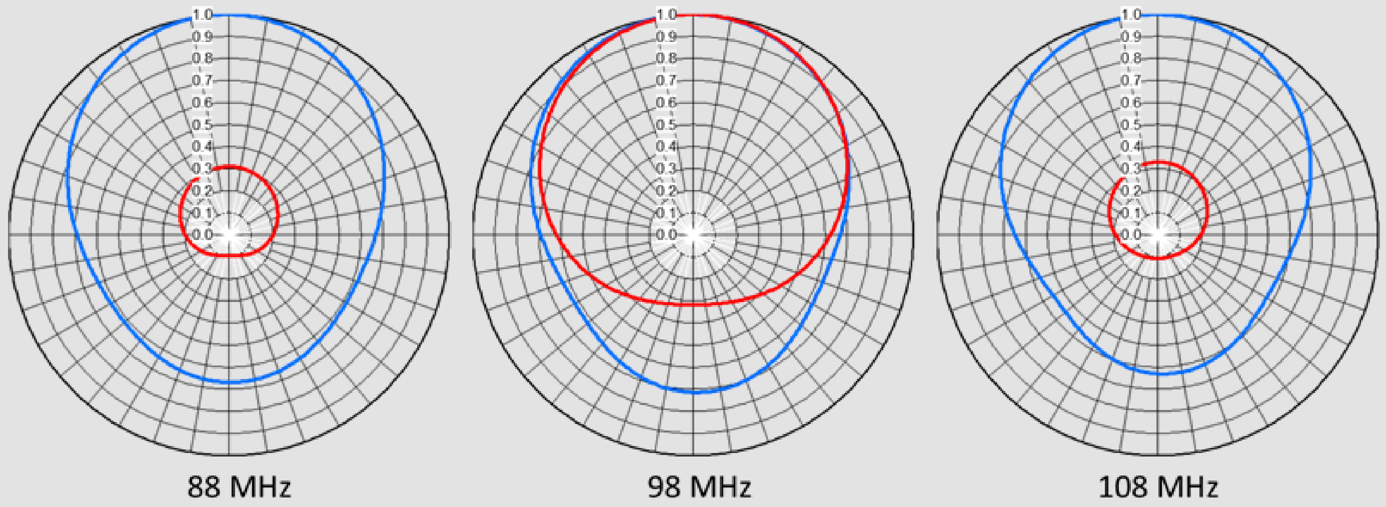
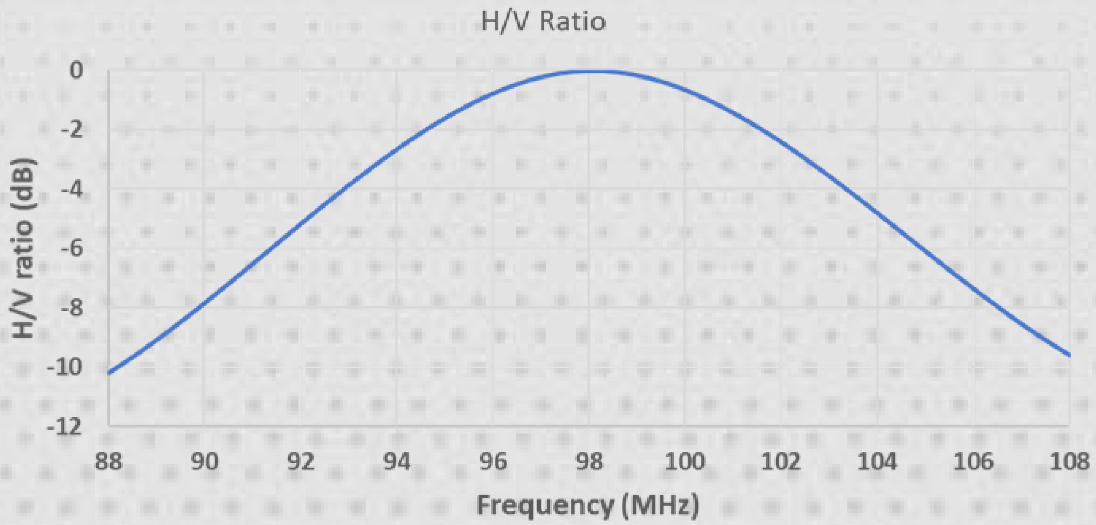
Polarization Ratio Stability

- Started with our standard floating tilted dipole
- Limited in bandwidth
- Wider dipole helps….





Blue – Horizontal Polarization
Red – Vertical Polarization



- Not acceptable for FM full band performance
- Expand on the same simple dipole concept

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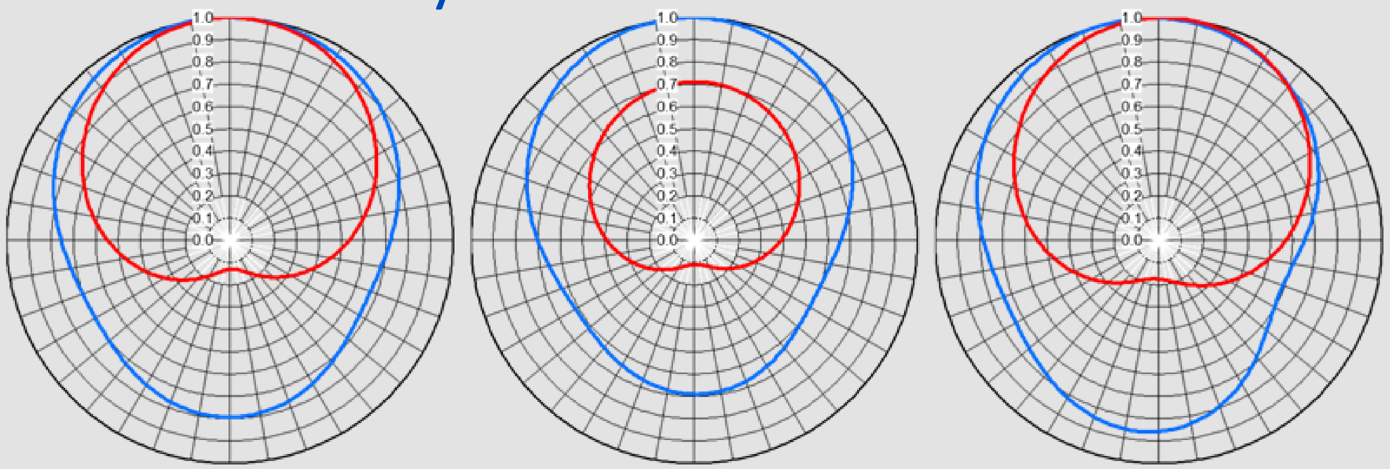
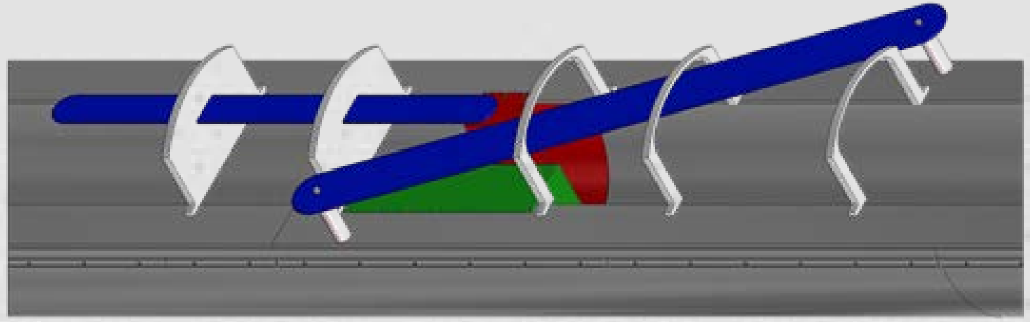
Improving the Polarization Ratio Stability

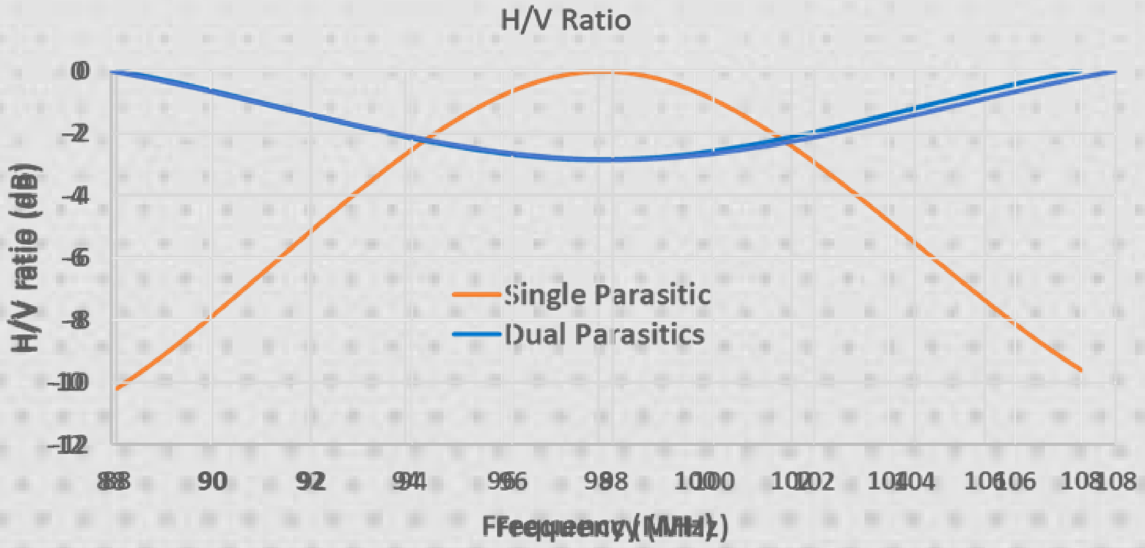
- Moved to a dual parasitic floating tilted dipole
- Appling Log Periodic principals
    - Each dipole resonates at different part of the band



