ANTENNA RADIATION EFFICIENCY

By: Larry Randall

This article discusses the "why" and "how" of achieving maximum transfer of power to the antenna. The single most important thing for any antenna to radiate effectively is that voltage and current on the antenna be IN PHASE at the feedpoint.

- No, that does NOT mean that the antenna must be resonant.
- ANY metal object will radiate effectively if voltage and current are applied in phase.

What determines the amount of applied power that is radiated?

Power is divided across the series circuit of $R_R + R_C + R_G$ (Radiation Resistance + Coil Resistance + Ground Resistance). Radiation resistance is an ***effective resistance***, because it is the value of the radiation from the antenna as radio waves. In other words, it is the **REAL** (i.e., non-reactive) value of the antenna element impedance -- that is, *the value of resistance that would consume the same power radiated by the antenna*.

Only R_R is beneficial for radiation. Therefore, *we want R_R to be as large as possible*, and R_C and R_G to be as *small* as possible. So, yes, a short antenna (e.g., a mobile) can be ***relatively*** efficient; BUT ***we cannot escape the pesky equation:***

For a monopole, $R_R = h^2 / 312$

- R_R is Radiation Resistance in Ohms
- h is antenna length *in electrical degrees*

8-foot Base Loaded Antenna at 7.2 MHz

Speed of radio wave in metal	284802835	Meters per second
Divide by 1,000,000	284.802835	
284.803 / freq (MHZ)	39.55597222	Full wavelength at 7.2 MHZ (meters)
Multiply by 3.28	129.7435889	Full wavelength at 7.2 MHZ (feet)
Divide feet by 360 degrees	0.360398858	Feet per degree
Divide length (ft) by feet / degree	22.1976286	Height in electrical degrees
Square the height in Degrees	492.7347157	
Divide by 312	1.579277935	Radiation Resistance in Ohms

Increasing Efficiency

We can increase the ability of a short antenna to radiate by placing a loading coil in the center, (raising R_R) b*ut we cannot change the fact that a short antenna (in electrical degrees) has lower Radiation Resistance than a long antenna.*

We gain an advantage in R_R with center loading, however, because the antenna *appears* electrically longer. In essence, the 8-foot-long center loaded antenna *appears* (i.e., in Radiation Resistance value) to be around 11 feet long.

WHY?

The power available to be radiated depends upon the power applied, the phase relationship of that power at the feed point AND upon the ratio of Radiation Resistance to Loss resistances.

In other words, $Radiated\ Power = In\ Phase\ Power\ in\ x \frac{R_R}{R_R + Rc + Rg}$.

Matched means that voltage and current are *relatively* in phase – in other words, not necessarily exactly in phase, but very close.

- When voltage and current are out of phase, we get a low POWER FACTOR.
- Low Power Factor means that we have WATTLESS POWER, which CANNOT be radiated.

Degree-Ampere Area is Important

Many people assume that one mobile antenna is pretty much the same as another, or that the longer, the better. It is far more important that we consider how much in-phase voltage and current can be pushed into the antenna in the most effective manner. This boils down to basic trigonometry and geometry.

Degree-Ampere Area -- Base Loading

Because a simple whip (or half element of a dipole) has maximum current at the feedpoint that tapers to zero at the end, we have *triangular* current distribution. The degree-Ampere area is defined by the equation for the area of a triangle: $Area = \frac{1}{2} x\ Base\ x\ Height$

In the antenna case $DegreeAmpArea = \frac{1}{2}\ x\ Amperes\ x\ Length$ (Length in ***electrical degrees***).

Degree-Ampere Area -- Center Loading

When we add a loading coil near the center of the antenna, we INCREASE the degree-Ampere area of the antenna.

Rectangular below the coil $DegreeAmpArea = Amperes\ x\ Length.$
Triangular above the coil $DegreeAmpArea = \frac{1}{2}\ x\ Amperes\ x\ Length.$

Thus, with center loading, about 2/3 of the radiation from the antenna occurs below the coil *PROVIDED* that the lower portion of the antenna is not shielded by metal.

Real-world Example

Of the three mobiles in the same convoy, only I was able to communicate *on the same frequency, from the same location, at the same time, to the same stations*. One had a 100-Watt radio with a “remotely tuned” screwdriver mobile antenna. The other had a 100-Watt radio with “built-in tuner” feeding a “linear loaded” mobile antenna.

