KJ6ER Antennas Primer

PERformer Quarterwave
with 2 Elevated Radials

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KJ6ER
Extra-Class
Amateur Radio Operator

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KJ6ER Antennas

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Dominator Halfwave on
a Wide-Angle Tripod

Welcome! I am **Greg Mihran** (*mear’-on*)

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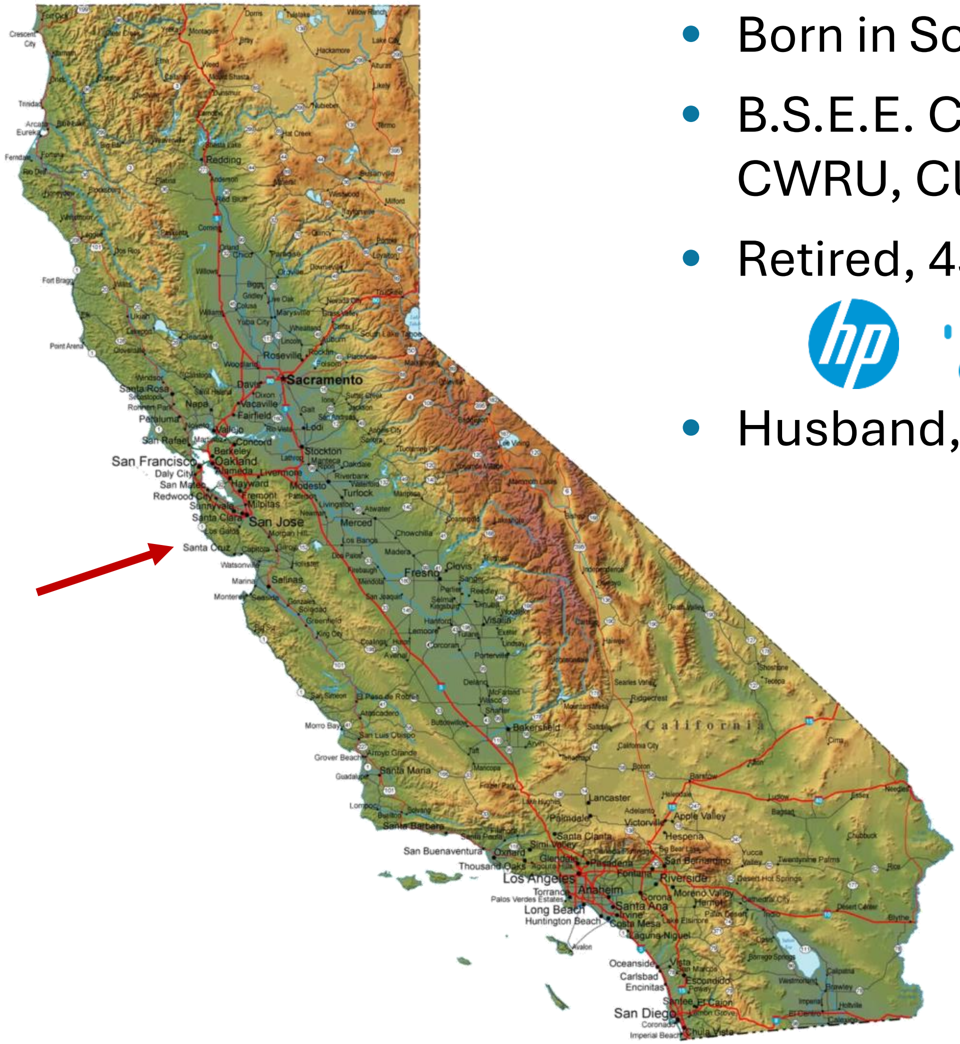

- Born in Schenectady, New York
- B.S.E.E. Case Institute of Technology, CWRU, Cleveland, Ohio
- Retired, 45 years in Silicon Valley

  hp cisco flex + *Start-Ups*
- Husband, 5 grown kids, 5 grandchildren

POTA PARKS ON THE AIR

900+ Activations
70K+ SSB QSOs

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KJ6ER Antennas Content Always Available in the Cloud

Contact me if you would like to be added to my antenna geeks email list!

Google Cloud Drive File Links (KJ6ER):

- **KJ6ER Antennas Primer –**
  https://drive.google.com/file/d/1MxEQ0CfcLBhZ-TKTMg2xiMZeGdjsKnBN/view
- **PERformer 40M-6M Quarterwave Vertical –**
  https://drive.google.com/file/d/1LwSbXXeovjJdT8ijpOi-9FYR--nNsxgD/view
- **Challenger 20M-6M Halfwave Vertical –**
  Coming soon!
- **Dominator 17M-10M Halfwave Vertical –**
  https://drive.google.com/file/d/1o1QYlNhYp-JY_Azqn0XJWM7q7Tit0x1m/view
- **Dominator 17M-10M Halfwave 2-Element Vertical Beam –**
  https://drive.google.com/file/d/1-DvVBdEbcXjrCu5khyLeoEp5gsb9wwlA/view

Always Free PDFs for the Amateur Radio Community!

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Appreciate Antenna Theory, But Really a Hands-On Pragmatist

- Begin with basic **theory** but quickly evolve to **computer modeling**
- Spend countless hours in my **backyard** *antenna proving ground*
- Put them to the test at **POTA activations** for real world analyses

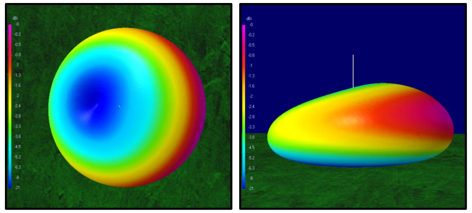
Theory → **Modeling** → **Backyard** → **POTA Parks**

Theory
(Math, Physics)

$$
\begin{aligned}
&= \frac{x^2}{2}\arctan x\Big|_0^{\frac{\pi}{4}} - \frac{1}{2}\int_0^{\frac{\pi}{4}} \frac{x^2}{x^2+1}\,dx \\
&= \frac{(\frac{\pi}{4})^2}{2} - \frac{1}{2}\int_0^{\frac{\pi}{4}} 1 - \frac{1}{x^2+1}\,dx \\
&= \frac{\pi^2}{32} - \frac{1}{2}(x - \arctan x)\Big|_0^{\frac{\pi}{4}} \\
&= \frac{\pi^2}{32} - \frac{1}{2}\left(\frac{\pi}{4} - 1\right).
\end{aligned}
$$

5% of my time

Modeling
(4NEC2, EZNEC)



15% of my time

Backyard
(Campbell, CA)

80% of my time

POTA Parks
(California)

Real-World Evaluation

★ Antenna Users
(Over 2,000 Worldwide)

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Portable Antenna Plans Sharing Platform & Design Principles

- Develop **antenna plans** with model graphics, parts list, instructions and metrics
- Share ***free* PDF-format** plans broadly with global amateur radio community
- Highly **interactive** with users to answer questions and collect feedback

3 Design Principles:

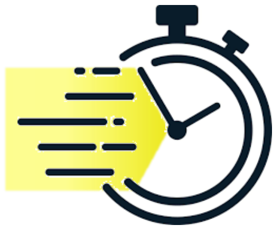
1 

Highly Efficient & Effective

(Resonant, One-Band-at-a-Time)

90% efficient or more

Performance

2 

Fast & Simple Deployment

(Set-up and Take-down)

5 minutes or less

Elegance

3 

Easy to Pack & Transport

(Backpack, Picnic Table, HOA)

5 pounds or less

Convenience

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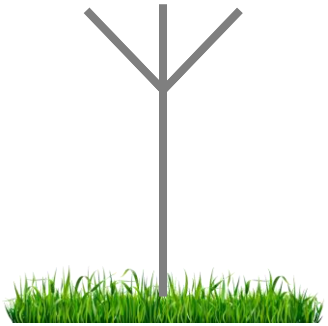
Understanding a Few Antenna Fundamentals

(*Keeping it High-Level*)



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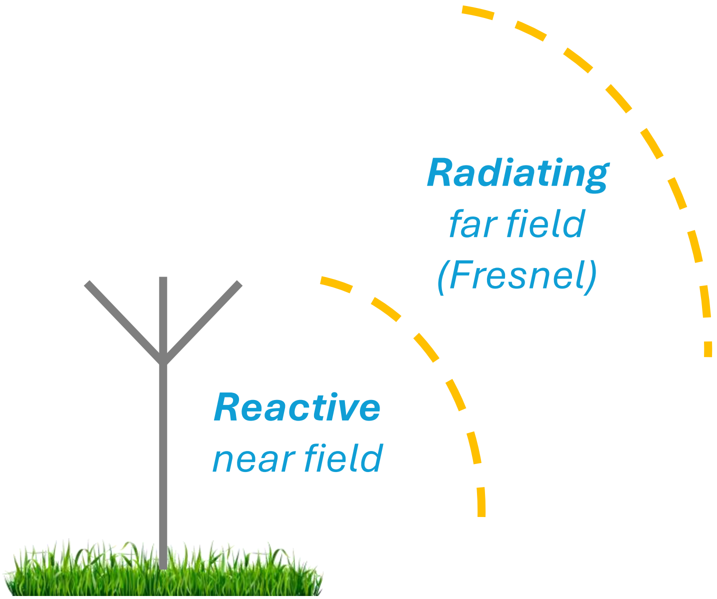
Field Regions Around an Antenna



The effects of the ground and the *artificial* ground system are twofold:

- Near the antenna (in the *reactive near field*), you need a good ground system to **collect the antenna return currents without losses**. This will determine the **radiation efficiency** of the antenna.
    - ✓ Operators have *reasonable control* over the radiation efficiency.
- At distances farther away (in the *radiating far field*, the *Fresnel zone*), the wave is reflected from the earth and combines with the direct wave to generate the overall radiation pattern. The absorption of the reflected wave is a **function of the ground quality and the incident angle**. This determines the **reflection efficiency**.
    - ✓ Operators have *limited control* over reflection efficiency.

Source: ON4UN, John Devoldere & DJ2YA, Uli Weiss (2010)

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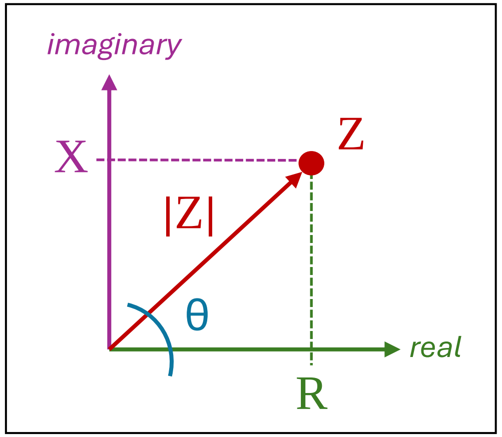
Understanding Antenna Impedance (Complex Number)

Impedance $Z = R \pm j\,X$ (ohms)

R = Resistance (real number)

$j = \sqrt{-1}$ (imaginary number)

X = Reactance (inductance, capacitance)



- Impedance Z (x, y point)
- Resistance R (real, x-axis)
- Reactance X (imaginary, y-axis):
  (+) inductive, (-) capacitive
- Impedance Magnitude:
  $|Z| = \sqrt{(R^2 + X^2)}$
- Phase $\theta = \arctan(X / R)$

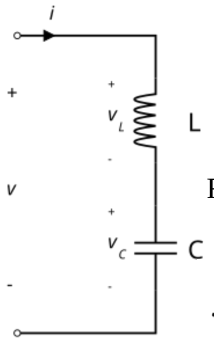
Inductors and capacitors introduce a *phase shift* between voltage and current but *do not* dissipate energy:

$X_{Inductor\ (L)} = 2\pi f L$, where L = Inductance (*henrys*) > current lags

$X_{Capacitor} = -1 / 2\pi f C$, where C = Capacitance (*farads*) > current leads

- Relates the sinusoidal voltage V to the current I at the input to an antenna and varies with *frequency*.
- Consists of two components:
  - ✓ Resistance R (*real*) represents power that is either *radiated* away or *absorbed* within the antenna.
  - ✓ Reactance X (*imaginary*) represents *non-radiated* power stored in the near field of the antenna.
- For a 50Ω transmission line (coax), *perfect* impedance is purely resistive: $Z = 50 + j\,0$, where the voltage is in-phase with the current. This is considered a **resonant** antenna.
- If impedance is purely imaginary: $Z = 0 + j\,50$, the voltage leads the current by 90 degrees. This is considered a **very bad** antenna.

Antenna as a Series RLC Network

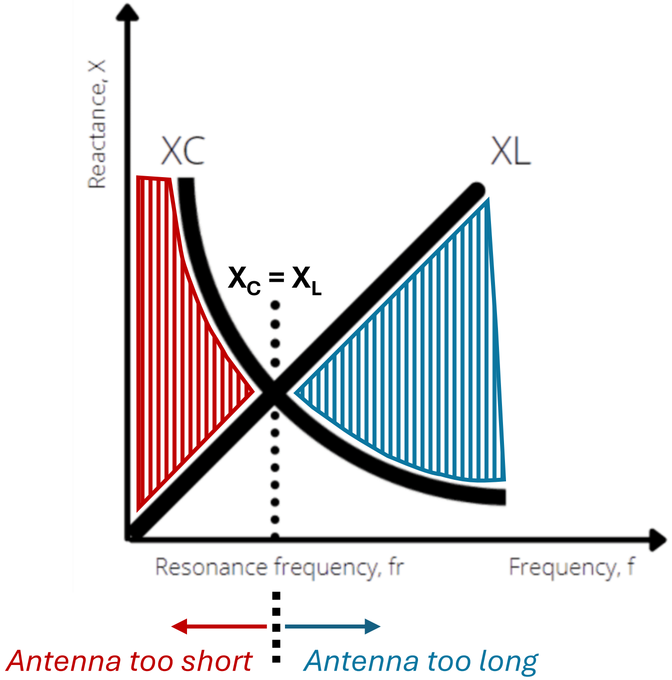


$$V = V_L + V_C,$$
$$I = I_L = I_C.$$

Resonant frequency (f_0):

$X_L = X_C$

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$$



- An antenna can be thought of as a **complex resistance, inductance and capacitance** (RLC) network in *series*. At some frequencies, it will appear like a *capacitive* reactance (X_C), while at others, like an *inductive* reactance (X_L). At the **resonant** frequency, these reactances will be equal in magnitude, but opposite in influence, canceling each other out. At **resonance**, the impedance is at its minimum being purely **resistive** *(real,* $Z = R + j X$*, where* $j X = 0$*)* and **efficiency** (current in the circuit = I) is at its maximum.

- When an antenna is not at its resonant length, the voltage source (V) will see something other than pure resistance (R). In this case, the impedance is now **complex** which includes reactance (X):

✓ If the antenna is too short, capacitive reactance (X_C) is present. To resolve this imbalance, *inductance* is added to offset capacitance.

✓ If the antenna is too long, inductive reactance (X_L) will be present. To resolve this imbalance, *capacitance* is added to offset inductance.

Radiation Resistance (R_{rad}) and Loss Resistance (R_{loss})

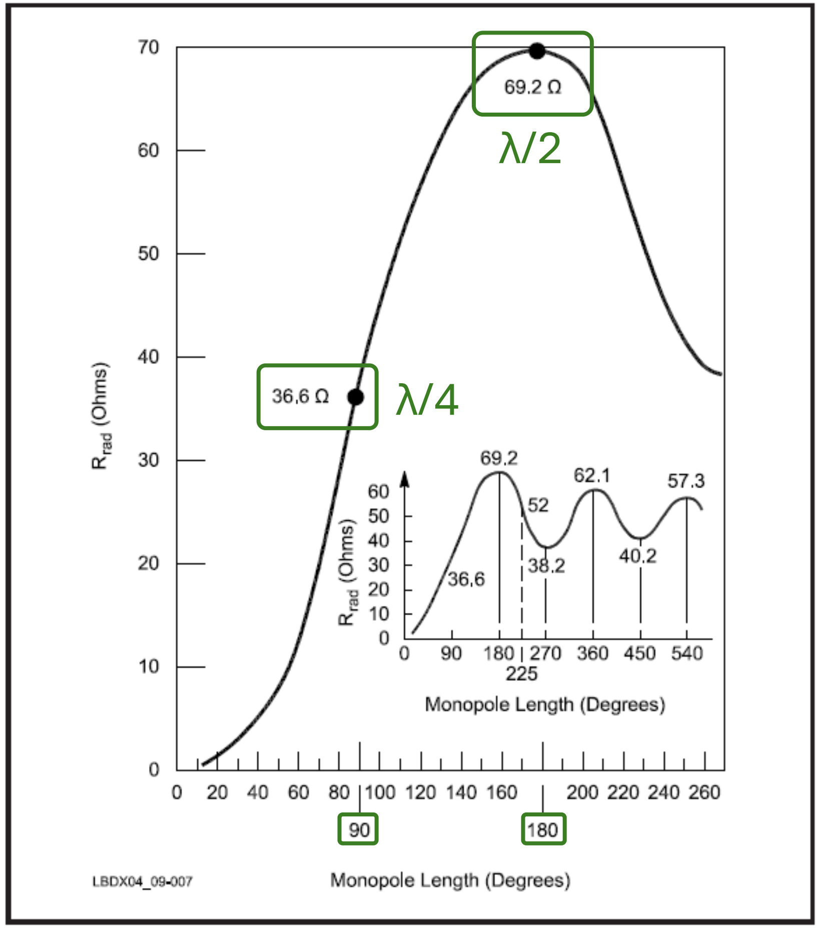
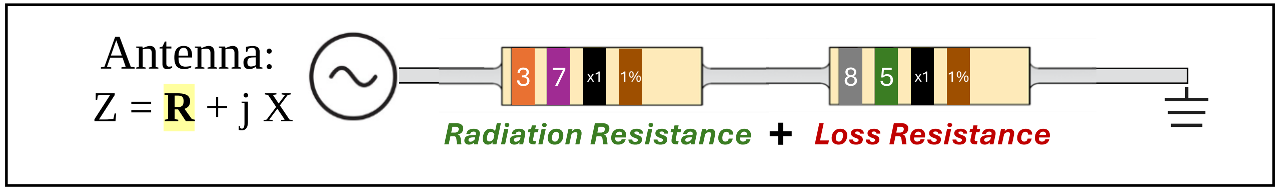


Fig 9-7—Radiation resistances ($R_{rad(I)}$), at the current maximum) of monopoles with sinusoidal current distribution. The chart can also be used for dipoles, but all values must be doubled.



***Resonance** when Reactance (X) = 0*

- **Radiation resistance** (R_{rad}) is the total power radiated as electromagnetic waves in all directions – ***productive energy***.
- **Loss resistance** (R_{loss}) includes conductor RF resistance, losses of insulators and loading elements, ground losses of the antenna current return circuit and ground absorption in the near field – ***wasted energy***.
- **Radiation efficiency** (Eff%) is dependent upon the sum of the radiation resistance (R_{rad}) of the antenna in series with the loss resistance (R_{loss}). These make up the **resistive (R)** part of the feed-point impedance.

$$\text{Eff\%} = \frac{R_{rad}}{R_{rad} + R_{loss}} \times 100\%$$

→ Goal: *minimize* R_{loss}

R_{rad} converted to radio waves (*productive*)
R_{loss} converted to heat (*wasted*)

Source: ON4UN, John Devoldere & DJ2YA, Uli Weiss (2010)

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Loss Resistance (R_{loss}) Components

$$\text{Eff} = \frac{R_{rad}}{R_{rad(B)} + R_{loss}} \qquad \text{(Eq 9-4)}$$

The loss resistance of a vertical is composed of:

Ohmic
- Conductor RF resistance
- Parallel losses from insulators
- Equivalent series losses of the loading element(s)

Ground
- Ground losses part of the antenna current return circuit
- Ground absorption in the near field

Ohmic losses **within the antenna:**

- **Conductor RF *resistance*** includes the conductivity of the antenna components used.
- ***Losses* from base insulators** including dielectric material losses at high voltage points.
- **Equivalent series *losses* of loading element(s)** providing inductance (coils) and capacitance (hat).

Ground losses **associated with the nearby soil:**

- **Ground losses through the antenna return circuit** include antenna return currents that *travel through the ground and back to the feed point*, right at the base of the antenna impacted by *resistivity ρ (Ω-m)* of the soil.
- **Ground absorption in the near field** includes the *conductivity σ (mS/m)* and the *dielectric properties of* the ground that determine absorption losses, caused by an electromagnetic wave penetrating the ground.

Unless the vertical antenna uses *elevated radials*, **return current will flow through the *lossy* ground**.

Source: ON4UN, John Devoldere & DJ2YA, Uli Weiss (2010)

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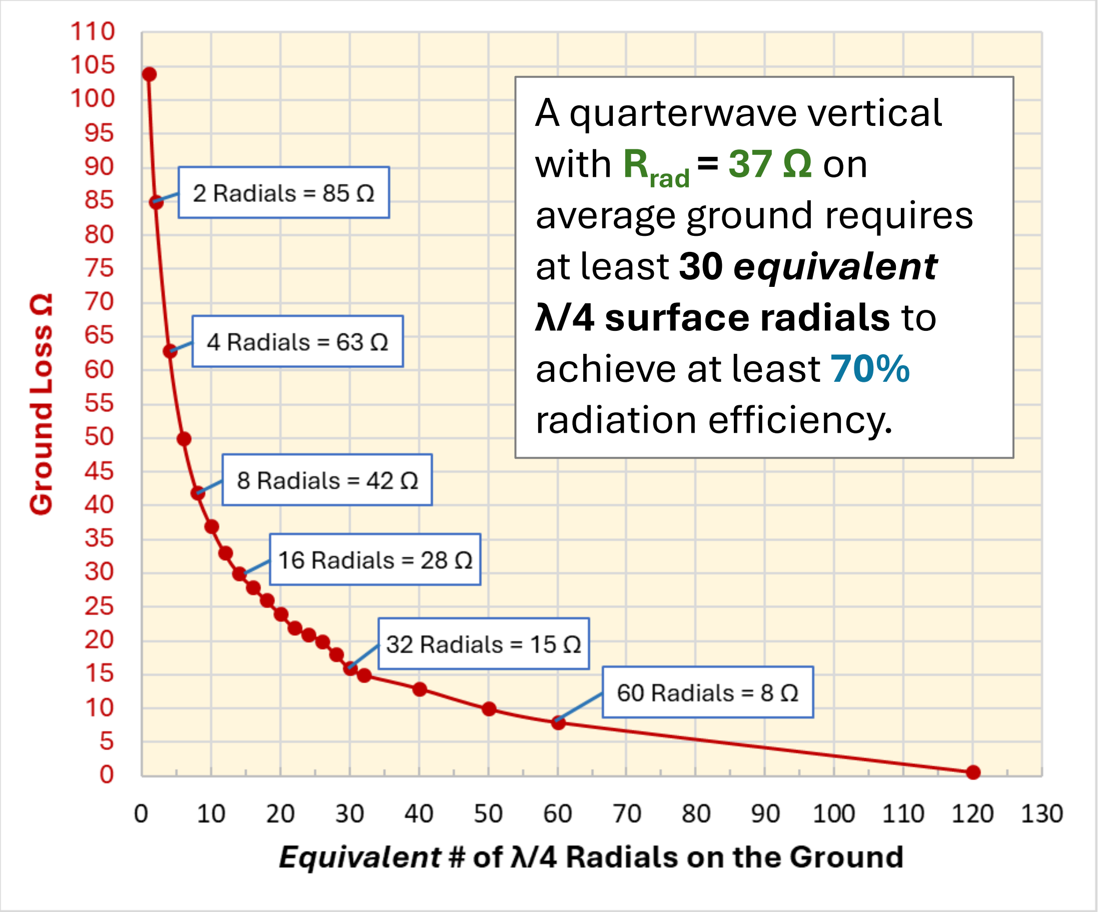
Loss Resistance (R_{loss}) of *Ground* Radials

# of λ/4 radials	Ground Loss Ω	λ/4 Vertical Efficiency
1	104	26%
2	85	30%
4	63	37%
6	50	43%
8	42	47%
10	37	50%
12	33	53%
14	30	55%
16	28	57%
18	26	59%
20	24	61%
22	22	63%
24	21	64%
26	20	65%
28	18	67%
30	16	70%
32	15	71%
40	13	74%
50	10	79%
60	8	82%
120	0.6	98%



Loss Resistance = *Measured Feedpoint Resistance - Calculated* ***Radiation Resistance***

- If only **two λ/4 radials** are used, the **R_{loss} = 85 Ω**. Given **R_{rad} = 37 Ω** for a quarterwave vertical, the radiation efficiency = 37 Ω / (37 Ω + 85 Ω) = **30%**.
- Using that same efficiency formula for other numbers of λ/4 radials:
  - ✓ 4 radials = **37%** efficiency
  - ✓ 8 radials = **47%** efficiency
  - ✓ 16 radials = **57%** efficiency
  - ✓ 32 radials = **71%** efficiency
  - ✓ 64 radials = **84%** efficiency
- Comparatively, computer models with **2 elevated radials @ 36"** indicate a **R_{loss} ~ 4 Ω**, yielding a radiation efficiency = 37 Ω / (37 Ω + 4 Ω) = **90%**.

Source: KN5L, John Oppenheimer (2013) & G5TM, Tim Hier (2022)

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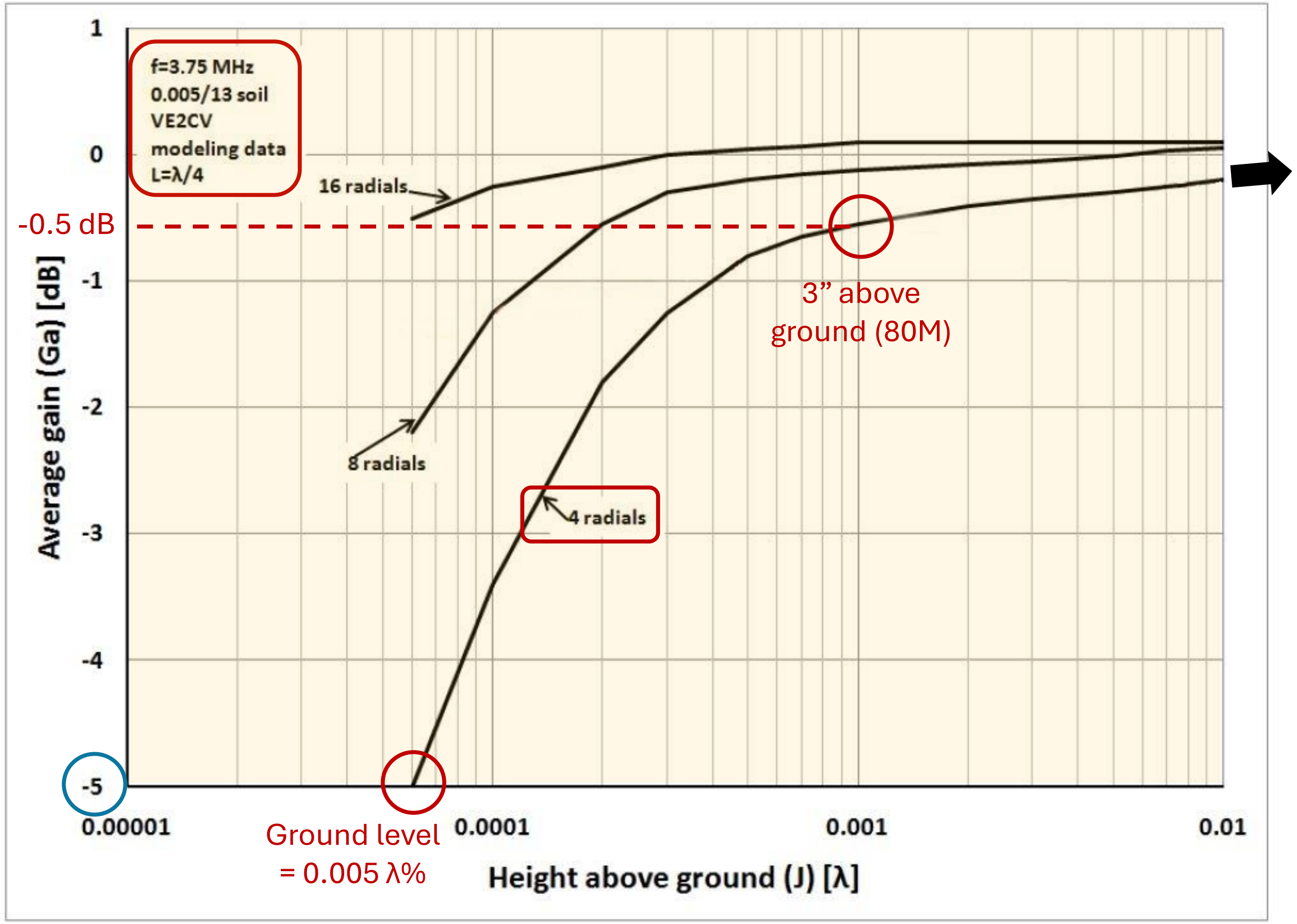
Loss Resistance (R_{loss}) of *Elevated* Tuned Radials



- As the radial height above ground is increased, the loss resistance (R_{loss}) is *significantly* reduced. As tuned radials are elevated above ground, *capacitive coupling* is decreasing as a reciprocal ($C = \epsilon_o A / d$).
- Even a very small increase in radial height above ground will make a large difference in loss *(inversely proportional)*, especially if number of radials is small.
  - ✓ **Four 80M ground radials at 0.005% λ** above ground (*laying on the ground, ~.02"*), there is *at least* **-5 dB loss** of potential gain.
  - ✓ Raising those same **4 radials to 0.100% λ** above ground (3.0" for 80M), the loss is reduced to just **-0.5 dB** of potential gain.
- Based upon my field testing, I recommend *at least* **2% λ** radial elevation or, *if possible*, **5% λ** radial elevation above ground (>39" on 20M).

Source: N6LF, Rudy Severns (2010)

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4 *to* 64 *Ground* Radials versus 4 *Elevated* Radials

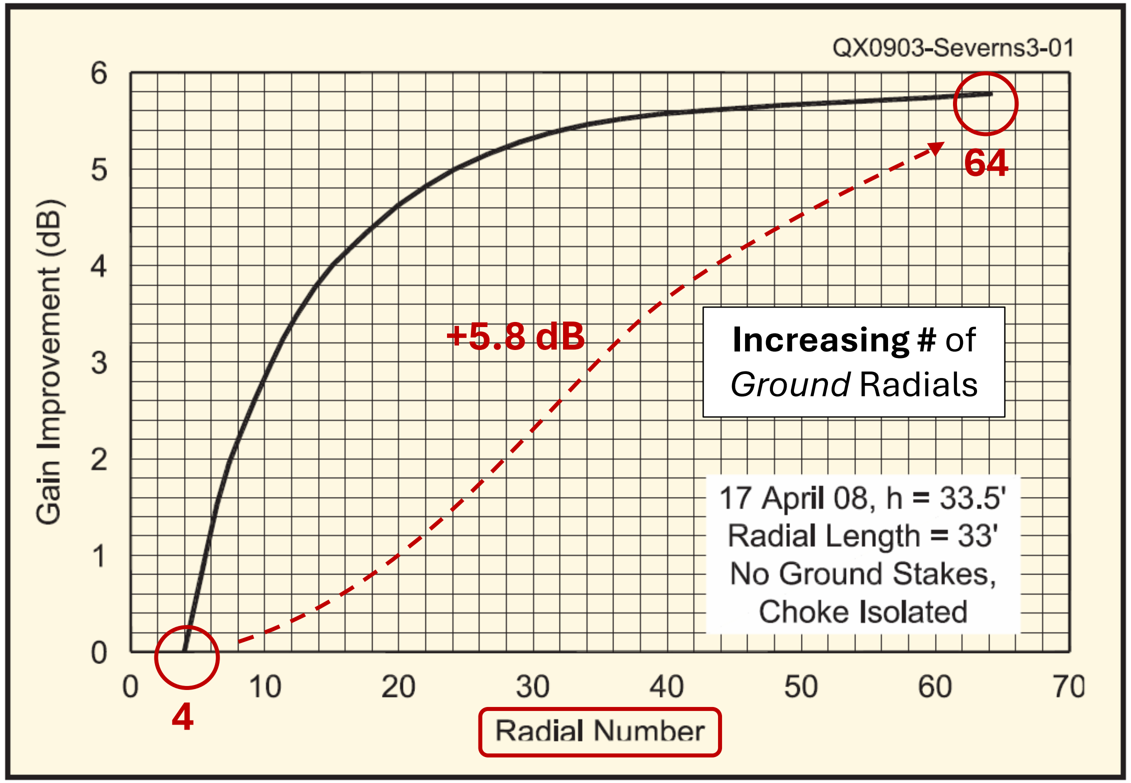

Figure 4 — Signal improvement as a function of radial number. All radials lying on the ground surface, F = 7.2 MHz.

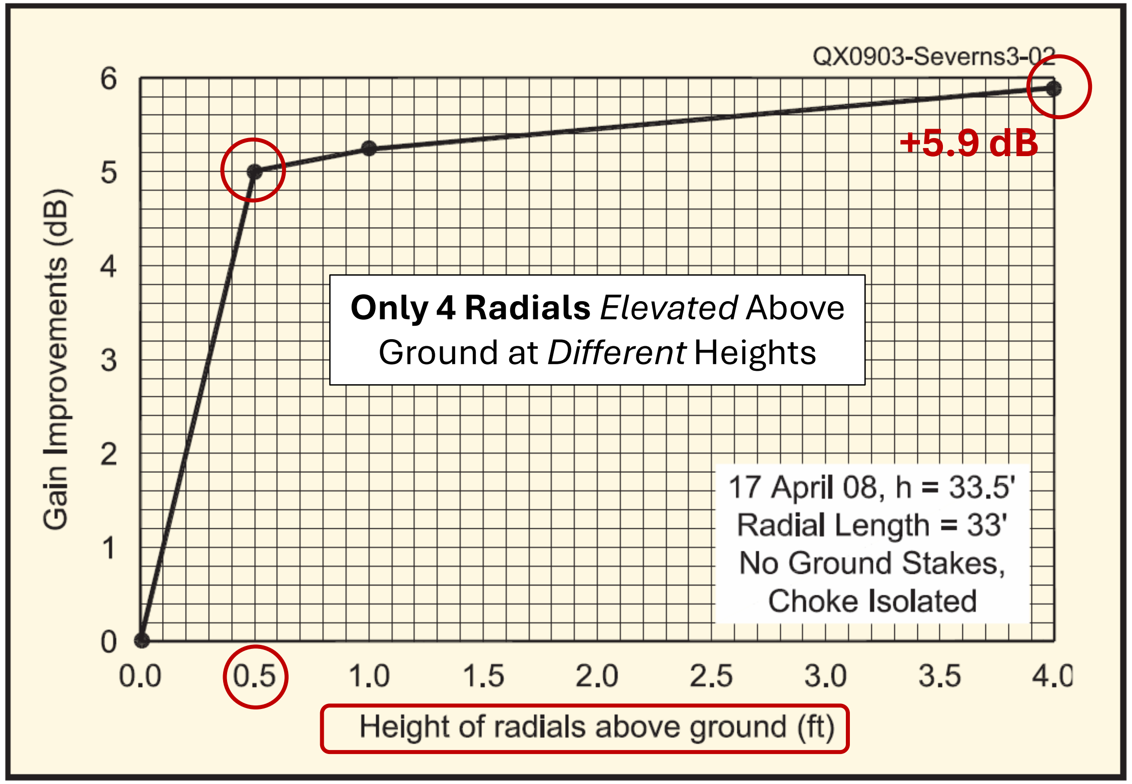

Figure 5 — Signal improvement with four radials and the antenna base at different heights. F = 7.2 MHz.