88 MHz 98 MHz 108 MHz

Blue – Horizontal Polarization
Red – Vertical Polarization

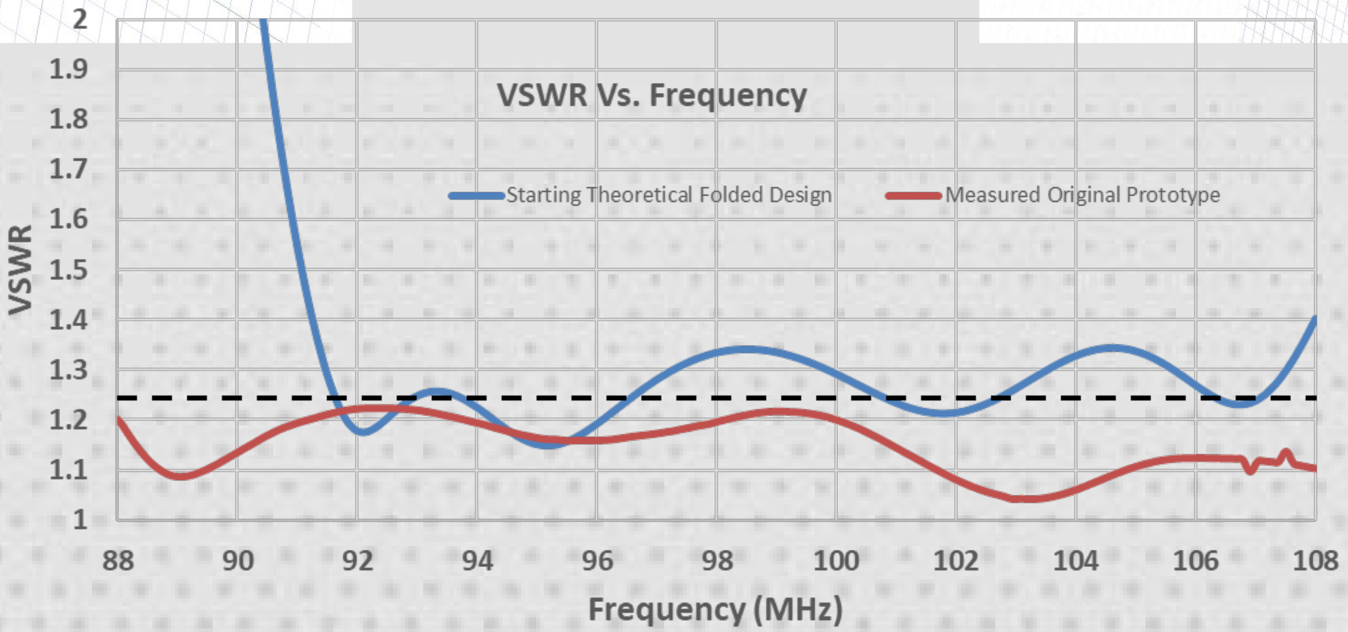




Variation is comparable to today's broadband single element designs

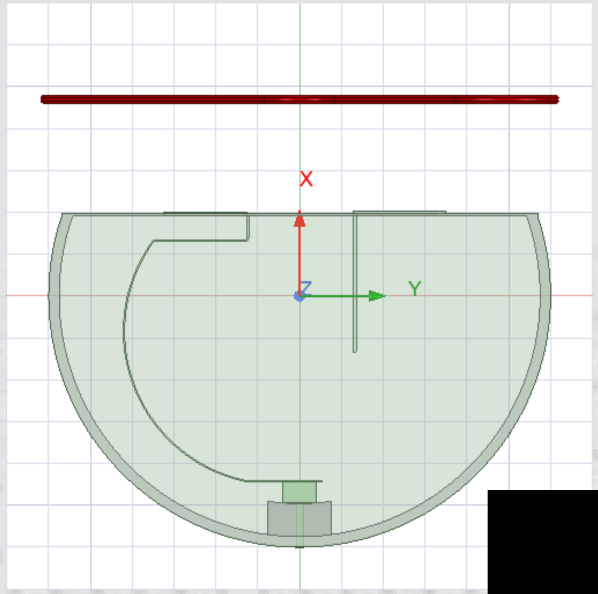
Improvements to the FM Pylon – What We've Learned

- Dual dipole design compromised antenna bandwidth – Babinet's principle
- Exploring options to improve bandwidth



Improvements to the FM Pylon – What We've Learned

- What about manufacturability?
  - Originally planned on a rounded extrusion
  - Transitioned to a folded box design for increased economic manufacturability
  - Continuing to explore ways to simplify design



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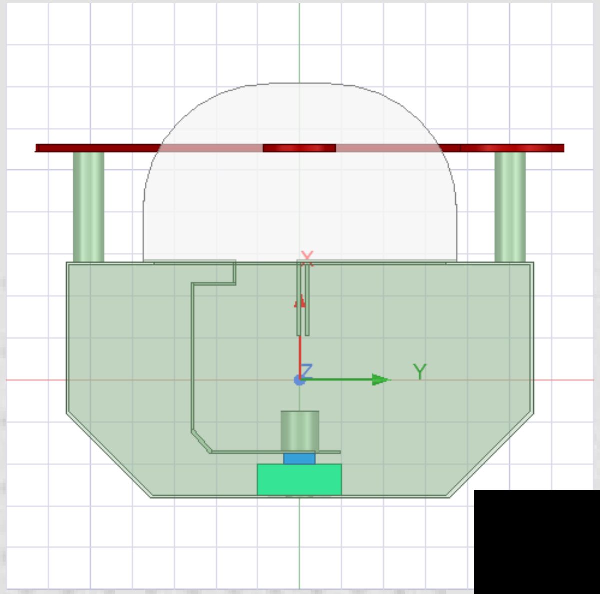


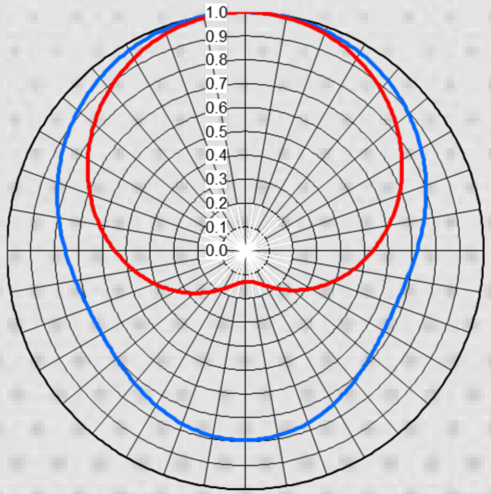
[redacted]

HPOL – VPOL Pattern Congruency

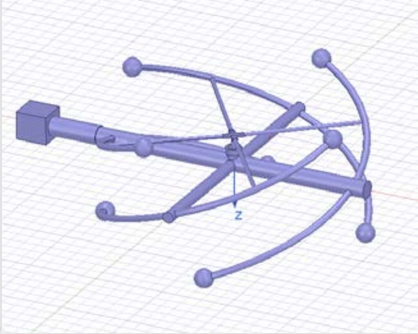
- FM Pylon's free space pattern is not omni. HPOL and VPOL are not congruent
- Is this a problem?

