# Notes on Effective Height and Capture Area of stationary wave wire antennas.

Gianfranco, I2VGO

Clarifications about power

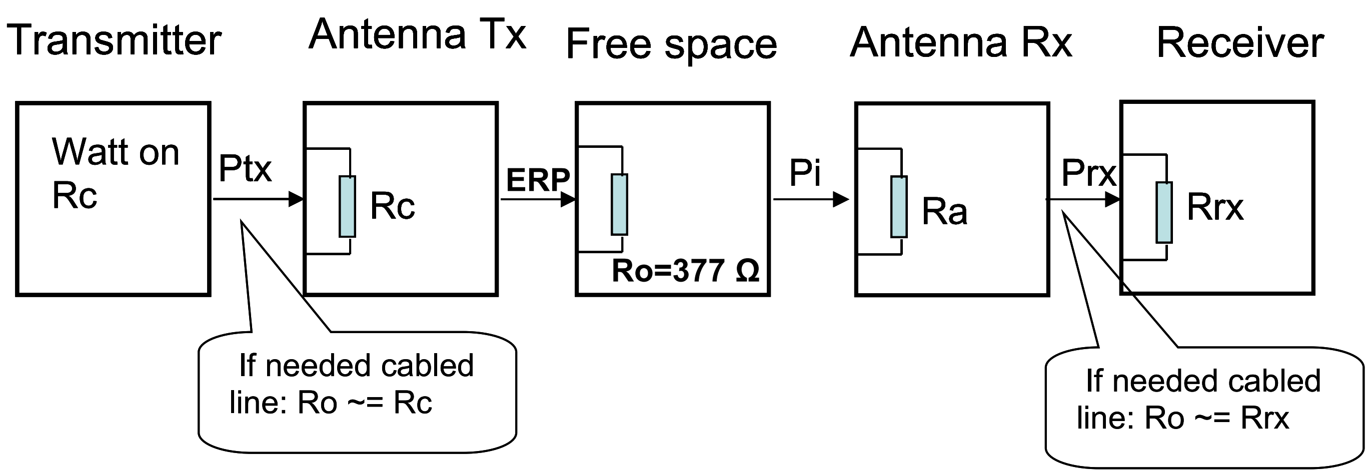
For power, active**, P** (Watt), means the power dissipated only and always from a resistive load, Rc, P = Rc * $I^2$. **Its average value is always positive**.

The product of a reactance, X, with $I^2$ is always a stored energy called Reactive Power, **Q** (VAR). **Its average value is always negative**. VAR average stored can be magnetic or electric energy respectively if X is inductive, Xl, or capacitive, Xc.

The product of an impedance, Z, with $I^2$ is always an apparent power, (VA). Its value is always positive as it contains both P and Q. The VA becomes equal to P for Z where X is negligible and becomes the same as Q where Rc is negligible. In a resonant dipole, (half wave) will be provided only the P (Watt). The Q stored is exchanged between the inductance/capacity distributed long the wire.

**In all inputs and outputs of two-port network, we have only power signals, P (watts).** There are no inputs and outputs signals of only voltage. We are obligated to indicate the signals with the only voltage whenever when Rc value is not known or normalized. E.g. HI-FI inputs, radio receiver before '50s-'60s, electrical schemes (faulty search) etc. You just need to know that the internal resistance of the voltmeter must be> 10 times the load Rc where you measure the voltage. So the voltage in linear or logarithmic units (dBu, dBv or dBuV) may exist on their own.

It is impossible knowing the value of the power supplied by a generator (upstream quadripole) without knowing the value of the load input resistance of the down stream quadripole.



Before calculating the capture area of antenna in Rx, then obtaining the gain, it is useful to review, even telegraphically, the fundamentals valid for all three types of antennas in the world: stationary wave (all open wires: dipoles, monopoles, slit, etc), progressive wave (wires terminated, all Rhombics, Beverages, etc.) and Optics (Parables, Cassegrain, Horn Reflector, etc).

