# INTRODUCTION

The MF/HF shipboard vertical fiberglass whip antenna has been used in many MF/HF applications throughout the US Coast Guard's inventory. The antenna is well designed, functions reliably and provides proper insulation from the weather. In effect, the antenna performs well within the environment for which it was originally designed -- shipboard applications. It is also used as a base station for MF/HF antennas. This second application has provided the impetus for this proposal.

Malloy Communications would like to demonstrate through drawing and a brief mathematical analysis of the fiberglass antenna (35' whip), comparing it to a vertical radiator specifically designed for the USCG, MF/HF base station operations. The Malloy Communications antenna may be mounted on the ground or on a hanger roof (see AutoCAD drawings), and will significantly improve the electrical efficiency and field strength and the radiated signal when compared to the fiberglass antenna. The Malloy antennas will provide an increased transmitting and receiving gain over the fiberglass.

The reader should note, to achieve maximum efficiency, a quarter wave radiator at the lowest frequency should be used. Designing an antenna starting at the SOLAS Mayday frequency of 2182.0 KHz, the antenna would need to be 110' in the air. The size, mass, and guy wire requirements severely limit the use of these types of radiators in modern times where land and space at a premium. A large antenna would also pose a risk to aviation assets. The only solution is to use a short, reasonably efficient antenna that is designed with these additional factors in mind.

Referenced to the above-mentioned variables, Malloy Communications' solution is to provide a 50' radiator with a capacitive hat located at the top. This design is only 15' higher than the existing fiberglass antenna already employed, but represents a significant improvement in the ability to radiated and receive electrical energy starting at the lowest frequency of 2 MHz.

# TECHNICAL CONSIDERATIONS

BASE DESIGN FREQUENCY: **2182.0 KHz**

WAVELENGTH: **(λ) = 450'**

# ANALYSIS OF THE FIBERGLASS WHIP ANTENNA

## STEP 1:

The gain of an antenna is proportional to the height of the antenna in relationship to the wavelength or frequency applied. The accepted size for a vertical antenna is a quarter wave at the base frequency. In this case, the base frequency is 2182.0 KHz, with a wavelength (λ) of 450'. A quarter wave of 450 ft. would be 112 ft. of antenna, as mentioned on page one.

The first step is to convert the wavelength to degrees. One wavelength of 450' will equal 360 degrees. If the fiberglass antenna is 35' tall, how many degrees of wavelength is 35"?

**Height of the antenna in degrees, in relationship of degrees of λ.**

$H^\circ = (H'/984) \times \text{freq (MHz)} \times 360^\circ$
$H^\circ = (35' / 984) \times 2.182 \text{ X } 360^\circ$
$H = 27.94^\circ$, rounded to $28^\circ$ of $360^\circ$.

We have established a relationship between the physical length of the antenna to the total wavelength (λ). From this initial analysis, it is now possible to explore more variables.

## STEP 2:

# RADIATION RESISTANCE

The radiation resistance (Rr) is directly related to the height of the antenna. The purpose of this report is to show that it is possible to obtain an acceptable level of Rr without building a 110' tall structure. Raising the radiation resistance is important because it will determine the total antenna efficiency.

*NOTE: Radiation resistance (Rr) is: "…effective height of an electrically short thin monopole of uniform cross section is approximately equal to one half (1/2) of its physical height." according to Johnson & Jasik's Antenna Engineering Handbook.*

Based on this information, all calculations to determine radiation resistance will require dividing the 35' fiberglass's height in half (to 17.5') in order to determine Rr. Therefore:
$Rr = 160 \times \pi^2 (H/2 \div \lambda)^2$
$Rr = 160 \times \pi^2 (17.5 \div 450)^2$

$$Rr = 2.39\Omega \text{ (Fiberglass whip)}$$

H = Height of the antenna. For this purpose the H is divided by 2.
λ = lambda, or the wavelength. In this case, λ of 450' @ 2182.0 KHz.

## STEP 3:

## ANTENNA EFFICIENCY

The antenna efficiency (Aη) is directly related to the height of the antenna. The higher the Rr, the less loss will be presented to the signal arriving from the coax/helix.

$A\eta = Rr \div (Rr + {}^{*}Rt) \times 100$

Rr = radiation resistance
*Rt = Value extrapolated from the *ARRL Antenna Handbook* for electrically short antennas.

$A\eta = 2.39 \div (2.39 + 6) \times 100$

$A\eta = 28.3\%$ Rounded: $A\eta = 28\%$ efficient

There are several ways to look at that number. One could say it operates at a 72% loss of the signal, or one could say that the antenna is 28% efficient. How does that translate to an actual working environment?