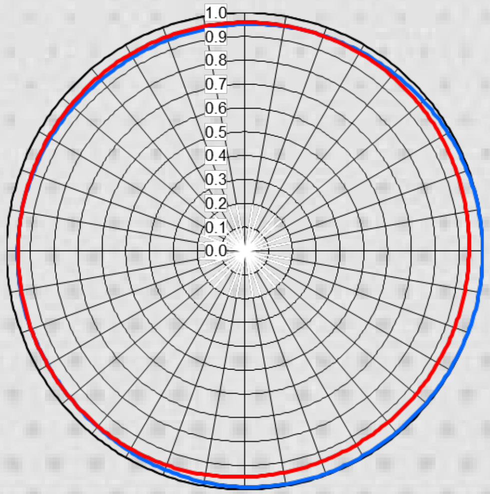
Blue – HPOL
Red – VPOL

FM Pylon free space

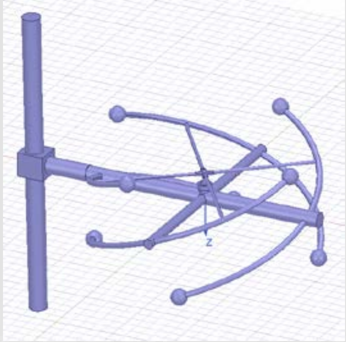


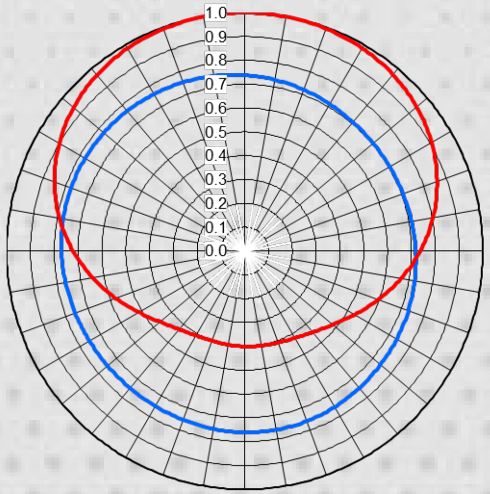
DCR-M free space





DCR-M feed line added

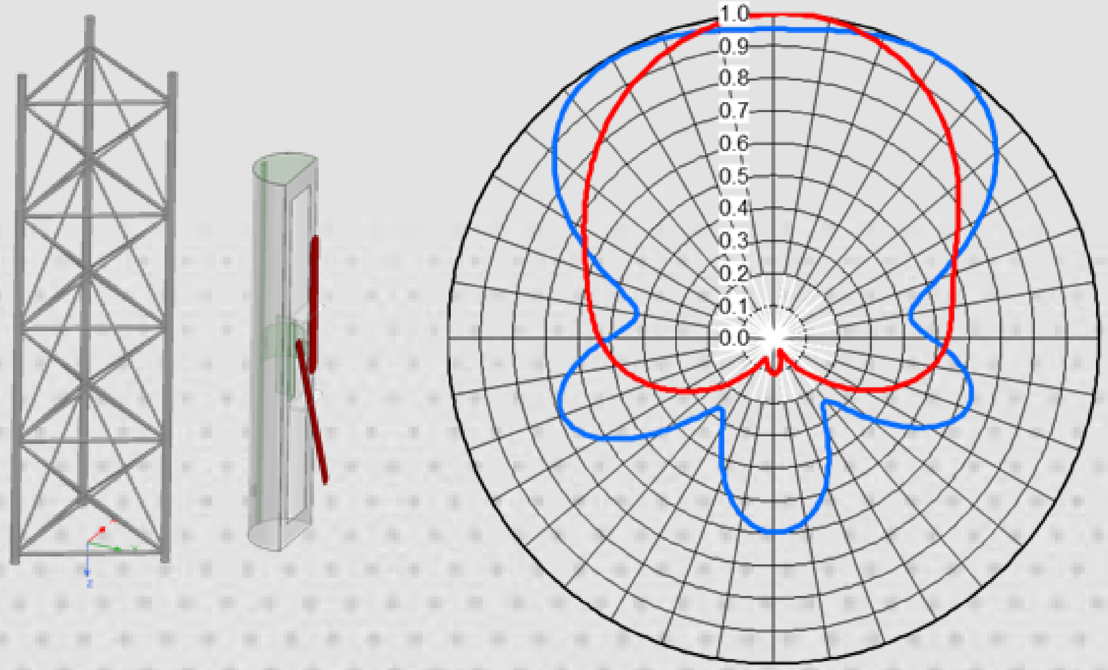




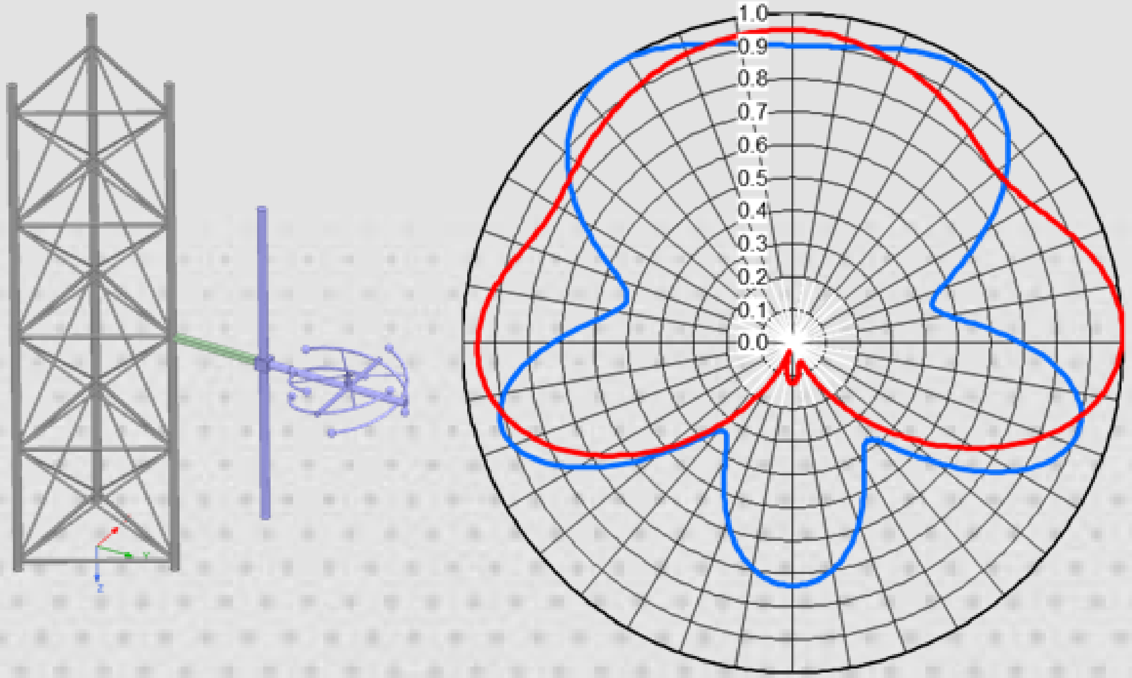
HPOL – VPOL Pattern Congruency

- Side mounting to a tower creates patterns similar in nature for both the FM pylon and ring style antennas

FM Pylon typical leg mount



DCR-M Typical leg mount



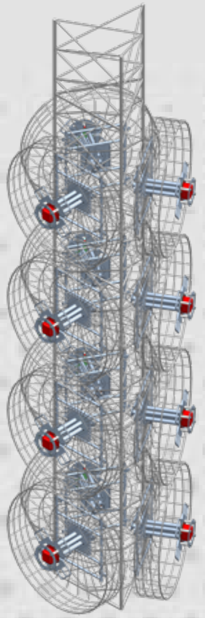
Blue – HPOL
Red – VPOL

Azimuth Pattern Flexibility

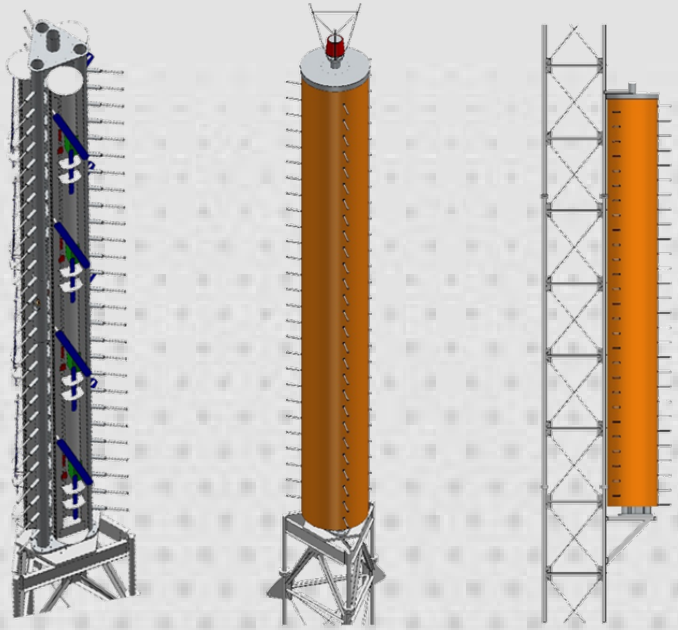
- Azimuth pattern options not limited to a single bay
- Single bay can be used as an array element in a circular configuration
- Provides the same pattern flexibility as complicated panel antennas
- Patterns created by - # of bays around, amplitude and phase to each face
- Configurations can be top or side mounted

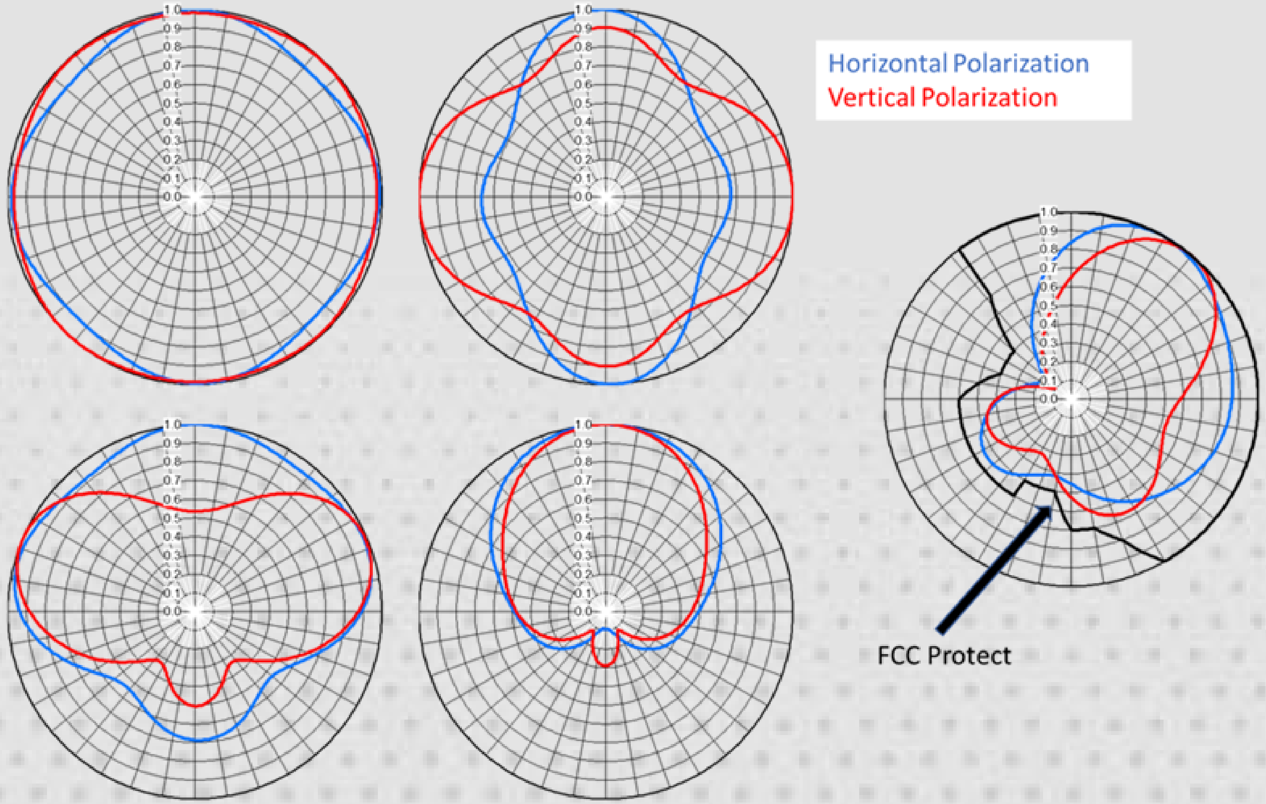
Standard patterns to very custom patterns to fit challenging FCC protects