- **0 dB point is *normalized*** to the signal strength of **four λ/4 radials** lying on the surface (0 dB).
- **4 elevated radials at a height of 4 feet** are *equivalent* to **sixty-four λ/4 radials** lying on the ground.

Source: N6LF, Rudy Severns (QST, 2010)

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Antenna Return Current Paths

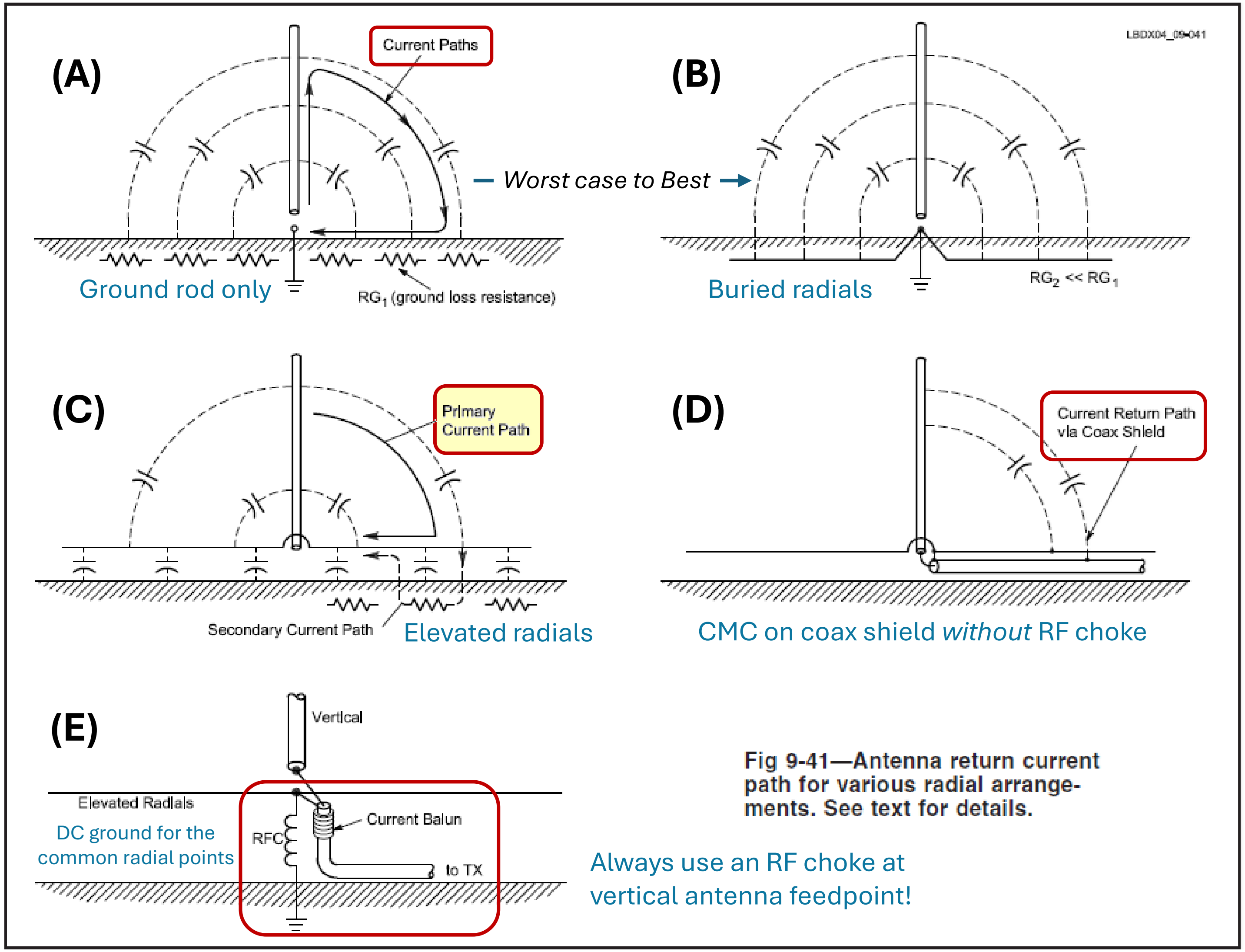

Fig 9-41—Antenna return current path for various radial arrangements. See text for details.

(A) **Using only a ground rod** forces return currents to travel entirely through lossy soil resulting in *very low* radiation efficiency.

(B) **Buried radials reduce losses** improving efficiency through low-loss radial conductors in the ground.

(C) **Two elevated radials** resulting in 2 current return paths: *lossless* path through radials and *potentially lossy* capacitive path through soil. Raising radials higher (5% λ) *dramatically* reduces capacity to lossy soil.

(D) **Unwanted common mode currents** (CMC) flow on the *coaxial shield* as a *random length radial* resulting in lower efficiency.

(E) **Current balun and/or RF choke** at feedpoint *significantly* alleviates unwanted common mode currents on coax shield.

Source: ON4UN, John Devoldere & DJ2YA, Uli Weiss (2010)

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Ground Mounting versus Elevated Mounting: Efficiency

Ground Mounting

Advantages

- ☑ The radials are non-resonant so one length (.1 wl minimum at lowest frequency) works on all frequencies
- ☑ Easy to mount
- ☑ Easy access
- ☑ Lower visual profile
- ☑ Sixteen 0.25 wl (wavelength) radials of lowest intended frequency give 55%-60% efficiency

Disadvantages

- ☒ Takes 120 radials to equal an elevated vertical with 2 resonant radials (90% efficiency)
- ☒ Surrounding objects can reduce signal strength

Elevated Mounting

Advantages

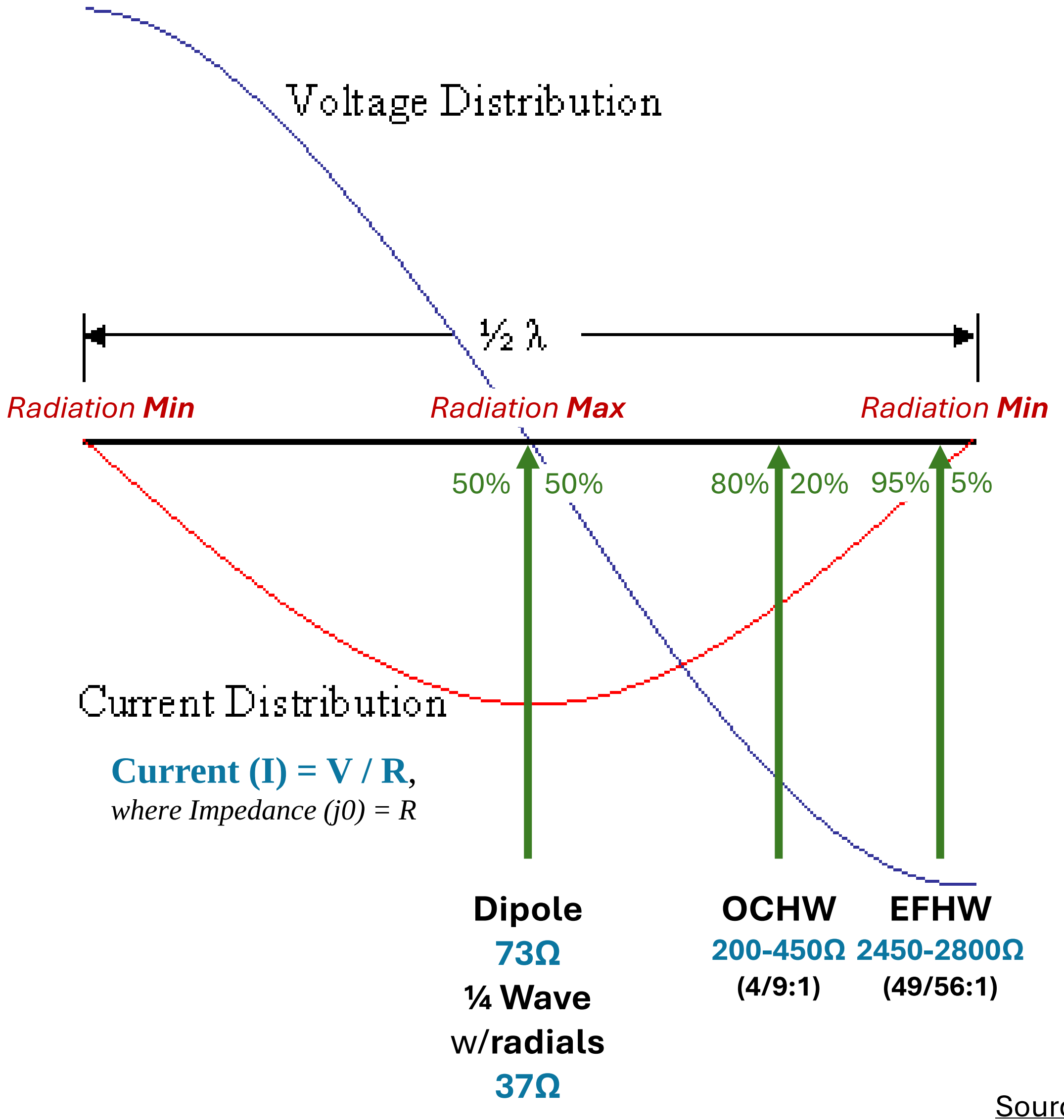
- ☑ >90% efficient with two .25 wl radials
  → PERformer efficiency avgs **90.8%** from 20M-6M
- ☑ Antenna is generally more "in the clear", so surrounding objects don't cause as much attenuation
- ☑ A peaked metal roof will make a very good all-frequency radial system
- ☑ Contrary to conventional wisdom the vertical doesn't have to be elevated very high, 6 inch-es elevation results in much lower losses, even on 80m— 5 feet is just fine for 80m (2%λ)
  → PERformer elevated radial end height ranges from **5% λ** on 20M to **16% λ** on 6M

Disadvantages

- ☒ Mounting is generally more involved
- ☒ Requires two .25 wl radials (minimum) for each band of operation (radials interact, so spacing will affect length)
- ☒ Visually higher profile
- ☒ Must be mounted high enough so that people or animals will not accidentally make contact with the radials
- ☒ Elevating lowers the impedance so radials may need up to a 30 degree downward slope to achieve a reasonable match → PERformer droop angle = **5º - 22º**

Source: K7IR, Mike Mertel (2010)

Why Elevating ¼ Wave Radials Is Important – RF Current!



- When RF energy is applied to a halfwave antenna at its **resonant frequency**, a **standing wave** is created with both current and voltage 90° out of phase.
- **Current maximum *(radiation max)*** is at center of halfwave with low impedance (70Ω), **voltage maximum *(radiation min)*** is at ends with high impedance (1000sΩ).
- **High current in the ¼ wave radials** is radiated when *elevated* or is absorbed in earth when *laying* on the ground. Radials are the other half of ¼ wave antenna!
- **Much *less current*** in OCHW counterpoise (*high voltage*) and ***negligible current*** in EFHW counterpoise. As a result, these do not need to be elevated for efficiency.

Source: AA5TB, Steve Yates (2010)

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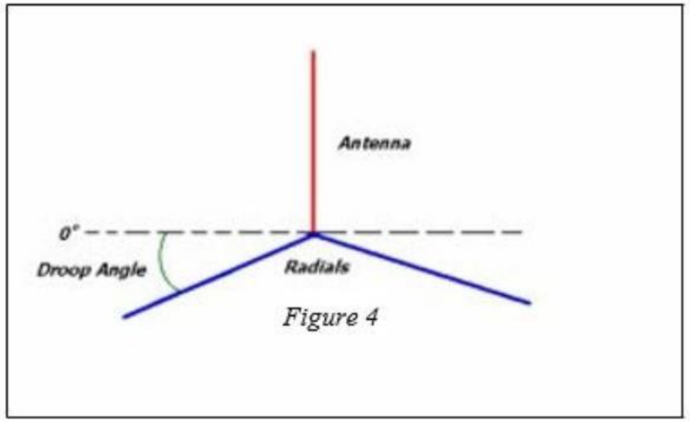
Elevated Radials and the Droop Angle



Radial Droop Angle	=	Antenna Impedance
0°	=	22 Ohms
10°	=	28 ohms
20°	=	35 ohms
30°	=	47 ohms
40°	=	53 ohms
50°	=	55 ohms

Note: above 50° results in diminishing returns

- As radials are elevated, the capacitive coupling losses go down dramatically. In fact, two elevated λ/4 radials have a loss resistance of *a few ohms* **~4 Ω** versus ground λ/4 radials with a loss resistance of **85 Ω**.
- Thus, **Eff%** = **37 Ω** / (**37 Ω** + **4 Ω**) = **90%** efficiency with 2 *elevated* radials, and **Eff%** = **37 Ω** / (**37 Ω** + **85 Ω**) = **30%** efficiency with 2 *ground* radials. When 100W is applied to these antennas, delta dB increase = 10 x log (90 watts / 30 watts) = **+4.8 dB gain**!
- Elevated tuned radials will lower the resistive impedance of the antenna due to their lower loss resistance. To raise impedance closer to 50 Ω, the elevated radials can be ***drooped*** or *angled downward slightly*.
- If *droop angle* cannot be angled downward enough, **antenna element can be lengthened up to 20% longer** to raise **resistive** impedance but the **radials will need to be shortened** accordingly for resonance. In essence, this can be thought of as **off-center feeding (OCF)** a dipole.

Source: K7IR, Mike Mertel (2010)

Summary of Key Points for a Quarterwave Vertical Antenna

- The ground system (radials) in the *reactive near field* of an antenna *primarily* determines *loss resistance* (R_{loss}) which, when coupled *in series* with the *radiation resistance* (R_{rad}), has a huge impact on *radiation efficiency*: Eff% = R_{rad} / (R_{rad} + R_{loss}) x 100%, → goal is to *minimize* R_{loss}

- The *loss resistance* of ground radials becomes very *significant* when using a small number of λ/4 radials on a quarterwave. Two ground radials have a loss resistance of 85 Ω which yield a radiation efficiency of only 30%. At least 30 ground radials are required to have an efficiency over 70%.

- Elevating radials off the ground *significantly* reduces *loss resistance*. In fact, 120 ground radials are required to equal the >90% *radiation efficiency* of just 2 elevated tuned radials. As radials are raised off the ground, the *loss resistance* drops as the reciprocal of distance (d): *capacitance* = ϵ_o Area / d.

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PERformer Quarterwave Vertical Antenna with *two* **Elevated Tuned Linked Radials**

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PERformer Quarterwave Vertical (**P**ortable, **E**levated, **R**esonant)

PERformer shown with a 40" furniture-grade PVC tube on a **Chameleon™** ground spike.

PERformer shown with a portable 78" **Polarduck™** tripod with very broad and adjustable leg lengths.

- The **PERformer** is a **P**ortable, **E**levated and **R**esonant *quarterwave* vertical antenna for **40M-6M** sitting on a PVC ground spike or tripod with the feedpoint about 4'-5' off the ground and *2* elevated *tuned* linked radials which are placed **90 degrees** apart.
- Computer modeled extensively in 4NEC2 to design and optimize performance. Efficiency averages ***over 90%*** across all six bands with an SWR ***less than 1.10:1*** on each band (20M-6M).
- Designed to be **lightweight** and **easy to deploy** for all types of portable operations. Also used at HOAs and other types of locations that do not allow permanent antenna installations.

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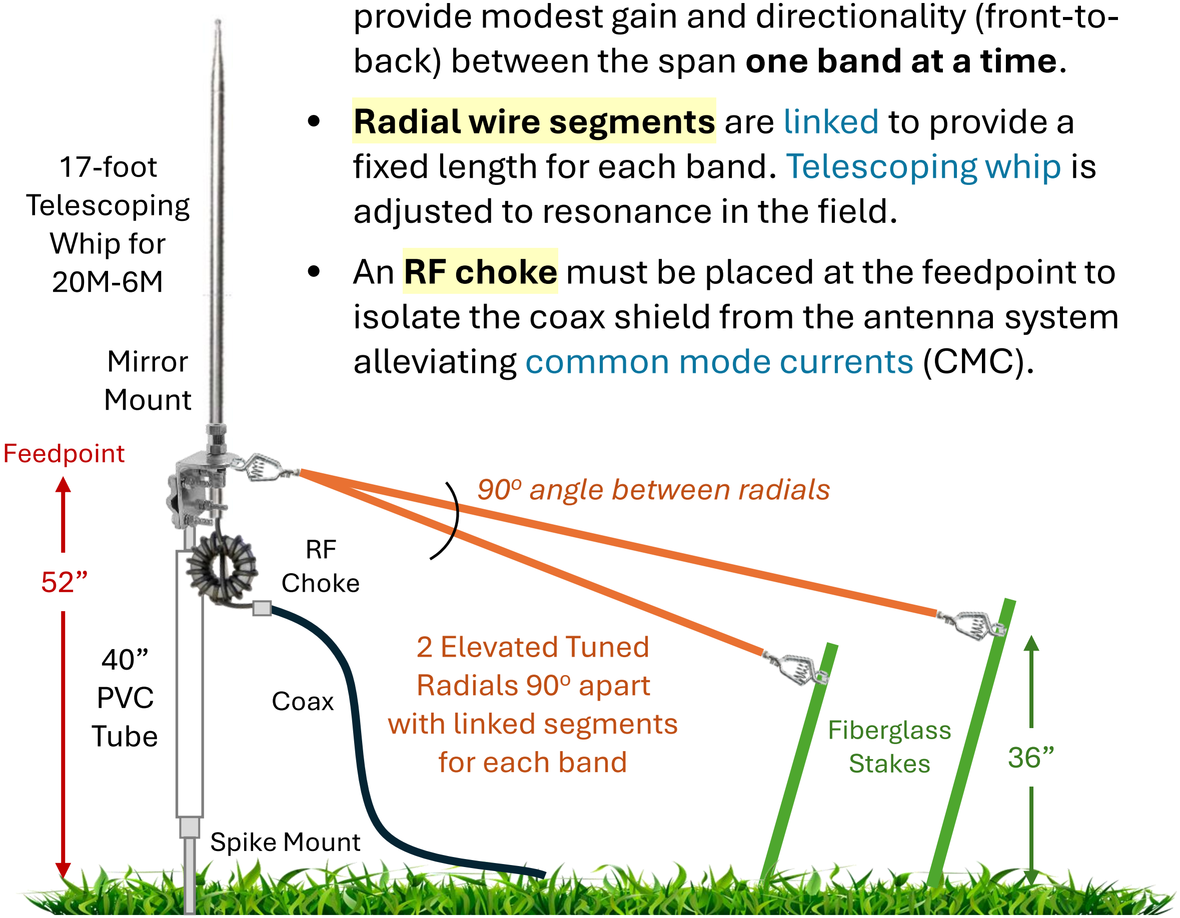
PERformer Vertical with Two Elevated Tuned Linked Radials

- **Two elevated radials** are placed 90º apart to provide modest gain and directionality (front-to-back) between the span **one band at a time**.
- **Radial wire segments** are linked to provide a fixed length for each band. Telescoping whip is adjusted to resonance in the field.
- An **RF choke** must be placed at the feedpoint to isolate the coax shield from the antenna system alleviating common mode currents (CMC).



Antenna System Parts List: *(substitute as desired)*

- Chameleon™ 17' telescoping whip
- WRC™ Sporty Forty coil for 40M operation
- Furniture grade 40" PVC 1" ID (*tripod alternative*) with Chameleon™ spike mount including end caps
- Polarduck™ 78" tripod with widespread, adjustable legs (*PVC alternative*)
- Palomar Engineers™ RF feedline choke at the feedpoint to isolate the coax shield
- Mirror mount with 3/8" x 24 nut to SO-239 stud mounted on a short (6"-8") threaded rod
- BNTECHGO™ bright orange 18-gauge wire radials
- Mueller™ clips to combine 2 radials at feedpoint and at each radial end to attach to end stakes
- Fiberglass 48" end stakes to elevate radials (*must be non-conductive without any interior metal*)

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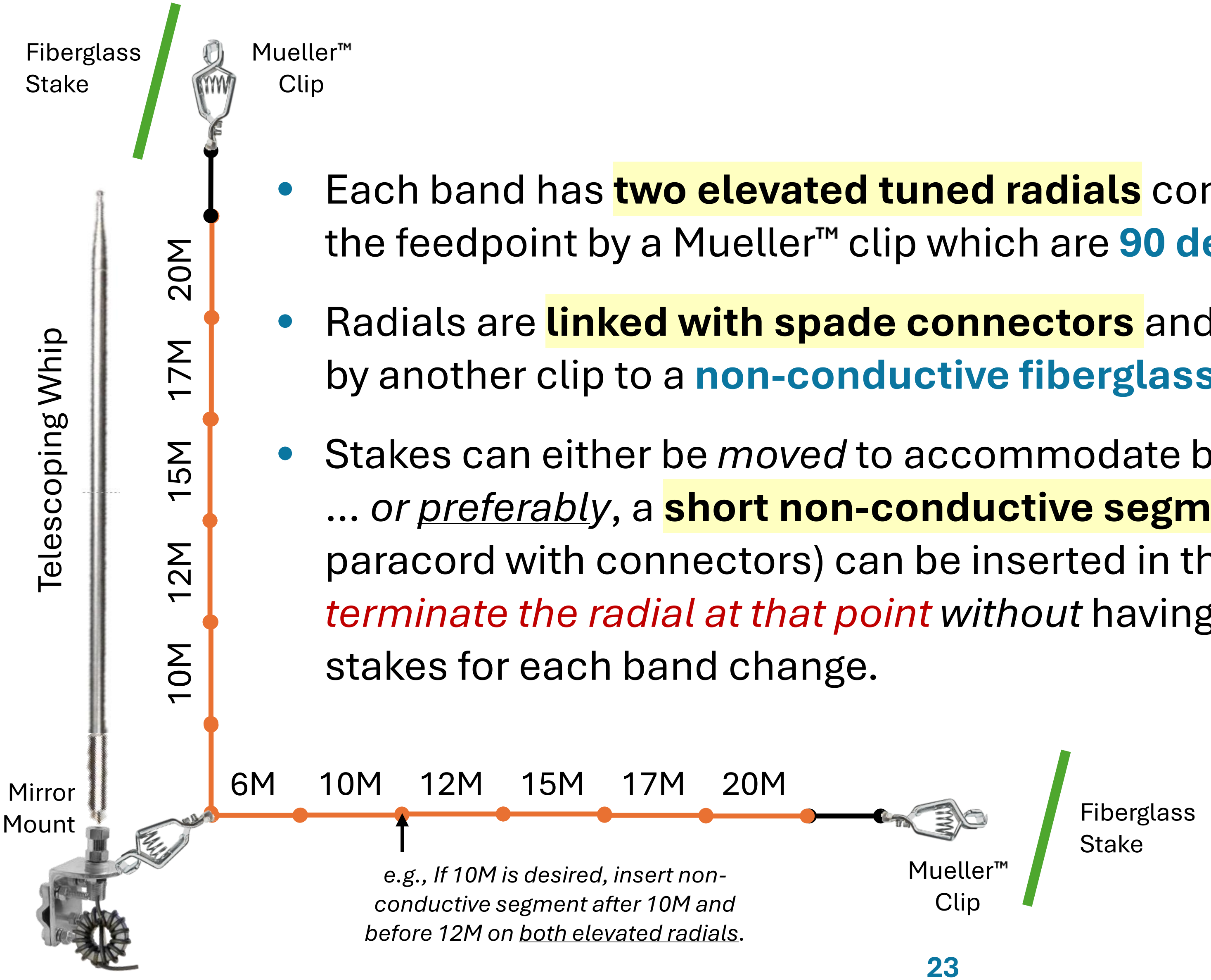
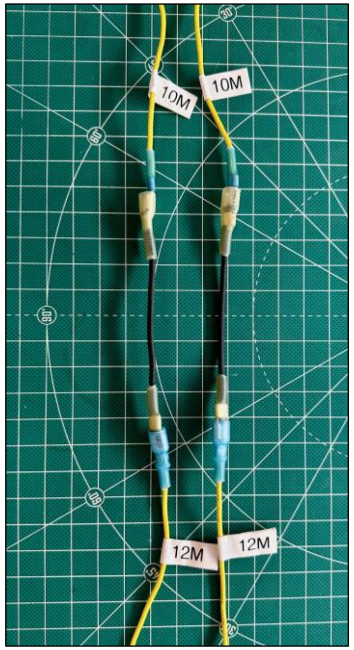
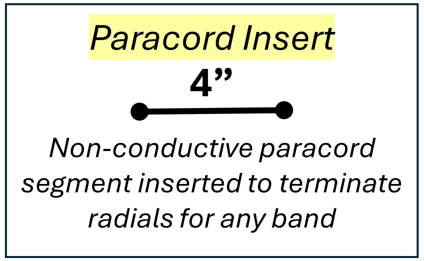
PERformer Vertical with Two Elevated Tuned Linked Radials

- Each band has **two elevated tuned radials** connected to the feedpoint by a Mueller™ clip which are **90 degrees apart**.
- Radials are **linked with spade connectors** and terminated by another clip to a **non-conductive fiberglass stake**.
- Stakes can either be *moved* to accommodate band change … *or preferably*, a **short non-conductive segment** (e.g., a paracord with connectors) can be inserted in the wire line to *terminate the radial at that point without* having to move the stakes for each band change.



e.g., If 10M is desired, insert non-conductive segment after 10M and before 12M on both elevated radials.





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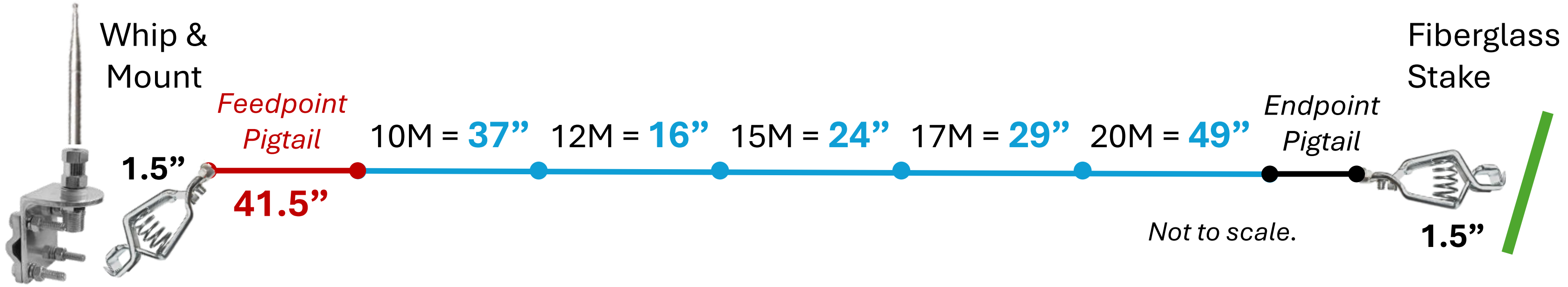
PERformer Vertical with Two <u>Elevated</u> <u>Tuned</u> <u>Linked</u> Radials



- To construct this elevated radial system, first cut <u>two</u> **41.5”** pigtails connected together at the feedpoint for each linked radial string. The feedpoint clip of 1.5” plus the 41.5” 6M feedpoint pigtail becomes the **43”** 6M radial length.
- Next, cut a **<u>pair</u>** of **<u>five</u> band incremental wires**, one for each elevated radial. These sections extend the length of each radial wire for a particular band. Ultimately, the finetuning for each band resonance is accomplished by **adjusting the whip length**.
- When the **paracord segment** is inserted, the **total** length of <u>each</u> elevated radial is:
  - 6M = **43”** (**1.5”** feedpoint clip + **41.5”** feedpoint pigtail)
  - 10M = **80”** (**43”** 6M radial length + **37”** incremental 10M section)
  - 12M = **96”** (**80”** 10M radial length + **16”** incremental 12M section)
  - 15M = **120”** (**96”** 12M radial length + **24”** incremental 15M section)
  - 17M = **149”** (**120”** 15M radial length + **29”** incremental 17M section)
  - 20M = **198”** (**149”** 17M radial length + **49”** incremental 20M section)

Paracord Insert
4”
Non-conductive paracord segment inserted to terminate radials for any band

PERformer Vertical Antenna Deployment on a Tripod

PERformer shown with a portable 78” **Polarduck™** tripod with very broad and adjustable leg lengths for stability. This portable tripod is recommended for its lightweight frame and adjustable broad leg spread for all types of locations.

A **Chameleon™** 17’ whip on a mirror mount is attached securely to a 2’ aluminum tube with 1” OD. A **Mueller™** clip is used to combine two elevated tuned radials and clipped firmly to the mount to provide an effective elevated counterpoise.

A **Mueller™** clip is used at the end of each elevated radial to attach onto a 48” fiberglass (non-conductive) stake. The clip can easily be slid up and down (droop) to finetune the feedpoint impedance for low SWR. These stakes are used for both deployment options.

- The **PERformer** antenna tripod deployment option is ideal for those locations where a spike mount into the ground is not available or permitted. It provides a very stable and effective base when the whip is extended.
- The 17’ telescoping whip is attached to a standard mirror mount up ~52” to provide the radiating element. The mount is attached to an aluminum tube which is inserted into the tripod. A rubber cap is installed at the top of the tube to insulate it from the elements.
- A Mueller™ clip is used to combine the two elevated radials and attach them to the mirror mount. A Mueller™ clip at the end of each radial is attached to a non-conductive fiberglass stake to keep it taut and elevated.

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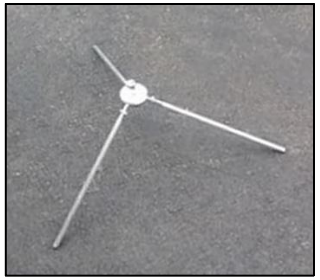
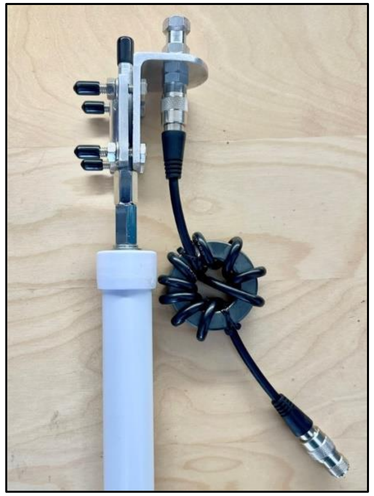
PERformer Vertical Antenna Deployment on a PVC Spike Mount

PERformer shown with a 40" furniture grade PVC tube (1" ID) on a **Chameleon™** spike mount. The non-conductive support structure provides both elevation and a secure mount for the telescoping whip and 2 elevated tuned radials.

A 3/8" hole is drilled into the **PVC bottom cap** to insert a 3/8"x 24 bolt (1.5"- 2" long) and nut to easily screw into the **Chameleon™** spike mount or short tripod, e.g. WRC Mini-Pod.



A 3/8" hole is drilled into the **PVC top cap** to insert a 3/8"x 24 bolt and nut (about 1.5" long) to accept a mirror mount that supports the 17' **Chameleon™** whip. A split lock and fender washer is used on both the inside and outside for a secure fit.



The mirror mount screws into the long bolt at the PVC top cap for the telescoping whip. A **Palomar Engineers™** RF choke (or suitable equivalent) must *always* be used at the feedpoint to isolate the coax shield from the antenna system.

- The **PERformer** spike mount deployment option is ideal for those locations where the ground can accept a spike that can be pushed in by hand or tapped in with a rubber hammer. *Alternatively*, it can screw into a short tripod on the surface.
- The 40" furniture PVC tube and spike is a study mount for the telescoping whip. It provides a non-conductive support structure that elevates both the antenna feedpoint and the tuned radials about 52" above the earth when combined with the mirror mount.

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PERformer Vertical with Two Elevated Tuned Linked Radials

The **elevated radial system** is composed of pre-cut 18-gauge wire segments that are linked together within a string by spade connectors. These connectors allow the fast and easy insertion of a non-conductive segment to terminate the radial at that point for each band.

The ratcheting **Wirefy™ crimping tool** and heat shrink male/female **spade connectors** are used for fast and easy attachment of radial segments. The connectors not only have heat shrink tubing but also have internal glue that, when heated, provides a very secure connection.

Two 4” **non-conductive radial segments** (using paracord) have spade connectors on each end. The segments are inserted in each elevated radial line to terminate it at the band of operation. By doing so, the fiberglass end stakes *do not* have to be moved for each band change.

PERformer elevated radial system shown coiled up with a Velcro™ strap for easy transport and fast deployment. A **Mueller™ clip** is used at one end to combine the radials, and another at the end of each radial. Each band segment is clearly labeled.

A **zippered clear plastic bag** (commonly used for travel toiletries) provides the perfect enclosure for the radial system and accessories. It also holds the **WRC™ Sporty Forty** for 40M operation and a **RigExpert™ Stick** analyzer for easy antenna tuning resonance in the field.

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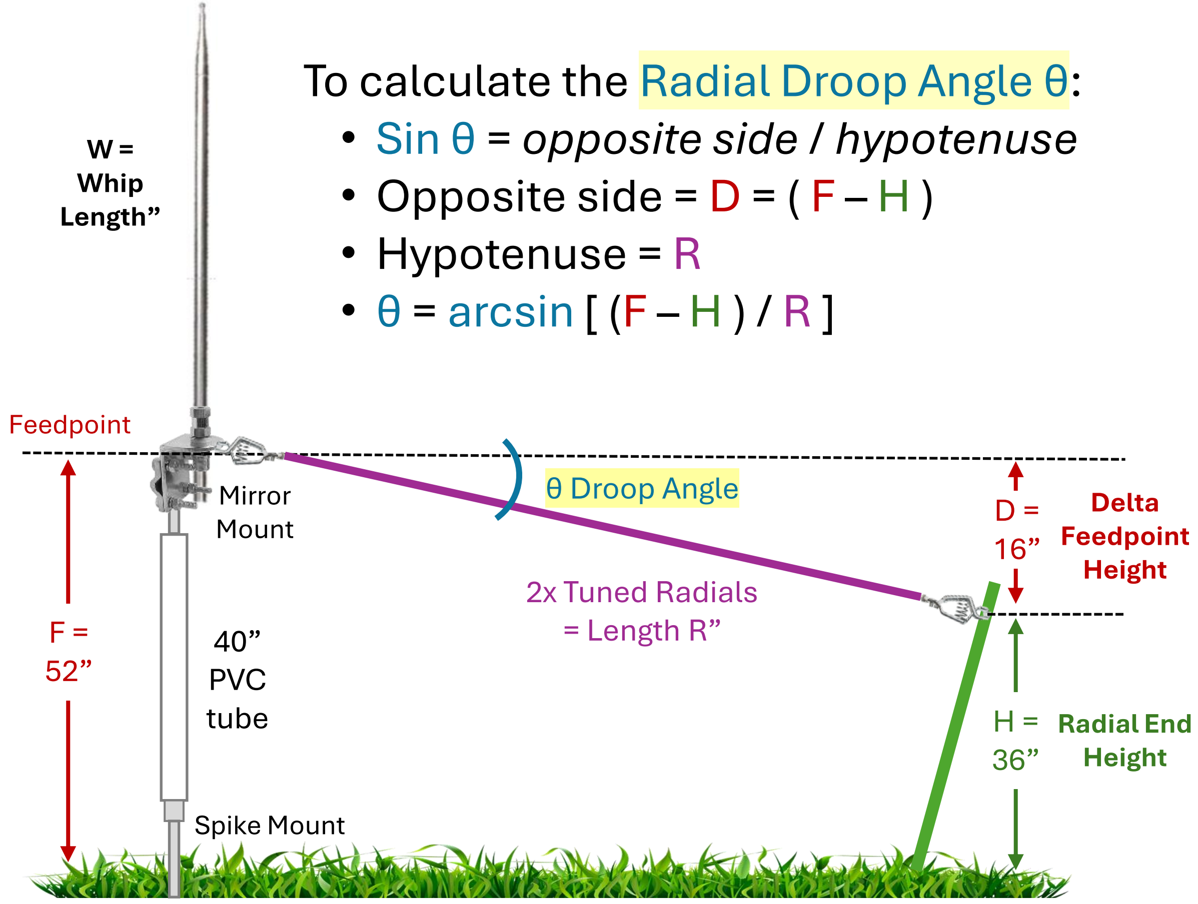
4NEC2 Model Computations Provide Radial Droop Angle



If you *move* the end stakes for each band change, your radial droop angle will change. Alternatively, if you *insert* a non-conductive segment in the line, the droop angle will remain consistent at the 20M band droop.

