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Shortened Groundplane-Calculator

On the lower bands, it is often impossible to erect a Lambda/4 GP at full height, so it must be electrically extended by inserting an inductor.
The tool determines the required size of the extension inductance and the complex input resistance as well as the efficiency, taking into account the coil and ground losses.
It also calculates the LC element required for adjustment and the overall efficiency of the antenna.

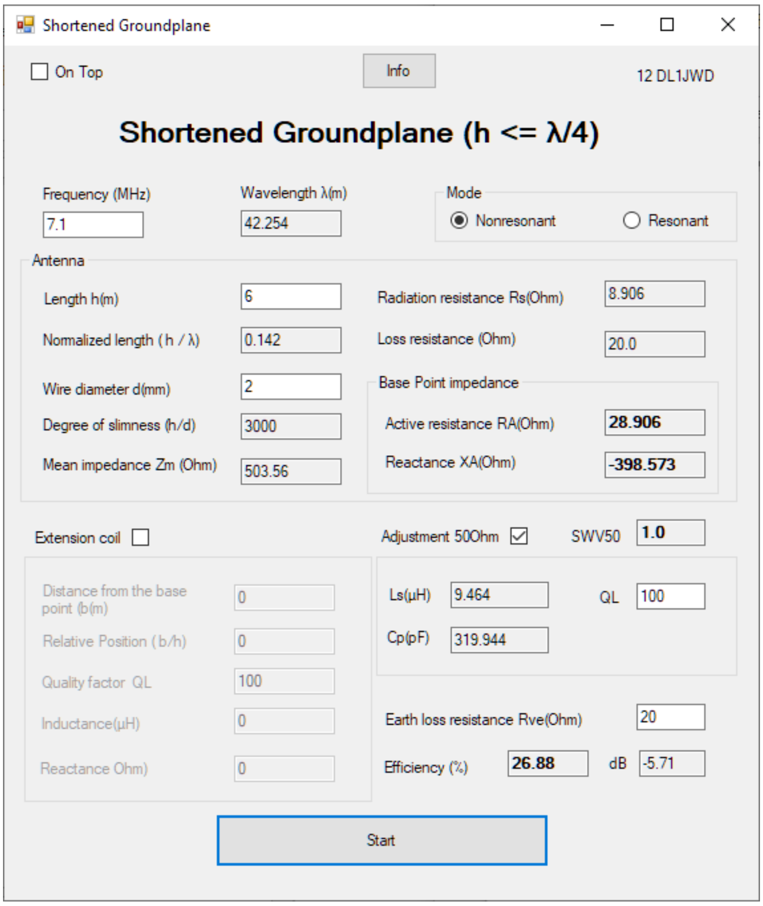
Example 1: Short Groundplane without extension coil

For the 40m band (7.1MHz) you want to build a GP, but you only have a 6m long GRP mast available (a λ/4 emitter would have to be 10.4m long).
The diameter of the antenna wire is 2mm and the loss resistance of the grounding system is estimated at 20Ohm (for this you need some good radials).

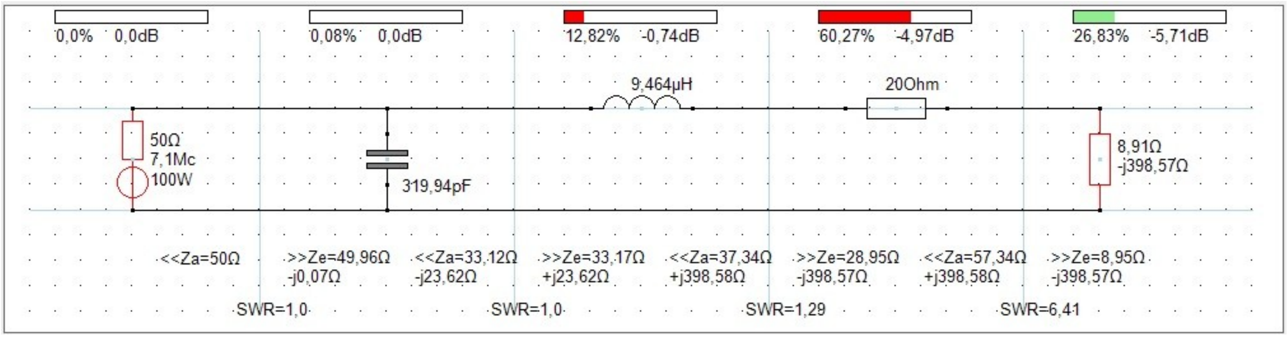
We are looking for the values of Ls and Cp of the adjustment circuit (directly at the antenna base point) as well as the overall efficiency of the antenna system.