Panel configuration



FM Pylon configurations

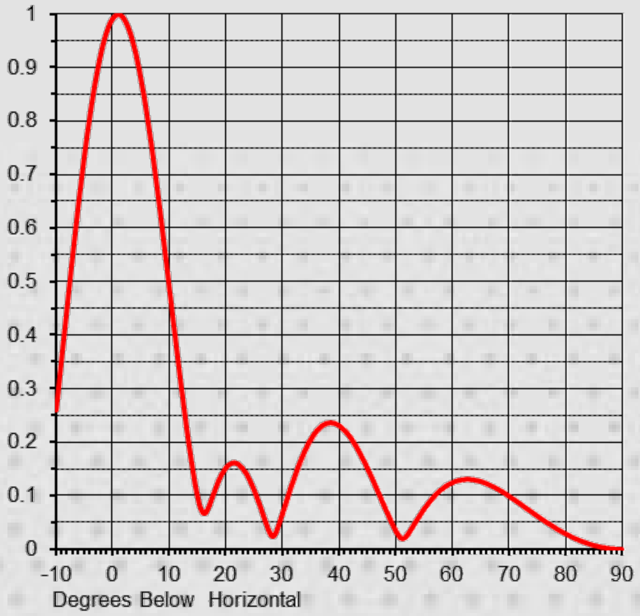




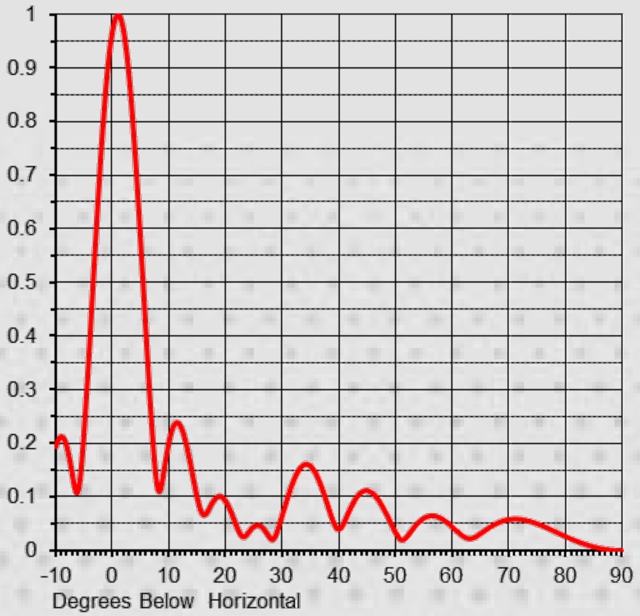
Elevation Pattern Flexibility

- The elevation pattern, gain, beam tilt, and null fill can be varied by stacking multiple sections
- Each section feed with an external feedline from a power divider

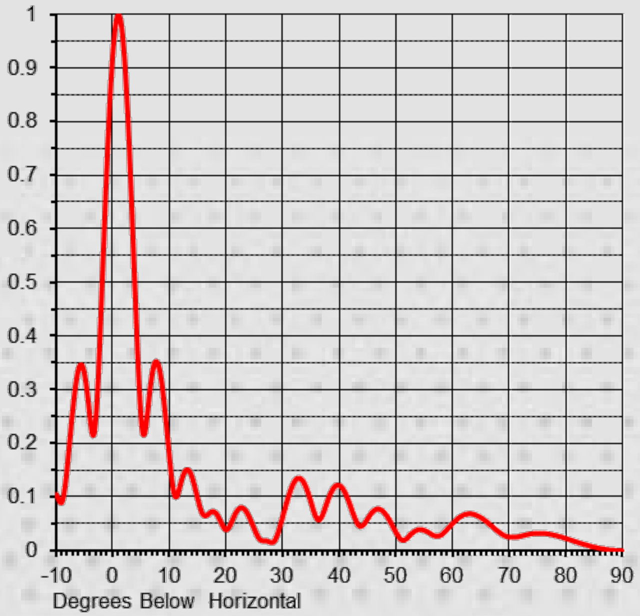
Elevation Patterns



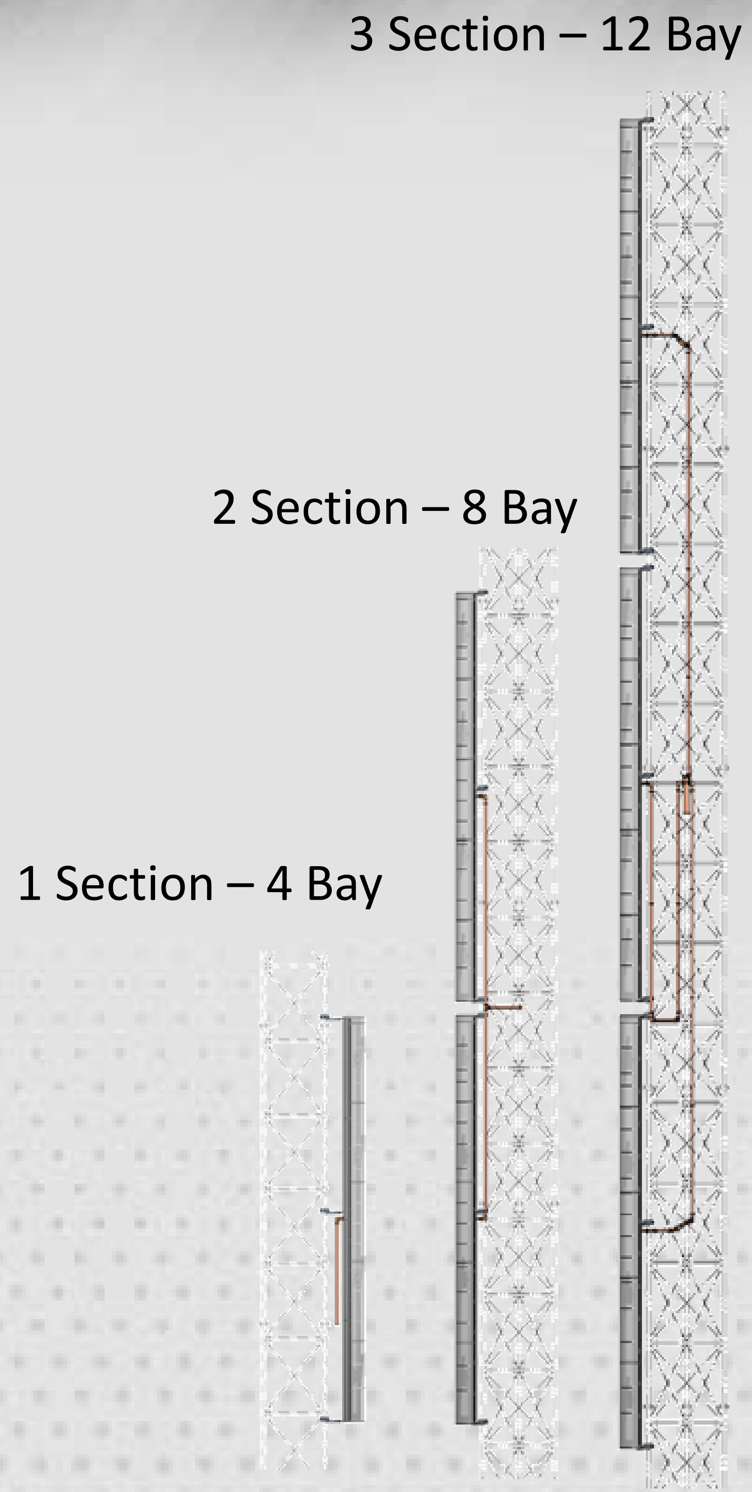
4 Bay



8 Bay



12 Bay



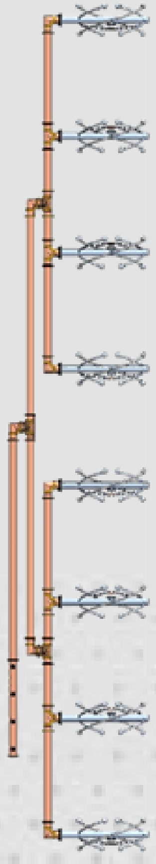
Simplicity Equals Reliability

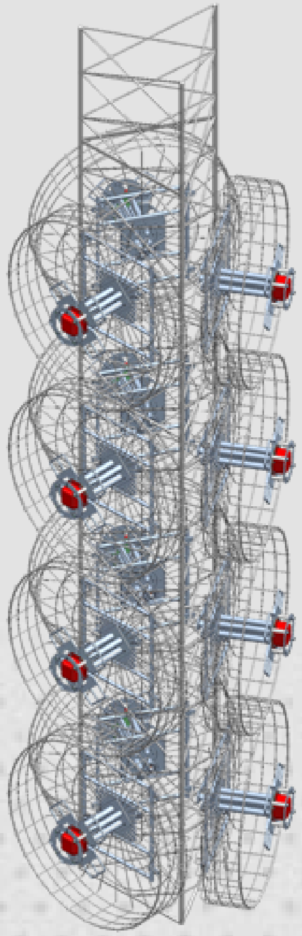
- Pylon antennas know for their simplicity
- Failure rate defined by:

$$\lambda = \sum_{i=1}^{n} N_i \lambda_i \pi_{Qi}$$

$n =$ # of part categories
$N_i =$ Quantity of i[th] part
$\lambda_i =$ Failure rate of i[th] part
$\pi_{Qi} =$ Quality factor of i[th] part