Examples – 4NEC2 computes **W**, **R** for **H = 36"**:

- **20M** Whip Length (**W**) = **207"** (+4.8% longer than 234/*f*)
- Radial Length (**R**) = **198"** (+0.5% longer than 234/*f*)
- Droop **θ** = arcsin (D=16" / R=198") x 180/π = **5º**

- **6M** Whip Length (**W**) = **64"** (+16.5% longer than 234/*f*)
- Radial Length (**R**) = **43"** (-21.9% shorter than 234/*f*)
- Droop **θ** = arcsin (D=16" / R=43") x 180/π = **22º**

4NEC2 model calculations are a great *starting point* but *field testing over real ground* must be performed!

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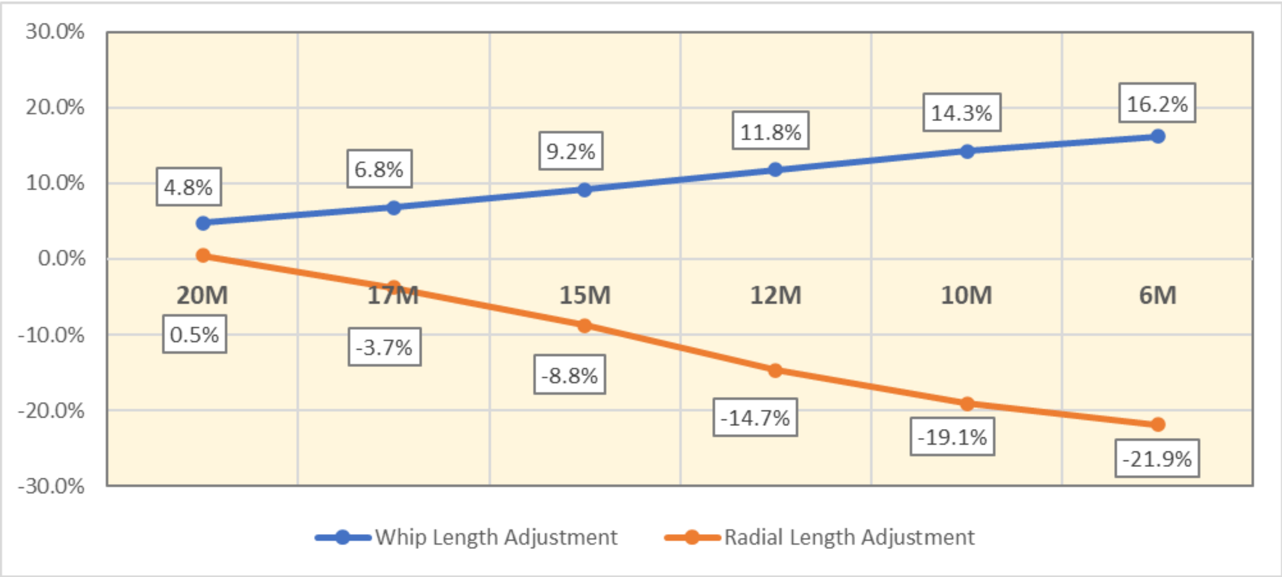
4NEC2 Model Computations for the PERformer Antenna

Band	Target Freq (Mhz)	234 / f		Radiator				Counterpoise					
		Length	Inches	Length	Inches	Whip vs. Calc	Whip OCF %	Length	Inches	Radial vs. Calc	Radial End (in)	Radial End vs. λ	Droop Angle (deg)
20M	14.250	16' 5"	197	17' 3"	207	4.8%	51.1%	16' 6"	198	0.5%	36	5%	5
17M	18.140	12' 11"	155	13' 9"	165	6.8%	52.6%	12' 5"	149	-3.7%	36	6%	6
15M	21.350	11' 0"	132	12' 0"	144	9.2%	54.5%	10' 0"	120	-8.8%	36	7%	8
12M	24.940	9' 5"	113	10' 6"	126	11.8%	56.7%	8' 0"	96	-14.7%	36	8%	10
10M	28.400	8' 3"	99	9' 5"	113	14.3%	58.5%	6' 8"	80	-19.1%	36	9%	12
6M	51.000	4' 7"	55	5' 4"	64	16.2%	59.8%	3' 7"	43	-21.9%	36	16%	22



- The model calculated **whip and radial lengths** for each of the six bands. Whip length ranges from **+5% λ/4 on 20M** to **+16% λ/4 on 6M**. Elevated radials from **+0.5% λ/4 on 20M** to **-22% λ/4 on 6M**. The whip OCF % from **51% on 20M** to **60% on 6M**.
- The **radial end height** is fixed at **36"** which provided great elevation for each band ranging from **5% λ/4 on 20M** to **16% λ/4 on 6M** at the end. The overall elevation reduces capacitive coupling to the ground and increases efficiency.
- With the feedpoint height at **52"** and the radial end at **36"**, the **radial droop angle** from the feedpoint to the radial end ranged from **5º on 20M** to **22º on 6M** which requires a longer radiator for Z ≈ 50. If you don't move the end stake, the droop angle remains consistent at the 20M band droop.

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4NEC2 PERformer Performance Specifications across 6 Bands

Band	Target Freq (Mhz)	234 / f		Radiator				Counterpoise						Specifications							
		Length	Inches	Length	Inches	Whip vs. Calc	Whip OCF %	Length	Inches	Radial vs. Calc	Radial End (in)	Radial End vs. λ	Droop Angle (deg)	SWR	Ref Coef (dB)	Rad Angle (deg)	Gain (dBi)	FtB (dB)	-3 dB BW (deg)	Efficiency	Impedance
20M	14.250	16' 5"	**197**	17' 3"	**207**	4.8%	51.1%	16' 6"	**198**	0.5%	**36**	**5%**	**5**	**1.01**	**-47.4**	**26**	**0.00**	**3.55**	**49**	**88.1%**	49.6 + j 0.14
17M	18.140	12' 11"	**155**	13' 9"	**165**	6.8%	52.6%	12' 5"	**149**	-3.7%	**36**	**6%**	**6**	**1.02**	**-41.5**	**25**	**0.14**	**3.48**	**48**	**89.5%**	49.2 + j 0.22
15M	21.350	11' 0"	**132**	12' 0"	**144**	9.2%	54.5%	10' 0"	**120**	-8.8%	**36**	**7%**	**8**	**1.01**	**-50.3**	**24**	**0.26**	**3.19**	**46**	**90.4%**	49.7 + j 0.12
12M	24.940	9' 5"	**113**	10' 6"	**126**	11.8%	56.7%	8' 0"	**96**	-14.7%	**36**	**8%**	**10**	**1.01**	**-43.4**	**24**	**0.38**	**2.93**	**43**	**91.3%**	50.7 - j 0.03
10M	28.400	8' 3"	**99**	9' 5"	**113**	14.3%	58.5%	6' 8"	**80**	-19.1%	**36**	**9%**	**12**	**1.02**	**-40.7**	**23**	**0.50**	**2.66**	**41**	**91.9%**	50.9 - j 0.29
6M	51.000	4' 7"	**55**	5' 4"	**64**	16.2%	59.8%	3' 7"	**43**	-21.9%	**36**	**16%**	**22**	**1.02**	**-40.4**	**20**	**1.20**	**2.75**	**38**	**93.9%**	49.1 + j 0.21
													Averages:	**1.02**	**-44.0**	**24**	**0.41**	**3.09**	**44**	**90.8%**	**Z = R + j X**

- The model computed several *performance* specifications including **SWR, reflection coefficient**, **peak radiation angle**, **gain**, **front-to-back**, **-3.00 dB beamwidth** as well as overall **antenna efficiency** and **impedance**.
- The *average* performance specifications *across all six bands* are:
  - ✓ Antenna Efficiency = **90.8%**
  - ✓ SWR = **1.02:1**
  - ✓ Reflection Coefficient = **-44.0 dB**
  - ✓ Gain = **0.41 dBi**, Front-to-Back = **3.09 dB**
  - ✓ Peak Radiation Angle = **24°** (*beamwidth* 54°, 9°)
  - ✓ -3.00 dB Beamwidth = **44°** (*delta* +30°, -15°)

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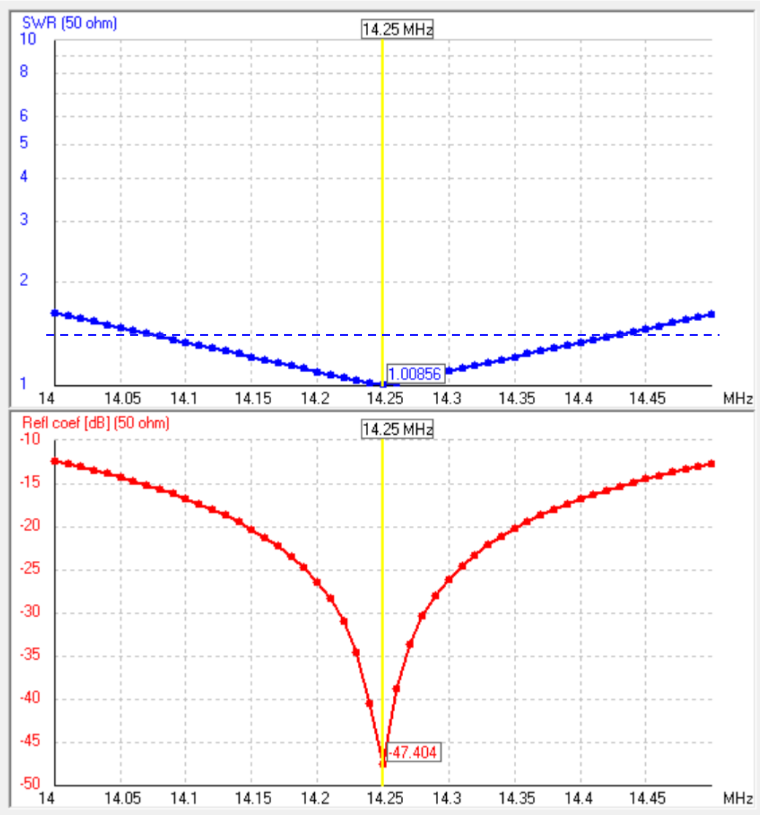
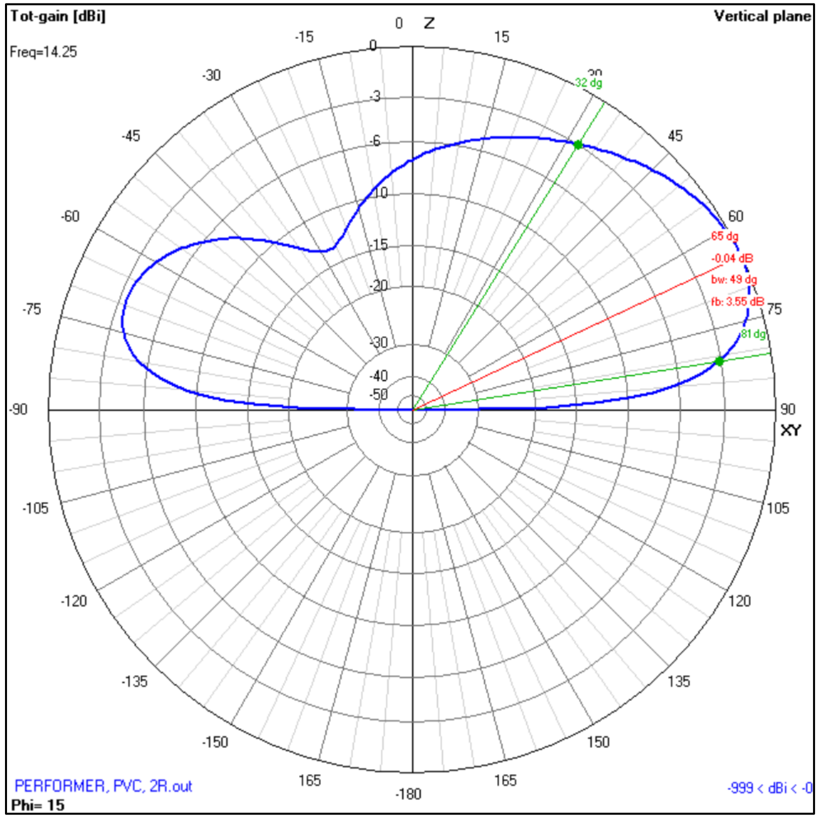
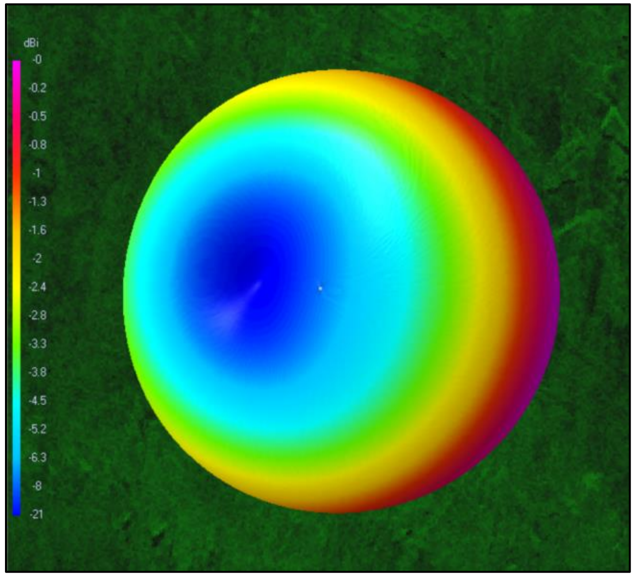
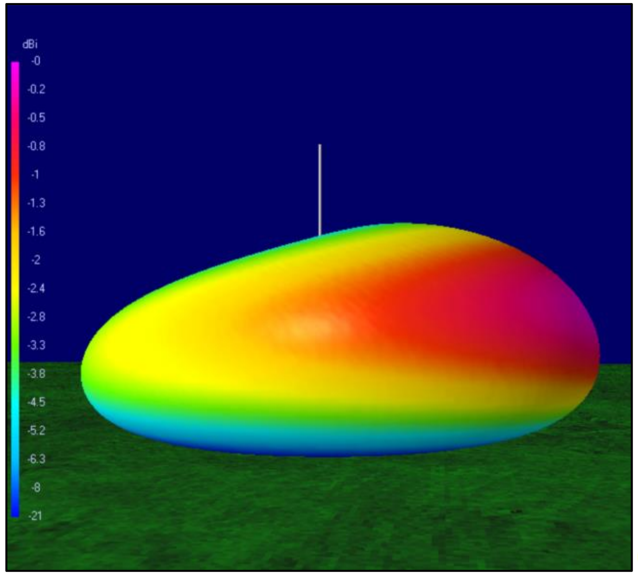
4NEC2 Model Graphics for the **PERformer:** 20M (14.250 MHz)









3D radiation modeling as seen from both the top and side views.

Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.01:1** at **14.250 MHz** with a **reflection coefficient** of **-47.4 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 26º** with **+0.00 dBi gain** and **3.55 dB FtB** within a **-3dB beamwidth** of **49º** (-17º, +32º) = **9º** to **58º**.

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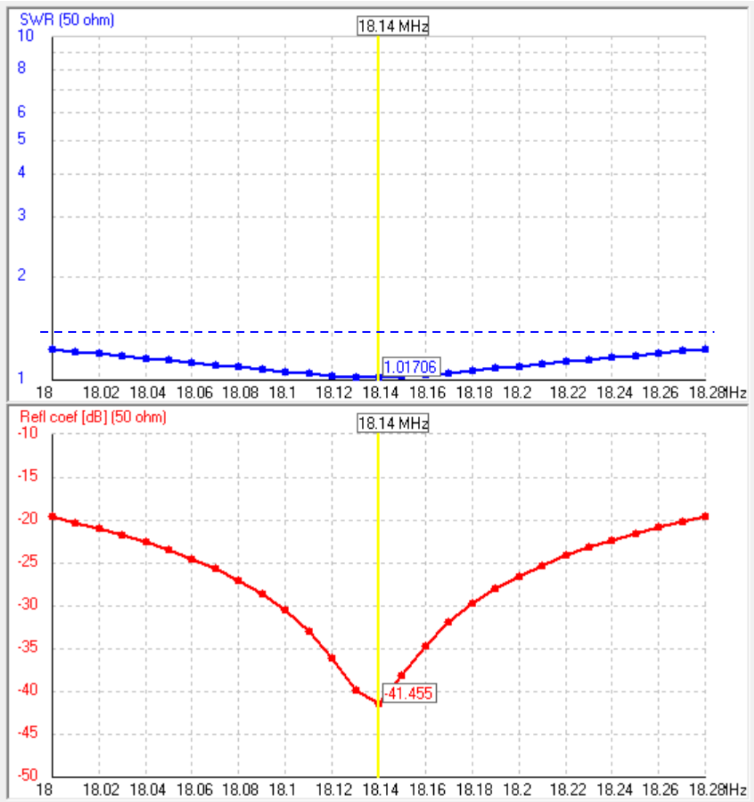
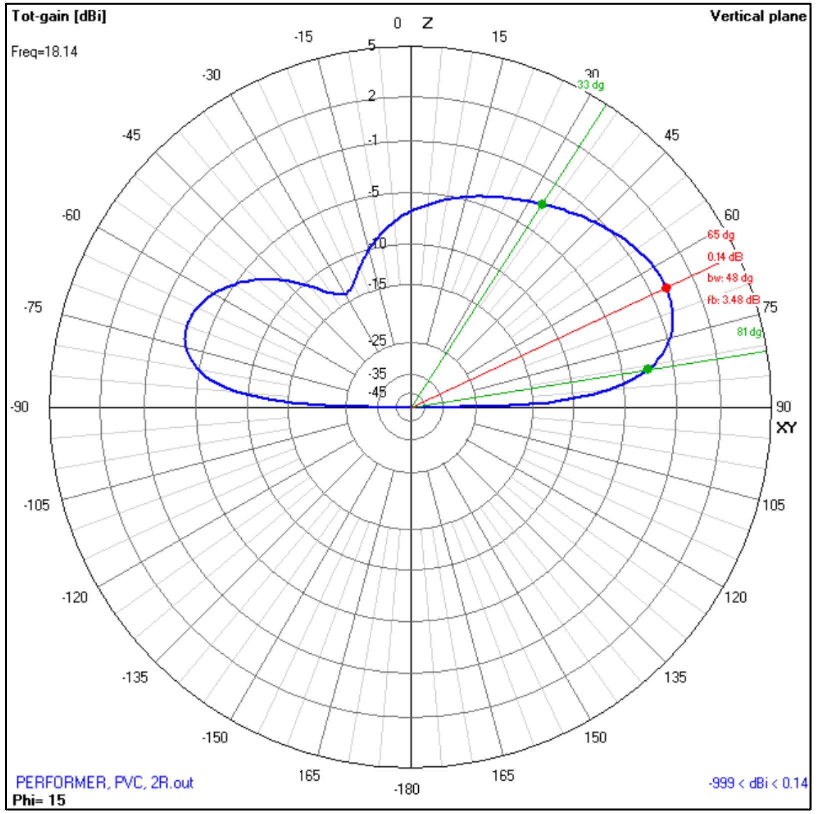
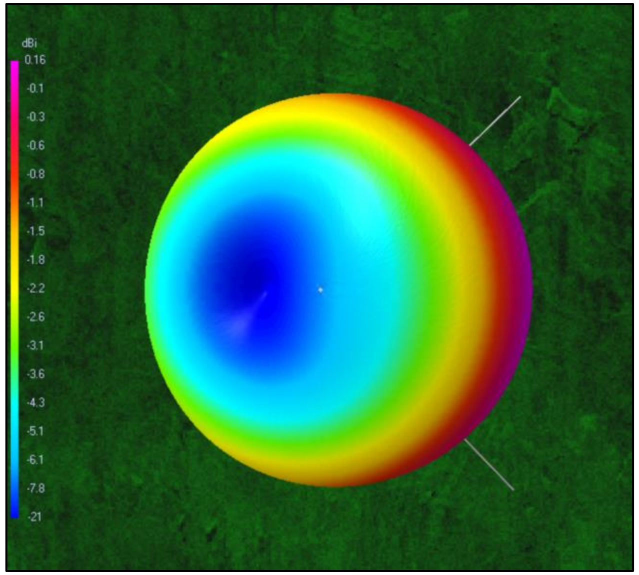
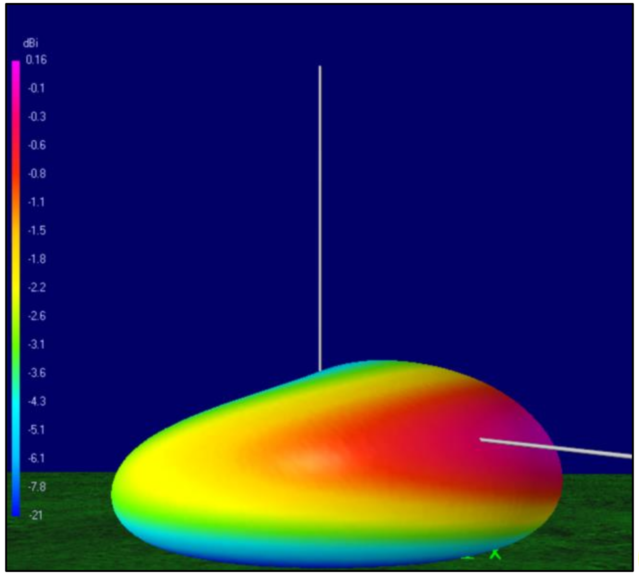
4NEC2 Model Graphics for the **PERformer:** 17M (18.140 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.02:1** at **18.140 MHz** with a **reflection coefficient** of **-41.5 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 25°** with **+0.14 dBi gain** and **3.48 dB FtB** within a **-3dB beamwidth** of **48°** (-16°, +32°) = **9** to **57°**.

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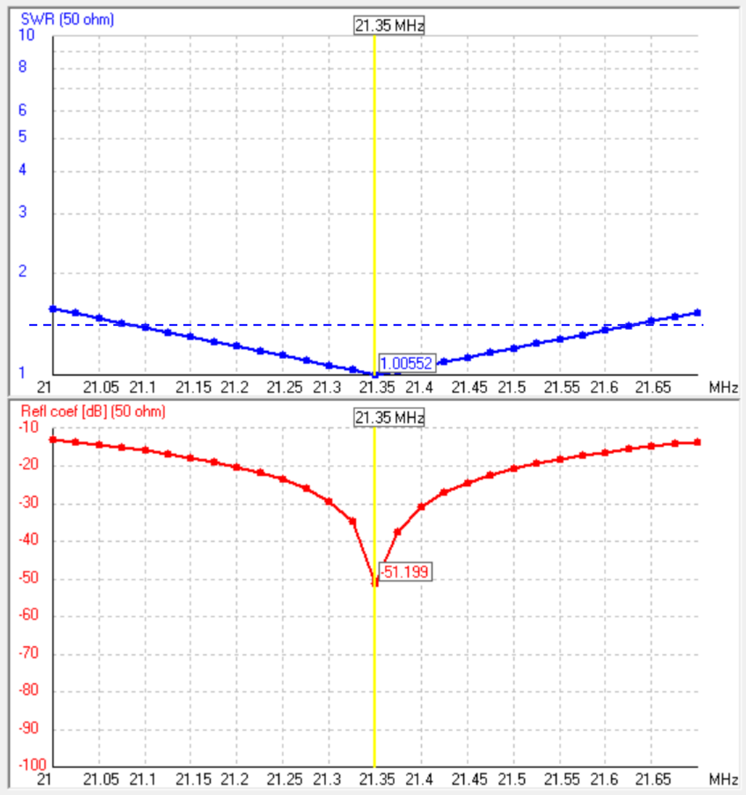
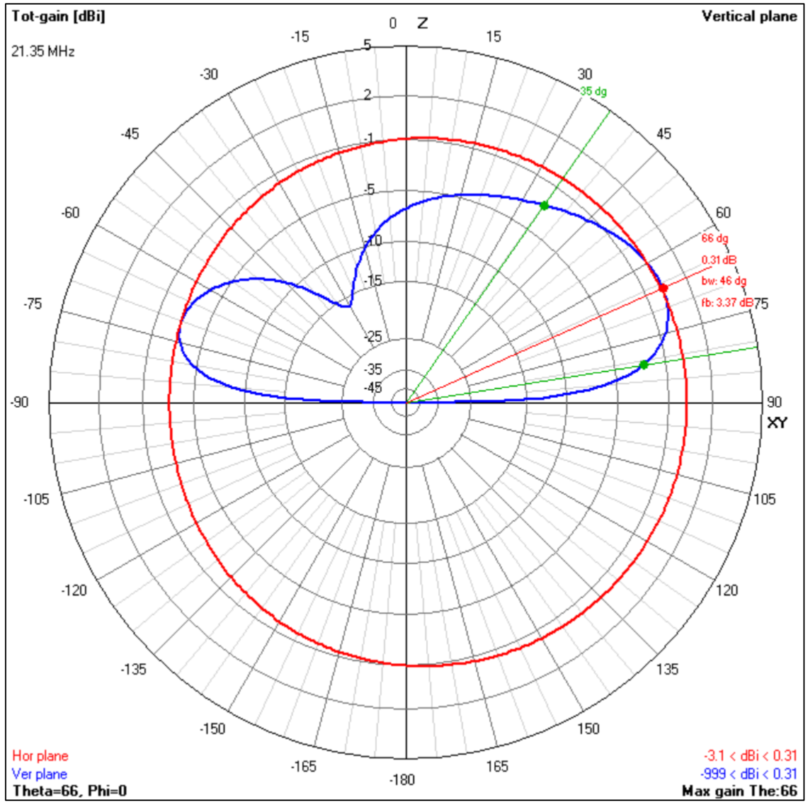
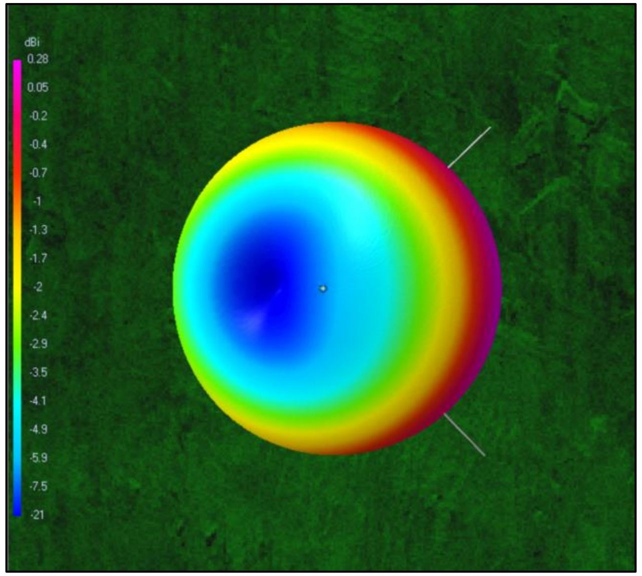
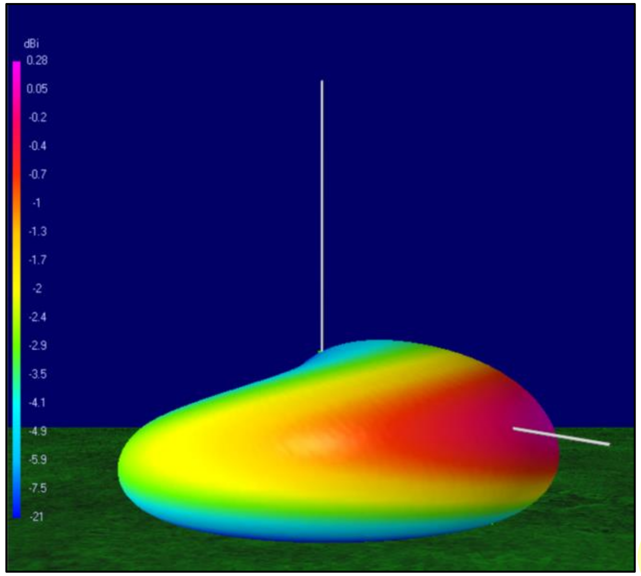
4NEC2 Model Graphics for the **PERformer:** 15M (21.350 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.01:1** at **21.350 MHz** with a **reflection coefficient** of **-51.2 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 24º** with **+0.31 dBi gain** and **3.37 dB FtB** within a **-3dB beamwidth** of **46º** (-15º, +31º) = **9º** to **55º**.

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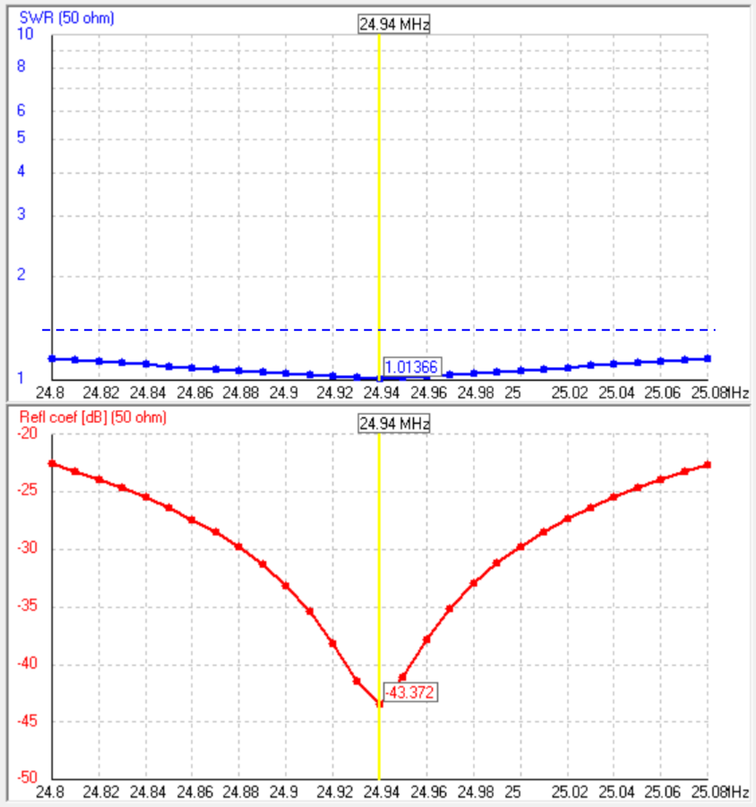
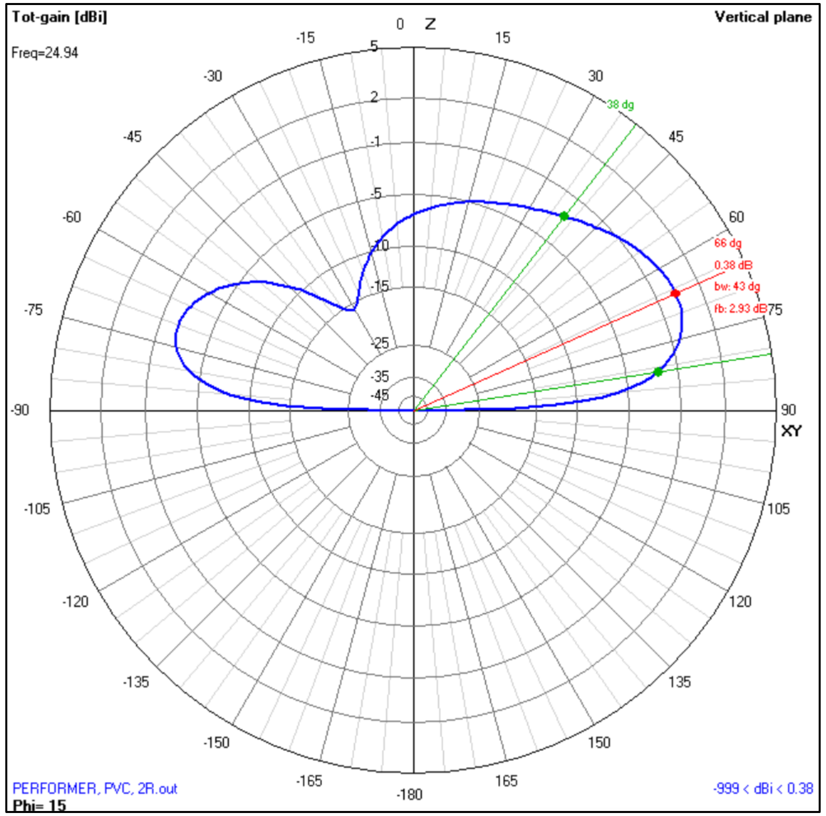
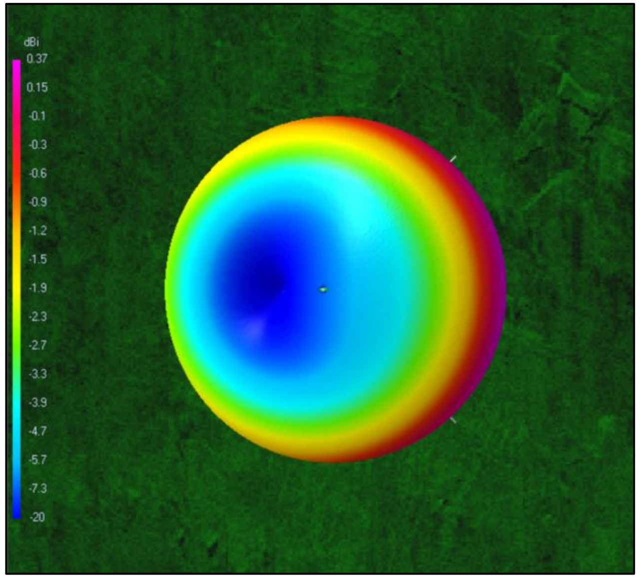
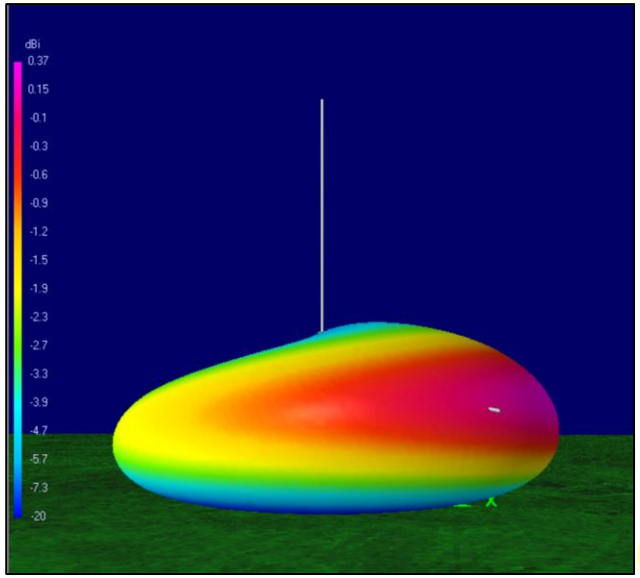
4NEC2 Model Graphics for the **PERformer:** 12M (24.940 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.01:1** at **24.940 MHz** with a **reflection coefficient** of **-43.4 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 24º** with **+0.38 dBi gain** and **2.93 dB FtB** within a **-3dB beamwidth** of **43º** (-15º, +28º) = **9** to **52º**.

