# FM Antennas – A Comparison and Evaluation of Fundamental Side Mount Designs

**Presented by: John L. Schadler**

**NAB Breakfast**

Date: 4/14/2014

# This Mornings Presentation

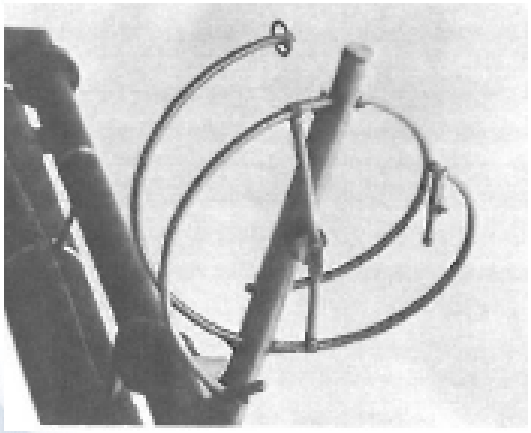
- A brief history of CP FM antennas
- An comparison of the two fundamental side mounted FM antenna designs
  - Broadband High Power
    - Quadrupole ring style
    - Tiller
- The role of horizontal polarization in new automotive antenna design

BANDWIDTH
CIRCULARITY
H/V RATIO
POWER / VOLTAGE HANDLING

# A Brief History - Ring Style Evolution

## 1967

Matti Siukola “Dual Polarization FM Broadcasting with a Single Antenna” NAB 1967

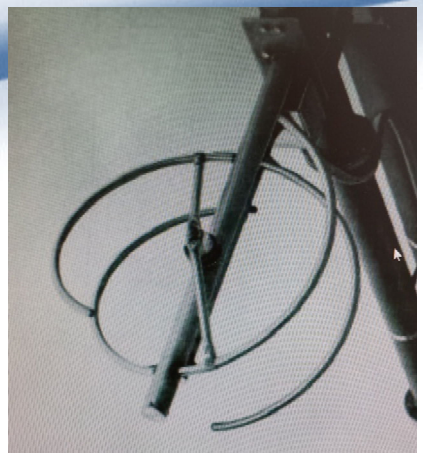


**RCA - BFC**

# A Brief History - Ring Style Evolution

BFC was both power limited and bandwidth limited

Bandwidth limited : 600 kHz
Average Power limited : 4 kW



BFC

Q of an antenna is directly related to its volume in space

$$Q = \frac{1}{(\beta a)^3} + \frac{1}{\beta a}$$

a is the volume radius

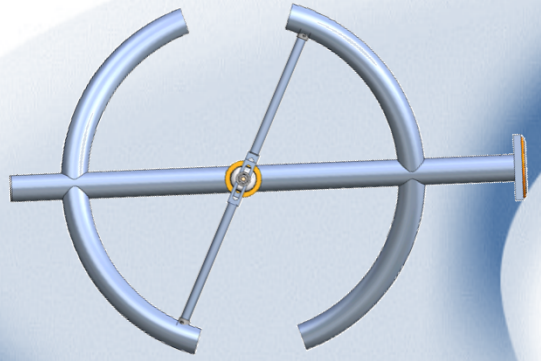
The fundamental bandwidth for antennas

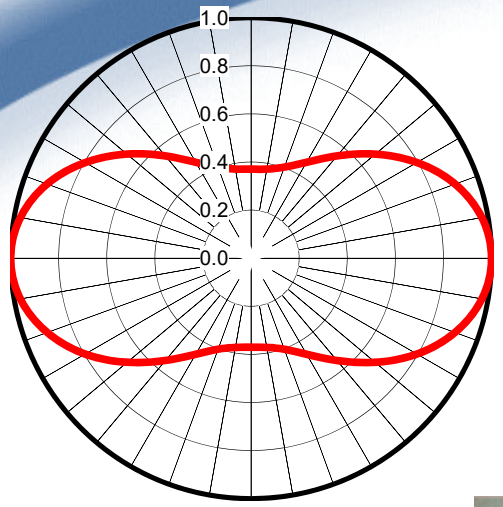
$$bw = \frac{\pi}{Q ln\left\{\frac{VSWR + 1}{VSWR - 1}\right\}}$$

VSWR is the maximum allowable within the passband

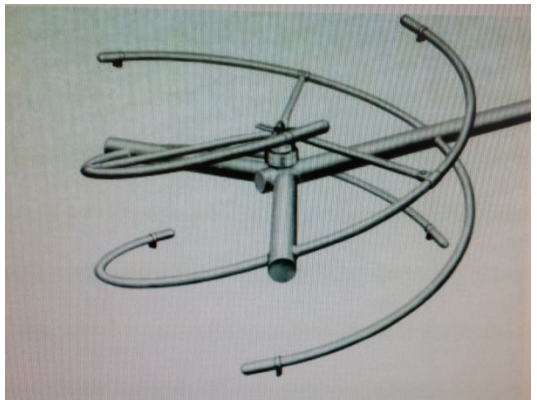
# A Brief History - Ring Style Evolution

Simply making the C bay bigger increases the bandwidth BUT at the expense of the circularity.