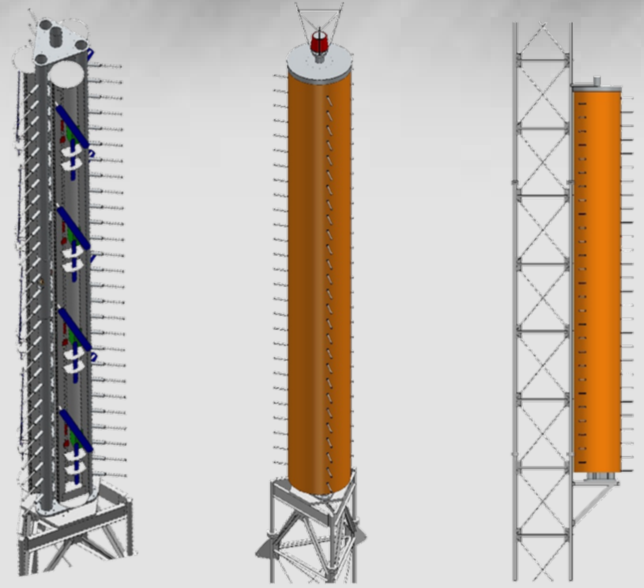
- By definition – failure rate is directly proportional to the number of parts
- FM pylon has:
  - 60% less parts than equivalent ring style
  - 90% less parts than equivalent panel





Inherently makes the FM pylon more reliable than any equivalent FM broadcast antenna on the market today

Power / Voltage Handling



- The voltage safety factor of an antenna system under combined multi-station operation

$$SF = \frac{.7V_{p-breakdown}}{\left(\sum_1^n \sqrt{2Z_0P_{avg-analog}} + \sum_1^n \sqrt{2Z_0P_{avg-IBOC}PAPR_{Lin}}\right)\left(\frac{2VSWR}{VSWR+1}\right)}$$

Schadler – " -10 dBc IBOC at Combined Transmission Sites", BEIT NAB 2015

- Recommended VSF's for antennas 5:1 VSF

Schadler – " ATSC 3.0 Ready – Designing Antennas for Higher OFDM PAPR", BEIT NAB 2018

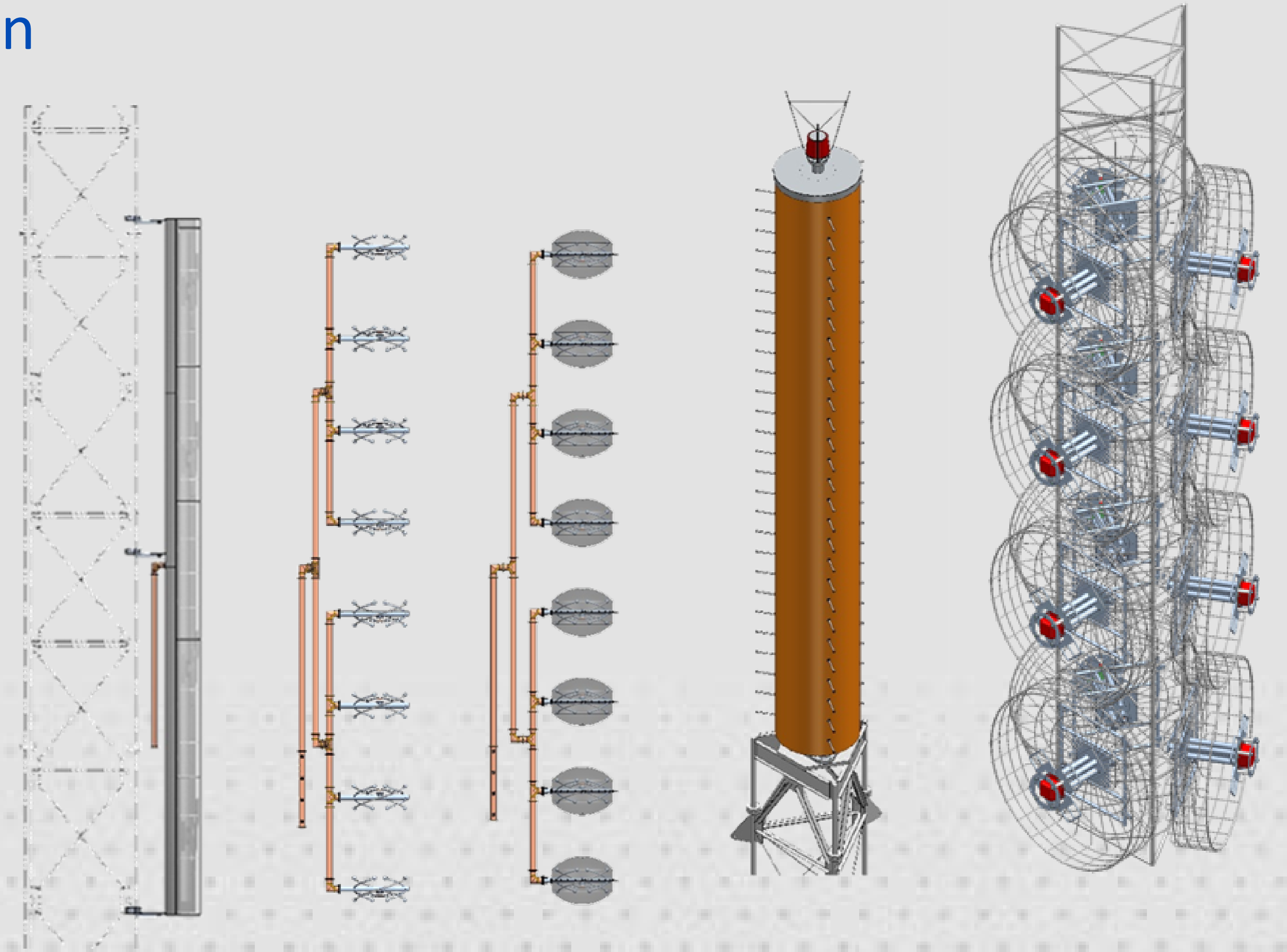
Average Power (kW) per Station with -14dBc IBOC for each Using 5:1 Voltage Safety Factor

	Number of stations						
# Sections	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	30	15	10	7.5	6	5	4
2	60	30	20	15	12	10	8
3	90	45	30	22.5	18	15	12
4	120	60	40	30	24	20	16

- Extensive Hi-pot testing
  - 5:1 VSF
  - Assuming each station running -14 dBc IBOC
- FM Pylon is not voltage limited until 7 stations are combined into it
- Example - Top mount omni master FM application
  - 4 Sections around – will accommodate 6 stations each at 20 kW with -14 dBc IBOC at a 5:1 VSF

Mechanical Windload Comparison

- G-Code
- 4 Bay pylon vs. 8 bay ½ wave spaced ring
  - Ring requires ½ wave spacing for bandwidth
  - Pylon has more windload but comparable – 18%
  - Pylon has less windload then ring with radomes – 22%
- 4 Bay top mount omni pylon vs. 3 around CBR
  - Pylon has less windload by 20%
  - Much less windload with ice – 50%

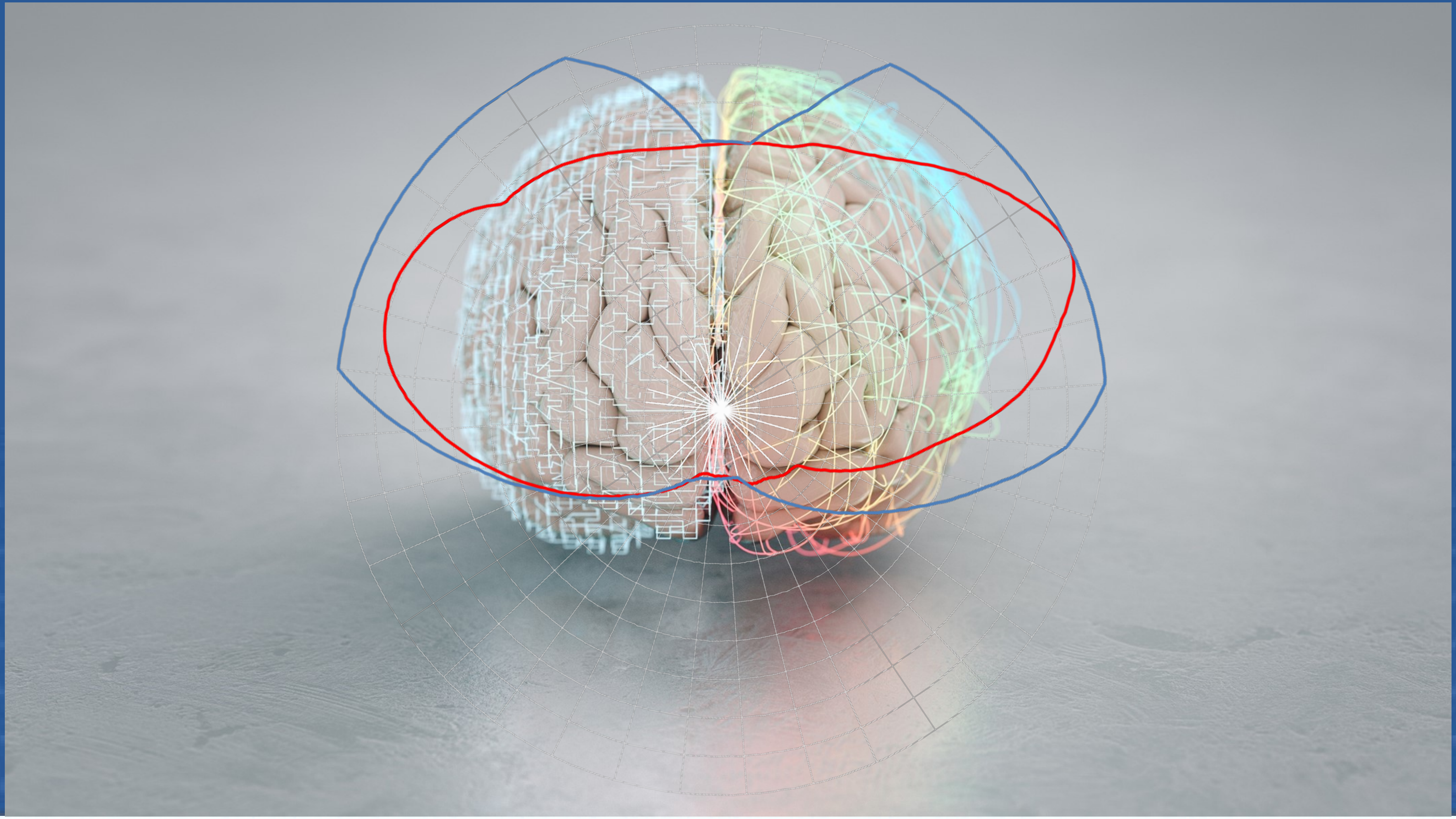


	EPA (ft2)
Single Section 4 Layer FM Pylon	51.1
8 Layer 1/2 Wave Spaced Ring	43.4
Side Mount FM Pylon vs Ring	118%