- At the beginning you enter frequency, antenna length and ground resistance and set the mode to "non-resonant". Since you want to do without an extension coil, the value 0 applies to their inductance.

- Click on "Start" and you will see that the base point impedance is about 30Ohm -j400Ohm (you would measure a similar value with your NanoVNA, for example).



- Check "Adjustment 50Ohm" and you will see that with Ls=9.46µH (in series to the antenna base point) and Cp=320pF (parallel to the 50Ohm feed) a SWR=1.0 at 50Ohm can be achieved.
  Nevertheless, the overall efficiency only reaches a meagre 26.88%, because the radiation resistance (8.9=ohms) is significantly lower than the earth loss resistance (20 ohms).
  A detailed loss analysis with the *Special NetworkAnalyser* confirms these values:

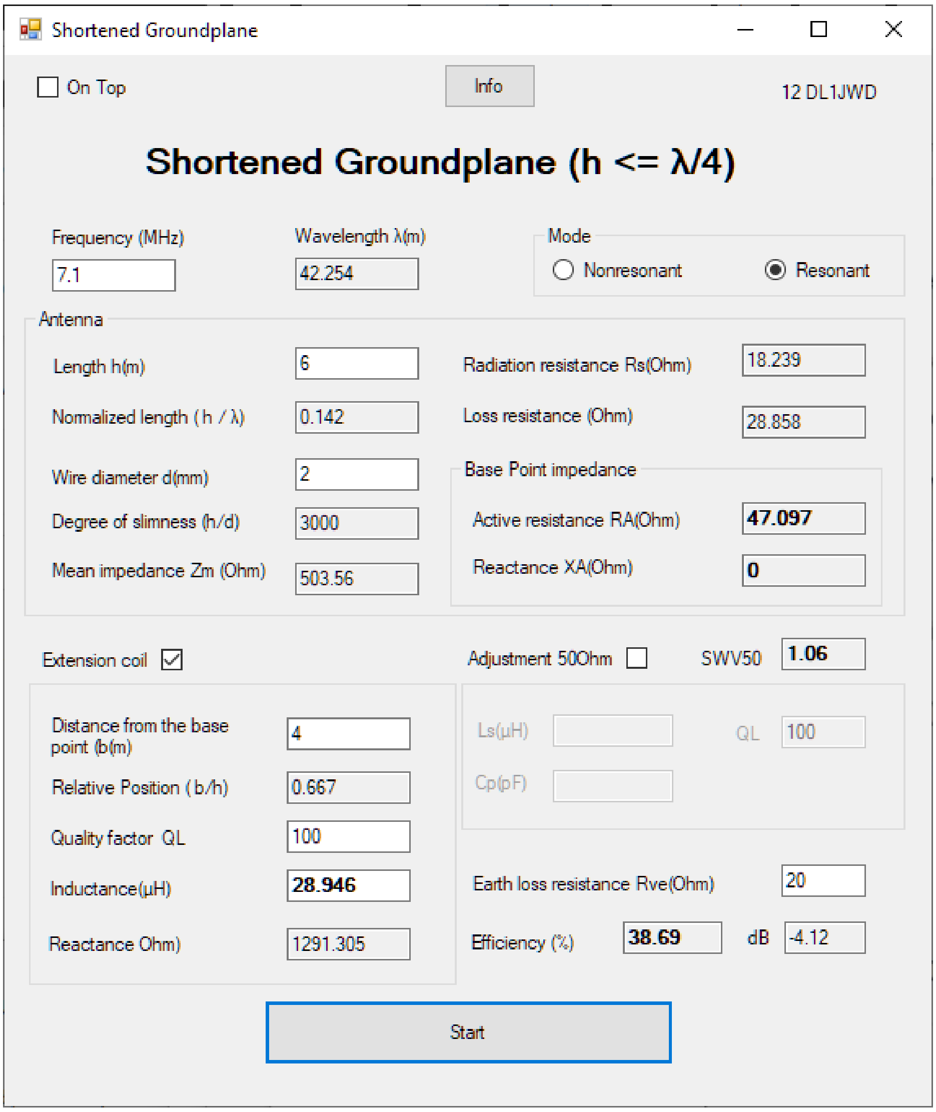


Example 2: Short Groundplane with extension coil

What improvement would an extension coil bring with which I tune the antenna to resonance?

- For the "distance from the base point" first enter the value 0 (coil directly at the base point) and change the mode to "Resonant".
  You can see that an 8.9µH coil is required to electrically extend the antenna so that there is resonance. To your disappointment, however, you have to realize that this time you can do without an adaptor, but the efficiency remains about its old value (about 27%).

- If you now gradually move the extension coil upwards (b > 0), you will notice that the inductance required for resonance increases significantly, as does the radiation resistance and efficiency.
  The maximum possible efficiency of approx. 40% can be achieved with a 29µH coil, which you attach approx. 4m away from the feeding point.



By "playing around" with the antenna parameters, you can gain the following insights:

- A smaller degree of slimness (squat antenna = thicker antenna wire) is better, because this leads to a smaller average impedance of the radiator and to a lower capacitive reactance, for which you would need a smaller extension coil.
  Their lower loss resistance ultimately leads to better efficiency.

- Moving the coil away from the base point causes a more favorable current distribution (instead of the triangular one) and improves the DX radiation, which can be proven, for example, with an EZENEC simulation.