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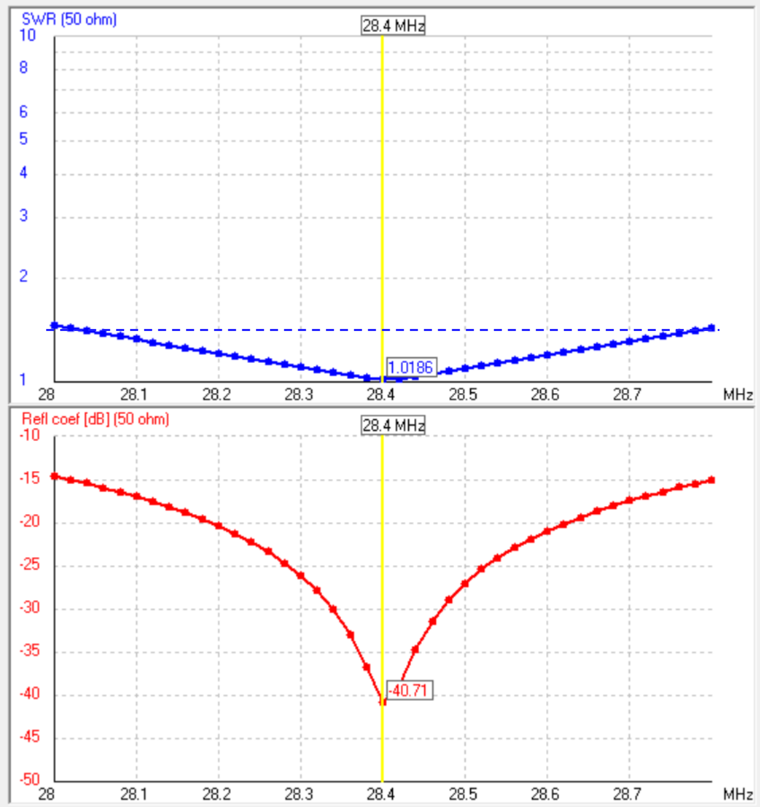
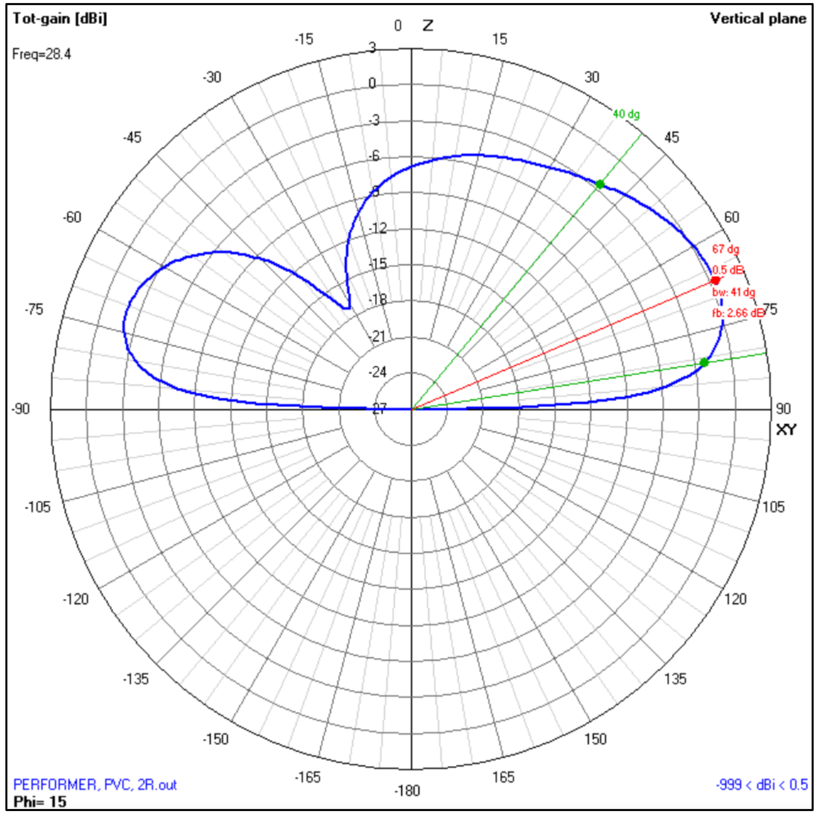
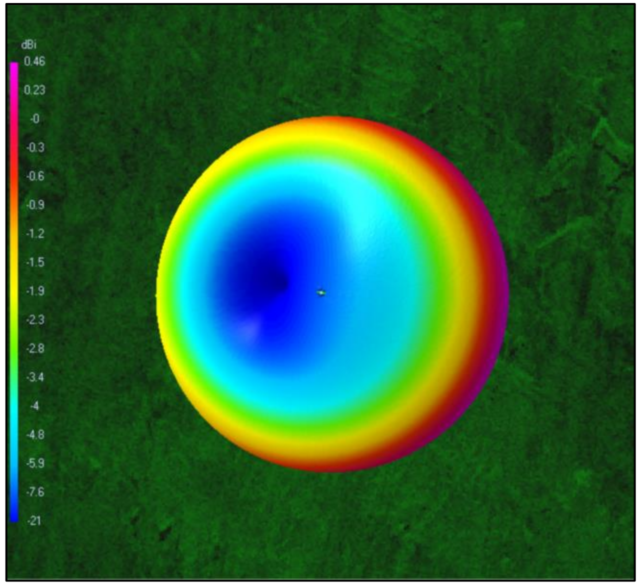
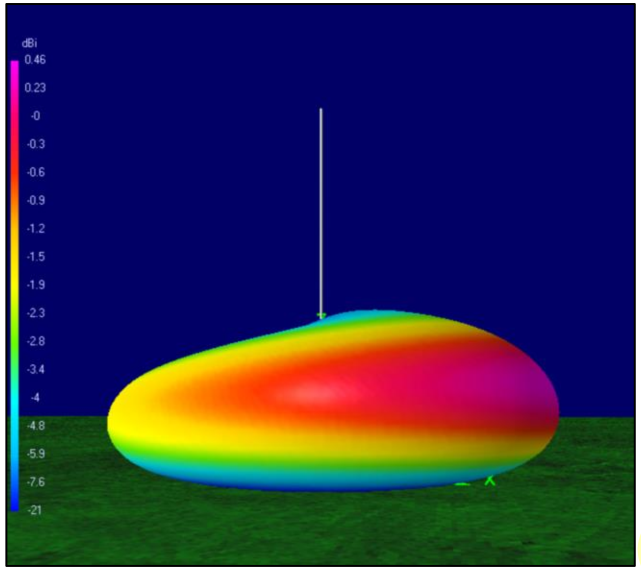
4NEC2 Model Graphics for the **PERformer:** 10M (28.500 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.02:1** at **28.500 MHz** with a **reflection coefficient** of **-40.7 dB**. The ±1.50:1 SWR bandwidth is **800 kHz**.
- It also calculated **maximum radiation** at **angle 23º** with **+0.50 dBi gain** and **2.75 dB FtB** within a **-3dB beamwidth** of **41º** (-14º, +27º) = **9º** to **50º**.

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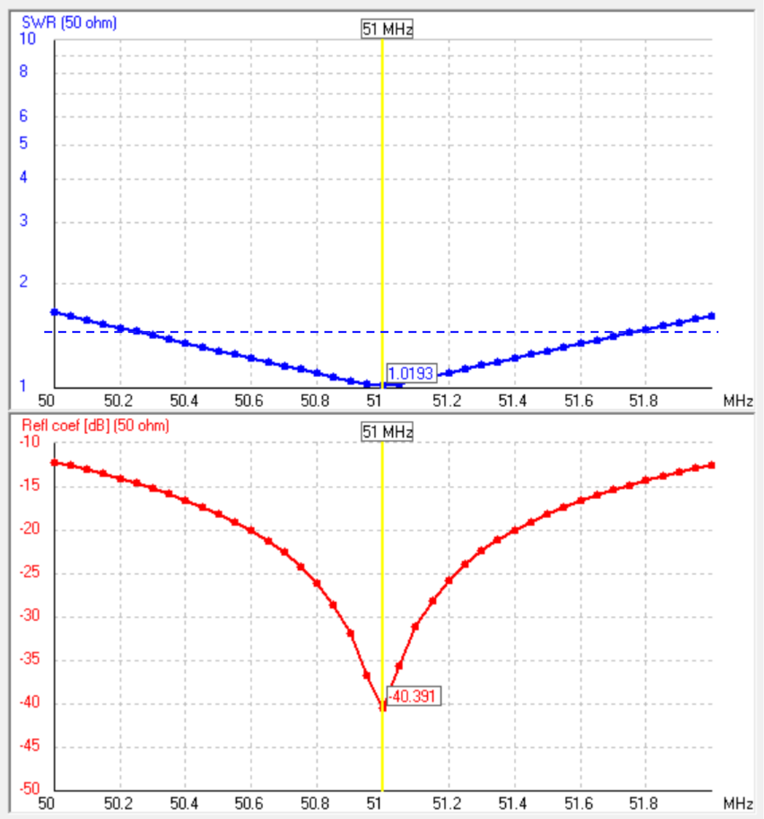
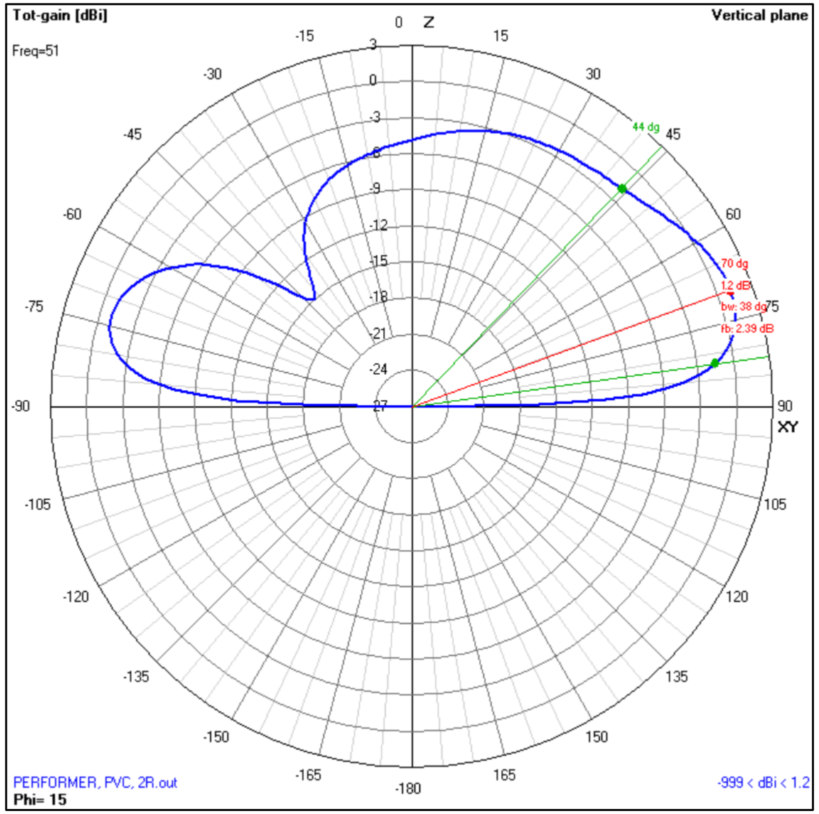
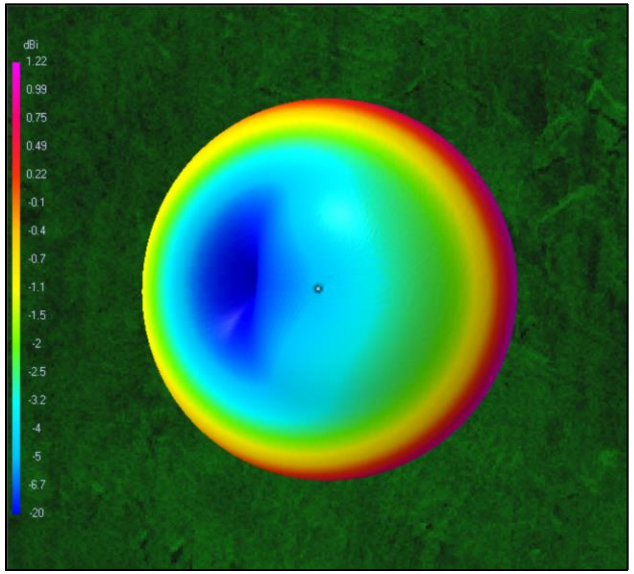
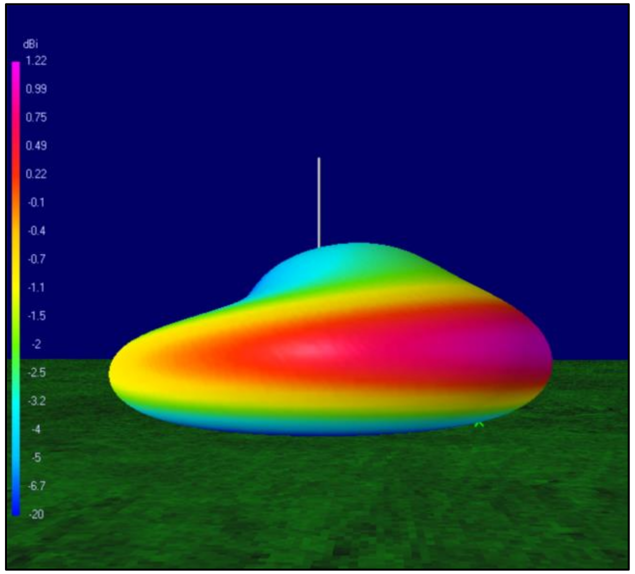
4NEC2 Model Graphics for the **PERformer:** 6M (51.000 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.02:1** at **51.000 MHz** with a **reflection coefficient** of **-40.4 dB**. The ±1.50:1 SWR bandwidth is **1400 kHz.**
- It also calculated **maximum radiation** at **angle 20º** with **+1.20 dBi gain** and **2.38 dB FtB** within a **-3dB beamwidth** of **38º** (-12º, +26º) = **9** to **46º**.

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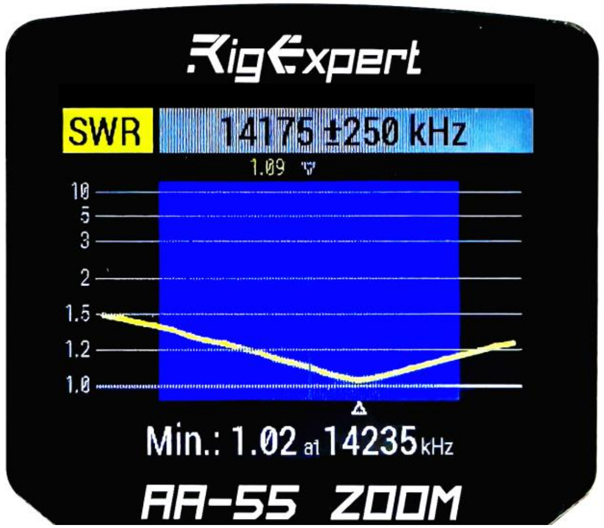
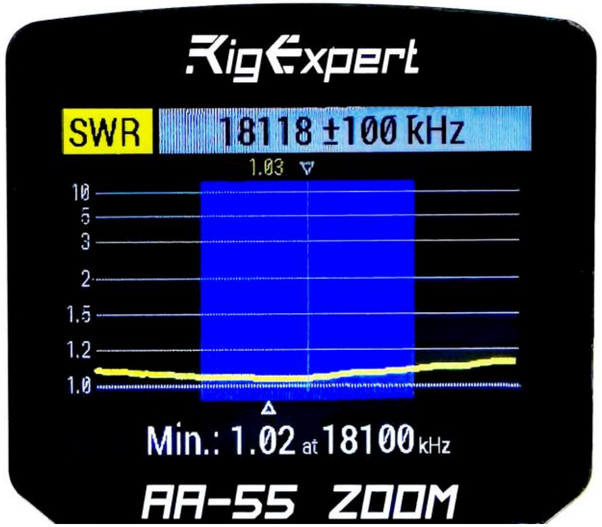
Field SWR Measurements for **PERformer** Quarterwave: 20M-6M

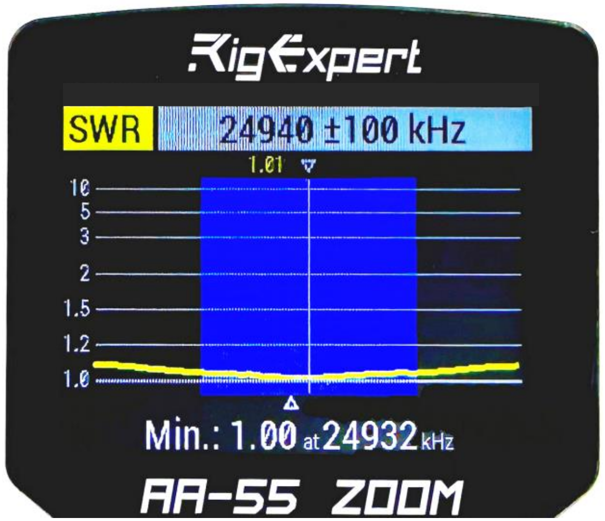


20M Band



17M Band

15M Band



12M Band

10M Band

6M Band

SWR Efficiency:

- 1.10:1 = 99.8%
- 1.20:1 = 99.2%
- 1.30:1 = 98.3%
- 1.40:1 = 97.2%
- 1.50:1 = 96.0%

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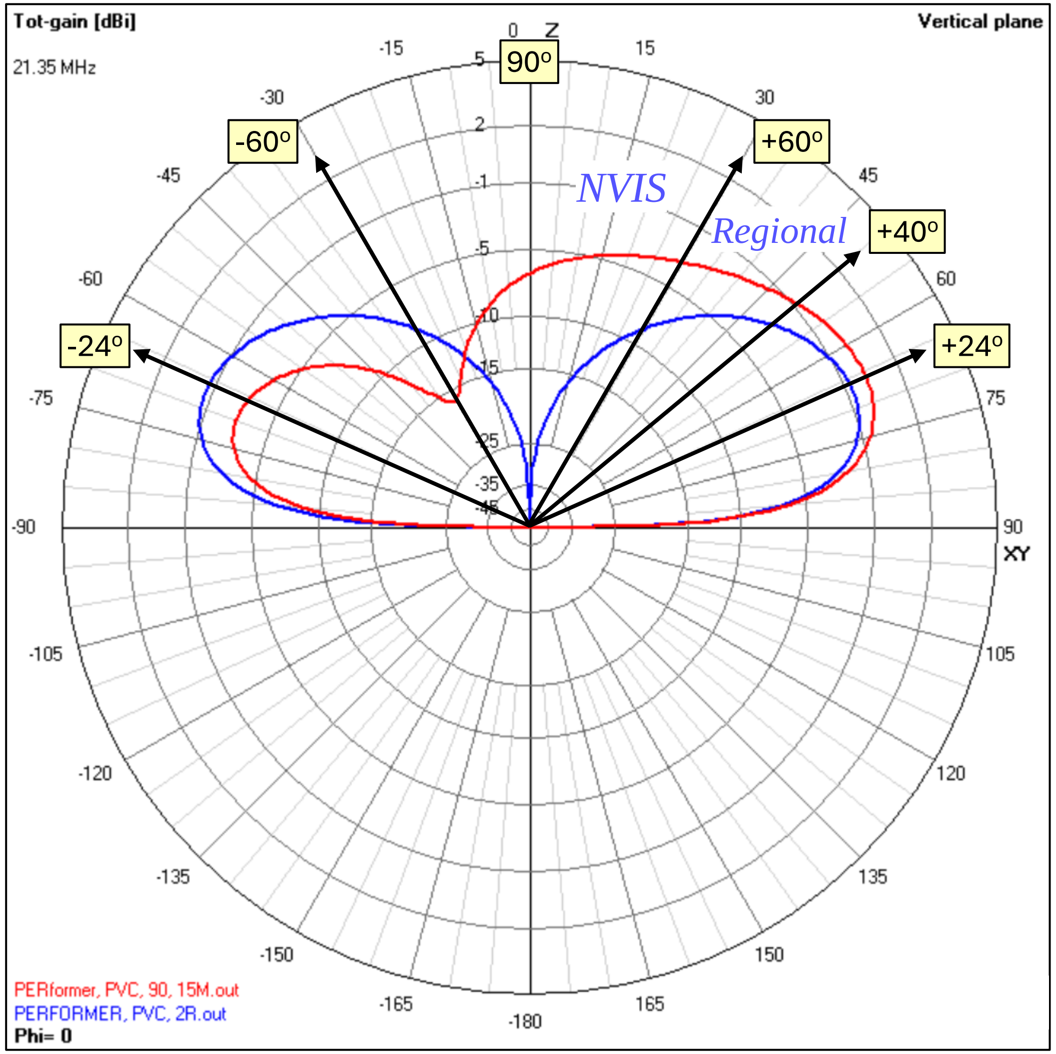
PERformer Radials @ 90° versus 180°: 15M (21.350 MHz)



- Comparing the **PERformer** computer model performance with *directional* radials @ 90° versus *omnidirectional* @ 180°

Elevation off Horizon	**90° Span** *(directional)*	**180° Span** *(omni)*	*Delta*
+24° ***Forward***	+0.31 dBi ✓	-0.67 dBi	***+0.98 dB***
+40° *Regional*	-0.31 dBi ✓	-2.67 dBi	***+2.36 dB***
+60° *NVIS*	-3.26 dBi ✓	-8.53 dBi	***+5.27 dB***
-24° ***Rear***	-3.09 dBi	-0.67 dBi ✓	***+2.42 dB***

- Directional configuration provides **3.37 dB front-to-back** at 24° elevation
- Radial span *does not* impact antenna **radiation efficiency** of **90.4%**

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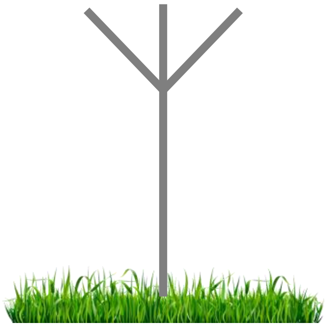
Understanding a Few *More* Antenna Fundamentals

(*Keeping it High-Level*)



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Comparing Quarterwave and Halfwave *Vertical* Antennas

Elements	Quarterwave	Halfwave
Antenna Height	• Quarterwave, Shorter ✓	• 2 x Quarterwave, Taller
Ground Configuration	• Ground plane *required* with λ/4 *equivalent* radials	• Single counterpoise wire *recommended*, 5% - 50% λ ✓
Radiation Resistance	• 34 - 38 Ω, when fed at *bottom*	• 68 - 72 Ω, when fed at *center* ✓
Feedpoint Impedance	• 45 - 75 Ω, reasonable match for traditional 50 Ω coax ✓	• 1,800 - 3,000 Ω, LC tuned circuit or transformer required for 50 Ω coax
Radiation Efficiency	• 20% - 90%, depending on type of the ground plane utilized	• 95% - 99%, *not* including the transformer insertion loss ✓
Radiated Gain	• Higher at angles > 25 degrees	• Higher at angles < 25 degrees
Peak Radiation Angle	• 25 - 35 degrees	• 10 - 20 degrees
Radiation Beamwidth -3dB	• Wider, broader, more regional	• Narrower, concentrated, more DX
Primary Reach	• Regional, Continental	• Continental, Global

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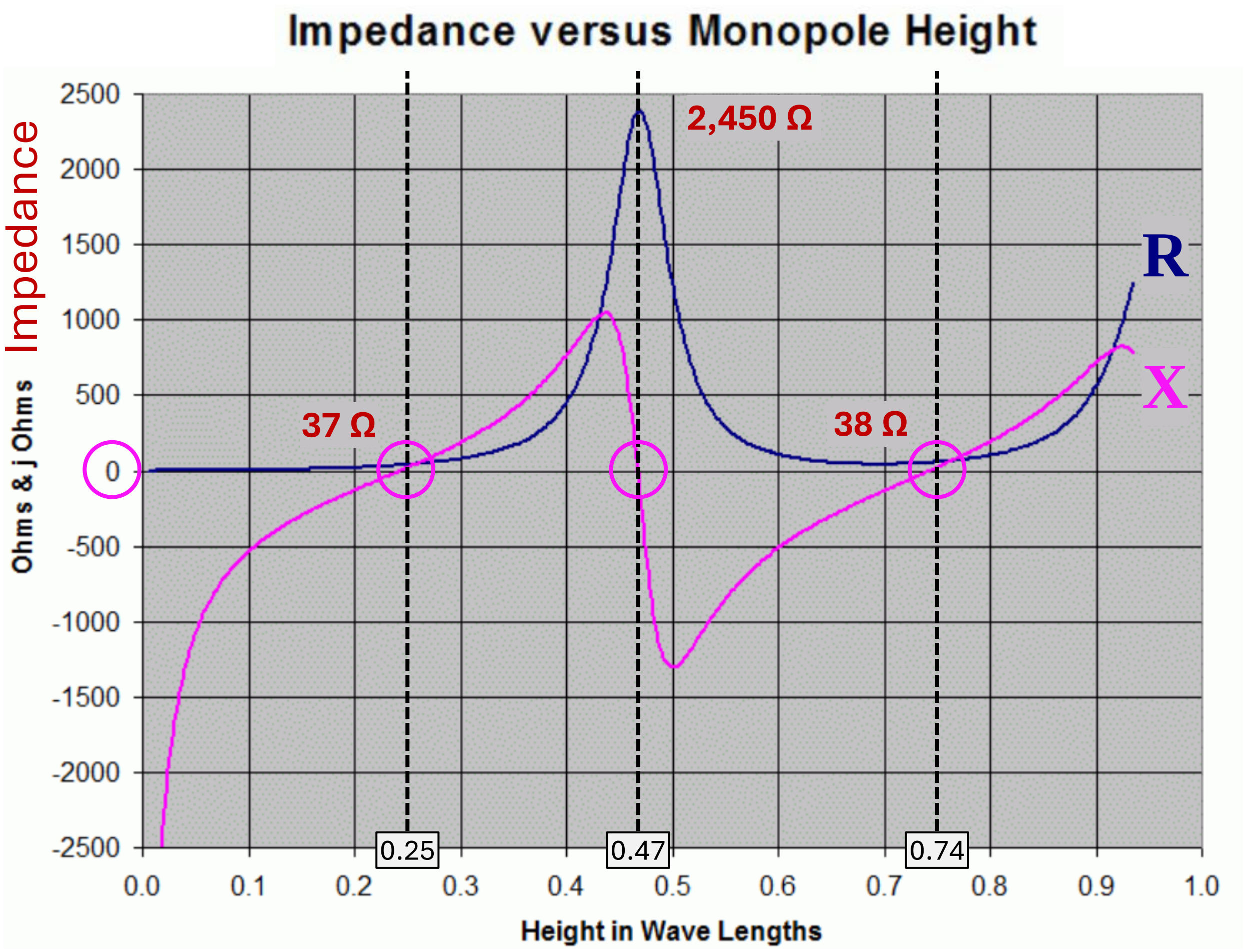
Feedpoint Impedance as Monopole Length Increases



Impedance: Z = **R** ± j **X** (ohms)

- According to modeling, impedance (Z) of a vertical monopole varies as its length is increased between **0.01** λ and **1.00** λ.
- *Assuming* the ground plane is perfectly electrically conducting (*not* real world), note the points where j **X** = 0 Ω. These are where the antenna is purely *resistive* and *resonant*: **0.25** λ, **0.47** λ, and **0.74** λ.
- The most significant difference between these points is the impedance (Z). For a monopole length of **0.25** λ, the *purely resistive* impedance is 37 Ω. At **0.47** λ, it is 2,450 Ω, and at **0.74** λ, it is about 38-40 Ω.

Source: AA5TB, Steve Yates (2010)

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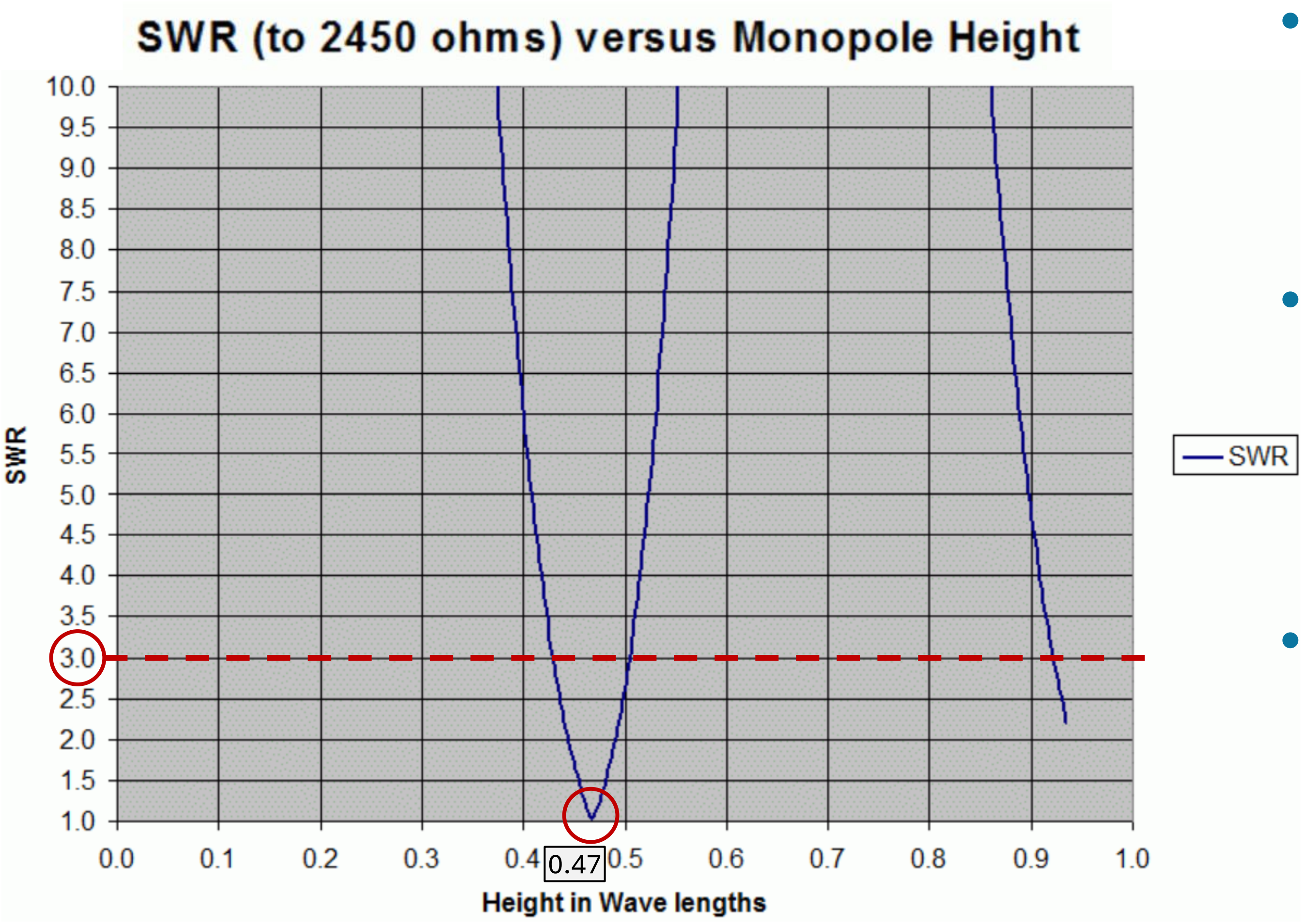
SWR with a 49:1 Transformer as Monopole Length Increases



- The key to matching any end-fed halfwave vertical is to ensure an efficient and effective matching system for the antenna feedpoint impedance of 2,450 Ω.
- Through modeling, it can be seen that a slightly shorter λ/2 vertical length of **0.47 λ** creates a *purely resistance* impedance component where j X = 0 Ω which provides optimal SWR with a 49:1 transformer.
- But when the antenna is installed in the *real world*, many other factors impact resonance including the ground type and near field surroundings. Through Dominator field testing, **0.45 λ** is found to be most effective.