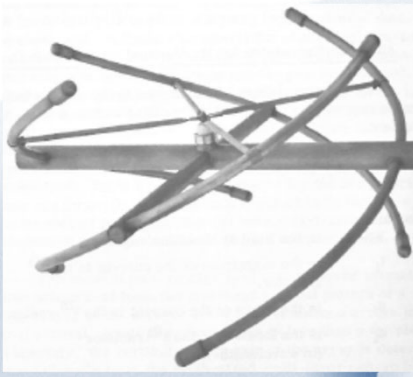



**1973** Introduction of the BFG. Tri-pole ring antenna



# A Brief History - Ring Style Evolution

**1978** Don Hymas "A New High Power Circularly Polarized FM Antenna " 1978 IEEE Symposium



**RCA - BFM**

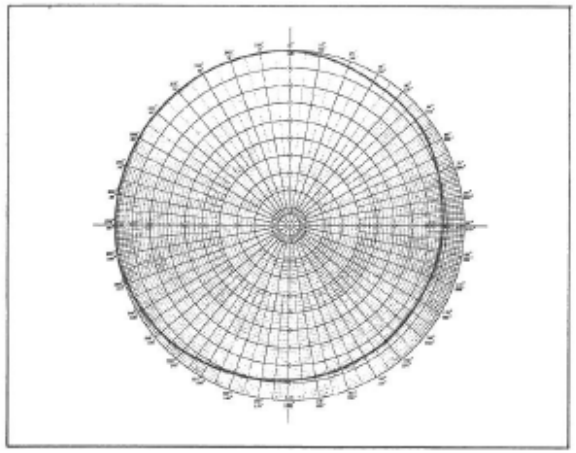


Figure 3 – Horizontal Pattern – Horizontally Polarized Component

Circularity +/- .65 dB

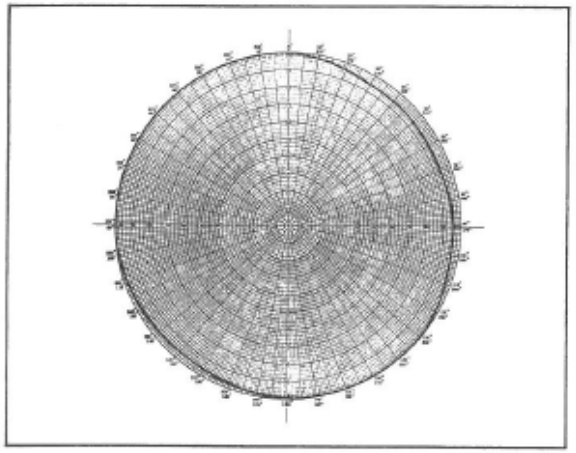


Figure 4 – Horizontal Pattern – Vertically Polarized Component

Circularity +/- .25 dB

**1978**

**United States Patent** [19]

**Silliman**

[11] **4,109,255**

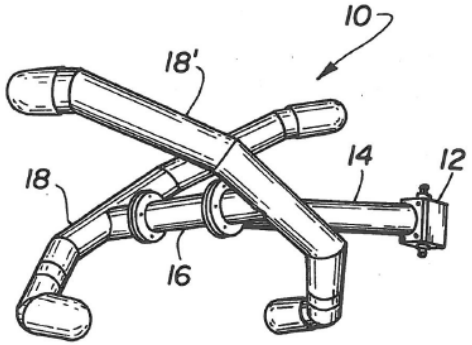
[45] **Aug. 22, 1978**

[54] **OMNIDIRECTIONAL BROADBAND CIRCULARLY POLARIZED ANTENNA**

[56] **References Cited**

**U.S. PATENT DOCUMENTS**

**ERI -Rototiller**



# A Brief History - Ring Style Evolution

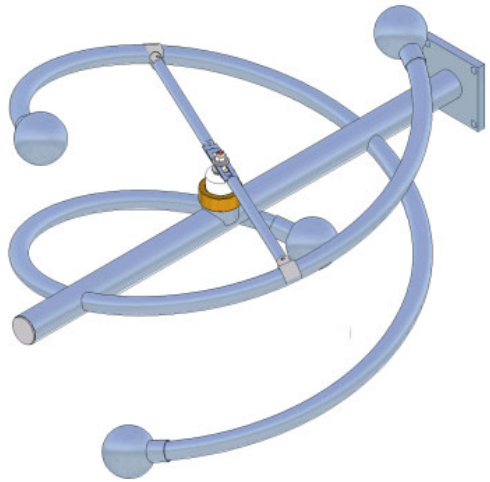
Power handling substantially increased with the addition of corona balls

The electric field intensity near a conductor is inversely proportional to the radius of curvature (r)

$$E_m \approx \frac{2V}{r\ ln\left(1+\frac{4d}{r}\right)}$$

Double the radius allows the applied voltage to be doubled and thus the power limit increase by 4X

$$P_{avg} = \frac{{V_p}^2}{2Z_0}$$



Power handling no longer limited by the radiators

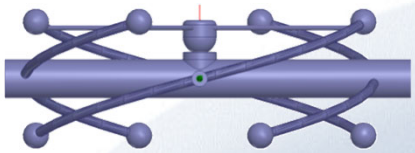
Dielectric

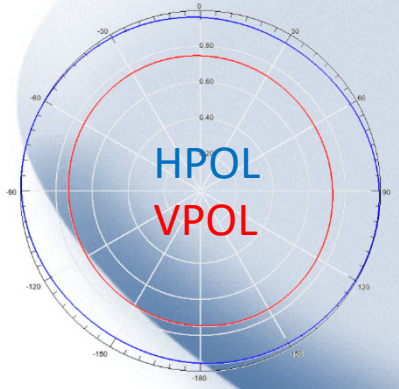
# Tiller or Quadrupole?

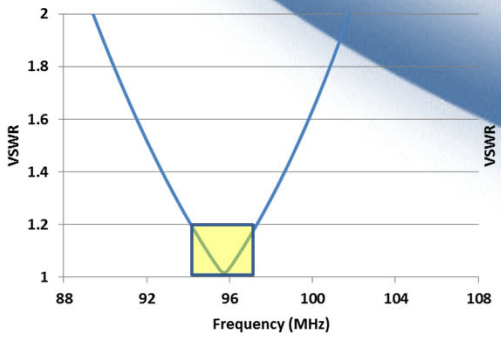
# Comparing the Tiller to the Quadrupole