	EPA (ft2)
Single Section 4 Layer FM Pylon	51.1
8 Layer 1/2 Wave Spaced Ring with Radome	65.7
Side Mount FM Pylon vs Ring	78%

	EPA (ft^2)	EPA (ft2) 1" Ice
4 Around Top Mount FM Pylon	160.4	333
3 Around CBR	201.6	667
Top Mount Omni FM Pylon vs CBR	80%	50%

AI Approach to FM Pattern Optimization



FCC Ruling Update

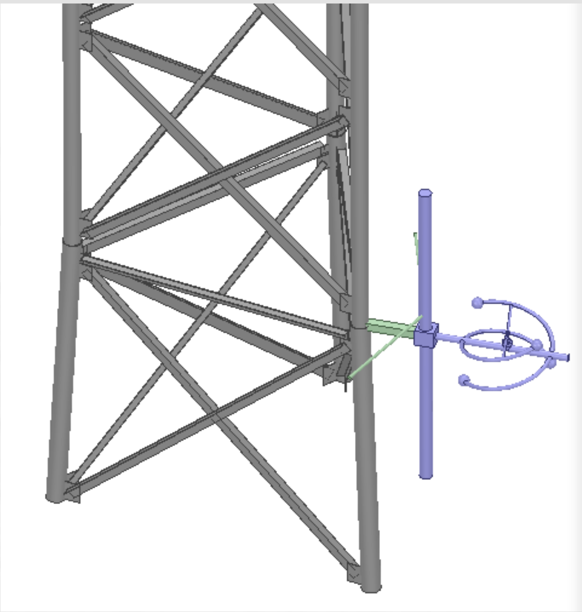
- June 2021 - Filed a PRM with the FCC to allow the use of computer simulation to verify performance of directional FM antennas
- November 2021 - Unanimous decision by the FCC to move forward with the NPRM
- FCC strong support - Public comment period reduced to only 30 days
  - 2-week extension granted due to Christmas and New Year holiday
- Public comments tally
  - 18 in favor – 1 opposed
  - Strong support from the Broadcast community
- The NPRM passed a final vote on the May 19th docket
- Filed with the register the following day
- Currently awaiting the Office of Management and Budget to approve
- Expecting approval this month

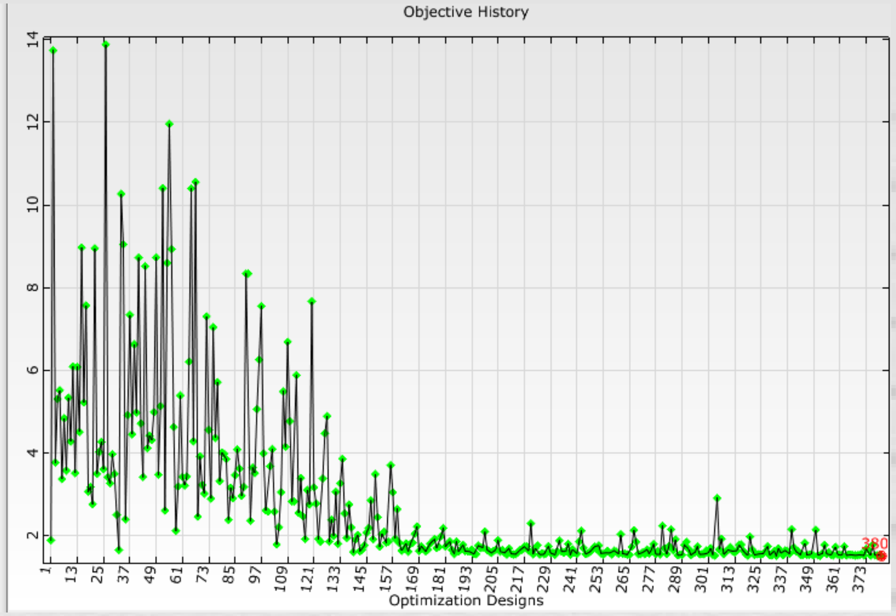
Process for FCC Validation and Acceptance

- Each FM antenna model must be verified by submitting both simulated measurements and range measurements
- “Reasonable correlation” between the two measurements
- We use a mathematical calculation called correlation coefficient, >95%
- Once a bay is verified using a particular simulation software, the FCC will permit all subsequent directional pattern studies using the same antenna model and software to be completed by simulation
- Must cross-reference the original submission by providing the application file number

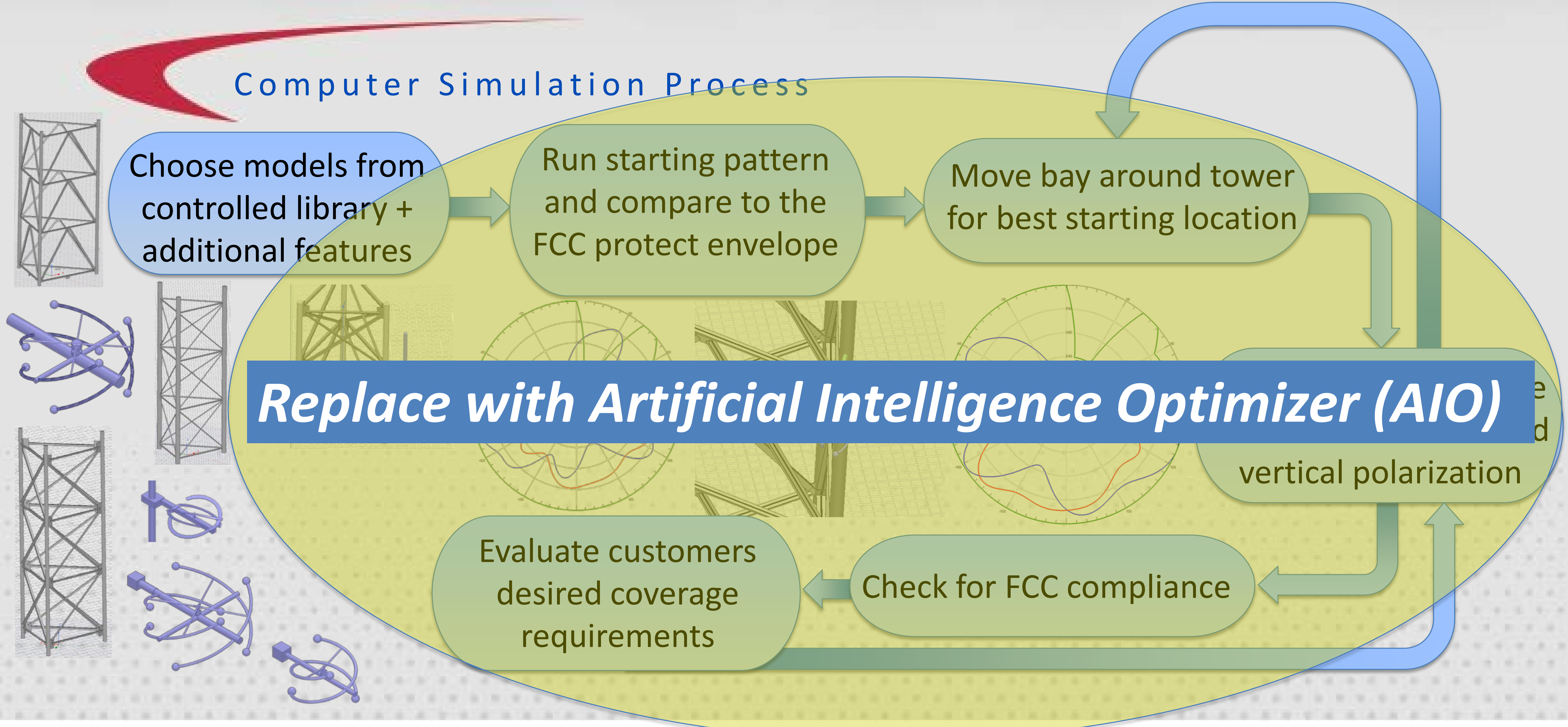
The Use of Simulation for FM DA Pattern Studies

- Petition based on the many benefits simulation has over traditional range measurements
  - Cost advantage, reflection free environment, mechanical tolerancing, human error, complete optimization, time constraints, standardization, quality, reproducibility……