**A) To radiate waves in the far field, there must be moving charges (**electrical current) **along a wire.**

**B) The radiation's resistance, of an antenna is a Rr fictitious (does not exist physically), which is like if dissipating all power that is radiated, Pir, into space; this allows us to calculate it:**

$$Pir = |I|^2 Rr \qquad \text{watt} \qquad (1)$$

**C) The SWR in a line only depends on the downstream termination (load) and is independent of any of the impedance value, Z, has the source (TX or antenna Rx).** E.g. Z of the Tx or linear upstream of the line toward antenna. Z antenna upstream of the downline toward the Rx.

**D) The Gain** dB) = **Directivity** (dB) **- losses** (dB). We will consider only directivity: zero losses.

**E) In Tx antenna its directivity is invariant with respect to the impedance it sees at the terminals.** E.g. The half wave dipole has a directivity of 2.16 dBi, in the free space, whatever the value of the SWR between antenna and cabled line.

On the contrary:

**F) Given an antenna in Rx, its directivity is variant respect the impedance it sees at its terminals. Its directivity will be maximum only, and only if the antenna is terminated with the same value as its radiation resistance: Ra= Rrx or Ra= Ro** if there is cabled line towards Rx. Of course, you also have to compensate the reactive power (VAR) coming out of gap antenna: perfect matched. Energy Adaptation for maximum power delivered to Rx.

Therefore, it is important that:

**G) The directivity or gain antenna Rx have to determined knowing the receiving antenna effective length, Le, or the receiving antenna capture area,** also called effective area in Rx, **Aef.**

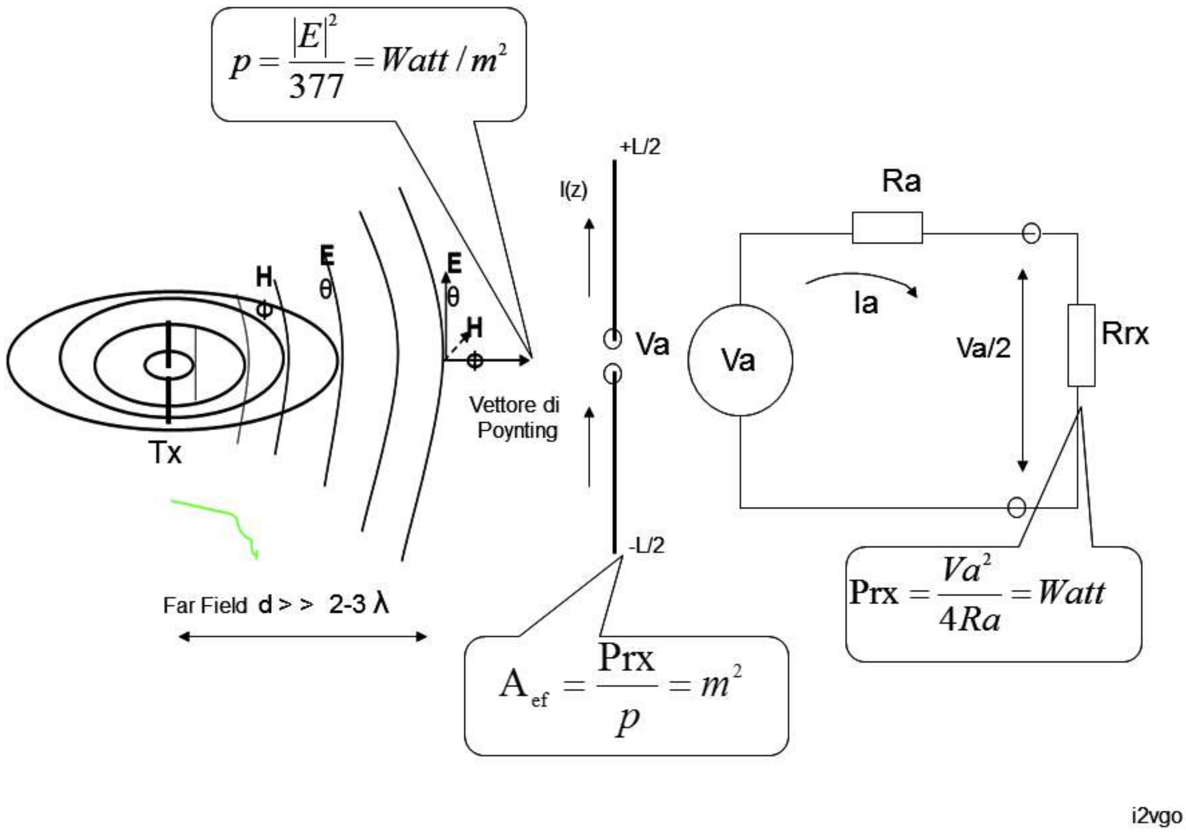
The Effective Length and the Effective Capture Area.