Quadrupole

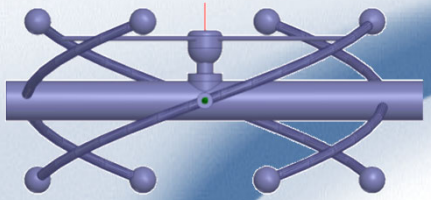
15° Pitch

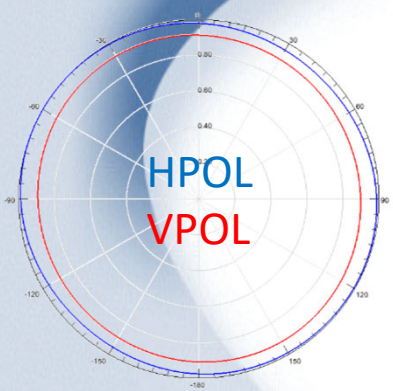


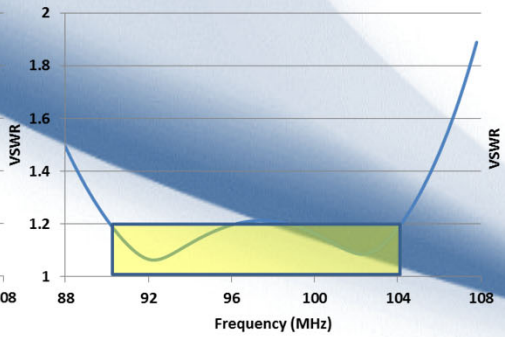


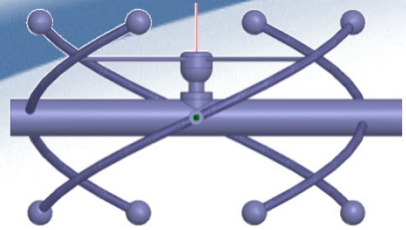

20° Pitch

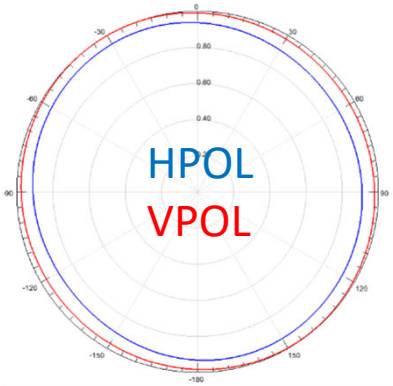


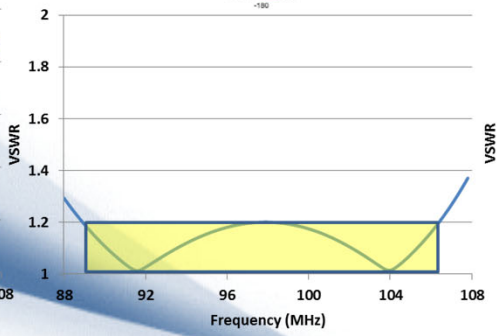


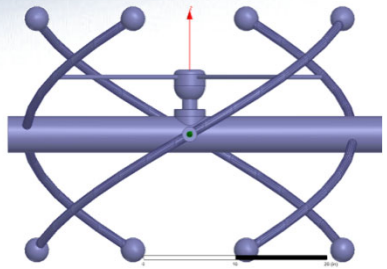

25° Pitch

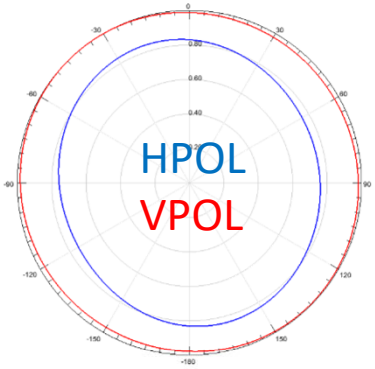


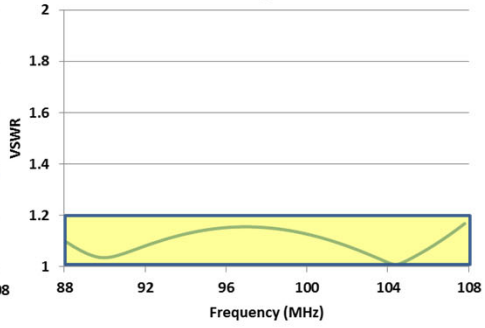



30° Pitch






H/V ratio, bandwidth and circularity are all functions of the arm pitch

# Comparing the Tiller to the Quadrupole

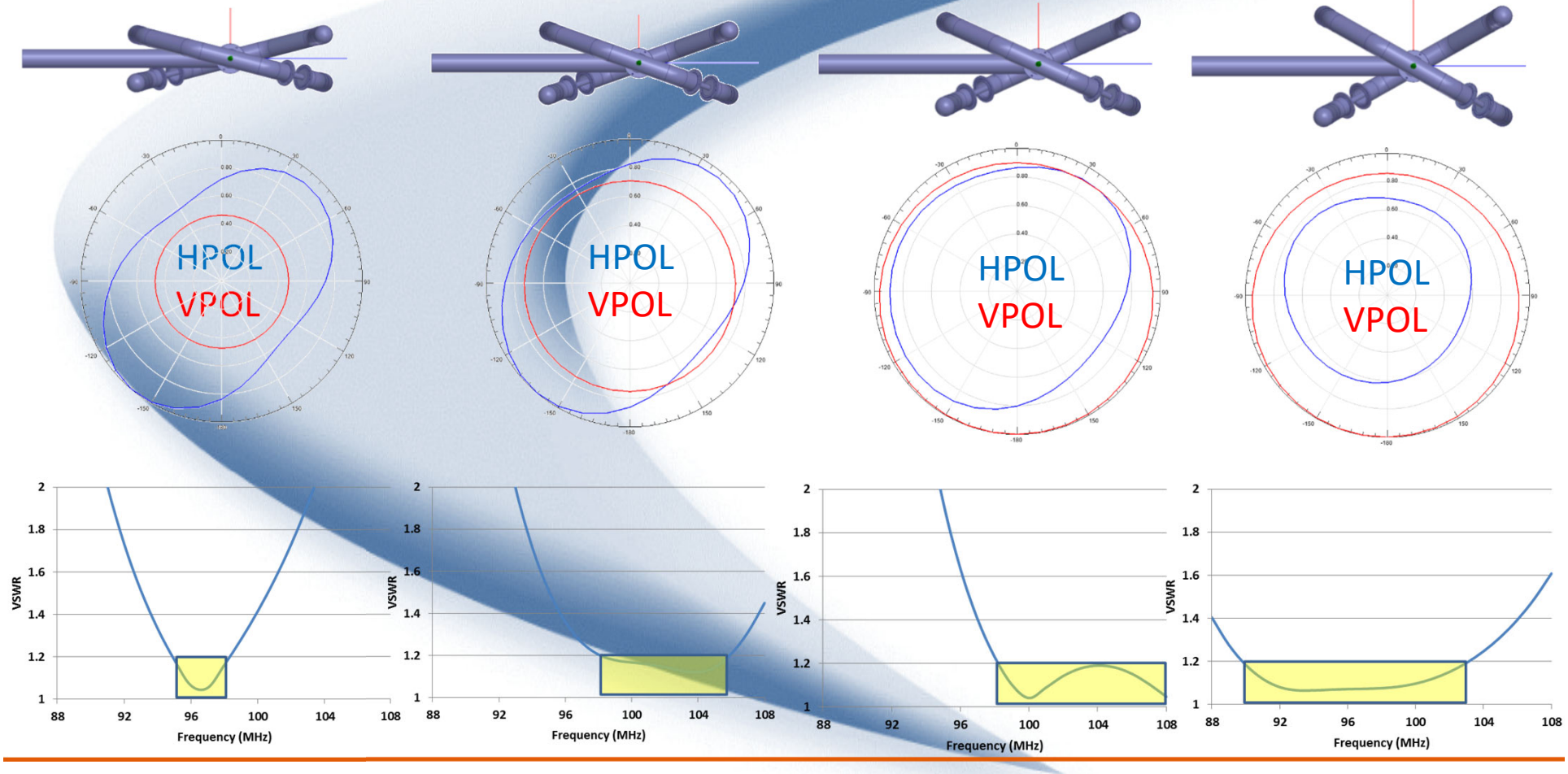
Tiller

15° Pitch

20° Pitch

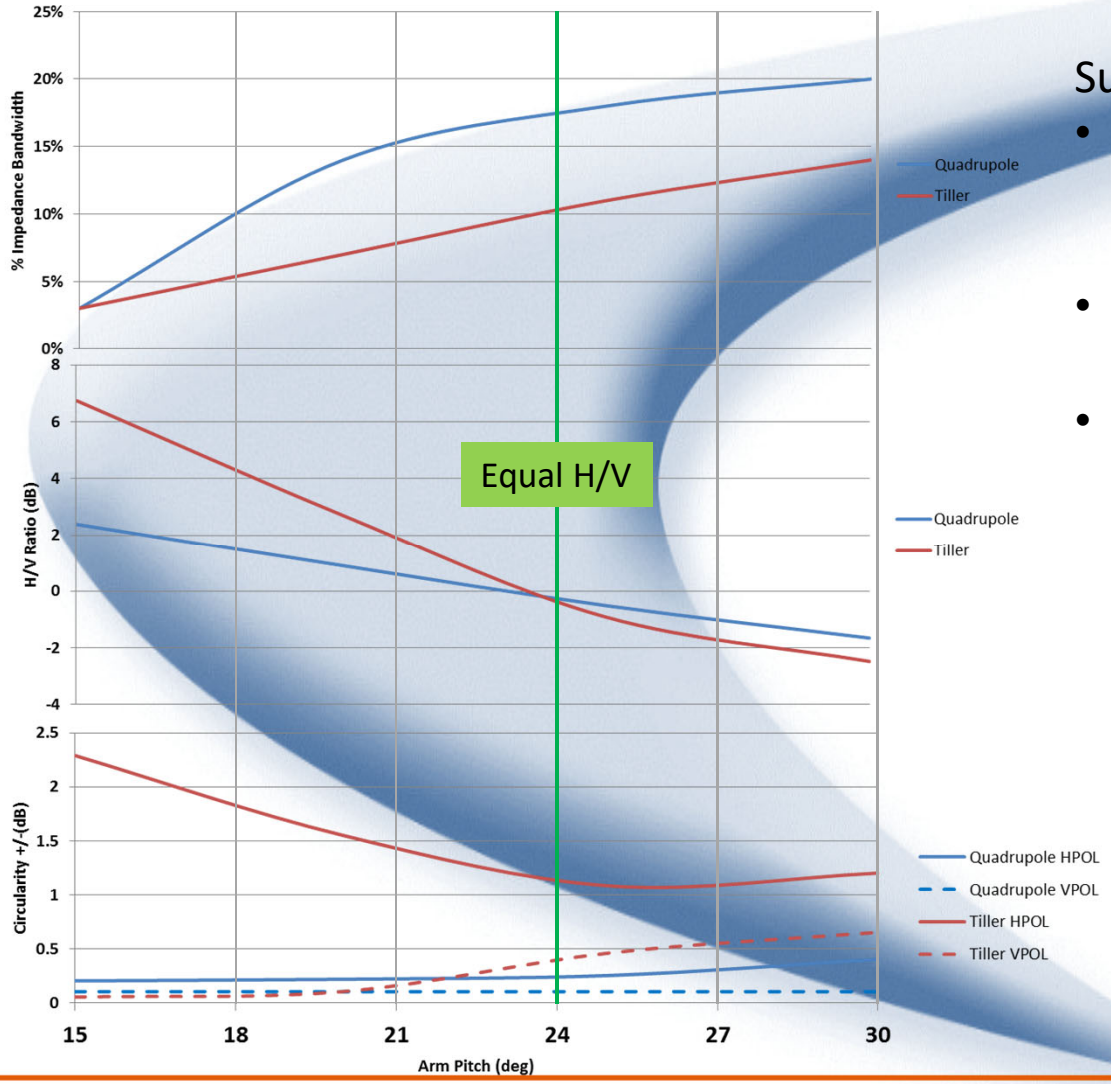
25° Pitch

30° Pitch




H/V ratio, bandwidth and circularity are all functions of the arm pitch

# Comparing the Tiller to the Quadrupole




Summary

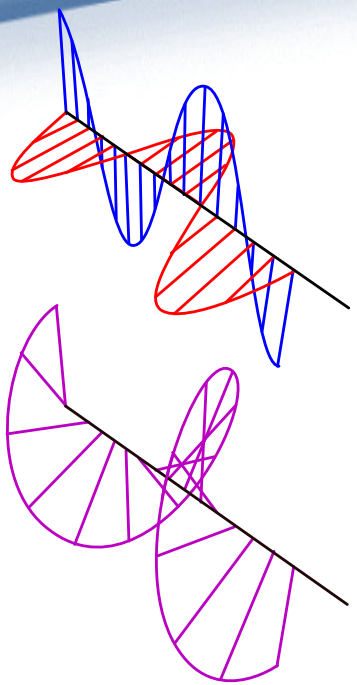
- Both the tiller and quadrupole have equal H/V at pitch angle = 24 degrees
- At 24 degrees, the quadrupole has 8% more bandwidth then the tiller
- Circularity of the quadrupole is excellent at all pitch angles

Quadrupole offers broadband performance with excellent circularity without increasing the vertical polarization beyond the horizontal polarization.

H/V ratio, bandwidth and circularity are all functions of the arm pitch