Computer Simulation Process



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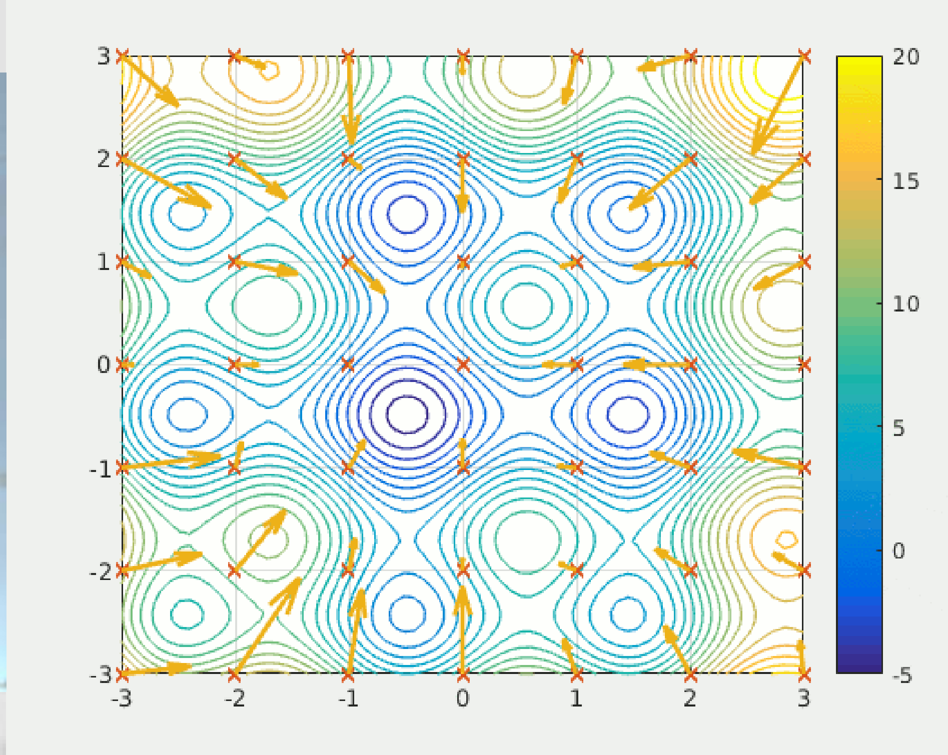
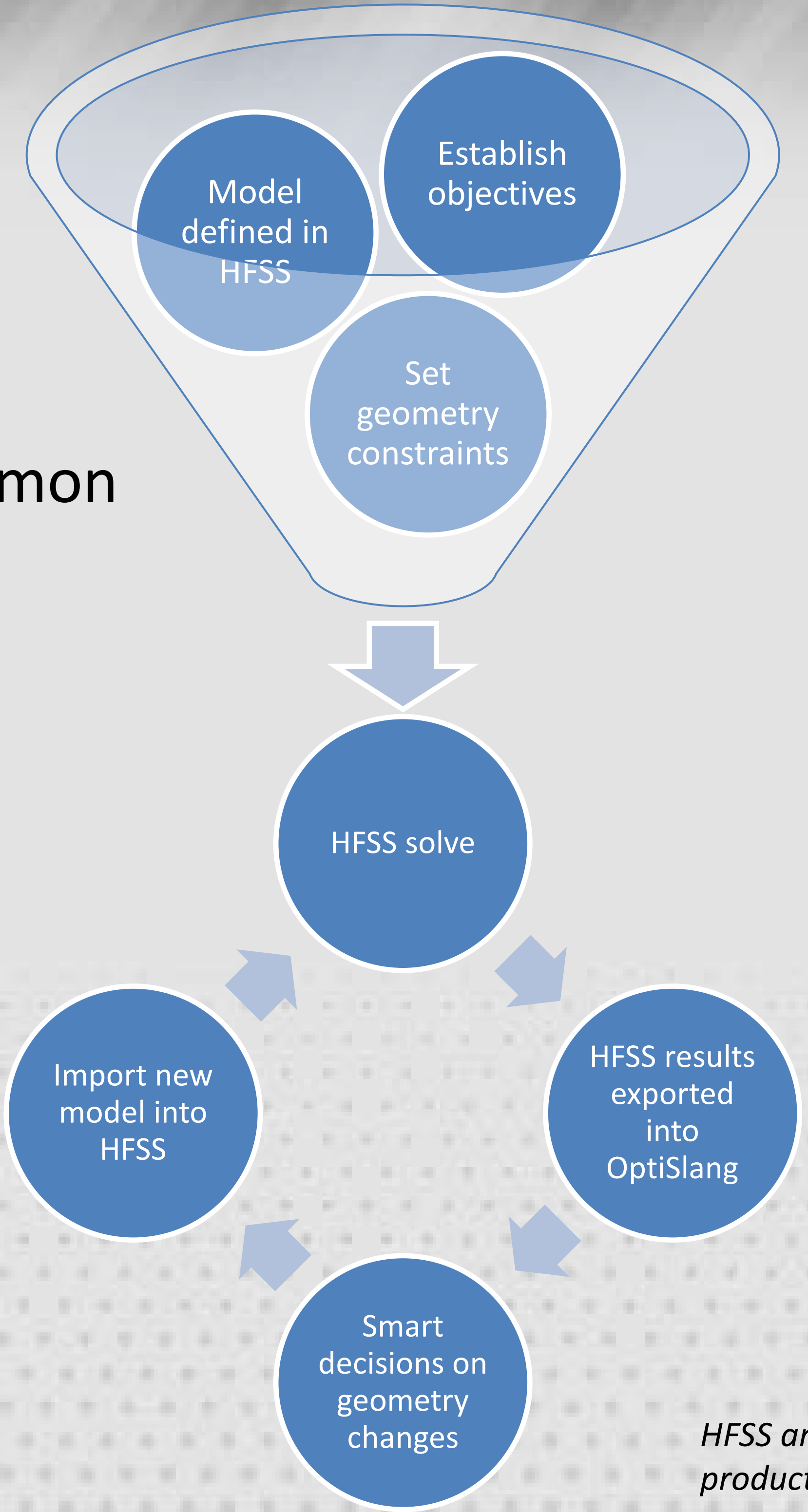
Pattern Study – AI Optimization(AIO)

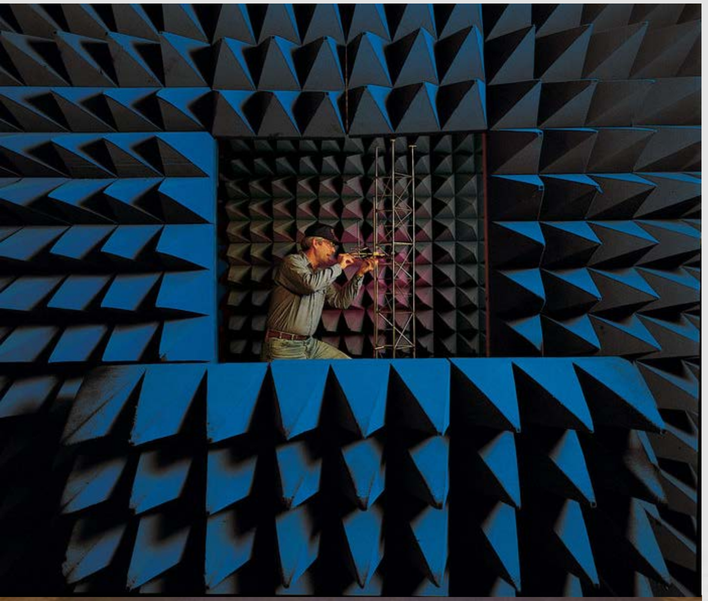
- Process modeled after how bees swarm and converge to a common location (Particle Swarm Optimization Theory)
- Intelligent decision making outside of the simulation software



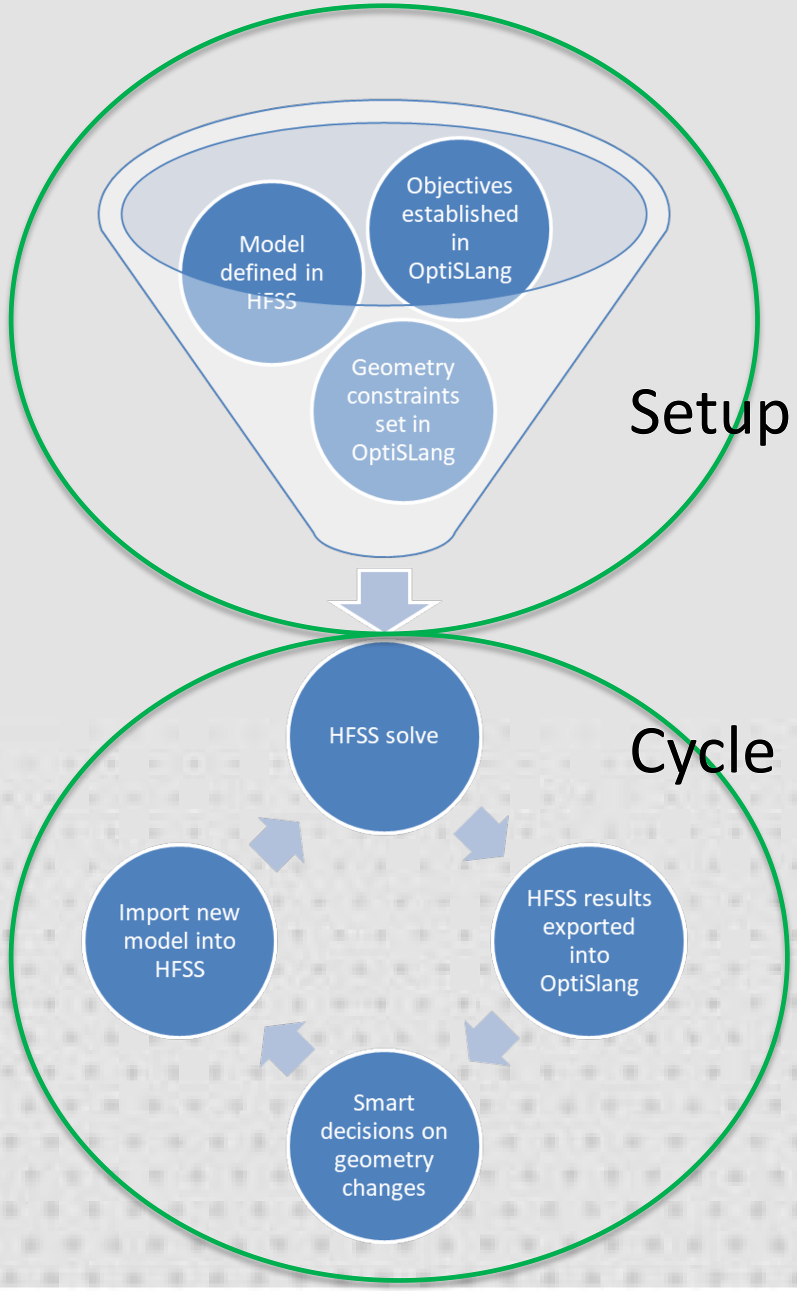


HFSS and OptiSLang are products of Ansys Inc.