Let's take a 1,000 watt generator, which is a common value for a maritime base station amplifier. If 1,000 watts are fed into the base of the antenna (assuming there is no loss in the coax) then:

$$1000w \times 28\% = 280 \text{ watts radiated}$$

What happened to the additional 720 watts? They were lost, due to the low radiation resistance.

## STEP 4:

## POWER DENSITY (RF SIGNAL)

Power density is an immediate step in order to obtain field strength. However, both are related to the intensity of the magnetic field that surrounds that surrounds the transmitting antenna, which translates to gain.

One of the variables in the power density formula is total power. At first glance, it would seem that the 1,000 watts from the RF amplifier would be the likely candidate for power density (Pd). However, this paper is making a comparison between two transmitting antennas, therefore, the radiated power of each antenna based of efficiency (Aη) will provide a more accurate comparison. The power generated by the antenna is the only value considered.

$$Pd = Pt \div (4\pi \times r^2)$$

Pd = Power density. Unit is Watts/$m^2$.
Pt = Power value based on electrical energy radiated (in watts).
$r^2$ = A radius from the transmitting antenna. In this case, 1500 meters was chosen.

$$Pd = 280 \div (4\pi \times 1500^2)$$
$$Pd = 280 \div (28274333.882)$$
$$Pd = 9.903 \times 10^{-6}\ W/m^2$$
or written another way as
$$Pd = 0.000009903\ W/m^2$$

## STEP 5:

## FIELD STRENGTH
## (Transmitting Measurement)

Field strength is a measure of the transmitted electrical energy surrounding the antenna. The higher the FS, the stronger the transmitted signal -- and the easier it is to overcome a high noise content found on the 2 MHz frequency during the summer, permitting the receiving station to receive a clear and loud signal.

$$FS = \sqrt{120 \times \pi \times Pd}$$

FS = Field Strength. Note that the unit of measurement is now W/m (the $m^2$ has been canceled out).
Pd = Power density
120 = Constant

$$FS = \sqrt{(120 \times \pi \times 0.000009903\ W/m^2)}$$
$$FS = .061\ W/m,\ 1500 \text{ meters from antenna}$$

## STEP 6:

# APERTURE
# (Antenna Receiving Ability)

The capture area, or as it is sometimes called, aperture, determines the ability of the antenna to receive or capture an incoming signal. the principle is based on the work of Harold T. Friss, formally of the Bell Telephone Laboratories.

The larger the antenna is in relationship to the incoming wave, the higher the amplification of the signal that is sent to the receiver.

EFFECTIVE APERTURE

$$Aeff = \lambda^2 \times G \div (4\pi)$$

Aeff = Capture area of an antenna in square feet.
$\lambda$ = Wavelength (450')
G = Gain in power ratios. Note: must convert -5.5dB loss back to a power ratio of .28.

To determine Aeff, we must first determine gain. As noted in Step 3, the fiberglass antenna radiates out 280 watts when 1,000 watts are fed to the input. The gain (or loss) based on dB must be determined.

DECIBELS
(Power)

$$dB = 10 \log (P1 \div P2)$$
$$dB = 10 \log (280w \div 1000w)$$
$$dB = 10 \log (0.28w)$$
$$dB = -5.5 \text{ dB (loss)}$$

APERTURE
(Antenna Receiving Ability)

$$Aeff = (450 \text{ ft.})^2 \times .28 \div (4\pi)$$
$$Aeff = 4{,}512 \text{ ft.}^2$$

# PART 2:

# SHUNT FED CAPACITIVE VERTICAL

## STEP 1:

Height of the antenna in degrees, in relationship to the degrees of $\lambda$.

$*H^\circ = [(50' + *31') \div 984] \times 2.182 \times 360$
$H^\circ = 64.6^\circ$, rounded to $65^\circ$ of $360^\circ$
$*H^\circ$ = Height in degrees. Note that the physical height is 50', but the capacitive hat accounts for an additional 31'.

## STEP 2:

## RADIATION RESISTANCE

As noted on page 2, the radiation resistance is directly related to the height of the antenna, with the ideal Rr being 36Ω.

Radiation Resistance:

$Rr = 160 \times \pi^2 (H/2 \div \lambda)^2$
$Rr = 160 \times \pi^2 [(50' + 31') / 2* \div 450)^2$
$Rr = 12.79\Omega$
* Height is divided in two based on the Antenna Engineering Handbook, found on page 2 of this report.

## STEP 3:

## ANTENNA EFFICIENCY

Antenna efficiency ($A\eta$) is directly related to the height of the antenna.

$A\eta = Rr \div (Rr + *Rt) \times 100$
$A\eta = 12.79 \div (12.79 + *6) \times 100$

$A\eta$ = 68% efficient

*Value extrapolated from the ARRL Antenna Handbook for electrically short antennas.