# Common Misconceptions FM and Vertical Polarization

- “The vertical component is our bread and butter for mobile reception”
- “Vertical polarization has less ground attenuation then horizontal polarization”
- “Horizontal polarization is totally filtered out near metal ground planes”



# FM and the Horizontal Polarization Component

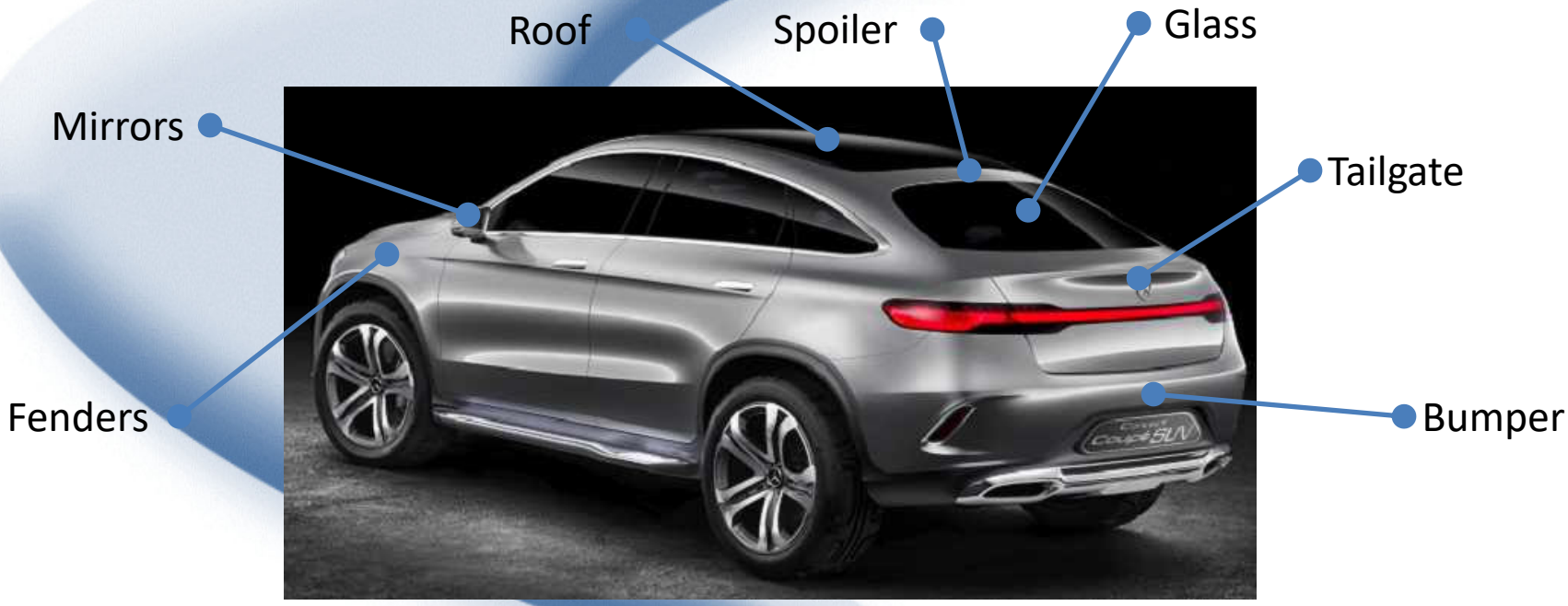
In the past vertical polarization was FM's "bread and butter"


Antenna of choice – 1/4λ mast

- Omni-directional VPOL
- Inexpensive
- Uncomplicated
- But..
  - Ugly
  - Subject to damage

# Possible Automotive Antenna Placement

- Shift away from the traditional quarter wavelength mast antenna towards more aesthetically pleasing antennas using conformal and hidden solutions
- Integrated printed antennas into plastic body parts
- In glass antennas




- Very little vertical aperture
- Reception quality depending more and more on the horizontally polarized component

# Propagation Near the Ground

- Surface waves are not only subject to the same attenuation factors as space waves but also suffers ground losses
  - Ohmic resistive losses from the conductive earth

1941 – Ken Norton formulated the attenuation factor for ground wave attenuation

$$f_E(p,b) = \left| 1 + i\sqrt{\pi p e^{ib}}\, e^{-pe^{ib}} \frac{2}{\sqrt{\pi}} \int_{-i\sqrt{pe^{ib}}}^{\infty} e^{-x^2} dx \right|$$