Source: AA5TB, Steve Yates (2010)

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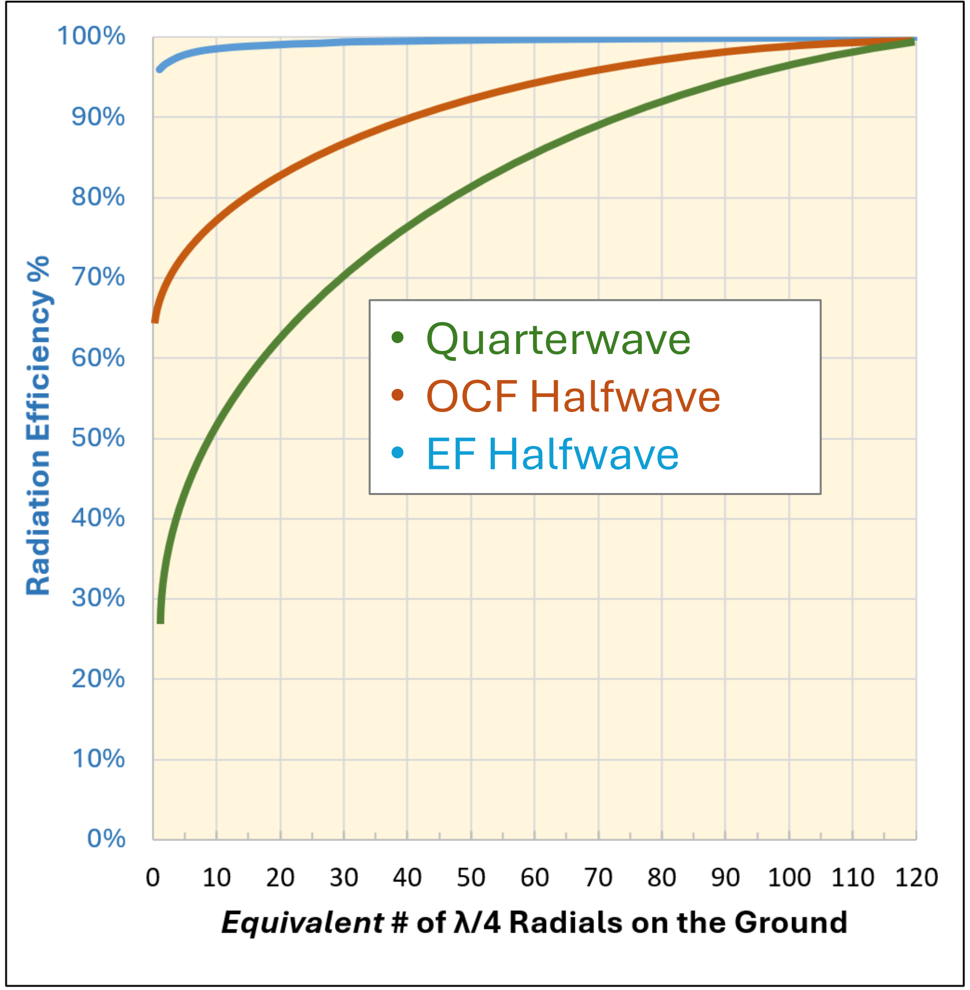
Loss Resistance (R_{loss}) of Surface Radials on *Average* Ground

# of λ/4 radials	Ground Loss Ω	λ/4 Efficiency	λ/2 OCF Efficiency	λ/2 EF Efficiency
R_{rad}		37	200	2450
1	104	26%	65.8%	95.9%
2	85	30%	70.2%	96.6%
4	63	37%	76.0%	97.5%
6	50	43%	80.0%	98.0%
8	42	47%	82.6%	98.3%
10	37	50%	84.4%	98.5%
12	33	53%	85.8%	98.7%
14	30	55%	87.0%	98.8%
16	28	57%	87.7%	98.9%
18	26	59%	88.5%	98.9%
20	24	61%	89.3%	99.0%
22	22	63%	90.1%	99.1%
24	21	64%	90.5%	99.2%
26	20	65%	90.9%	99.2%
28	18	67%	91.7%	99.3%
30	16	70%	92.6%	99.4%
32	15	71%	93.0%	99.4%
40	13	74%	93.9%	99.5%
50	10	79%	95.2%	99.6%
60	8	82%	96.2%	99.7%
120	0.6	98%	99.7%	100.0%



- As the feedpoint is moved from a *quarterwave* to *halfwave*, the R_{rad} increases *significantly* from 37 Ω to 200 Ω OCF or 2,450 Ω EF. This has a dramatic positive impact on **radiation efficiency**.
- Acknowledging that radials are *not* used on a *halfwave*, from a purely mathematical perspective, R_{loss} becomes less significant:

  = 37 Ω / (37 Ω + 104 Ω) = **26%**
  = 200 Ω / (200 Ω + 104 Ω) = **66%**
  = 2450 Ω / (2450 Ω + 104 Ω) = **96%**
- Field testing R_{loss} estimates of a single counterpoise wire on a *halfwave* range from 12 Ω to 25 Ω.

Source: KN5L, John Oppenheimer (2013) & G5TM, Tim Hier (2022)

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Summary of Key Points for a Halfwave Vertical Antenna

- When a vertical antenna is fed at the base, the radiation resistance R_{rad} increases from 37 Ω at the 0.25 λ length to ~2,450 Ω at the 0.47 λ length. This significant increase in *good resistance* promotes a *high radiation efficiency*: Eff% = R_{rad} / (R_{rad} + R_{loss}) x 100%, → in this case, R_{rad} is *maximized*

- The large radiation resistance R_{rad} of a halfwave vertical *significantly minimizes* the impact of any loss resistance R_{loss} associated with the required ground counterpoise wire. Assuming a modeled loss of ~12 Ω in the counterpoise, Eff% = 2,450 Ω / (2,450 Ω + 12 Ω) x 100% = **99.5% efficiency**

- It would require over 100 *equivalent* λ/4 ground radials for a quarterwave vertical to reach a radiation efficiency of over **90%** to come close to the efficiency of a halfwave vertical. Additionally, the halfwave vertical provides a *lower radiation angle for DX* and about *double the peak radiation gain*.

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Challenger and Dominator Halfwave Vertical Antennas with a **Linked Counterpoise**

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Challenger and **Dominator** Halfwave Vertical Antennas

Challenger and **Dominator** shown on a portable **78” Polarduck™ tripod** with very broad and adjustable leg lengths.

The **LDG™ 4:1 unun** *or the* **TennTennas™ 49:1** with **RF choke** are already mounted to the tripod for fast and easy deployment.

- The **Challenger** is a portable, elevated, resonant ***OC-fed*** *halfwave* vertical antenna for **20M-6M,** the **Dominator** is a portable, elevated, resonant ***End-Fed*** *halfwave* vertical antenna for **17M-10M** sitting on a tripod with the feedpoint about 3-4’ off the ground and *a linked counterpoise* wire.
- **Computer modeled extensively** in 4NEC2 to design and optimize performance. Efficiency averages ***over 90%*** across all bands with an SWR ***less than 1.10:1*** on each band.
- Designed to be **lightweight and easy to deploy** for all types of portable operations. Also used at HOAs and other types of locations that do not allow permanent antenna installations.

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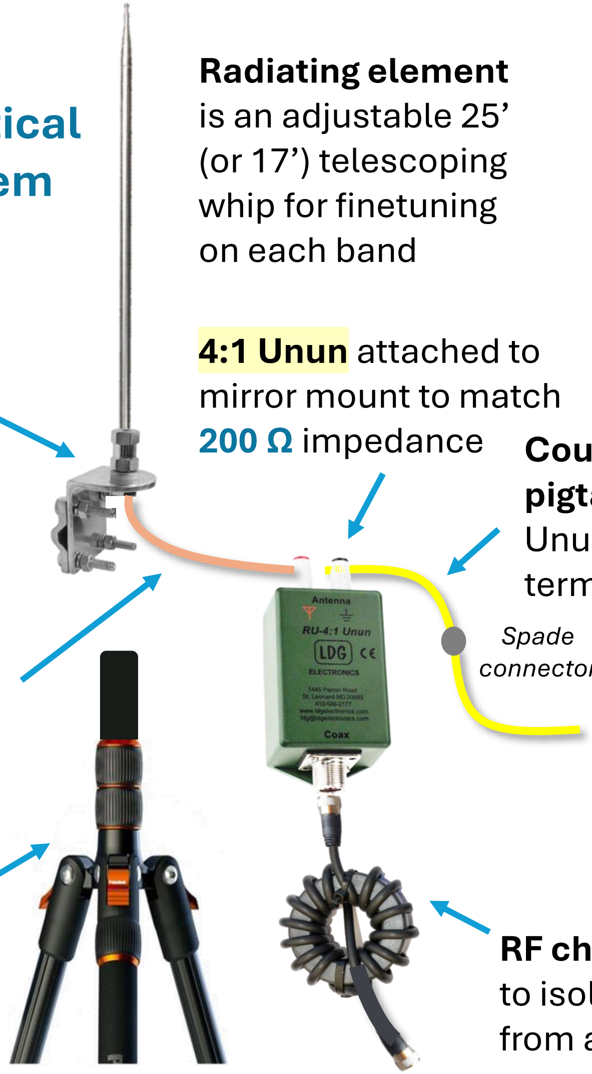
Challenger and **Dominator** Halfwave Vertical Antennas

Challenger Halfwave Vertical Antenna System (20M-6M)

Mirror mount with 3/8” x 24 coupling nut on top and *insulated* 3/8” x 24 bolt at bottom

Whip pigtail (12”) off unun positive with **ring terminal** attached to bolt on mirror mount

Tripod to elevate feedpoint 36-52” above ground



Radiating element is an adjustable 25’ (or 17’) telescoping whip for finetuning on each band

4:1 Unun attached to mirror mount to match **200 Ω** impedance

Counterpoise pigtail (6”) off Unun ground terminal

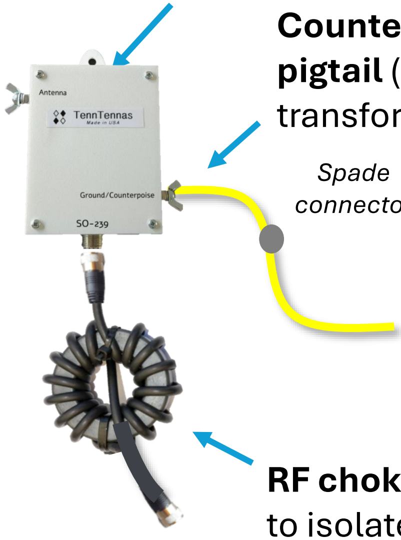
Spade connector

Linked counterpoise wire with spade connectors for each band (20M-6M)

RF choke at feedpoint to isolate coax shield from antenna system

Dominator Halfwave Vertical Antenna System (17M-10M)

49:1 transformer to match **2450 Ω** impedance at feedpoint



Counterpoise pigtail (6”) off transformer negative

Spade connector

Linked counterpoise wire with spade connectors for each band (17M-10M)

RF choke at feedpoint to isolate coax shield from antenna system

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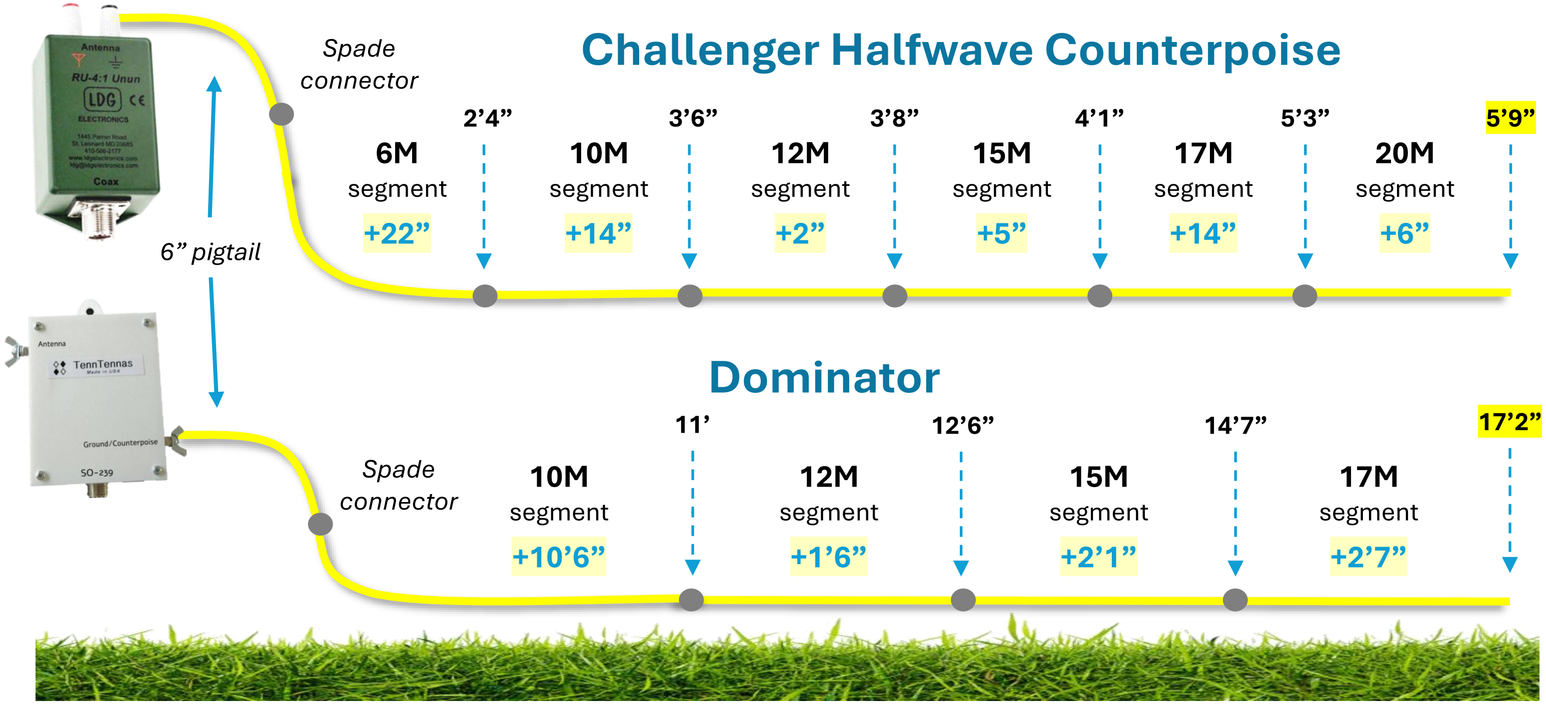
Challenger and **Dominator** Linked Counterpoise Wires

- A **counterpoise completes the remaining halfwave for the Challenger and Dominator, and also provides a return path** for the nearfield radiated RF current to get back to the transmitter on both antennas.
- An **RF choke is required at the feedpoint** to prevent the **coax shield** from becoming a *random and uncontrolled counterpoise* which typically results in *unpredictable* radiation patterns, efficiency and impedance.



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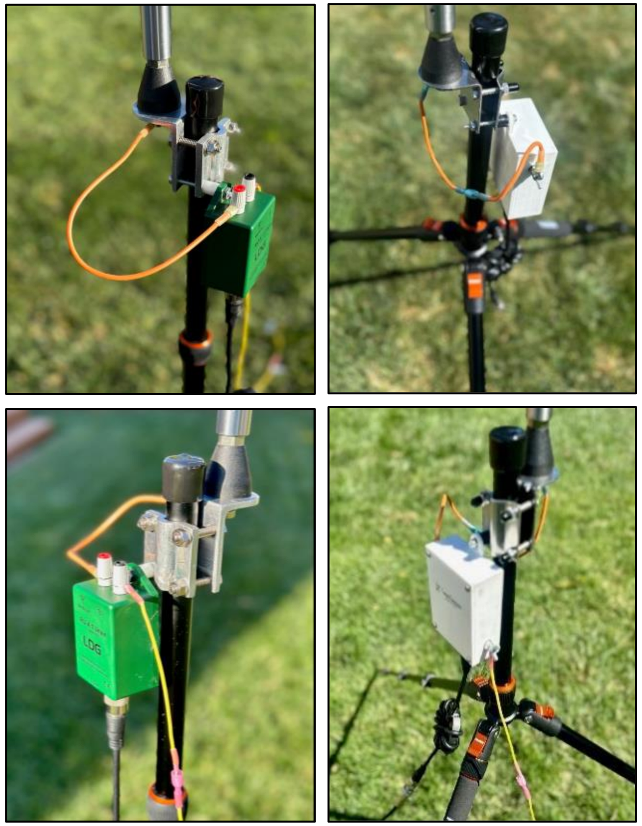

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Challenger and **Dominator** Impedance Matching Components

Challenger

LDG RU-4:1

$30

Insertion Loss: -0.34 dB

Efficiency: 92.4%

Power Range: 200 watts

Bandwidth: 1.8-30 MHz

FT-140-43 Toroid

Palomar JC-1-1500

$30

Insertion Loss: -0.12 dB

Efficiency: 97.3%

Power Range: 1,500 watts

Noise Reduction: -32 dB

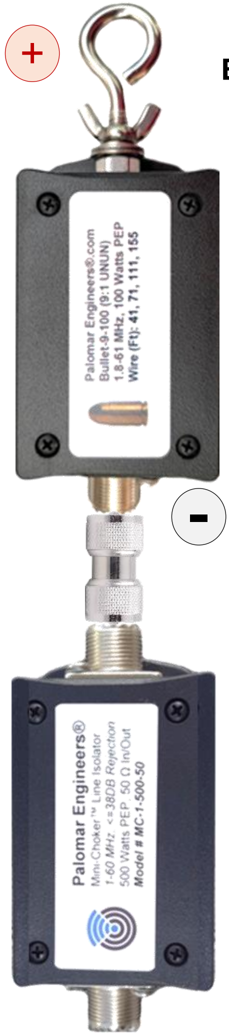
Bandwidth: 1.8-65 MHz

FT-240-31 Toroid

-0.46 dB

Challenger+

Palomar Bullet-4U-100



$70

Insertion Loss: -0.24 dB

Efficiency: 94.6%

Power Range: 100 watts

Bandwidth: 1.8-61 MHz

Dual Port Ferrite Bead Mix 43

Palomar MC-1-500-50

$70

Insertion Loss: -0.11 dB

Efficiency: 97.4%

Power Range: 500 watts

Noise Reduction: -42 dB

Bandwidth: 1-60 MHz

Ferrite Bead Mix 31

-0.35 dB

Dominator

TennTennas 49:1 Transformer

FT-240-43 Toroid

$45

Insertion Loss: -0.96 dB

Efficiency: 80.1%

Power Range: 100 watts

Bandwidth: 1.8-30 MHz

Palomar JC-1-1500

$30

Insertion Loss: -0.12 dB

Efficiency: 97.3%

Power Range: 1,500 watts

Noise Reduction: -32 dB

Bandwidth: 1.8-65 MHz

FT-240-31 Toroid

-1.08 dB

Dominator+

MyAntennas 56:1 MEF-130-LP Transformer

$89

Insertion Loss: -0.40 dB

Efficiency: 91.2%

Power Range: 250 watts

Bandwidth: 1.8-30 MHz

FT-140-43 Toroid

Palomar MC-1-500-50

$70

Insertion Loss: -0.11 dB

Efficiency: 97.4%

Power Range: 500 watts

Noise Reduction: -42 dB

Bandwidth: 1-60 MHz

Ferrite Bead Mix 31

-0.51 dB

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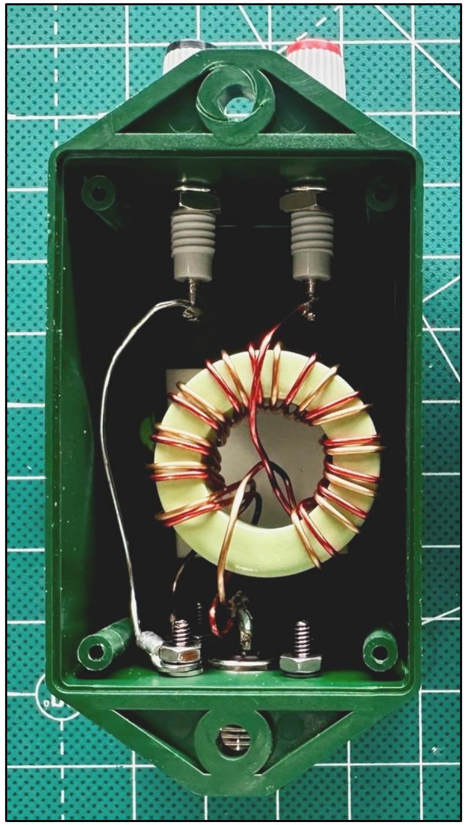
Challenger and **Dominator** Impedance Matching Components

Challenger
LDG
RU-4:1



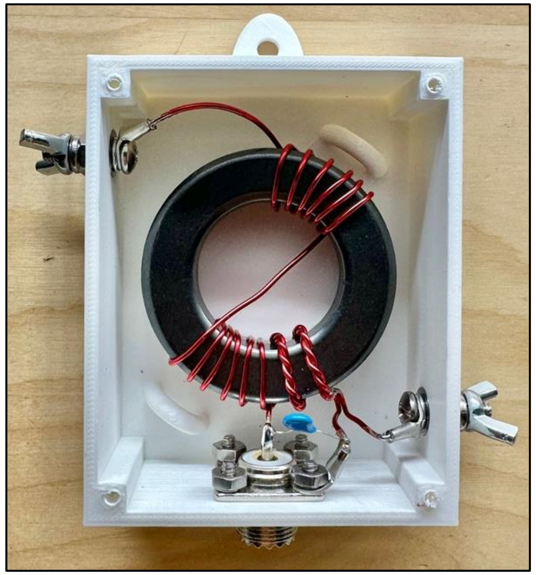
FT-140-43 Toroid Mix 43
1.4” O.D. x 0.9” I.D. x 0.5“ Height

Challenger+
Palomar
Ferrite Beads

Bullet-4U-100
Dual ¼” Port
Ferrite Bead
Mix 43
1.125” Height x
1.125” Width x
0.5“ Depth

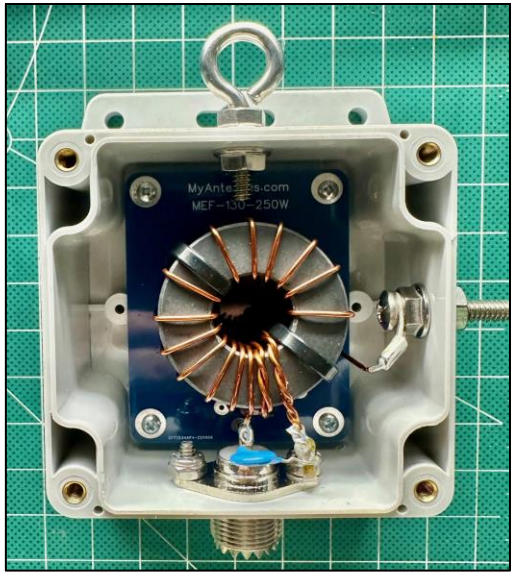
MC-1-500-50
Ferrite Bead
Mix 31
0.687” O.D. x
0.375” I.D. x
1.125” Height

Dominator
TennTennas 49:1
Transformer



FT-240-43 Toroid Mix 43
2.4” O.D. x 1.4” I.D. x 0.5“ Height

Dominator+
MyAntennas 56:1
Transformer



FT-140-43 Toroid Mix 43
1.4” O.D. x 0.6” I.D. x 1.0“ Height

Equivalent to 3x FT-140-43 Toroids

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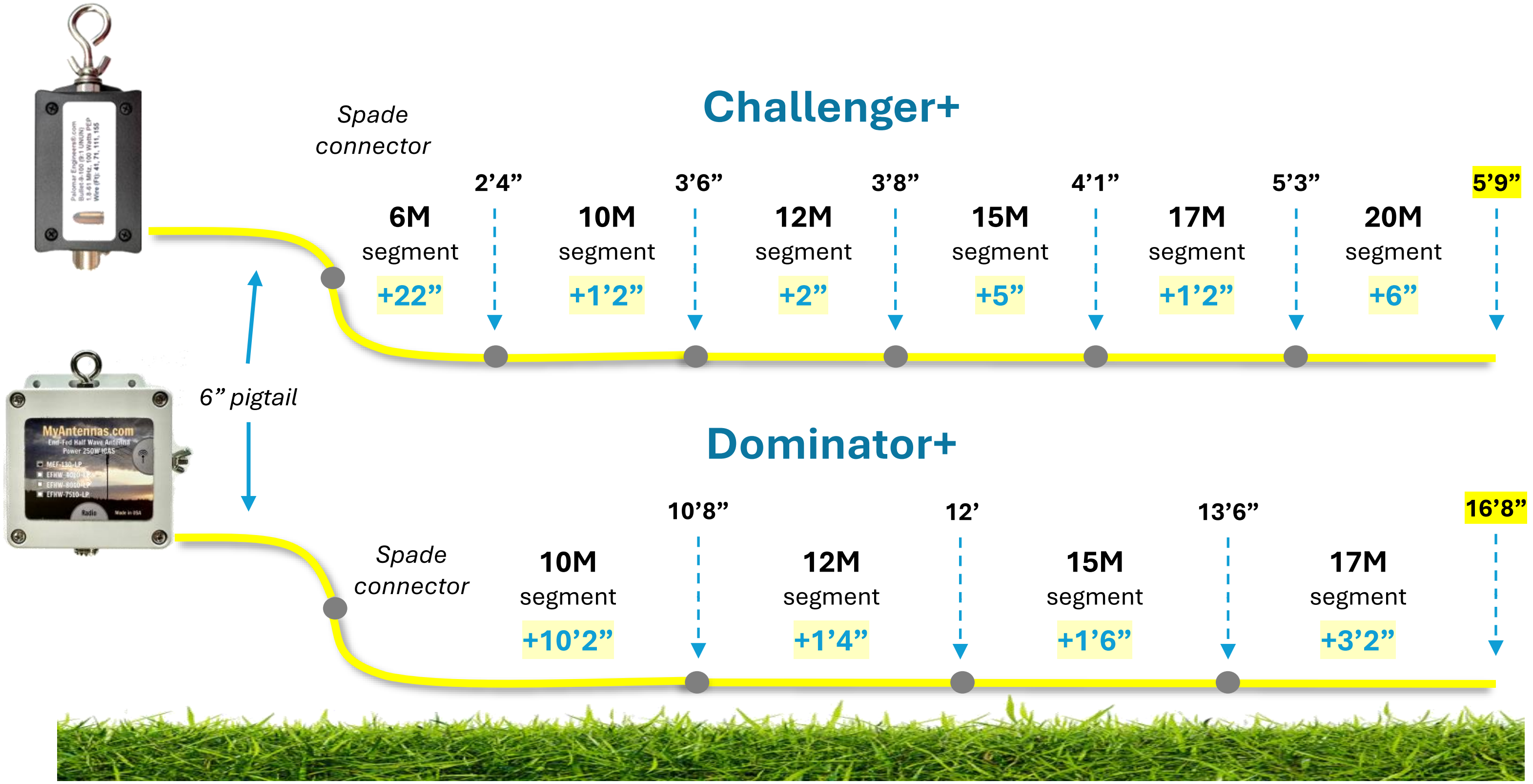
Challenger+ and Dominator+ Linked Counterpoise Wires

- **Challenger+** leverages a Palomar™ **4:1 dual port ferrite bead unun** which is a similar impedance match as the **Challenger** LDG™ 4:1 toroid unun.
- **Dominator+** leverages a Palomar™ **56:1 transformer** which requires shorter counterpoise lengths than **Dominator** with a TennTennas™ **49:1 transformer**.



Not to scale

Dominator+ and Challenger+ mounted side-by-side on the Polarduck™ tripod.

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4NEC2 **Challenger** Performance Specifications across 6 Bands

Band	Target Freq. (MHz)	468 / f: Length	468 / f: λ (in)
20M	14.250	32' 10"	788
17M	18.140	25' 10"	619
15M	21.350	21' 11"	526
12M	24.940	18' 9"	450
10M	28.400	16' 6"	395
6M	51.000	9'4"	220

Band	Radiator: Inches	Radiator: % λ	Counterpoise: Inches	Counterpoise: % λ	OCF %	Total % λ
20M	304	38.6%	99	12.5%	75.5%	51.1%
17M	240	38.7%	76	12.3%	75.9%	51.0%
15M	205	39.0%	65	12.3%	76.0%	51.2%
12M	175	38.9%	56	12.4%	75.9%	51.3%
10M	154	39.0%	49	12.3%	76.0%	51.3%
6M	87	39.6%	26	11.8%	77.1%	51.4%
Averages:		**38.9%**		**12.3%**	**76.1%**	**51.2%**

Band	Specifications: SWR	Ref Coef (db)	Rad Angle (deg)	Gain (dBi)	-3 dB BW (deg)	Structural Efficiency	Impedance
20M	1.04	-34.9	21	-0.66	35	93.0%	193 - j 1.78
17M	1.02	-38.9	21	-0.54	34	93.8%	196 + j 1.46
15M	1.04	-34.2	21	-0.32	33	94.0%	192 + j 1.25
12M	1.06	-30.8	20	-0.23	31	94.5%	189 + j 3.34
10M	1.06	-30.3	20	-0.12	31	94.7%	189 + j 3.31
6M	1.04	-34.8	20	0.27	30	95.9%	193 + j 2.30
Averages:	**1.04**	**-34.0**	**21**	**-0.27**	**32**	**94.3%**	**Z = R + j X**

- The model computed several *performance* specifications including **SWR, reflection coefficient**, **peak radiation angle**, **gain**, **-3.00 dB beamwidth** as well as overall **antenna efficiency** and **impedance**.
- The *average* performance specifications *across all six bands* are:
  - ✓ Structural Efficiency = **94.3%**
  - ✓ OCF Unun Efficiency = **92.4% - 94.6%**
  - ✓ SWR= **1.04**, Ref. Coef. = **-34.0 dB**
  - ✓ Peak Radiation Gain = **-0.27 dBi**
  - ✓ Peak Radiation Angle = **21°** (*beamwidth* 8° - 40°)
  - ✓ -3.00 dB Beamwidth = **32°** (*delta* -13°, +19°)

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4NEC2 **Dominator** Performance Specifications across 4 Bands

Band	Target Freq. (MHz)	468 / f		Radiator		Counterpoise		Specifications						
		Length	Inches	Inches	λ %	Inches	λ %	SWR	Ref Coef (db)	Rad Angle (deg)	Gain (dBi)	-3 dB BW (deg)	Structural Efficiency	Impedance
17M	18.140	25' 10"	310	315	50.8%	206	33.3%	1.00	-54.8	18	0.33	28	99.4%	2442 - j 3.33
15M	21.350	21' 11"	263	272	51.8%	175	33.3%	1.01	-50.0	18	0.60	28	99.4%	2463 + j 8.75
12M	24.940	18' 9"	225	233	51.7%	150	33.3%	1.02	-40.4	18	0.79	27	99.5%	2404 + j 0.38
10M	28.400	16' 6"	198	204	51.7%	132	33.4%	1.04	-33.8	18	0.96	27	99.5%	2353 - j 15.0
				Averages:	51.5%		33.3%	1.02	-44.8	18	0.67	28	99.5%	Z = R + j X

- The model computed several *performance* specifications including **SWR, reflection coefficient**, **peak radiation angle**, **gain**, **-3.00 dB beamwidth** as well as overall **antenna efficiency** and **impedance**.
- The *average* performance specifications *across all six bands* are:
  - ✓ Structural Efficiency = **99.5%**
  - ✓ EF Xformer Efficiency = **80.1% - 91.2%**
  - ✓ SWR= **1.02**, Ref. Coef. = **-44.8 dB**
  - ✓ Peak Radiation Gain = **+0.67 dBi**
  - ✓ Peak Radiation Angle = **18°** (*beamwidth* 7° - 35°)
  - ✓ -3.00 dB Beamwidth = **28°** (*delta* -11°, +17°)

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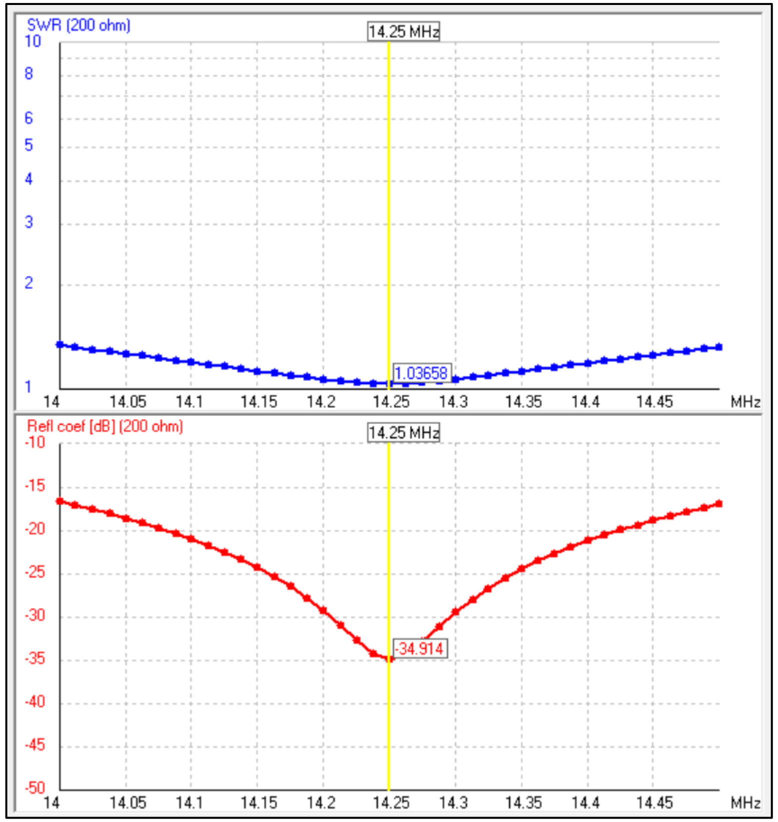
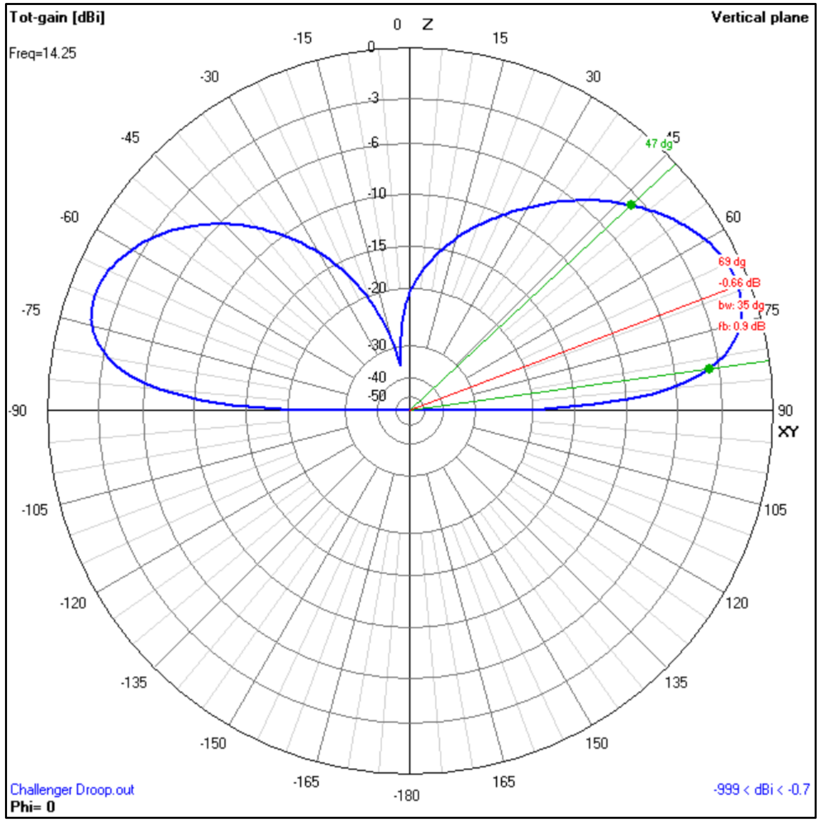
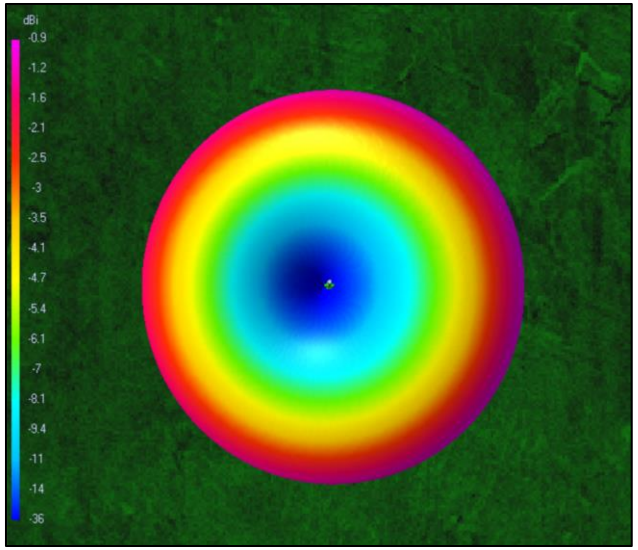
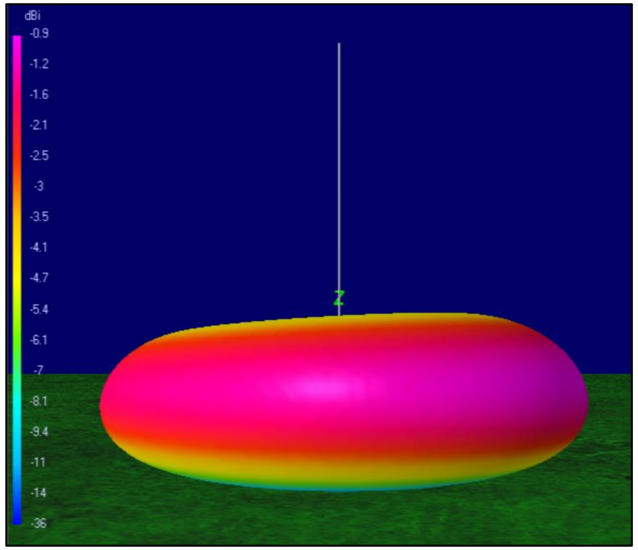
4NEC2 Model Graphics for the **Challenger**: 20M (14.250 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.04:1** at **14.250 MHz** with a **reflection coefficient** of **-34.9 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 21º** with **-0.66 dBi gain** within a **-3dB beamwidth** of **35º** (-13º , +22º) = **8º** to **43º**.