Using the Thevenin equivalent scheme, represent in the figure the model valid for all dipoles and monopoles, to derive the formula of the Aeff under the boundary conditions:

1) Dipole invested by a plane wave front, placed for the maximum value of its directivity, perpendicular to the flux wave and parallel to its electric force E: Vertical polarization. Antenna Generator, Va, in perfect energy adaptation, which means:

- Rrx was transformed to make it equal to Ra (if Ra were not)
- Compensate reactive power with an opposite sign (If the antenna were not already resonant: purely resistive)
- Made compatible with the antenna balance to Ro line (usually coax sbil): By Bal-Un current or voltage.

2) Antenna loss resistance = zero so its efficiency is = 100%. Since we consider the cable downstream Ro ~= Rrx, SWR~= 1.1, the power loss for SWR is almost zero (=0.002 dB) and its attenuation losses is negligible, the cable line does not appear in the calculation model.



The effective length. Le is calculated by:

$$Le = \frac{1}{I_0}\int_{-L/2}^{+L/2} I(z)dz$$

I (z) is stationary current distribution in transmitting mode.

For a half-wave dipole antenna the effective length, Le is:

$$Le = \frac{\lambda}{\pi} \quad \text{meters} \qquad (2)$$

For all short dipole or monopole Le is:

$$Le = \frac{L}{2} \quad \text{meters} \qquad (3)$$

Where L is length or height, respectively for short dipole or monopole (whip).

I remember that are called "short antennas" when **L** or **H = < λ /10.**

The induced voltage on open gap antenna, Va, of the incoming wave, perpendicular to its direction and in parallel (same polarization) to the electric force of the field E, is:

$$Va = E \cdot Le \quad \text{volt/m *m =volt} \qquad (4)$$

Now, Definition capture's area:

**The effective area, a reception antenna, represents the amount of power, Prx, delivered to the receiver and subtracted from the flow density p, of the incoming wavefront**.

$$Aef = \frac{P_{Rx}}{p} \quad \text{W*m}^2\text{/W= m}^2 \qquad (5)$$

**The wavefront power density (**watt/m$^{2)}$ **is the product of the orthogonal fields contained in the wave:**

$$p = E \cdot H = \frac{V}{m} \cdot \frac{A}{m} = watt/m^2 \qquad (6)$$

If wave incoming is plane the impedance Ro, is:

$$R_0 = \frac{E}{H} = 120 \cdot \pi = 377ohm \qquad (7)$$

Under these conditions, the maximum power that an electric antenna can capture every square meter of area is:

$$p = \frac{E^2}{377} \qquad \text{watt/m}^2 \qquad (8)$$

From Eq. (4) obtain E:

$$E = \frac{V_a}{Le} \qquad \text{volt/m} \qquad (9)$$

We replace the E field (Eq. 8) with Eq (9) and getting:

$$p = \frac{\frac{V_a^2}{Le^2}}{377} = \qquad (10)$$

In perfect matched the power incoming to receiver is:

$$P_{rx} = \frac{V_a^2}{4R_a} \qquad (11)$$

Ra is the radiation resistance of the antenna Rx.