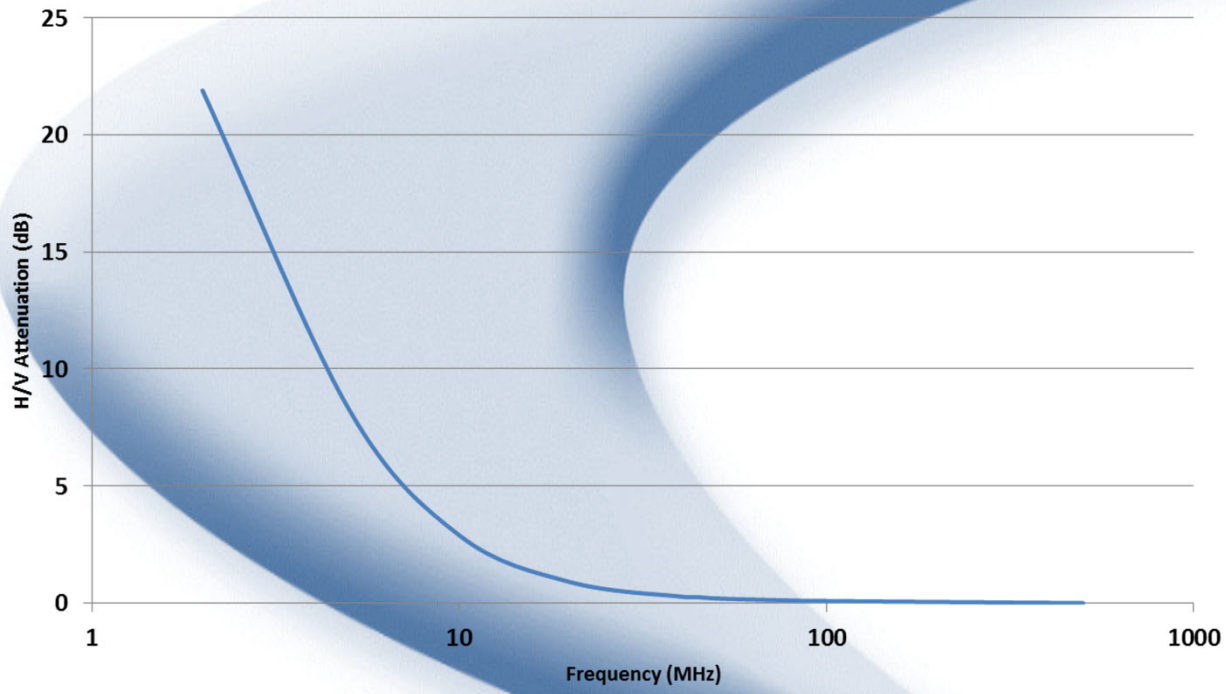
$$\mathrm{p} = \pi \frac{d}{\lambda} \frac{cos^2\left(tan^{-1}\frac{\varepsilon_r}{x}\right)}{x cos\left(tan^{-1}\frac{\varepsilon_r - 1}{x}\right)} \qquad b = 2\left(tan^{-1}\frac{\varepsilon_r}{x}\right) - \left(tan^{-1}\frac{\varepsilon_r - 1}{x}\right)$$ Vertical Polarization

$$\mathrm{p} = \pi \frac{d}{\lambda} \frac{x}{cos\left(tan^{-1}\frac{\varepsilon_r - 1}{x}\right)} \qquad b = \pi - \left(tan^{-1}\frac{\varepsilon_r - 1}{x}\right)$$ Horizontal Polarization

$$x = \frac{\sigma}{\omega \varepsilon_0}$$

# Propagation Near the Ground

Ground Attenuation Horizontal Polarization / Vertical Polarization

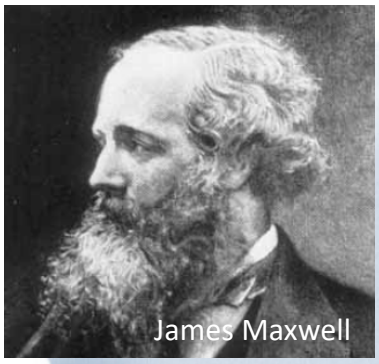



For dry ground
σ = .005 (S/m) (Conductivity)
ϵr = 15 (Relative Permittivity)

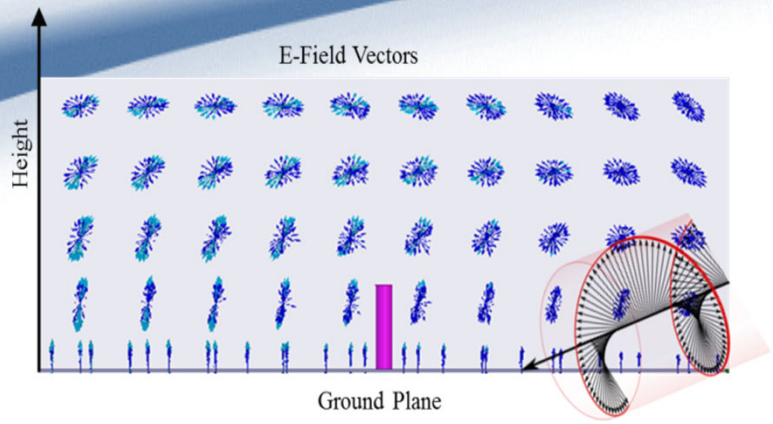
At FM, horizontal and vertical polarization attenuate equally from the earth's surface ohmic losses

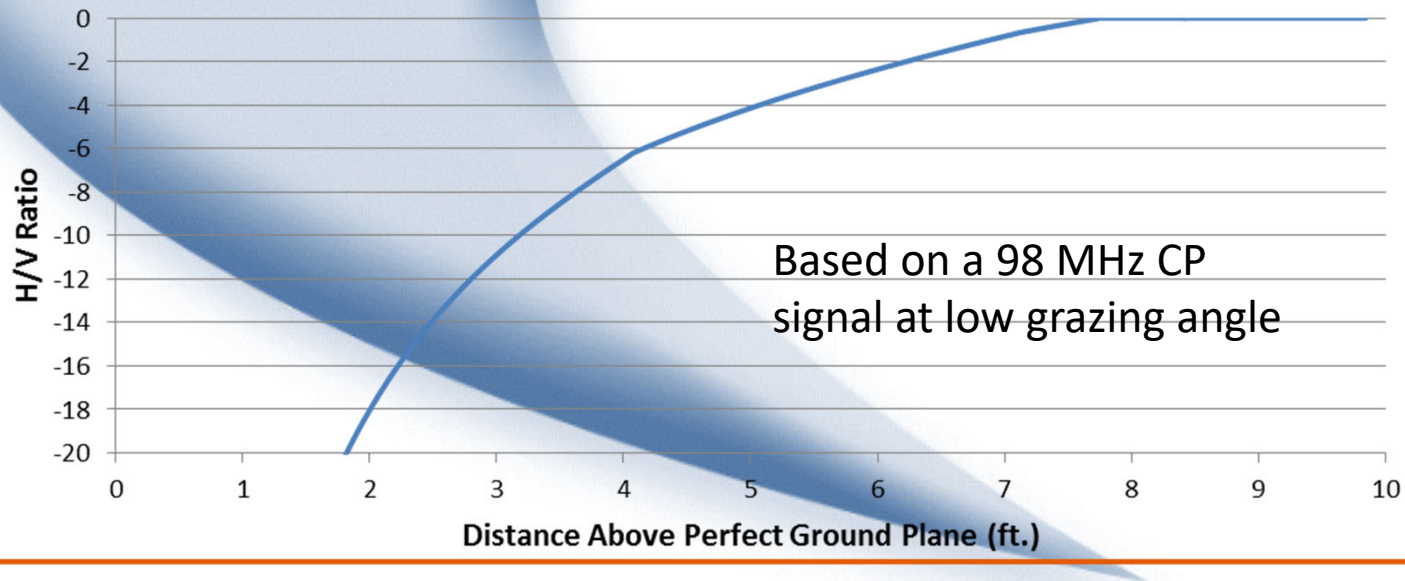
# Horizontal Polarization Near a Perfect Ground Plane