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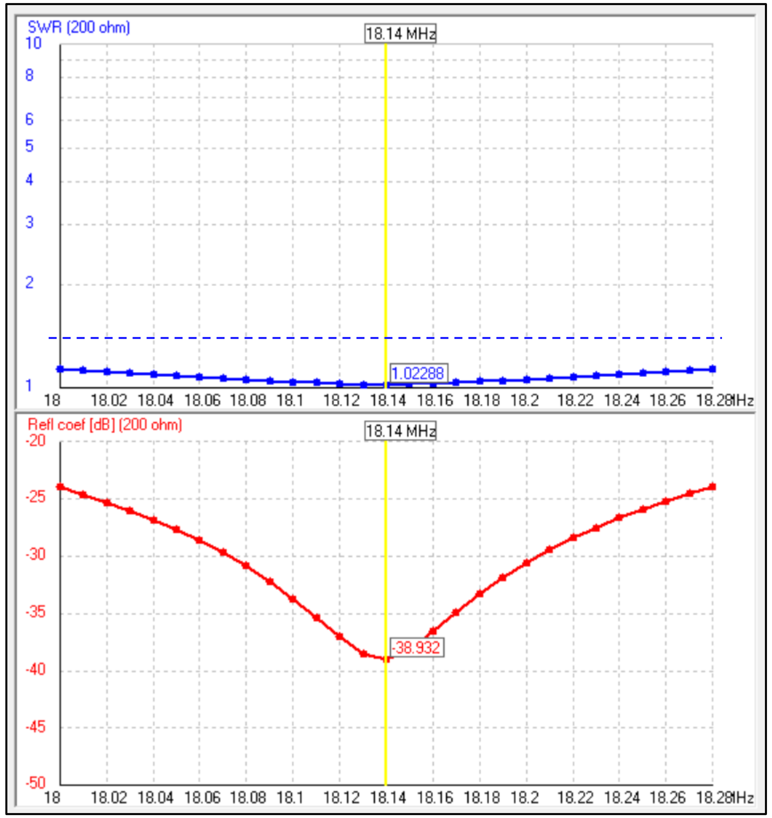
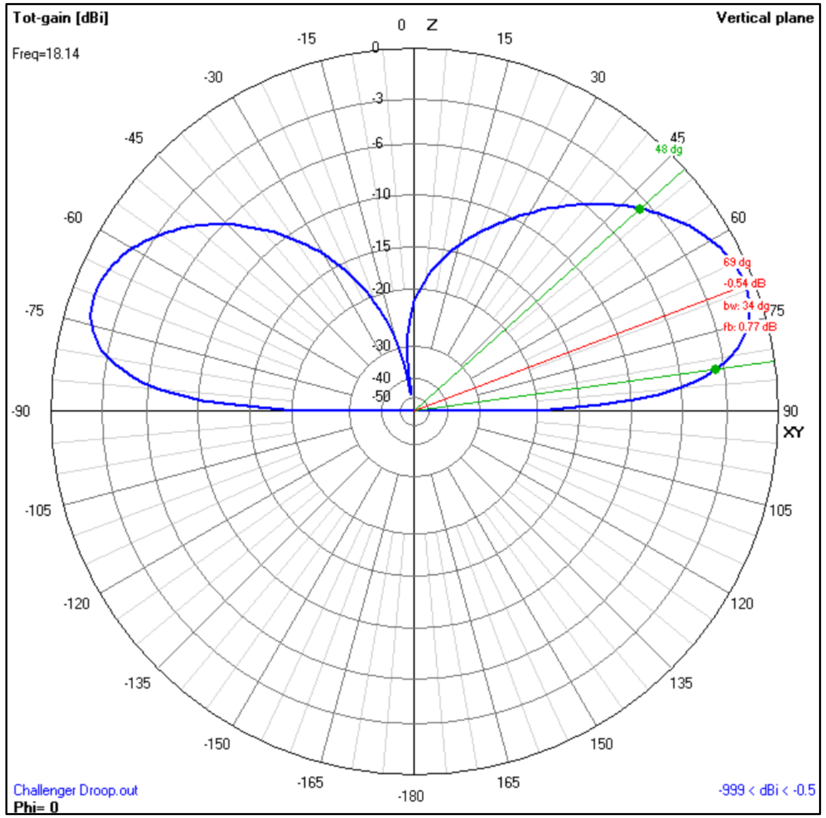
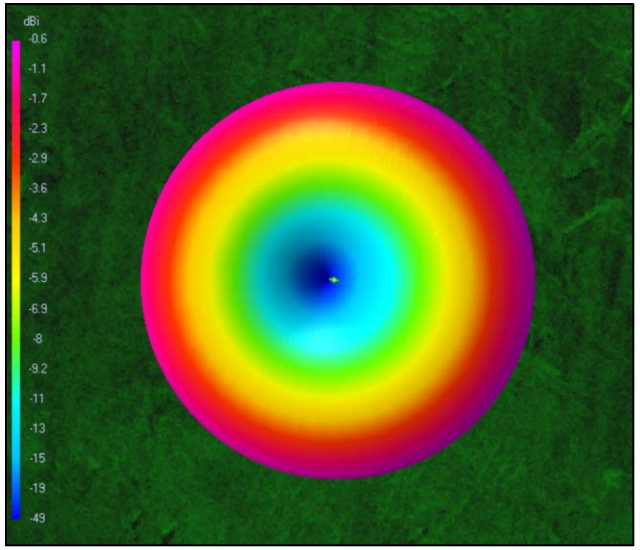
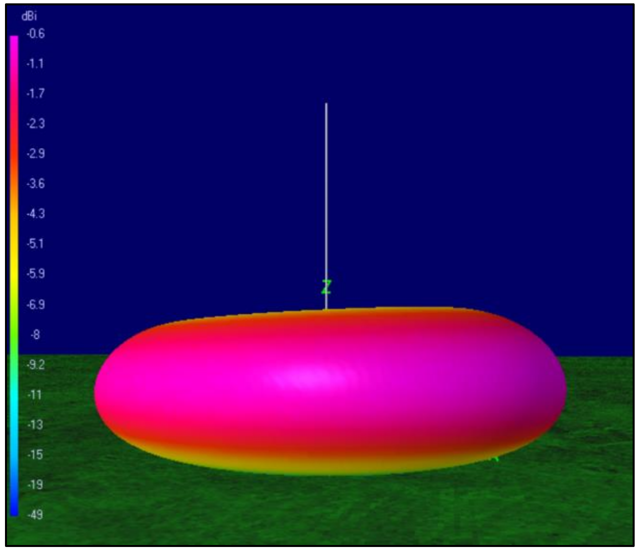
4NEC2 Model Graphics for the **Challenger**: 17M (18.140 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.02:1** at **18.140 MHz** with a **reflection coefficient** of **-38.9 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 21º** with **-0.54 dBi gain** within a **-3dB beamwidth** of **34º** (-13º , +21º) = **8º** to **42º**.

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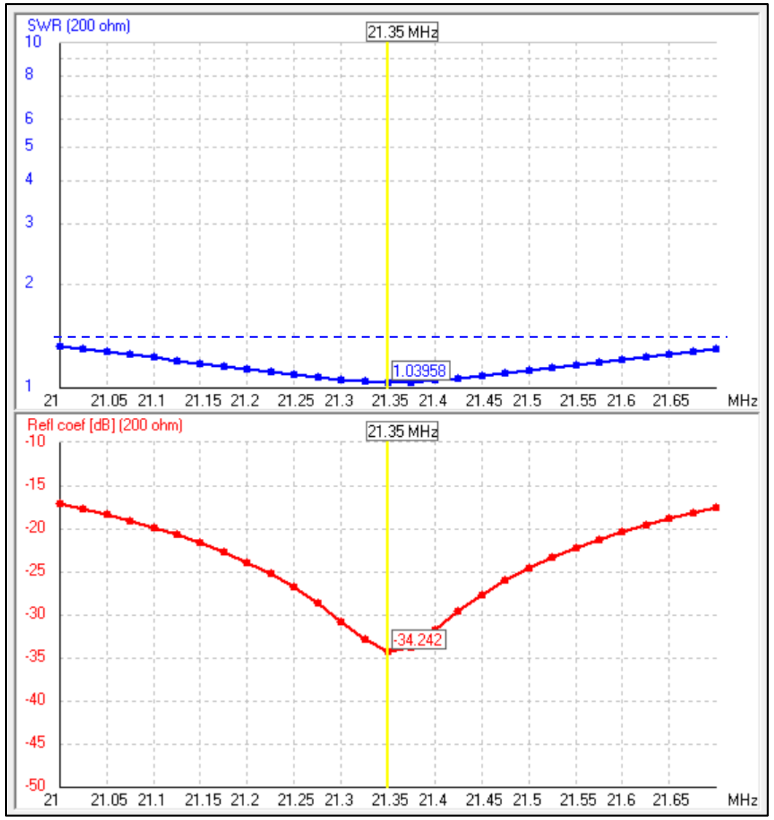
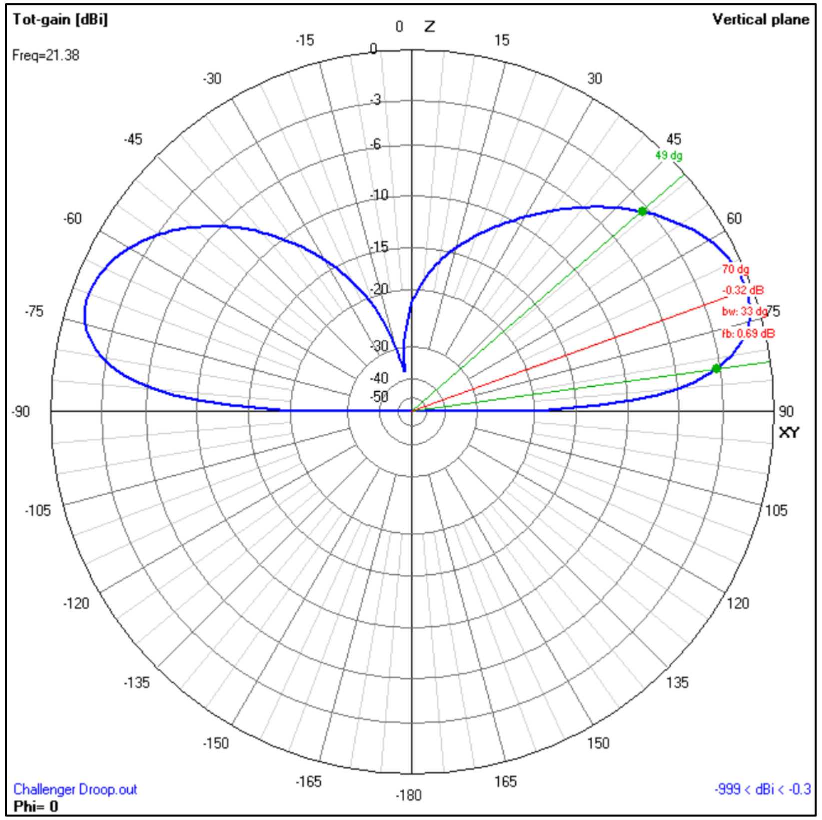
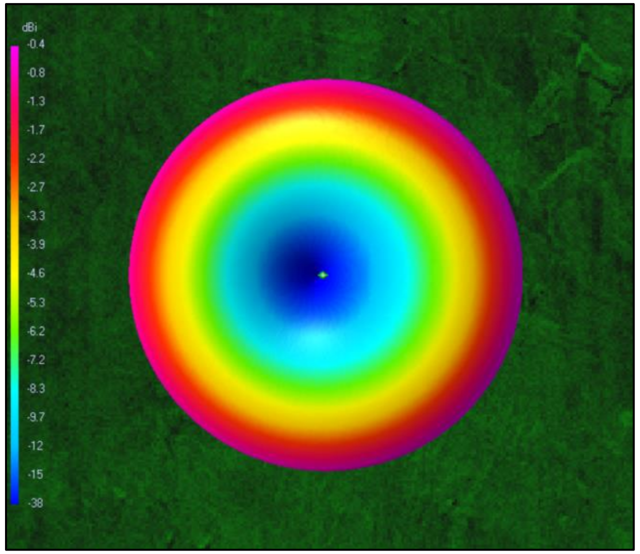
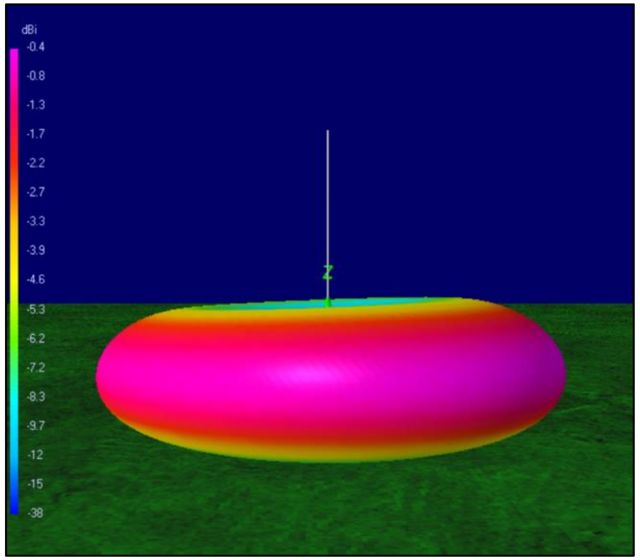
4NEC2 Model Graphics for the **Challenger**: 15M (21.350 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.04:1** at **21.350 MHz** with a **reflection coefficient** of **-34.2 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 20º** with **-0.32 dBi gain** within a **-3dB beamwidth** of **33º** (-13º , +20º) = **8º** to **41º**.

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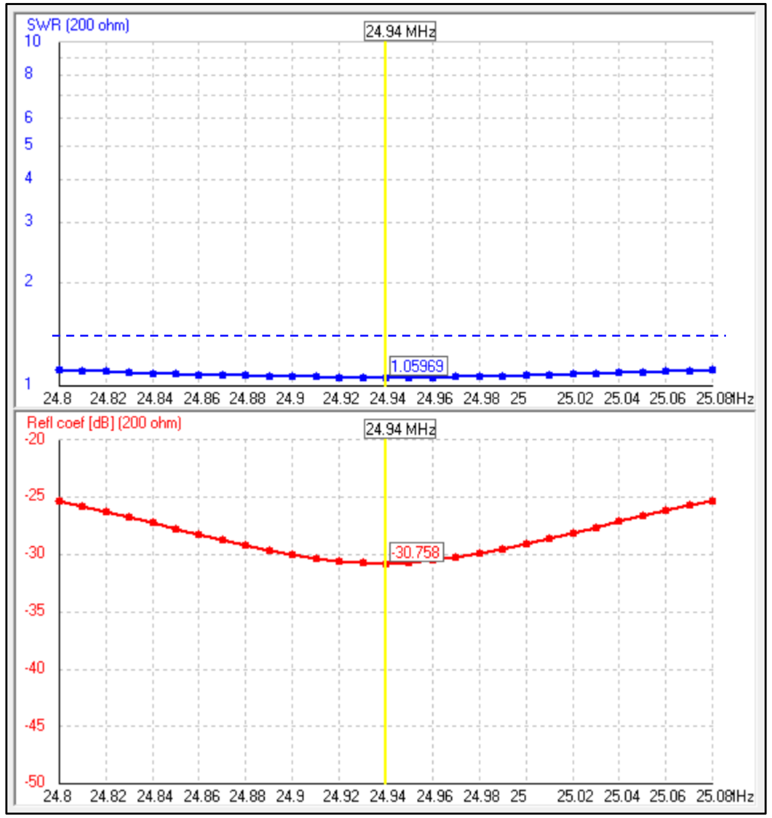
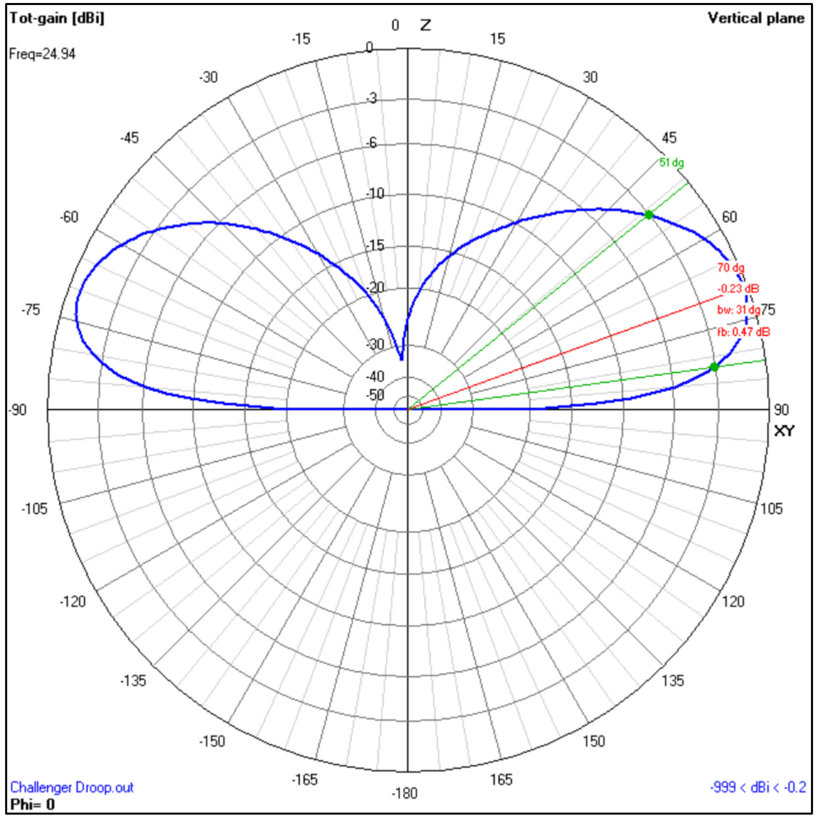
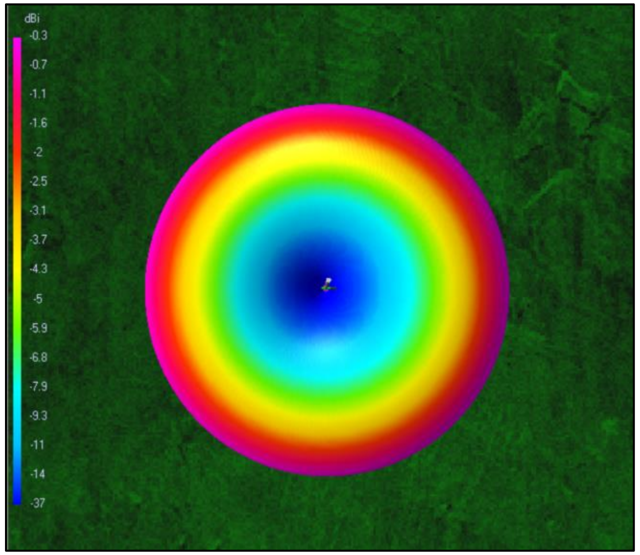
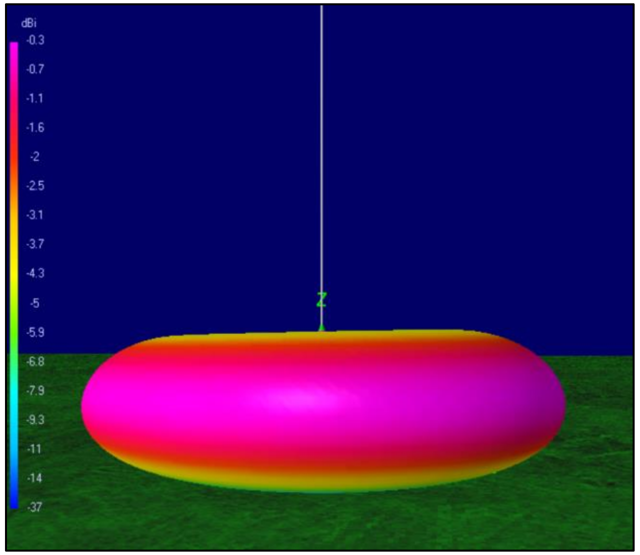
4NEC2 Model Graphics for the **Challenger**: 12M (24.940 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.06:1** at **24.940 MHz** with a **reflection coefficient** of **-30.8 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 20º** with **-0.23 dBi gain** within a **-3dB beamwidth** of **31º** (-12º , +19º) = **8º** to **39º**.

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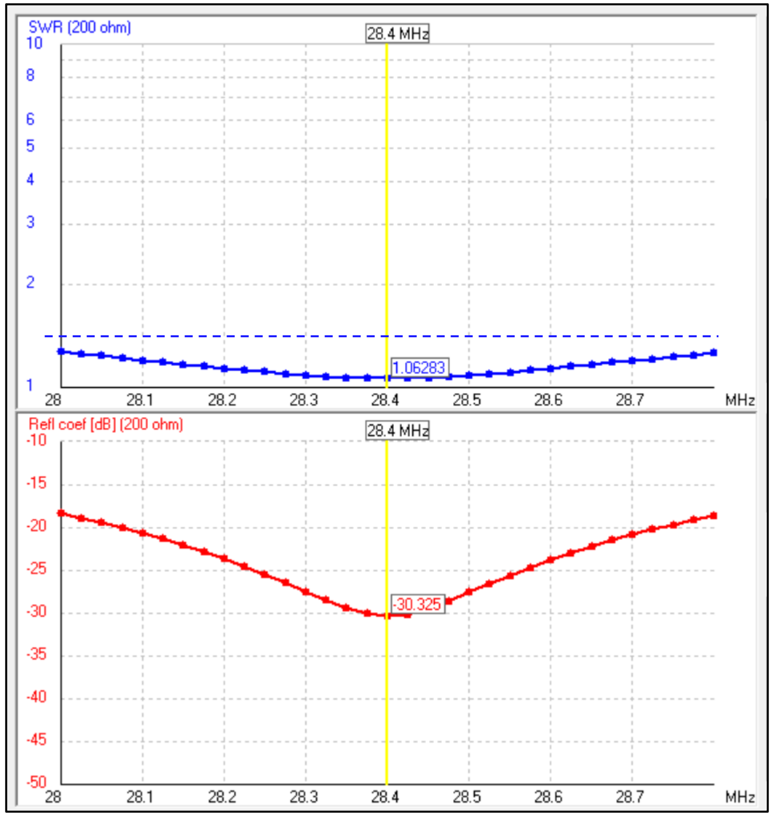
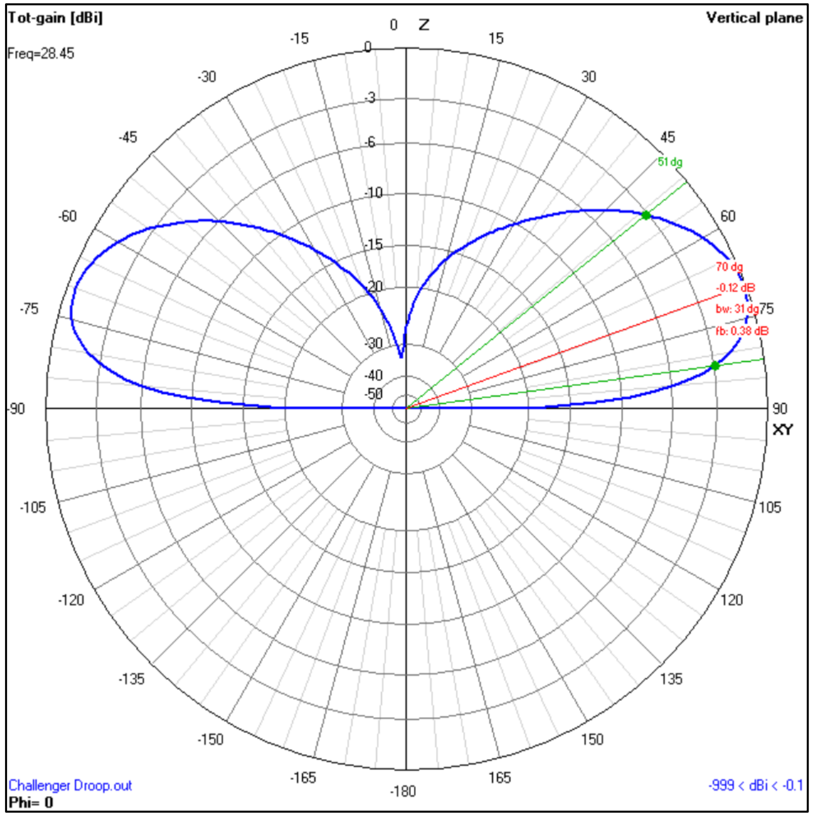
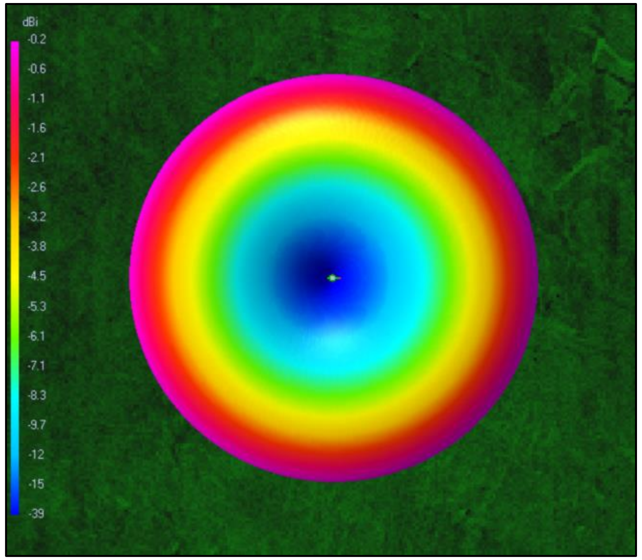
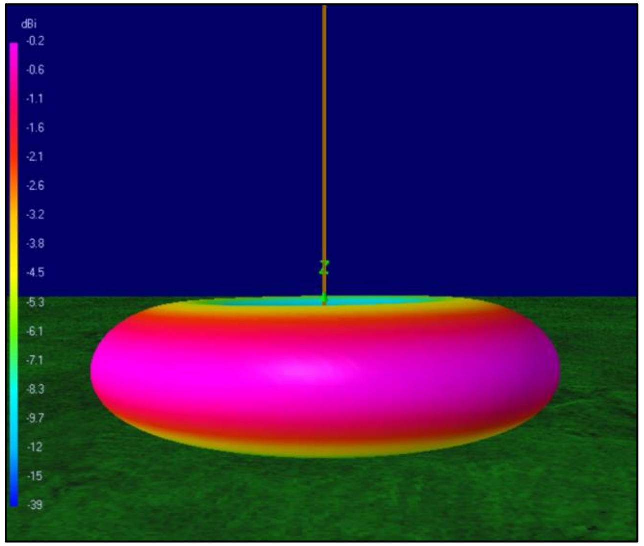
4NEC2 Model Graphics for the **Challenger**: 10M (28.400 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.06:1** at **28.400 MHz** with a **reflection coefficient** of **-30.3 dB**. The ±1.50:1 SWR bandwidth is **1000 kHz.**
- It also calculated **maximum radiation** at **angle 20º** with **-0.12 dBi gain** within a **-3dB beamwidth** of **31º** (-12º , +19º) = **8º** to **39º**.

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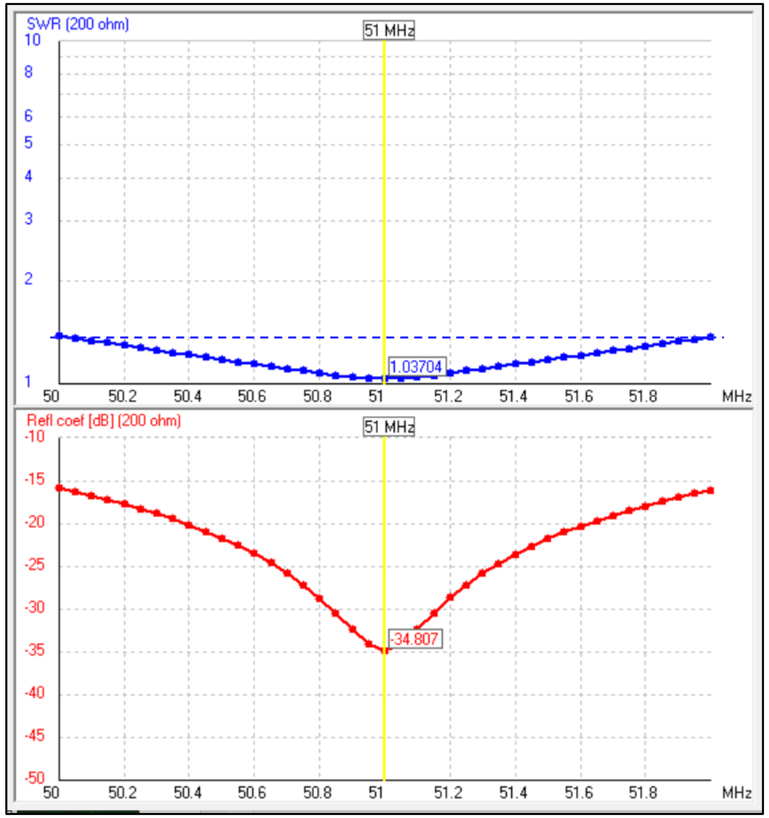
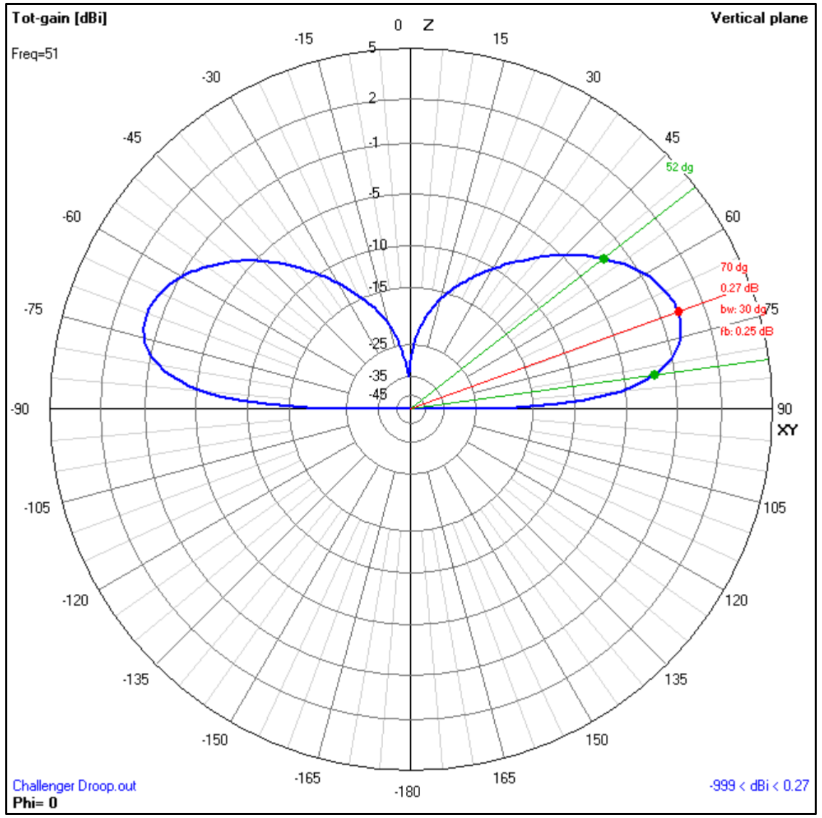
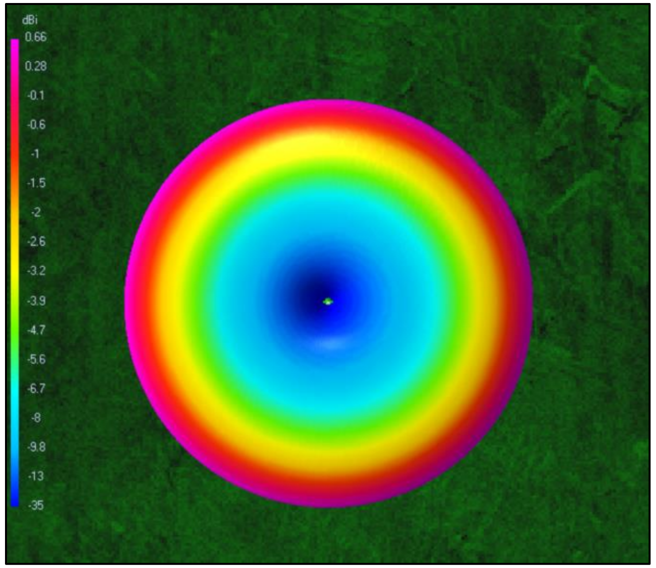
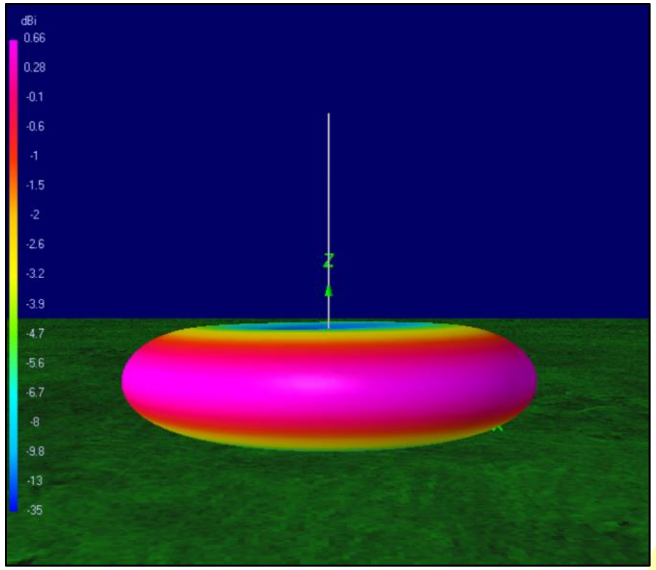
4NEC2 Model Graphics for the **Challenger:** 6M (51.000 MHz)









3D radiation modeling as seen from both the top and side views.

Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.04:1** at **51.000 MHz** with a **reflection coefficient** of **-34.8 dB**. The ±1.50:1 SWR bandwidth is **2000 kHz.**
- It also calculated **maximum radiation** at **angle 20º** with **+0.27 dBi gain** within a **-3dB beamwidth** of **30º** (-12º , +18º) = **8º** to **38º**.