I had a 100-Watt radio feeding a Hustler mobile antenna fed by an Icom AH4 Automatic Antena Matching Unit (a.k.a., “Tuner”).

Band 7 MHZ. Location on I-10 from San Antonio to Bogalusa, LA. (Doing relief after Katrina).

- Same 100-Watt power output.
- Different antennas.
- Different feed configurations.

The “Why”

The screwdriver antennas consist of an adjustable coil at the bottom of the antenna and a whip that may be 4 feet to 12 feet in length (standard supplied is 6 feet). “Tuning” is done by monitoring SWR at the radio while raising (exposing more) or lowering the coil with the supplied control. In other words, adjustment allows the transmitter to output into a ***reactive*** “load” that “kinda, sorta” looks like 50 Ohms.

Note that the coil is mounted to and connected to the ground point so essentially you have a simple base loaded whip with a coil that is adjusted for lowest SWR – without regard to the phase of voltage and current applied to the whip (i.e., the radiating element).

The other antenna had similar issues, with an “in radio tuner” that simply worries about the value of SWR in order to protect the radio, and does nothing to measure, sense, or correct the voltage and current phase relationship at the antenna.

A mobile antenna typically has an SWR bandwidth of less than 20 kHz or less. Outside of that narrow slice, it is highly reactive. An actual automatic antenna matching unit sits at the feedpoint and supplies a ***conjugate match*** to the antenna – thus aligning voltage and current at the REAL (i.e., non-reactive) value of impedance presented by the radiating element.

Don't Forget Losses

Never ignore the fact that $Radiated\ Power = InPhase\ Power\ \ x \frac{R_R}{R_R + Rc + Rg}$.

Radiation Resistance is Our Friend

We want R_R to be as high as possible, so we use antenna designs that maximize R_R and minimize losses.

Ground Loss (R_G)

To minimize R_G in a mobile, we move the antenna AWAY from ground, to as high on the vehicle as practical. If we are lucky, we can get R_G below 6 Ohms.

Since R_R may be well under 3 Ohms on low HF, low R_G is important, as is center loading to raise R_R.

Coil Loss

All coils have losses, but good coil design can minimize those losses. There is a point of vanishing returns; however, as coil size creates wind loading and adds requirements for mechanical design – especially in a mobile environment. Because the losses are greatest at low HF frequencies, and decreases (because coil size decreases) as frequency increases, the standard Hustler coils are a reasonable compromise.

Summary

The efficiency of a short antenna is highly dependent upon:

a) Length of the Radiating Element in Electrical Degrees
b) Method of loading
c) Phase relationship between voltage and current
d) The ratio of Radiation Resistance to the sum of Radiation Resistance plus Coil (or material) Loss plus Ground Loss.

Power transmitted = ***In Phase*** voltage and current multiplied by (R_R / (R_R+R_C+R_G).)