A boundary condition used to solve Maxwell's equations states, "The E-Field tangent to a ground plane is zero".




$$n \, X \, E = 0$$



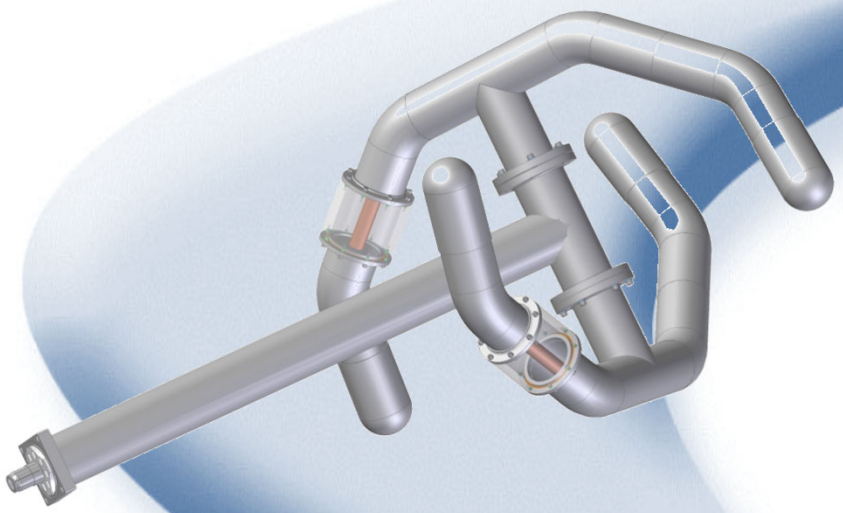

Based on a 98 MHz CP signal at low grazing angle

# Summarizing the importance of FM Horizontal Polarization

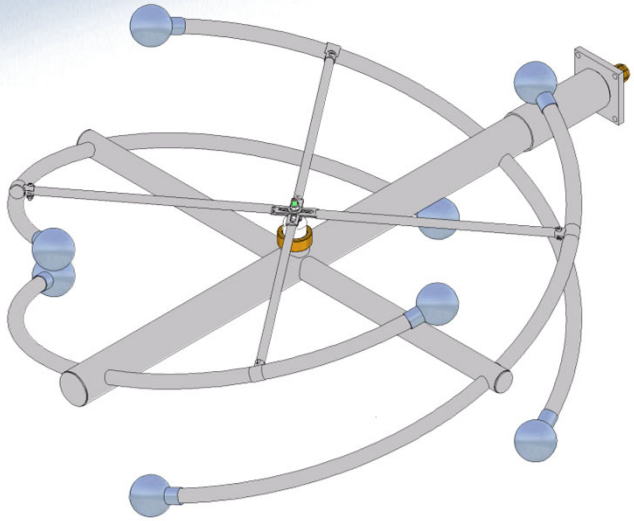
- Newer automobiles depending more on the horizontal polarization
- Ground attenuation is the same for both horizontal and vertical polarization at FM frequencies
- Horizontal ground planes limit the horizontally polarized antennas performance
  - **Makes the amount of available horizontal polarization and the circularity even more important**