The antenna is 68% efficient. It is losing 32% of its power due to the shortened length (110' quarter wave antenna = maximum efficiency). However, due to the physical constraints mentioned earlier, this design has significantly raised the performance over the existing fiberglass antenna.

If we take a 1,000 watt generator (amplifier) and feed it into an antenna that is 68% efficient, the antenna will radiate:

Radiated power = 1000w x 68%
Rp = 680 watts

## STEP 4:

## POWER DENSITY
## (RF Signal)

Power density is an intermediate step to obtain field strength.

POWER DENSITY

$Pd = Pt \div (4\pi \times r^2)$
$Pd = 680 \div (4\pi \times 1500^2)$
$Pd = 2.4 \times 10^{-5}\ W/m^2$ or $Pd = .000024\ W/m^2$

Pd = Power density. Unit is $Watts/m^2$.
Pt = Power based on electrical energy radiated.
$r^2$ = A radius from the transmitting antenna. In this case, 1500 meters.

## STEP 5:

## FIELD STRENGTH
## (Transmitting Measurement)

Field strength (Fs) is a measure (calculated, in this case,) of the transmitting electrical energy surrounding the antenna.

$Fs = \sqrt{(120 \times \pi \times Pd)}$
$Fs = \sqrt{(120 \times \pi \times .000024\ W/m^2)}$

Fs = .095 W/m at 1500 meters from antenna

## STEP 6:

## APERTURE
## (Antenna Receiving Ability)

The capture area or as it sometimes called, aperture, determines the ability of the antenna to receive or capture an incoming signal.

Effective Aperture: $Aeff = \lambda^2 \times G \div 4\pi$

Aeff = Capture area of antenna in square feet.
$\lambda^2 = (450')^2$
G = Gain in power ratio. Note: must convert the -1.6 dB (loss) to .68 power ratio.

To determine the Aeff, we must first determine gain.

DECIBELS
(POWER)

$dB = 10 \log (P1 \div P2)$
$dB = 10 \log (680w \div 1000w)$

$$dB = -1.6\ dB\ (loss)$$

**Therefore:** $Aeff = (450')^2 \times .68 \div (4\pi)$ $Aeff = 10{,}958\ ft.^2$

## TABLE OF VALUES

| VARIABLES | Fiberglass | Cap Hat | Unity |
|---|---|---|---|
| | | | |
| **Height of Antenna in Degrees** | 28° | 65° | 88° |
| **Radiation Resistance** | 2.38 ohms | 12.79 ohms | 23.5 ohms |
| **Antenna Efficiency** | 28% | 68% | 79.60% |
| **Radiated Power** | 280 watts | 680 watts | 796 watts |
| **Power Density** | 9 $W/m^2$ | 24 $W/m^2$ | 28 $W/m^2$ |
| **Field Strength** | .058 W/m | .095 W/m | .102 W/m |
| **Decibel Loss** | -5.5 dB | -1.6 dB | -1 dB |
| **Aperture** | 4,412 $ft.^2$ | 10,958 $ft.^2$ | 16,114 $ft.^2$ |

The mathematical analysis of these three antennas demonstrates that there is no perfect solution. However, our capacitive hat 50' Rohn 45G tower offers a compromise between what exists now in the USCG's inventory, and a full quarter wave radiator.

The configuration, when mounted properly, will withstand 100 mph of wind loading. The capacitive hat design will significantly increase the punch that is provided by the base station's 1kW amplifiers. It is suggested that if the USCG is interested in this antenna for their Group stations, the antenna tuners be returned to the factory for a tune-up and physical inspection.

If you are interested in this design, please feel free to e-mail or call.

Mike Malloy
Malloy Communications
Corpus Christi, Texas
361.937.1739

## REFERENCES

1. *47 CFR Part 80.369.a.* Definition of 2182.0 KHz.
2. *47 CFR Part 80.1077.* Definition of 2187.5 KHz.
3. *47 CFR Part 73.* Standards for AM Broadcast Antennas.
4. R.C. Johnson, H. Jasik. *Antenna Engineering Handbook,* second edition. Ch. 24. Low Frequency Antennas. McGraw-Hill.
5. P.H. Lee, *Vertical Antenna Handbook.* CQ Publishing. 1984.
6. J.A. Kuecken. *Antennas and Transmission Lines.* MFJ Publishing. 1996.
7. C.A. Balanis, *Antenna Theory, Analysis, and Design.* Second edition. Wiley Publishing. 1997.
8. *Antenna Handbook.* Chapter 16. Mobile and Maritime Antennas. ARRL 1988.
9. J. Devoldere, *Low Band Dxing,* 3rd edition. ARRL.