Replacing the **Prx**, Eq. (11) and **p**, Eq. (10) in the fundamental equation 5):

$$Aef == \frac{P_{rx}}{p} = \frac{V_a^2}{4R_a} \cdot \frac{377 \cdot Le^2}{V_a^2} =$$

We getting the effective area, Aef of a wire straight antenna receiving for its maximum directivity:

$$Aef = \frac{377 Le^2}{4 R_a} \quad m^2 \qquad (12)$$

**In free space, the ratio between Directivity and Area (in linear units) is a Constant Universal:**

$$\frac{D}{A} = \frac{4\pi}{\lambda^2} \qquad (13)$$

From which, the directivity of the antenna with Aeff area is:

$$D = \frac{4\pi \cdot Aef}{\lambda^2} \qquad (14)$$

<u>Example: Compute the directivity of half wave dipole for 14.2 MHz</u>

$\lambda = \frac{c}{f} = \frac{300 \cdot 10^6}{14.2 \cdot 10^6} = 21.1m$, From Eq. (2) we derive $Le = \frac{\lambda}{\pi} = \frac{21.1}{\pi} = 6.7m$.

From biography (1) it is known that a dipole, with the ratio length /diameter of wire > = 2000, and cut precisely at λ/2 = 10.56 m, has a Za = 73 + J43 Ω. Making a perfect resonance by antenna tuner (-J43) we have **Ra = 73** Ω terminated with Ro = 75 ohm cable and Rrx= 75 Ohm, we getting a perfect matched.

Entering the values Le= 6.7m and Ra= 73 Ω in the Eq. (12) we obtain an **Aef = 58.24 m$^2$**.

From Eq. (14) we derived the directivity in linear unit =1.64, that expressed in logarithmic units is 10 Log (1.64) = **2.16 dB**. <u>We find exactly the same value, to the thousandth of a dB ,known to all, obtained in transmission, of the dipole half wave in free space, respect to  isotropic dipole **= 2.16 dBi.**</u>

In reality we all know that if shorten the dipole by λ/2 of a K value (about 0.95 for minimum SWR measured in TX) we obtain a Ra of= ~ 55-60 Ω and X ~= zero (perfect resonance) then using cables and Rrx = 50 Ω, we getting an Aef = 56.2 m$^2$ with a maximum theoretical directivity of 2.0 dB.

The receiving dipole directivity or gain is practically constant versus height over ground (For H /λ>=0.2).

The same dipole used in transmission the directivity is function of height over ground. We can have a theoretical maximum gain of 8,16 dBi or over perfect ground. If the ground is not perfect, the transmitted dipole will suffer some deterioration, decreasing its maximum gain over perfect ground, but for receiving dipole its gain is always that of free space.

**Reciprocity of wire antennas is valid only in free space.**

From the Thevenin equivalent circuit, we can observe another difference between transmitting and receiving wire antenna. Only half power, Prx, is delivered to the receiver by the power coming into Rx antenna the other half power is dissipated by Ra. How is it possible? The Ra not exist physically.
What say the fundamental A) and B)? To radiate waves a wire must be crossed by moving charge that is current. On the Rx antenna circulates current, **Ia**, (If the Ia were zero, the capture area would be = zero and the receiver would not get any signal) so the receiving antenna is also transmitting: The exact re-irradiated power is = $Ia^2 * Ra$ as Eq. (1)

Half power is re-radiated into space as scattering (Hs * Es). Then around the surface of the receiving wire we have fields E and H which are the sum of the incident fields on the antenna, Hi and Ei (what is captured) and scattering fields, Es and Hs (what is scattered): **E=Ei+Es H = Hi+Hs.**

Gianfranco Verbana, I2VGO.

Ex I1-12559, I1VGO, ARI Honor Roll.

Biography.

1) J.D Kraus *"Antennas"* New York Mc Graw Hill, 1950.

2) V. Trainotti " *Vertically Polarized Dipoles and Monopoles, Directivity, Effective Height and Antenna Factors*"IEEE Trans. Brodcasting Vol.56 , page 379-409. Sep 2010.