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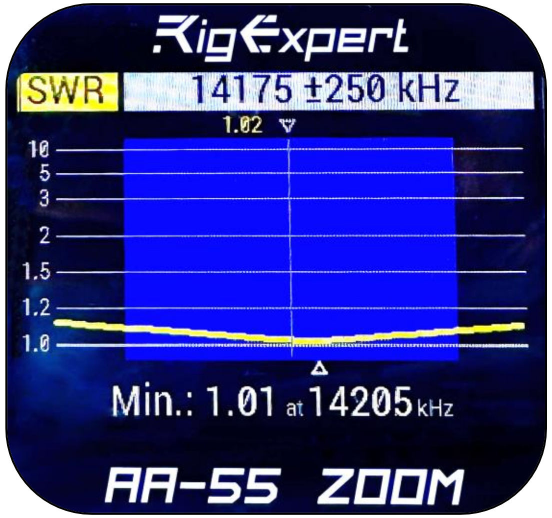
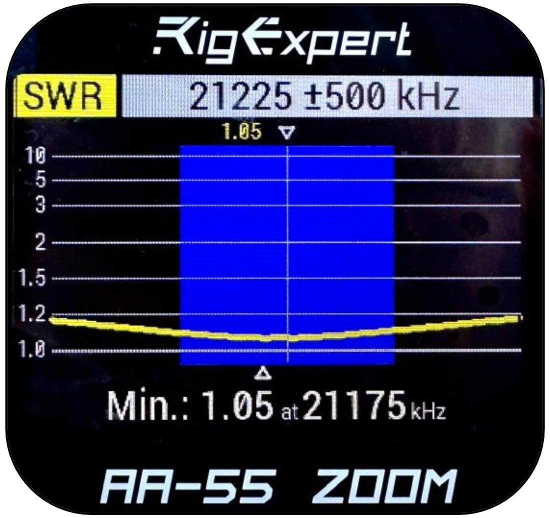
Field SWR Measurements for **Challenger** Halfwave: 20M-6M



20M Band

17M Band



15M Band

12M Band

10M Band

6M Band

SWR Efficiency:

- 1.10:1 = 99.8%
- 1.20:1 = 99.2%
- 1.30:1 = 98.3%
- 1.40:1 = 97.2%
- 1.50:1 = 96.0%

Note: A 17' whip instead of a 25' whip covers 17M-6M.

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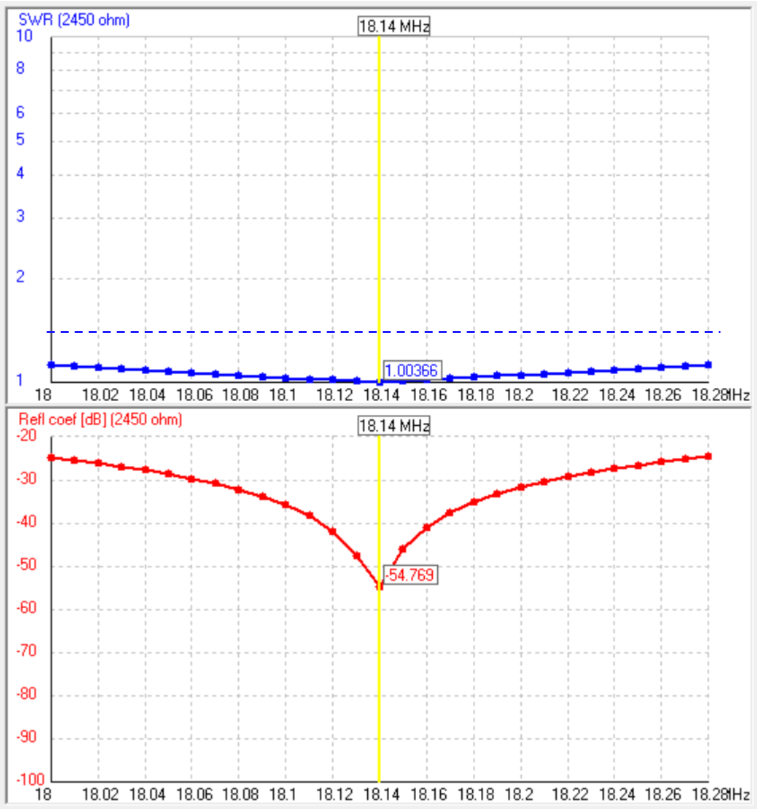
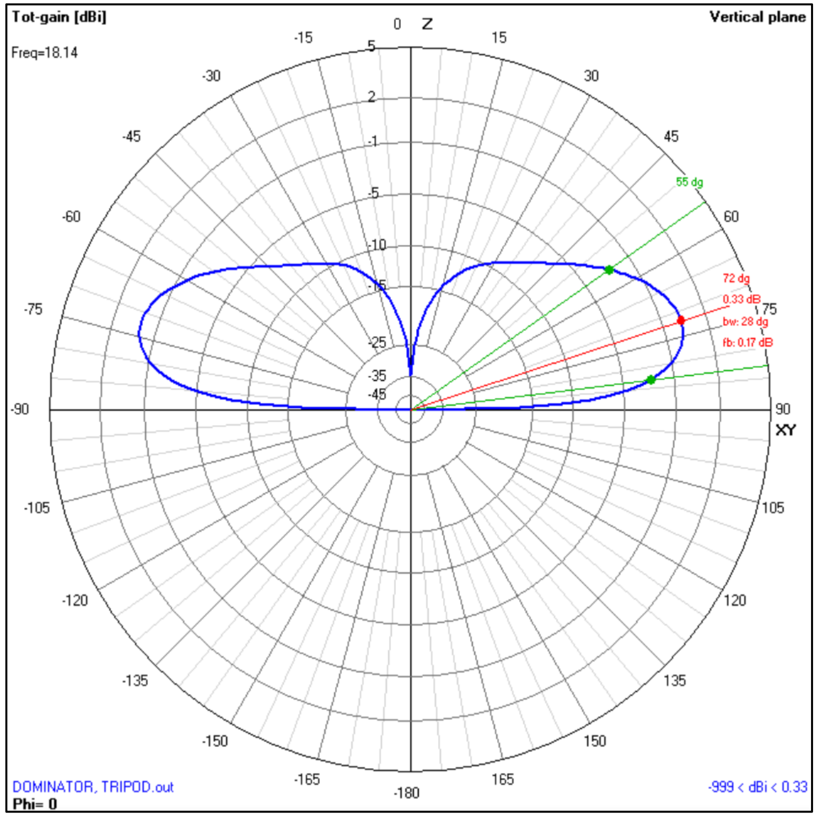
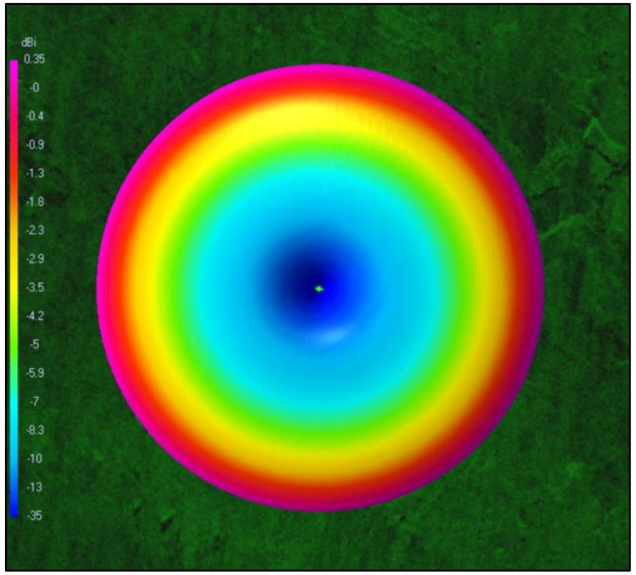
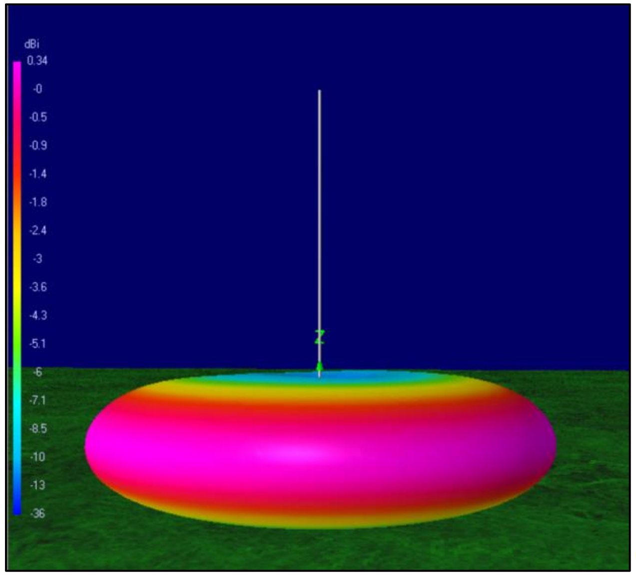
4NEC2 Model Graphics for the **Dominator:** 17M (18.140 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.00:1** at **18.140 MHz** with a **reflection coefficient** of **-54.8 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 18º** with **+0.33 dBi gain** within a **-3dB beamwidth** of **28º** (-11º, +17º) = **7º** to **35º**.

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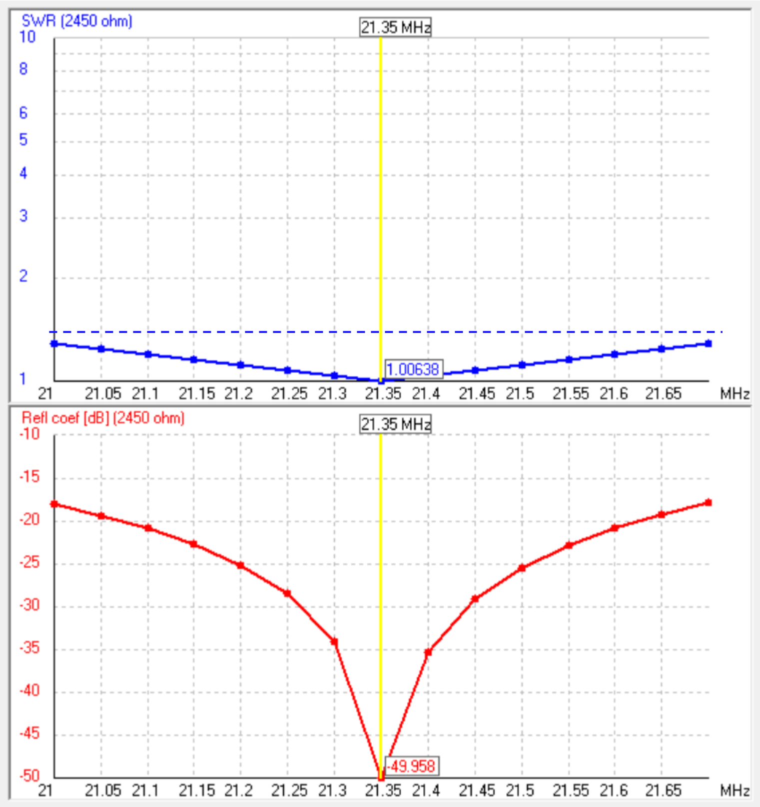
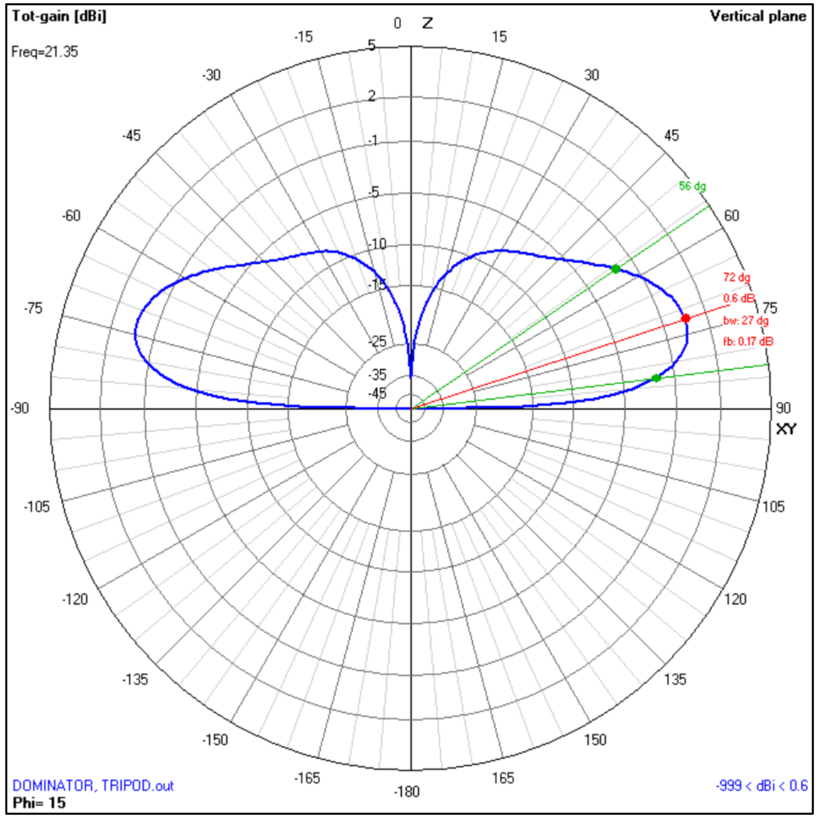
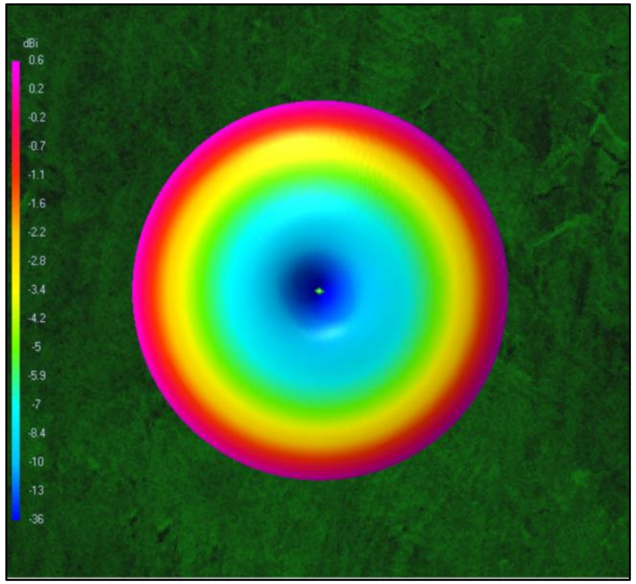
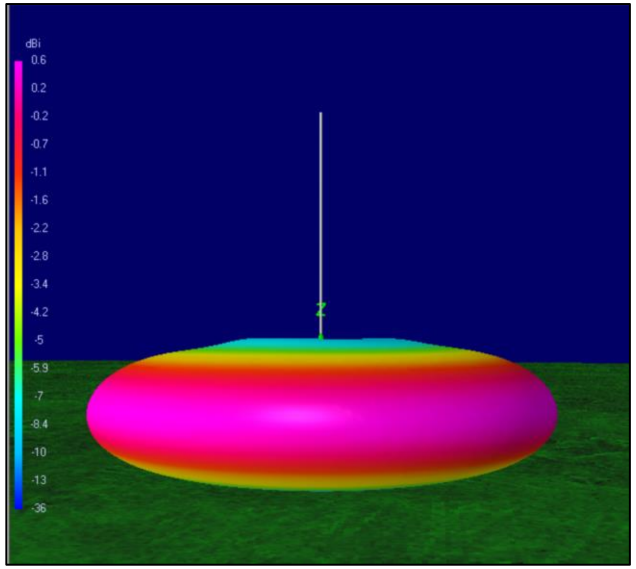
4NEC2 Model Graphics for the **Dominator**: 15M (21.350 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.01:1** at **21.350 MHz** with a **reflection coefficient** of **-50.0 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 18º** with **+0.60 dBi gain** within a **-3dB beamwidth** of **27º** (-11º, +17º) = **7º** to **34º**.

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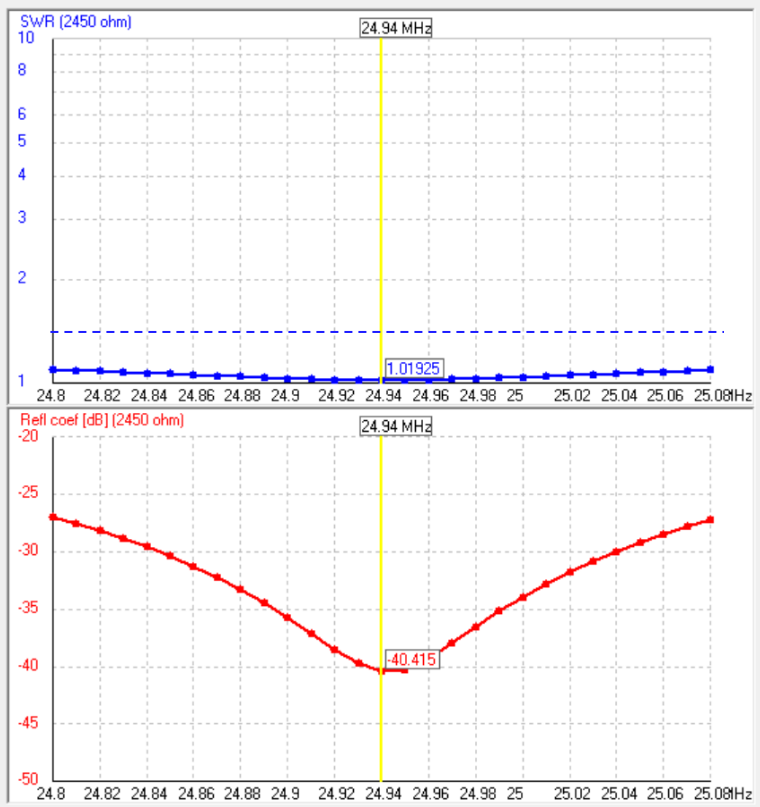
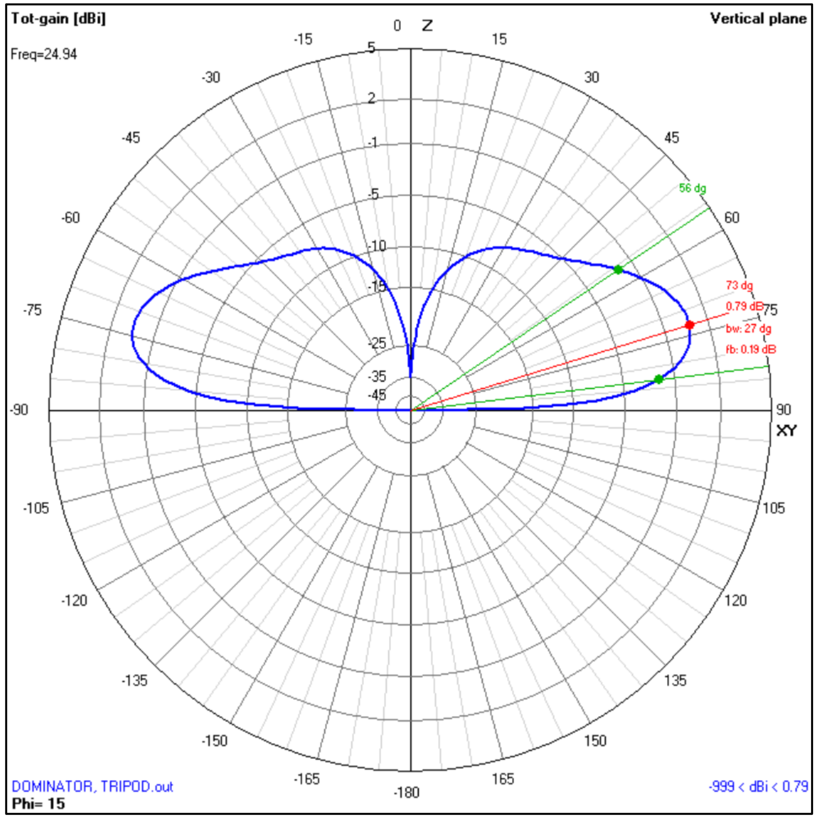
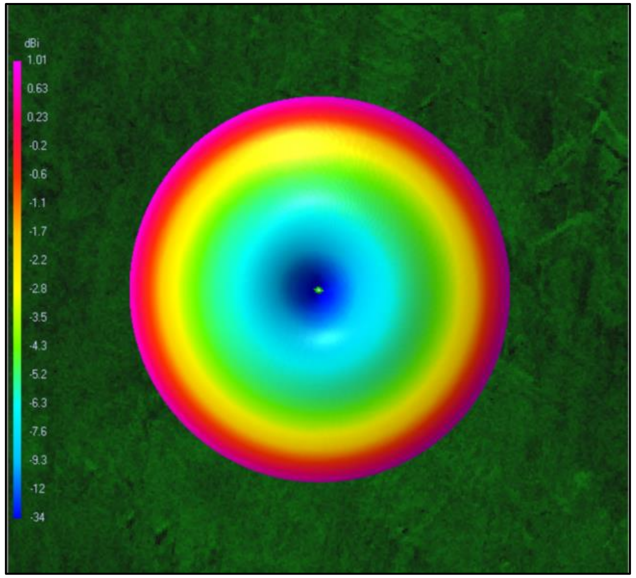
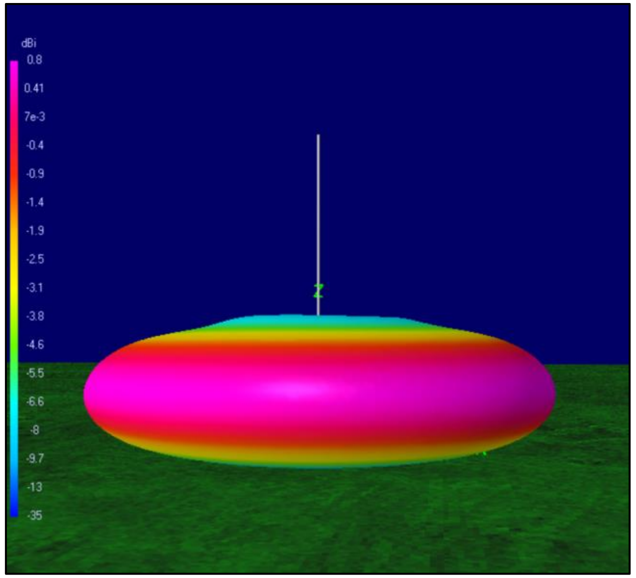
4NEC2 Model Graphics for the **Dominator**: 12M (24.940 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.02:1** at **24.940 MHz** with a **reflection coefficient** of **-40.4 dB**. The ±1.50:1 SWR bandwidth *covers the band*.
- It also calculated **maximum radiation** at **angle 18º** with **+0.79 dBi gain** within a **-3dB beamwidth** of **27º** (-11º, +16º) = **7º** to **34º**.

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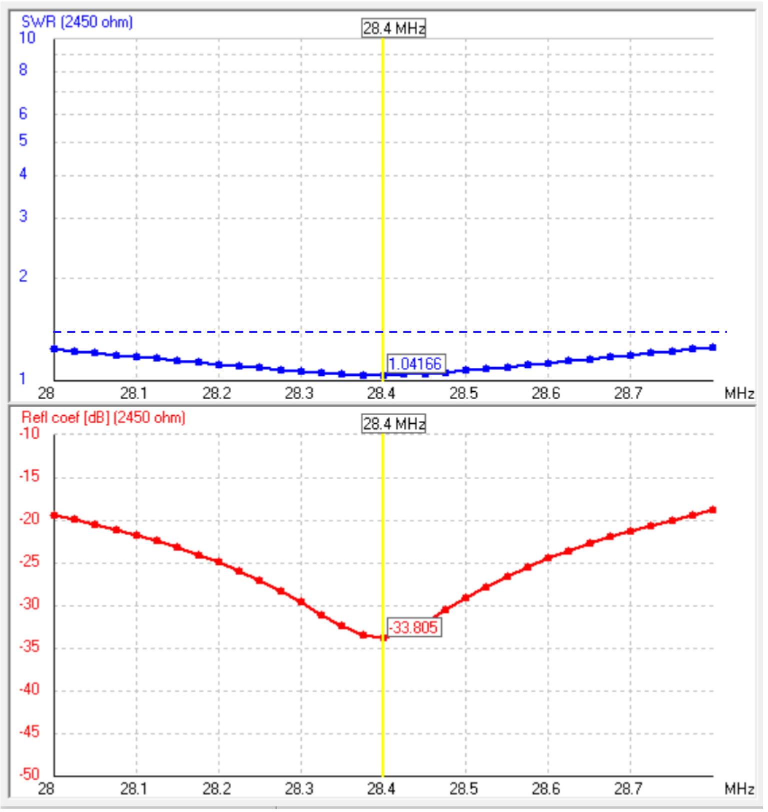
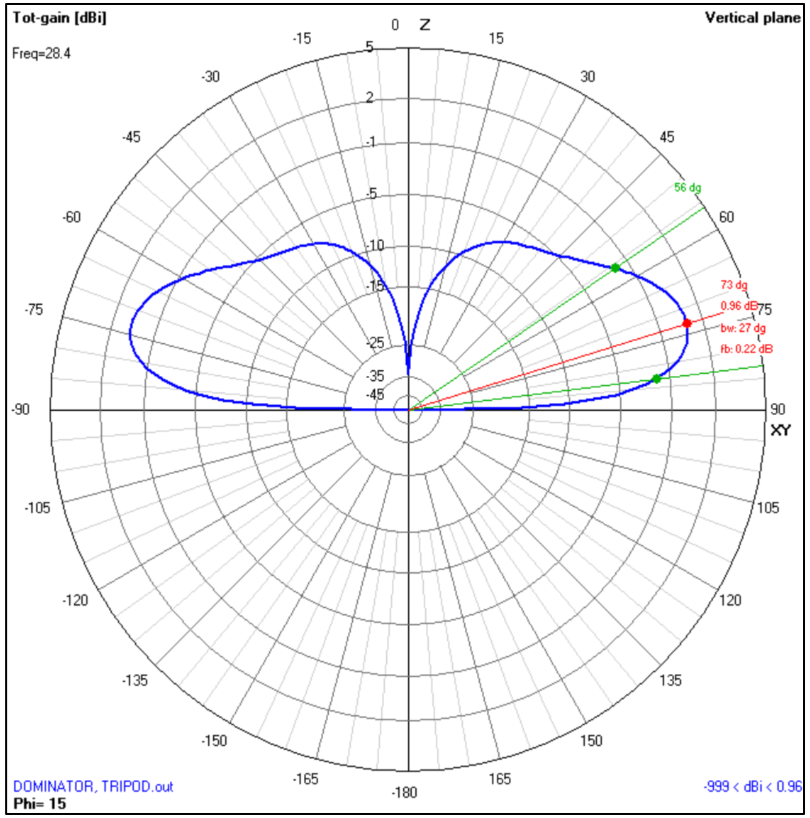
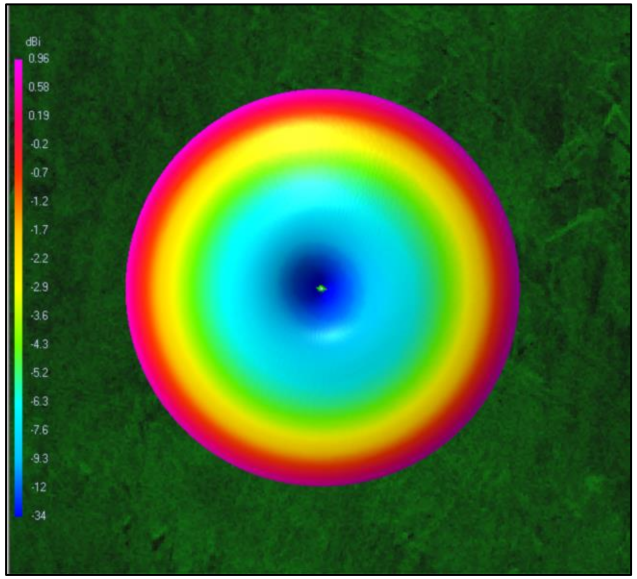
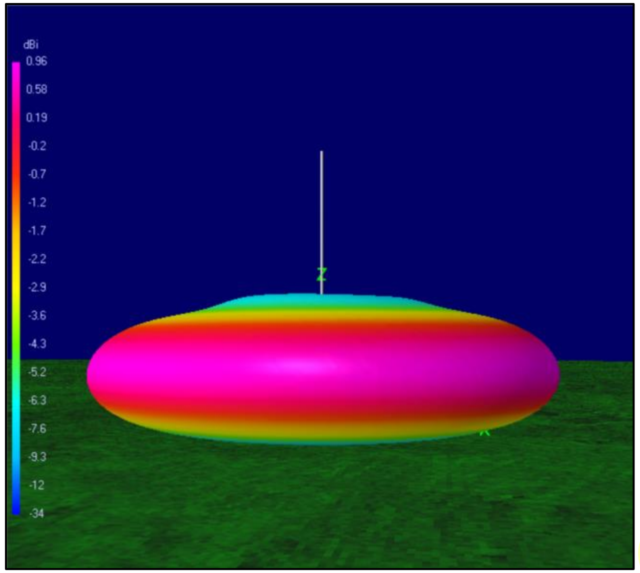
4NEC2 Model Graphics for the **Dominator:** 10M (28.400 MHz)







3D radiation modeling as seen from both the top and side views.



Note that **purple** and **red** are strongest radiation.

- The model calculated **SWR** to be **1.04:1** at **28.400 MHz** with a **reflection coefficient** of **-33.8 dB**. The ±1.50:1 SWR bandwidth is **1200 kHz.**
- It also calculated **maximum radiation** at **angle 18º** with **+0.96 dBi gain** within a **-3dB beamwidth** of **27º** (-11º, +16º) = **7º** to **34º**.

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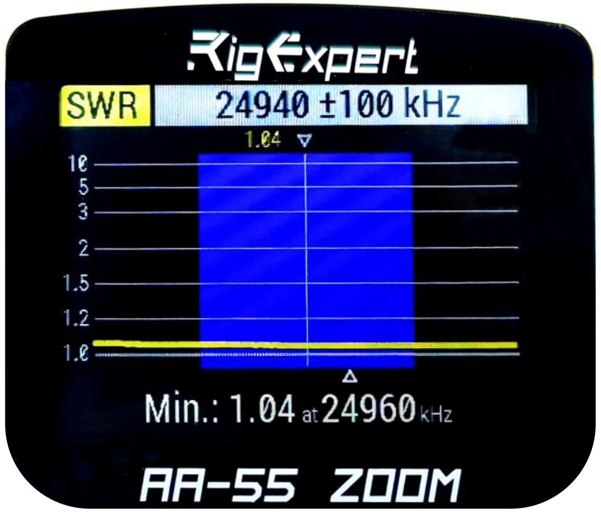
Field SWR Measurements for **Dominator** Halfwave: 17M-10M

17M Band

15M Band



12M Band

10M Band

SWR Efficiency:

- 1.10:1 = 99.8%
- 1.20:1 = 99.2%
- 1.30:1 = 98.3%
- 1.40:1 = 97.2%
- 1.50:1 = 96.0%

Note: A 17' whip instead of a 25' whip covers 12M-10M.

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Summary: Comparing the **PERformer, Challenger** and **Dominator** Vertical Antennas

Comparing PERformer, Challenger and Dominator Antennas

Specifications	PERformer	Challenger	Dominator
Vertical Wavelength	• **Quarterwave**	• **Halfwave**	• **Halfwave**
Antenna Configuration	• Omni/Directional • 2 Elevated Tuned Linked Radials 90/180° apart	• Omnidirectional • 1 Linked Counterpoise, ~10% λ per band	• Omnidirectional • 1 Linked Counterpoise, ~33% λ per band
Band Coverage	• **40M-6M**	• **20M-6M**	• **17M-10M**
Structural Efficiency	• 90.8%	• 94.3%	• 99.5%
50Ω Impedance Match	• ---	• **4:1 Unun** *Off-Center Fed*	• **49/56:1 Xformer** *End-Fed*
Key Component Loss	• -0.12 dB *(toroid choke only)*	• -0.46 *to* -0.35 dB	• -1.08 *to* -0.51 dB
Peak Radiation	• **-0.67 dBi / +0.41 dBi**	• **-0.27 dBi**	• **+0.67 dBi**
Angle of Peak Radiation (-3 dB BW)	• **24°** (9° *to* 54°)	• **21°** (8° *to* 40°)	• **18°** (7° *to* 35°)
-3.00 dB Beamwidth	• **46°** (-15°, +30°)	• **32°** (-13°, +19°)	• **28°** (-11°,+17°)
Primary Reach	• Regional, Continental	• Continental, Global	• Global

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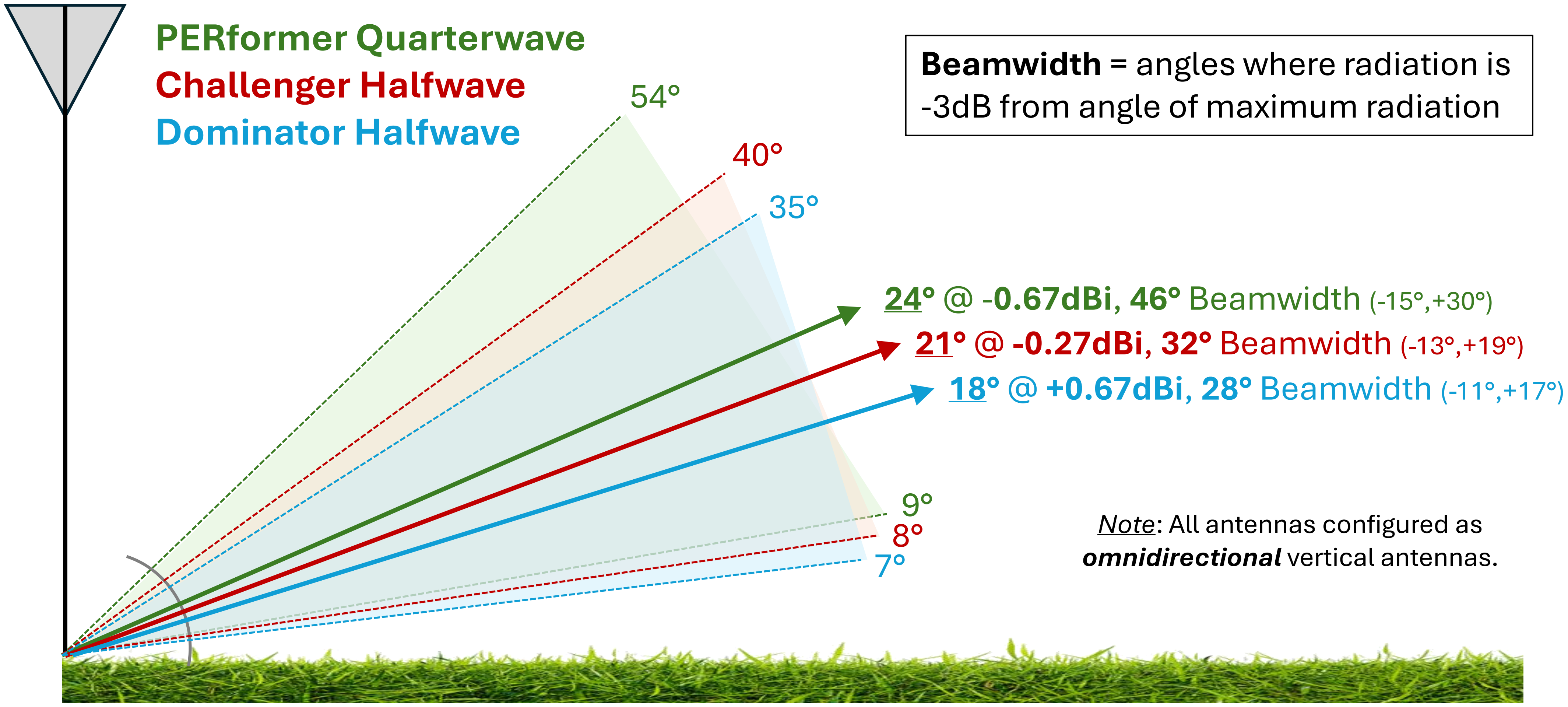
Comparing Max Radiation Angles and Beamwidths



Beamwidth = angles where radiation is -3dB from angle of maximum radiation

Note: All antennas configured as ***omnidirectional*** vertical antennas.