AIO Lead Time Improvement

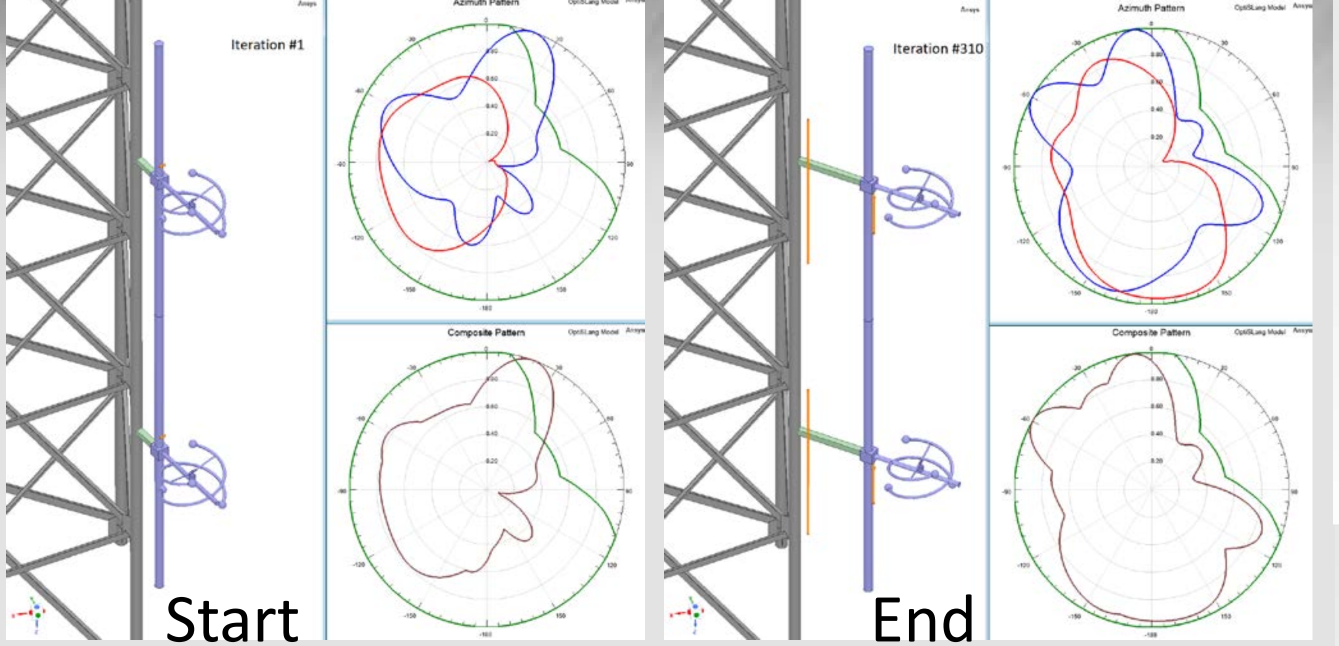


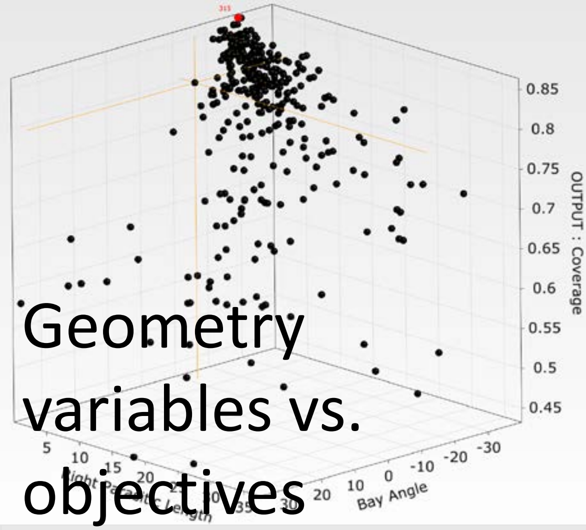
- Range (4.4:1 scale model range)
  - 4 hr. Setup time
  - 1 Pattern every 20 min
  - 1 Week range time
  - Total lead time = 5 days
  - 120 Iterations
  - Tech hours = 80
- AIO
  - 1 hr. Setup time
  - 20-30 hr. Cycle time
  - 300-400 Iterations
  - Total lead time = 2 days
  - Tech hours =1



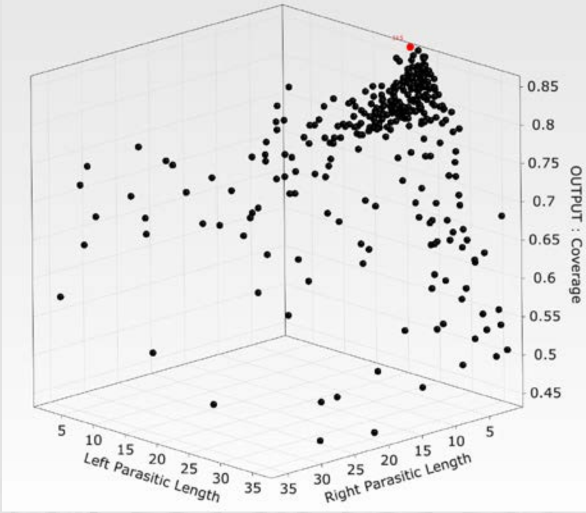
FM-AIO

HPOL – Blue
VPOL – Red
FCC Protect – Green
Composite - Brown

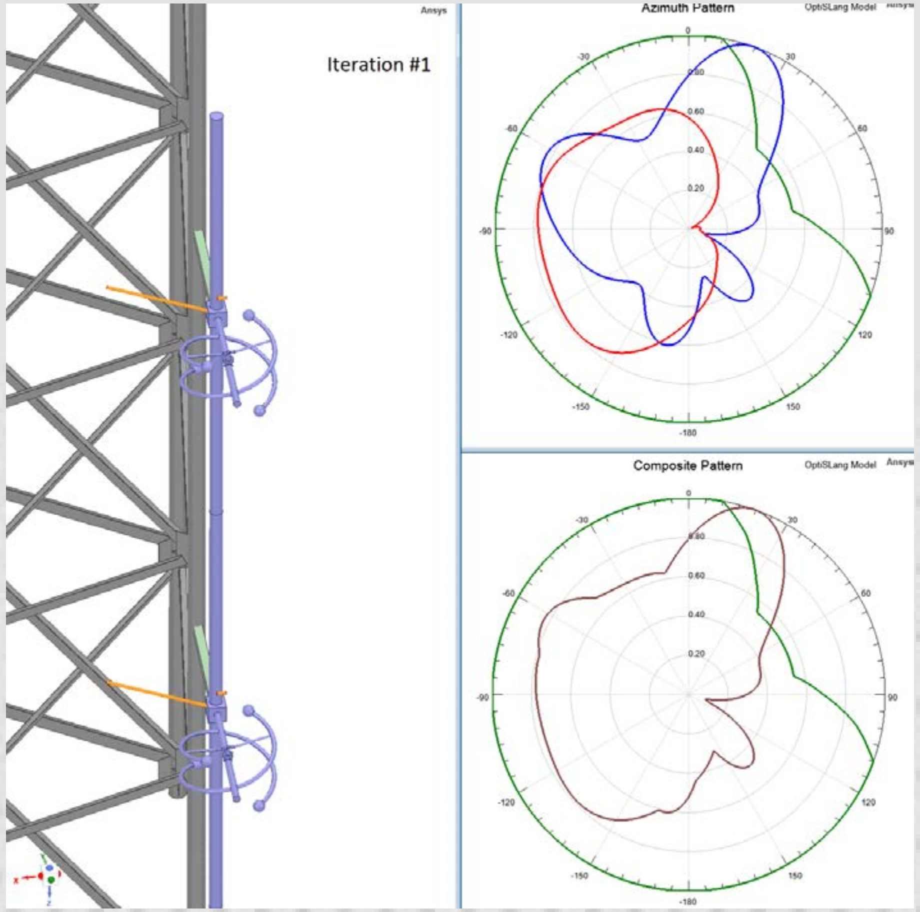


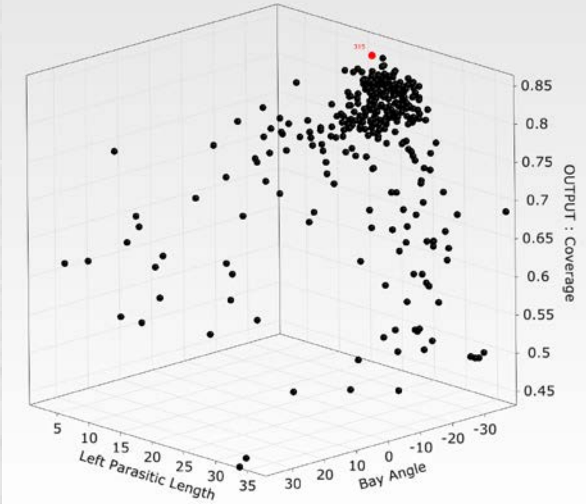


Geometry variables vs. objectives



- AIO Example
  - C- Bay on a 6 ½’ tower
- 310 Iterations
- First 100 iterations are very erratic
  - Geometry variables spread out
  - “Bees looking for a direction”
- Last 50 iteration have small changes
  - Geometry variable beginning to cluster
  - “Bees now swarming”
- Optimization completed in 21 hrs.





Conclusions

- The new FM Pylon broadcast antenna is unique
- Utilizes all the advantages that pylon technology has brought to UHF and VHF broadcasters for decades
  - Low windload
  - Simplicity – Less parts / connections – Increased reliability
  - Azimuth and elevation pattern flexibility
- Broadband and working towards full band operation
- Cost effective, simple alternative to FM element arrays as well as complicated panel antennas

- How we are preparing for the FCC ruling to allow simulation for FM pattern verification
  - The use of AIO will automate the simulation process
  - Adding a new level of efficiency and accuracy

THANKS FOR YOUR TIME!

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