# Power / Voltage Handling - Ring vs. Tiller

Tiller design has always had a power / voltage handling advantage



Dual tap points - Pressurized



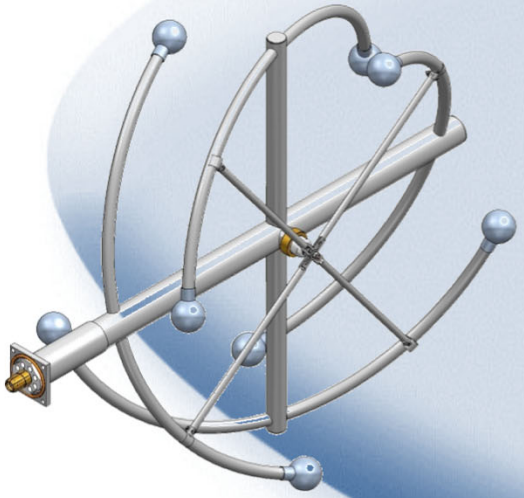
Single tap point - Unpressurized

# Introducing the DCRU - High power FM Bay

Dielectric

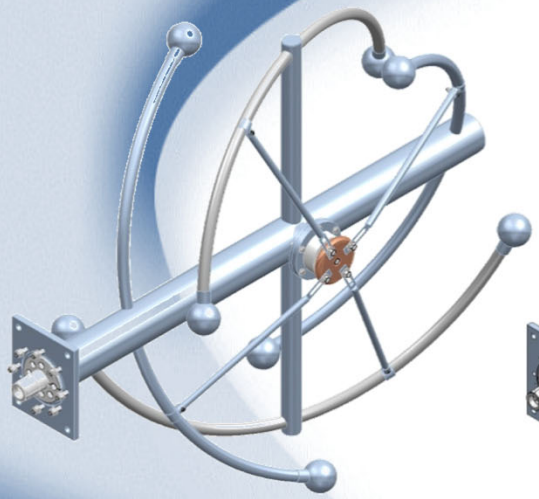
Evolution of the DCR-U

DCR-M



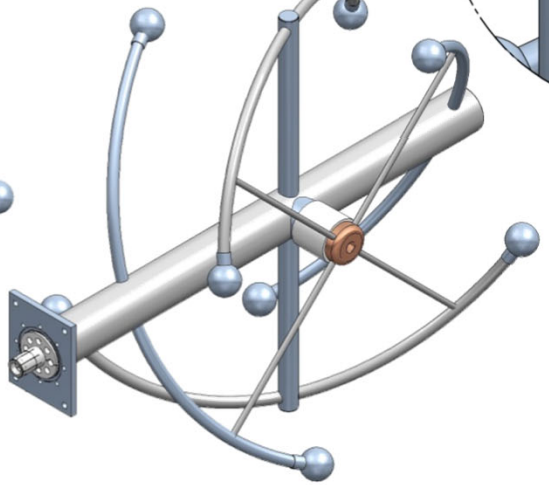
- 2.5” Balun

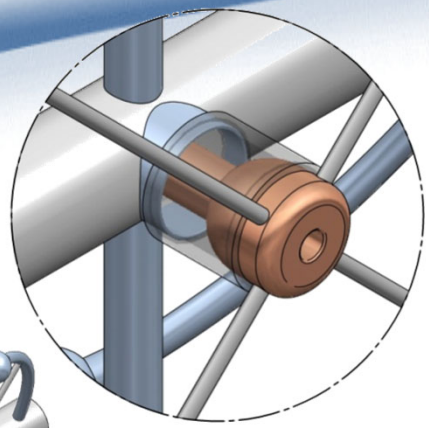
DCR-S



- 3.5” Balun
- “Mushroom” tap point

DCR-U

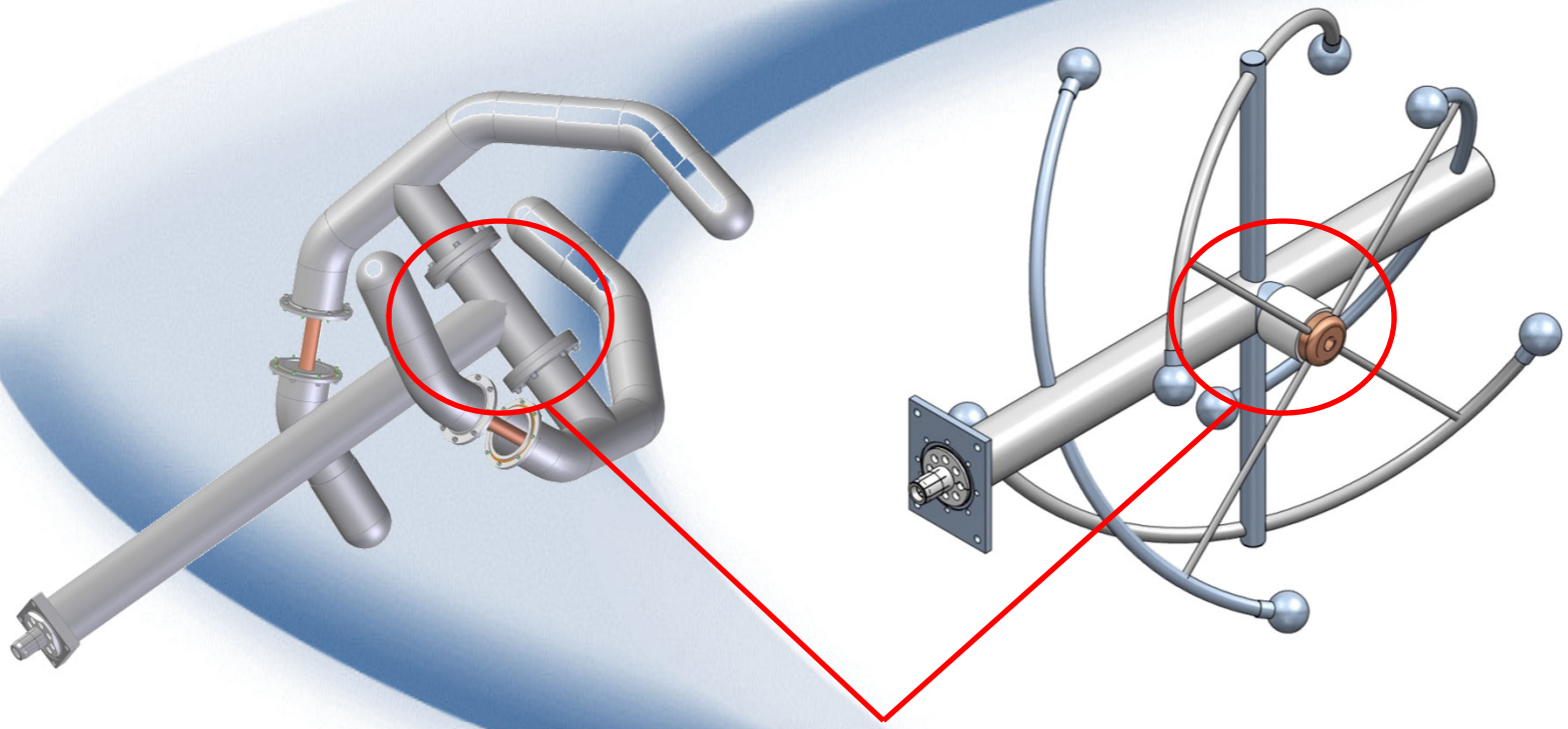




- 4” Balun
- “Spherical” tap point
- Pressurized tap point

# Power / Voltage Handling - Ring vs. Tiller

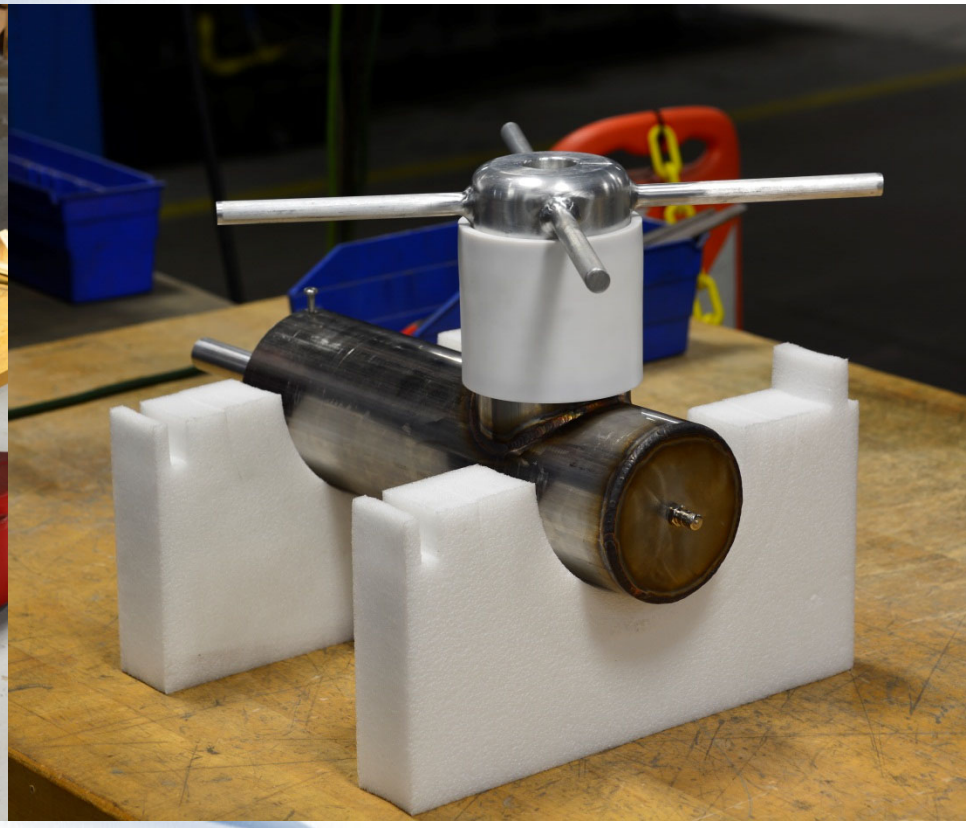
The features of the DCRU eliminate the Tiller's power / voltage handling advantage