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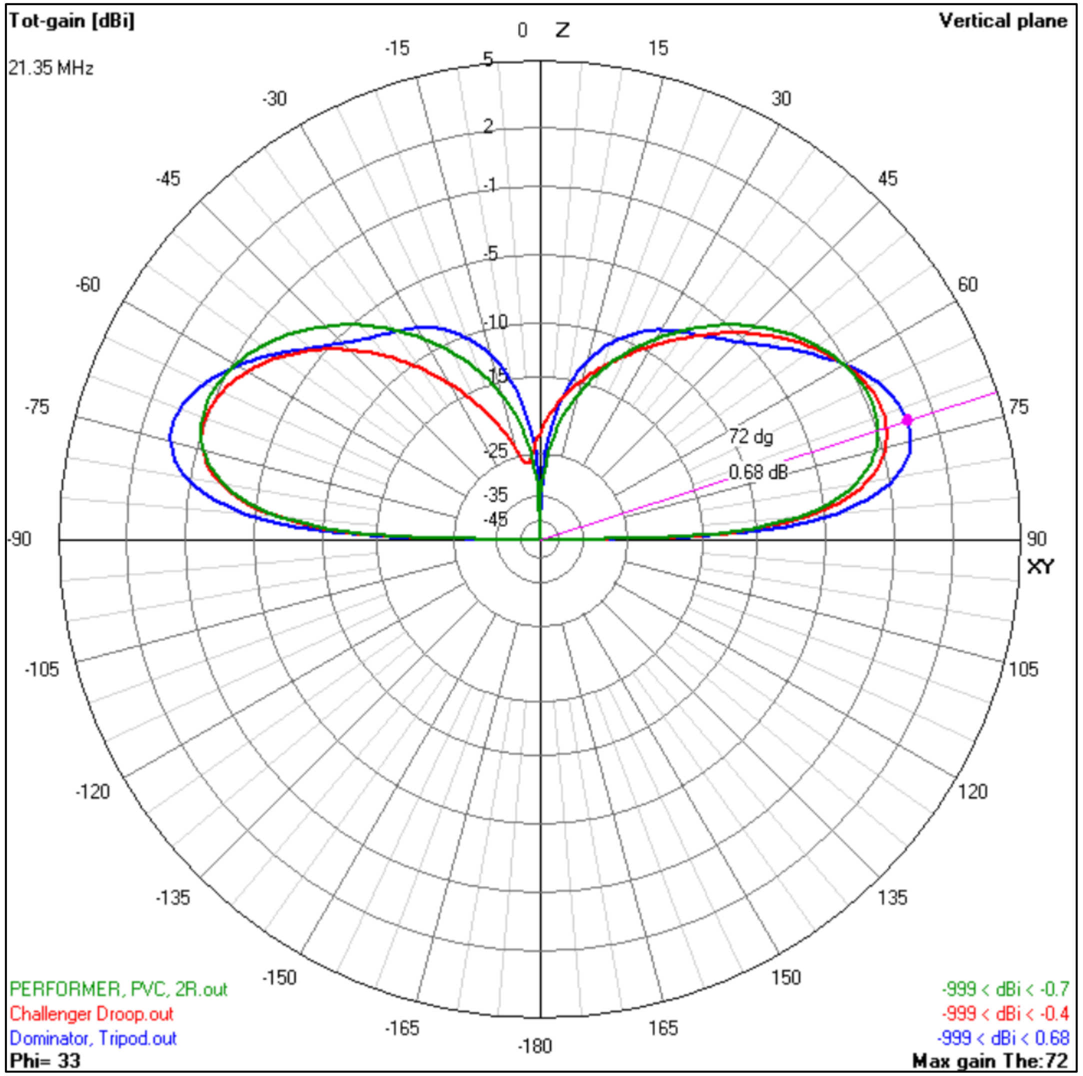
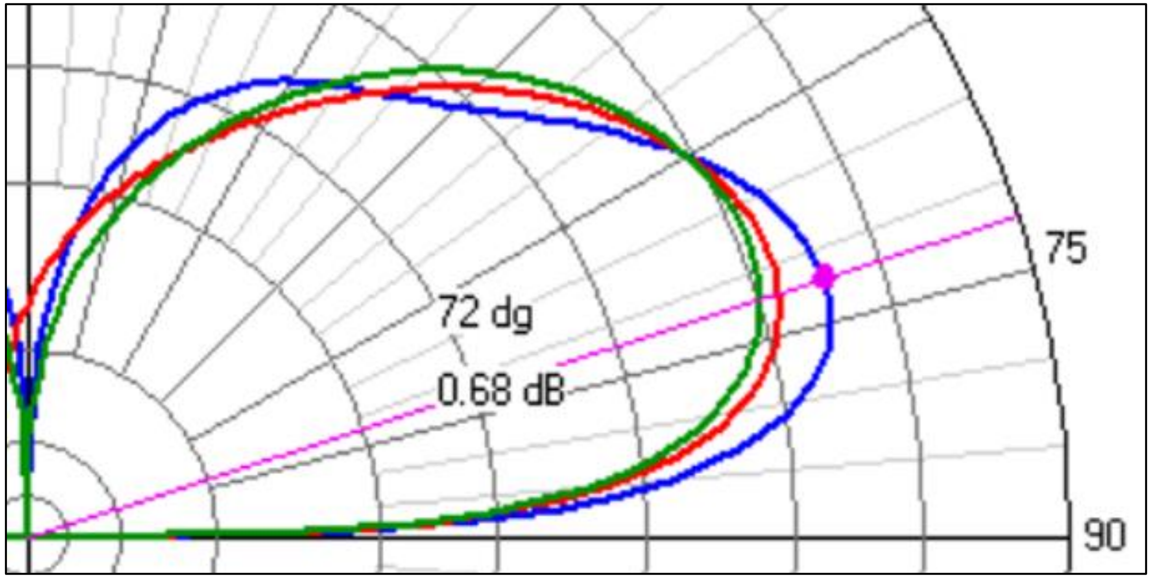
Comparing Omnidirectional Radiation Patterns of 3 Antennas



- Looking at the ***far field* radiation patterns** of all three antennas on **15M** (21.350 MHz): **PERformer** quarterwave, **Challenger** halfwave and **Dominator** halfwave.
- Comparing **radiated gain** at **18°** off the horizon: **Dominator: +0.68 dBi**, **Challenger: -0.32 dBi**, **PERformer: -1.00 dBi**.



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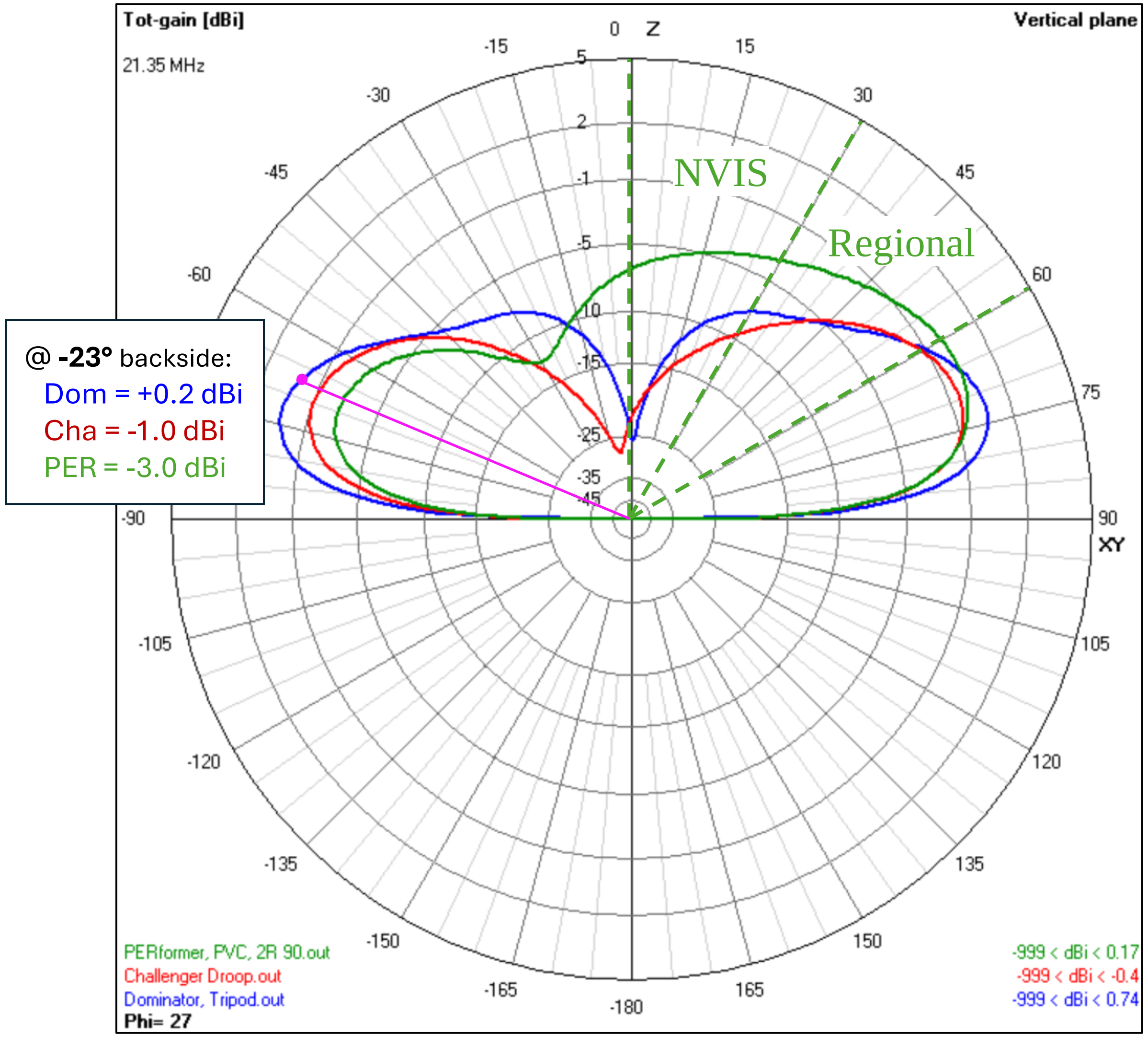
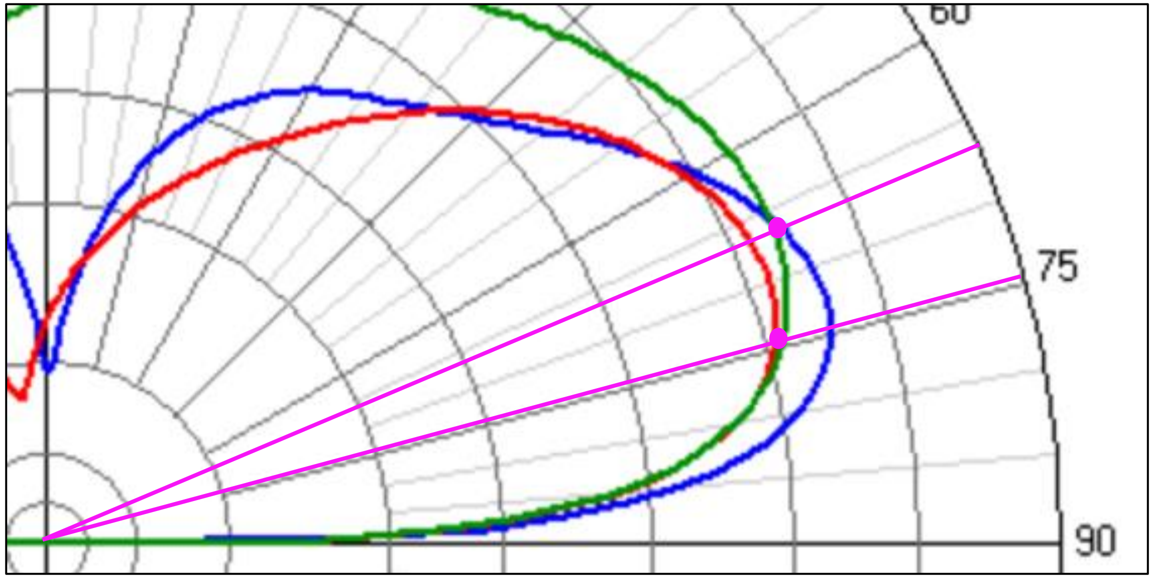
Comparing Directional PERformer: Radial Span @ 90°



- Looking at the ***far field* radiation patterns** of all three antennas on **15M** (21.350 MHz): **PERformer** Directional Radial Span, **Challenger** halfwave and **Dominator** halfwave.
- Comparing **radiated gain, PERformer** *exceeds* **Challenger** @ **16°** off the horizon and *exceeds* **Dominator** @ **23°** off the horizon.



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Comparing PERformer, Challenger and Dominator Antennas

- All three vertical antennas are actively used in the field because each has its own **best use case**. Considering all performance specifications, ***one antenna is not necessarily better than the other***.

All Three Antennas	PERformer Quarterwave (40M-6M)	Challenger OCF Halfwave (20M-6M)	Dominator EF Halfwave (17M-10M)
• 90%+ structural efficiency • Less than 5 minutes deployment • Easy to pack and transport	• 40M resonance unlike other two antennas • Directional option with 3 dB+ f-to-b • Best antenna for 30°-60° *regional* coverage	• 94%+ highest radiation efficiency • 20M and 6M halfwave resonance • Best antenna for *balanced* coverage	• 18° lowest angle of radiation • Strongest maximum radiation of +0.67 dBi • Best antenna for 5°-20° *global* coverage

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Dominator Halfwave **Vertical Beam** with a **Parasitic Director**

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Dominator 2-Element Vertical Beam (17M-10M)

Dominator 2-Element Vertical Beam for 10M pointed east at **US-3473** in California. **Parasitic director** creates up to **+4 dB gain** across four bands: 17M-10M.

Each band requires different **element lengths** (director is *always* **6% shorter**) and **element spacing**. The horizontal **PVC tube *telescopes* like a *trombone*** to accommodate band spacing.

Horizontal PVC section **rests on top of the tripod mirror mount** which can be manually **rotated** to any direction. The **counterpoise** wire runs under **director**.

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Dominator 2-Element Vertical Beam is Very Portable

Dominator Halfwave Beam on a **Polarduck™ tripod** easily fits within a zippered **36" long photography bag** including both 25' (or 17') whips.

Dominator Halfwave Beam Parasitic Director PVC Add-On easily comes apart into three sections for **flat transport** and **fast deployment**: ① horizontal telescoping trombone, ② vertical support for the director, and ③ ground support base at the bottom of the vertical support.

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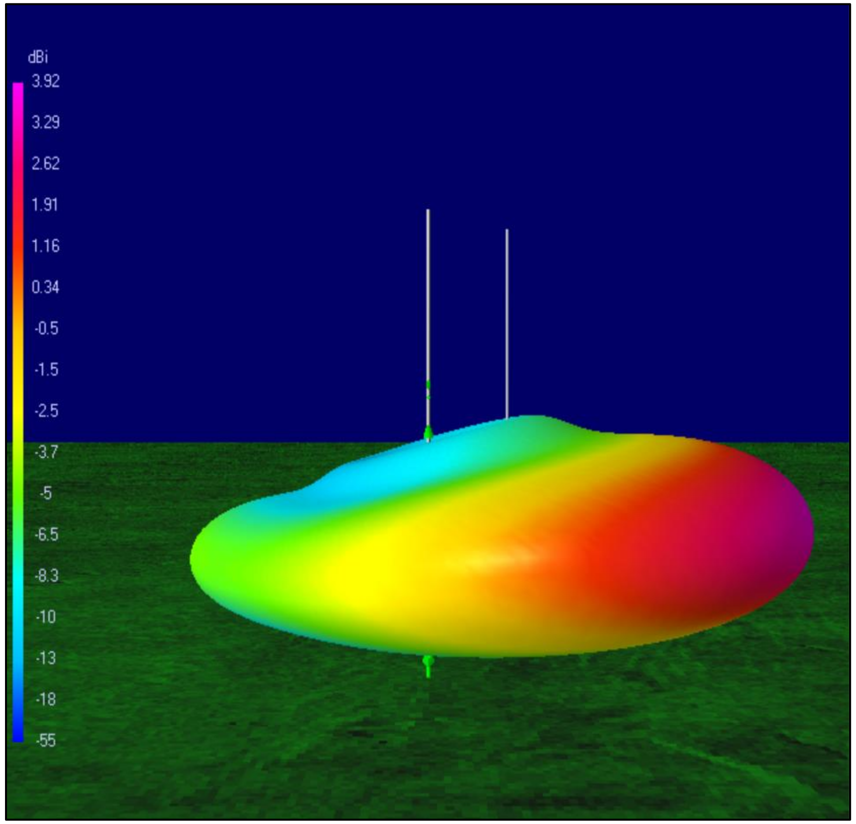
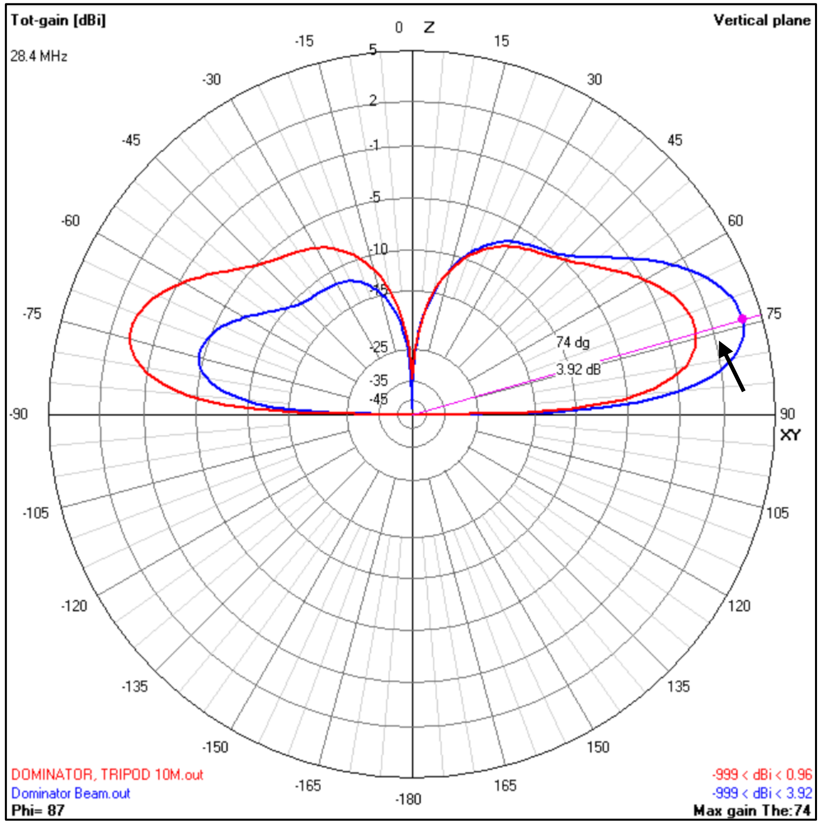
4NEC2 Model Graphics for **Dominator Beam:** 10M (28.400 MHz)





Model Specifications (10M):

- SWR 1.00:1
- Ref. Coef. -54.0 dB
- **Gain** **3.92 dBi**
- **Rad. Angle** **16°**
- Beamwidth 24°
- Front-Back 8.54 dB
- **Efficiency** **99.5%**
- Impedance 2460 – j 1.24

Purple and **red** edges of the radiation pattern highlight the **strongest forward gain** of the antenna **16 degrees off the horizon** on 10M.

The *beam* generates **+3.92 dBi forward gain** at **16 degrees** off the horizon *versus* the *omnidirectional* Dominator with **+0.96 dBi**.

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Field SWR Measurements for the **Dominator Beam:** 17M-10M

17M

15M

12M

10M

Very broad bandwidth with **two 25' whips** across **every band**!
Two 17' whips cover **12M-10M** only.

SWR Efficiency:

- 1.10:1 = 99.8%
- 1.20:1 = 99.2%
- 1.30:1 = 98.3%
- 1.40:1 = 97.2%
- 1.50:1 = 96.0%

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Comparing PERformer, Challenger and Dominator Antennas

Specifications	PERformer	Challenger	Dominator	Dominator Beam
Vertical Wavelength	• **Quarterwave**	• **Halfwave**	• **Halfwave**	• **Halfwave**
Antenna Configuration	• Omni/Directional • 2 Elevated Tuned Linked Radials 90/180° apart	• Omnidirectional • 1 Linked Counterpoise, ~10% λ per band	• Omnidirectional • 1 Linked Counterpoise, ~33% λ per band	• Directional • 2-Element Vertical Beam with Parasitic Director
Band Coverage	• **40M-6M**	• **20M-6M**	• **17M-10M**	• **17M-10M**
Structural Efficiency	• 90.8%	• 94.3%	• 99.5%	• 99.5%
50Ω Impedance Match	• ---	• **4:1 Unun** *Off-Center Fed*	• **49/56:1 Xformer** *End-Fed*	• **49/56:1 Xformer** *End-Fed*
Key Component Loss	• -0.12 dB *(toroid choke)*	• -0.46 *to* -0.35 dB	• -1.08 *to* -0.51 dB	• -1.08 *to* -0.51 dB
Peak Radiation	• **-0.67 dBi / +0.41 dBi**	• **-0.27 dBi**	• **+0.67 dBi**	• **+3.58 dBi**
Angle of Peak Radiation (with -3 dB Beamwidth)	• **24°** (9° *to* 54°)	• **21°** (8° *to* 40°)	• **18°** (7° *to* 35°)	• **16°** (7° *to* 31°)
-3.00 dB Beamwidth	• **46°** (-15°, +30°)	• **32°** (-13°, +19°)	• **28°** (-11°,+17°)	• **24°** (-9°,+15°)
Primary Reach	• Regional, Continental	• Continental, Global	• Global	• Global

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Additional Content

Chameleon™ Telescoping Whip Antennas

25-foot Telescoping Whip (CHA SS25) $100

Section from Top	Section Length (in)	Radiation Length (Bottom + Exposed Sections Above)			
		Inches	Feet	Ft-In	Meters
1	22.00	45.25	3.77	3' 9"	1.15
2	21.00	66.25	5.52	5' 6"	1.68
3	21.00	87.25	7.27	7' 3"	2.22
4	21.00	108.25	9.02	9' 0"	2.75
5	21.00	129.25	10.77	10' 9"	3.28
6	21.00	150.25	12.52	12' 6"	3.82
7	21.00	171.25	14.27	14' 3"	4.35
8	21.00	192.25	16.02	16' 0"	4.88
9	21.00	213.25	17.77	17' 9"	5.42
10	21.00	234.25	19.52	19' 6"	5.95
11	21.00	255.25	21.27	21' 3"	6.49
12	21.25	276.50	23.04	23' 1"	7.02
13	21.25	**297.75**	**24.81**	**24' 10"**	**7.56**
Bottom	**23.25**				

Total	**297.75**	**Inches**
	24.81	**Feet**
	7.56	**Meters**

17-foot Telescoping Whip (CHA SS17) $75

Section from Top	Section Length (in)	Radiation Length (Bottom + Exposed Sections Above)			
		Inches	Feet	Ft-In	Meters
1	21.500	43.50	3.625	3' 8"	1.11
2	20.250	63.75	5.313	5' 4"	1.62
3	20.250	84.00	7.000	7' 0"	2.13
4	20.125	104.13	8.677	8' 8"	2.65
5	20.125	124.25	10.354	10' 4"	3.16
6	20.125	144.38	12.031	12' 0"	3.67
7	20.125	164.50	13.708	13' 9"	4.18
8	19.875	184.38	15.365	15' 4"	4.68
9	20.125	**204.50**	**17.042**	**17' 1"**	**5.20**
Bottom	**22.000**				

Total	**204.50**	**Inches**
	17.04	**Feet**
	5.20	**Meters**

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Forward (P_f) Power and Reflected (P_r) Power % by SWR

VSWR	RETUR N LOSS (db)	TRANS. LOSS (db)	VOLT. REFL. COEFF.	POWER TRANS. (%)	POWER REFL.
1.00	—	0.000	0.00	100.0	0.0
1.01	46.1	0.000	0.00	100.0	0.0
1.02	40.1	0.000	0.01	100.0	0.0
1.03	36.6	0.001	0.01	100.0	0.0
1.04	34.2	0.002	0.02	100.0	0.0
1.05	32.3	0.003	0.02	99.9	0.1
1.06	30.7	0.004	0.03	99.9	0.1
1.07	29.4	0.005	0.03	99.9	0.1
1.08	28.3	0.006	0.04	99.9	0.1
1.09	27.3	0.008	0.04	99.8	0.2
1.10	26.4	0.010	0.05	99.8	0.2
1.11	25.7	0.012	0.05	99.7	0.3
1.12	24.9	0.014	0.06	99.7	0.3
1.13	24.3	0.016	0.06	99.6	0.4
1.14	23.7	0.019	0.07	99.6	0.4
1.15	23.1	0.021	0.07	99.5	0.5
1.16	22.6	0.024	0.07	99.5	0.5
1.17	22.1	0.027	0.08	99.4	0.6
1.18	21.7	0.030	0.08	99.3	0.7
1.19	21.2	0.033	0.09	99.2	0.8
1.20	20.8	0.036	0.09	99.2	0.8
1.21	20.4	0.039	0.10	99.1	0.9
1.22	20.1	0.043	0.10	99.0	1.0
1.23	19.7	0.046	0.10	98.9	1.1

VSWR	RETUR N LOSS (db)	TRANS. LOSS (db)	VOLT. REFL. COEFF.	POWER TRANS. (%)	POWER REFL.
1.23	19.7	0.046	0.10	98.9	1.1
1.24	19.4	0.050	0.11	98.9	1.1
1.25	19.1	0.054	0.11	98.8	1.2
1.26	18.8	0.058	0.12	98.7	1.3
1.27	18.5	0.062	0.12	98.6	1.4
1.28	18.2	0.066	0.12	98.5	1.5
1.29	17.9	0.070	0.13	98.4	1.6
1.30	17.7	0.075	0.13	98.3	1.7
1.32	17.2	0.083	0.14	98.1	1.9
1.34	16.8	0.093	0.15	97.9	2.1
1.36	16.3	0.102	0.15	97.7	2.3
1.38	15.9	0.112	0.16	97.5	2.5
1.40	15.8	0.122	0.17	97.2	2.8
1.42	15.2	0.133	0.17	97.0	3.0
1.44	14.9	0.144	0.18	96.7	3.3
1.46	14.6	0.155	0.19	96.5	3.5
1.48	14.3	0.166	0.19	96.3	3.7
1.50	14.0	0.177	0.20	96.0	4.0
1.52	13.7	0.189	0.21	95.7	4.3
1.54	13.4	0.201	0.21	95.5	4.5
1.56	13.2	0.213	0.22	95.2	4.8
1.58	13.0	0.225	0.22	94.9	5.1
1.60	12.7	0.238	0.23	94.7	5.3
1.62	12.5	0.250	0.24	94.4	5.6

VSWR	RETUR N LOSS (db)	TRANS. LOSS (db)	VOLT. REFL. COEFF.	POWER TRANS. (%)	POWER REFL.
1.64	12.3	0.263	0.24	94.1	5.9
1.66	12.1	0.276	0.25	93.8	6.2
1.68	11.9	0.289	0.25	93.6	6.4
1.70	11.7	0.302	0.26	93.3	6.7
1.72	11.5	0.315	0.26	93.0	7.0
1.74	11.4	0.329	0.27	92.7	7.3
1.76	11.2	0.342	0.28	92.4	7.6
1.78	11.0	0.356	0.28	92.1	7.9
1.80	10.9	0.370	0.29	91.8	8.2
1.82	10.7	0.384	0.29	91.5	8.5
1.84	10.6	0.398	0.30	91.3	8.7
1.86	10.4	0.412	0.30	91.0	9.0
1.88	10.3	0.426	0.31	90.7	9.3
1.90	10.2	0.440	0.31	90.4	9.6
1.92	10.0	0.454	0.32	90.1	9.9
1.94	9.9	0.468	0.32	89.8	10.2
1.96	9.8	0.483	0.32	89.5	10.5
1.98	9.7	0.497	0.33	89.2	10.8
2.00	9.5	0.512	0.33	88.9	11.1
2.50	7.4	0.881	0.43	81.6	18.4
3.00	6.0	1.249	0.50	75.0	25.0
3.50	5.1	1.603	0.56	69.1	30.9
4.00	4.4	1.938	0.60	64.0	36.0
4.50	3.9	2.255	0.64	59.5	40.5

VSWR	RETUR N LOSS (db)	TRANS. LOSS (db)	VOLT. REFL. COEFF.	POWER TRANS. (%)	POWER REFL.
4.50	3.9	2.255	0.64	59.5	40.5
5.00	3.5	2.553	0.67	55.6	44.4
5.50	3.2	2.834	0.69	52.1	47.9
6.00	2.9	3.100	0.71	49.0	51.0
6.50	2.7	3.351	0.73	46.2	53.8
7.00	2.5	3.590	0.75	43.7	56.2
7.50	2.3	3.817	0.76	41.5	58.5
8.00	2.2	4.033	0.78	39.5	60.5
8.50	2.1	4.240	0.79	37.7	62.3
9.00	1.9	4.437	0.80	36.0	64.0
9.50	1.8	4.626	0.81	34.5	65.5
10.00	1.7	4.807	0.82	33.1	66.9
11.00	1.6	5.149	0.83	30.6	69.4
12.00	1.5	5.466	0.85	28.4	71.6
13.00	1.3	5.762	0.86	26.5	73.5
14.00	1.2	6.040	0.87	24.9	75.1
15.00	1.2	6.301	0.88	23.4	76.6
16.00	1.1	6.547	0.88	22.1	77.9
17.00	1.0	6.780	0.89	21.0	79.0
18.00	1.0	7.002	0.89	19.9	80.1
19.00	0.9	7.212	0.90	19.0	81.0
20.00	0.9	7.413	0.90	18.1	81.9
25.00	0.7	8.299	0.92	14.8	85.2
30.00	0.6	9.035	0.94	12.5	87.5

No tuner is recommended if SWR is *less than or equal* to **1.50:1** which implies **96%** power transmitted

$$SWR = \frac{1 + \sqrt{P_r/P_f}}{1 - \sqrt{P_r/P_f}}$$

P_f = forward power
P_r = reflected power

Source: Menace Radio Control Ltd. (2019)

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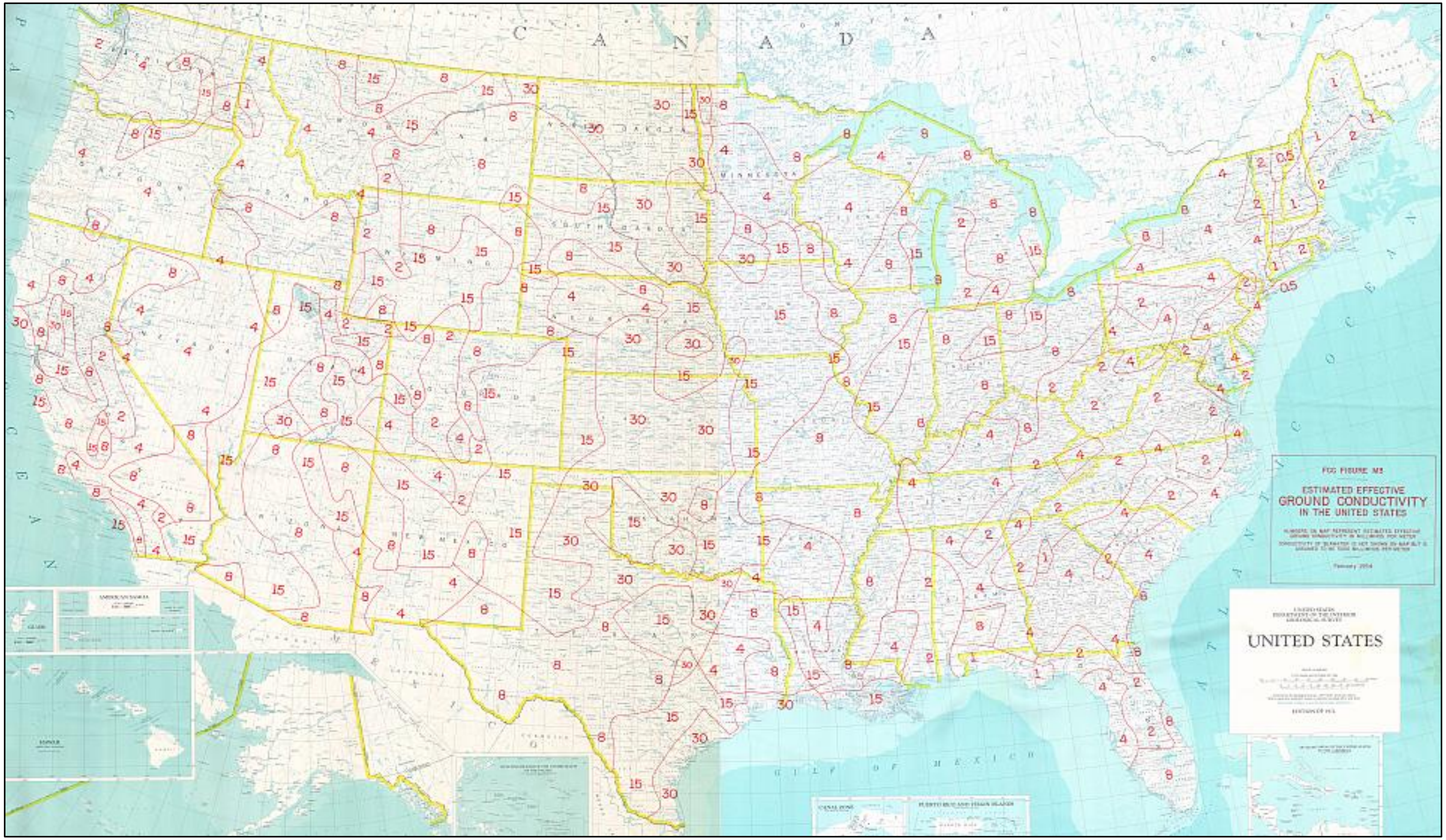
Ground Conductivity in the United States (0.5-30 milliSiemens per meter)



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