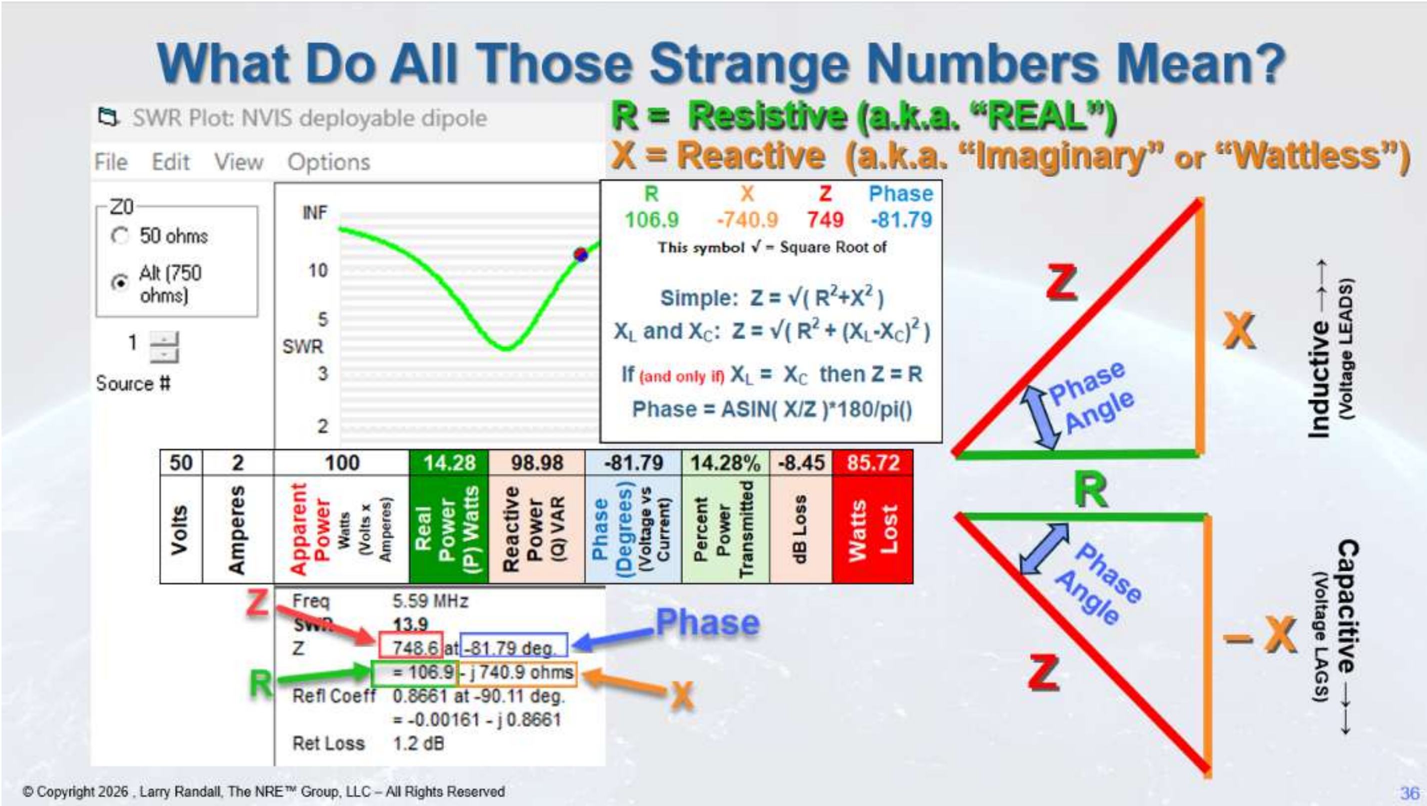
Any short antenna design is a compromise; however, we can maximize the amount of power available to be transmitted through careful design and installation choices. (Sometimes called good engineering practices.)

Bio

As an engineer and consultant, Larry Randall has aided militaries, governments, and companies in the fields of worldwide and tactical radio communication, diplomatic level communications security, emergency management, process design and improvement, and import/export operations. He has held every class of FCC Amateur Radio license and all levels of FCC Radiotelephone licenses through First Class. He currently holds Amateur Extra Class and GROL.

He has designed and delivered systems and training in multiple countries in the Middle East, South America, Central America, Europe, and Asia, as well as in the United States. Training subject matter created includes radio propagation, electronic theory, electronic troubleshooting, system operations, physical and communications security, and software development topics.

He and his wife make their home in Richardson, Texas.


What Do All Those Strange Numbers Mean?
SWR Plot: NVIS deployable dipole
File Edit View Options
Z0
50 ohms
Alt (750 ohms)
1
Source #
INF
10
5
SWR
3
2
R = Resistive (a.k.a. "REAL")
X = Reactive (a.k.a. "Imaginary" or "Wattless")
R X Z Phase
106.9 -740.9 749 -81.79
This symbol √ = Square Root of
Simple: Z = √(R²+X²)
XL and XC: Z = √(R² + (XL-XC)²)
If (and only if) XL = XC then Z = R
Phase = ASIN(X/Z)*180/pi()
50 Volts
2 Amperes
100 Apparent Power Watts (Volts x Amperes)
14.28 Real Power (P) Watts
98.98 Reactive Power (Q) VAR
-81.79 Phase (Degrees) (Voltage vs Current)
14.28% Percent Power Transmitted
-8.45 dB Loss
85.72 Watts Lost
Freq 5.59 MHz
SWR 13.9
Z 748.6 at -81.79 deg.
= 106.9 - j 740.9 ohms
Refl Coeff 0.8661 at -90.11 deg.
= -0.00161 - j 0.8661
Ret Loss 1.2 dB
Z
R
Phase
X
Z
X
Phase Angle
Inductive (Voltage LEADS)
R
Phase Angle
– X
Z
Capacitive (Voltage LAGS)
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