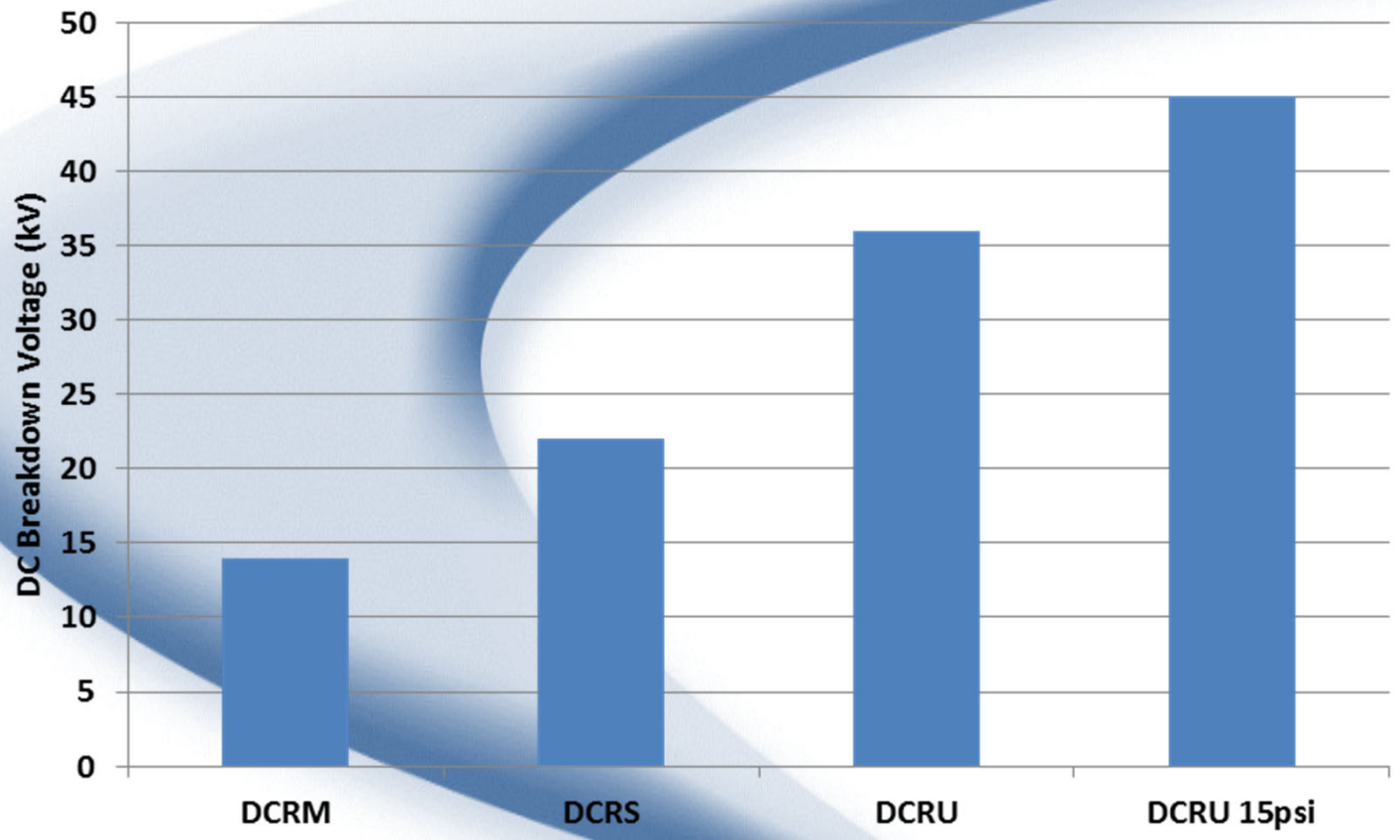
Both designs limited by the pressurized tee junction

# DCRU- Power Handling Capability

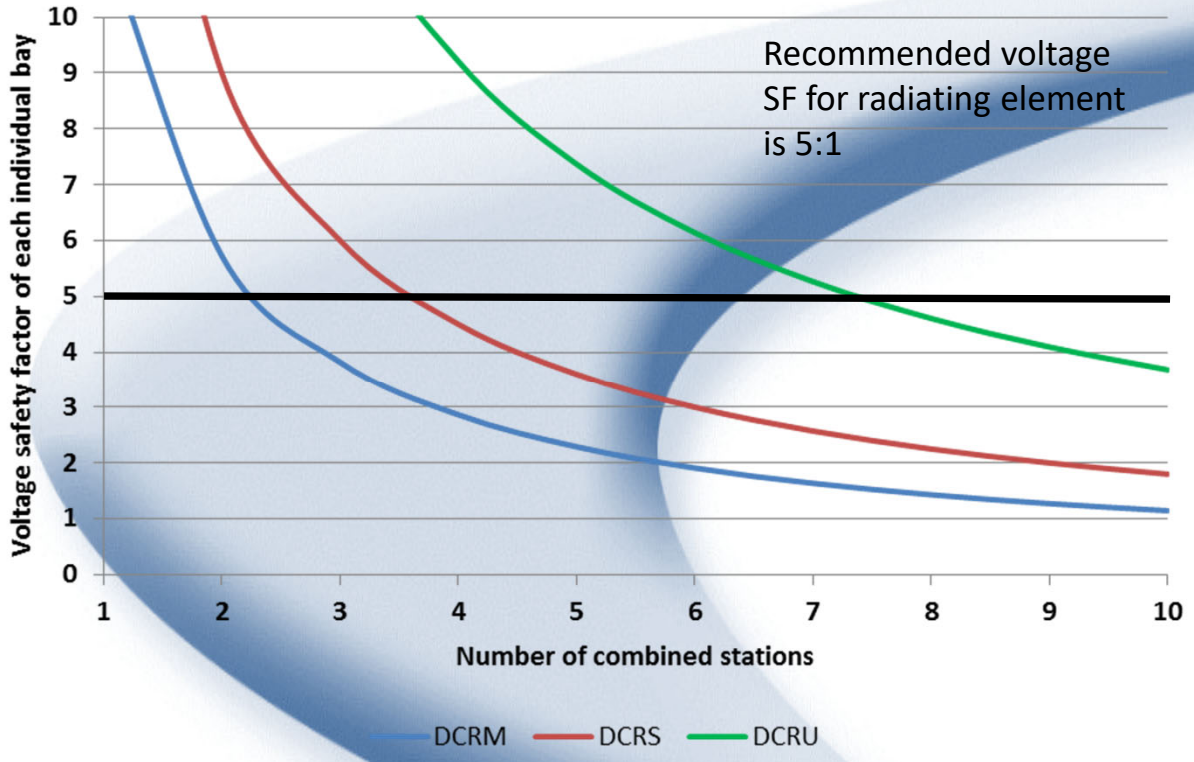
DC Hi-Pot testing the DCRU feed point design



# DCRU- Hi-Pot Testing Results



# DCRU Power / Voltage Rating




For this example:
DCRM can accommodate 2 stations with IBOC
DCRS can accommodate 4 stations with IBOC
DCRU can accommodate 8 stations with IBOC

## Based on:

DC Hi-Pot testing
8 bay antenna array

| | |
|---|---|
| Power / station | 20kW |
| IBOC level | -14dBc |
| PAPR | 3dB |
| VSWR | 2:1 |

$$V_{Peak\ RF} = .7 * V_{DC}$$

$$C_{VSWR} = \frac{2\ *\ VSWR}{VSWR + 1}$$

$$V_{p-analog} = \sqrt{2Z_0P_{avg-analog}}$$

$$V_{p-IBOC} = \sqrt{2Z_0P_{avg-IBOC}PAPR}$$

$$SF = \frac{V_{peak\ RF}}{\left(\sum_1^n V_{p-analog} + \sum_1^n V_{p-IBOC}\right)C_{VSWR}}$$

# Conclusion

- Quadrupole FM antennas offer superior circularity and bandwidth while maintaining equal horizontal and vertical pattern performance
- Advances in automotive antenna design rely on the horizontal polarization for FM reception
- The introduction of the new DRCU FM antenna provides equivalent power handling as tiller designs for high power multi-station operation with the benefit of quadrupole pattern and bandwidth performance

Dielectric

# Questions?

TRUSTED FOR DECADES,
READY FOR TOMORROW.