  The simultaneously increasing radiation resistance also has a positive effect on the efficiency.

- However, moving the coil away from the base point also increases its losses, since due to the decreasing current flow, the inductance must be increased to achieve the same electrical shortening.

- Both aforementioned points influence the efficiency in opposite directions. Its (very flat) maximum is reached when the coil is attached at a distance of about one to two thirds of the antenna length.

- In the interest of a better DX radiation (position of the current belly!) one often accepts a moderate deterioration of the efficiency and positions the coil in the upper third.

- The earth losses can totally deteriorate the efficiency of an otherwise well-sized GP!
  In practice, the earth losses range between 10 and 25 ohms.
  The calculation of the efficiency without taking into account the earth losses is pure window dressing!

- In general, earth losses can be recognized by the deviation of the effective resistance from the calculated value upwards. The difference is the loss resistance due to ground currents (or conductor resistance and contact resistances in the feed).

- The program does **not** calculate the additional losses that occur on the way from the antenna to the transmitter in the feed line and possibly in the antenna tuner.
  However, since a 50Ohm termination is produced at the antenna base, these losses are essentially limited to the basic attenuation of the cable and thus remain manageable (no SWV-related additional losses, see *Cable calculator*).

- **Important**: If possible, do not transform with the feed cable with GPs (there are high SWR-related additional losses!) but bring peace into the supply cable, i.e. 50 ohm adjustment directly at the antenna base and not with the antenna tuner!

Theory

The starting point of the calculations is the average impedance Z_m of a monopole antenna (ground plane), which is directly dependent on its degree of slimness (l / d):

$$Z_m[\Omega]=60[\ln(4\frac{l}{d})-1]$$

l = length of radiator
d = diameter of radiator

Under the condition that the antenna length normalized to the wavelength λ is smaller than that of a quarter-wave radiator (l / λ <≈ 0.25), the blank component of the input impedance XA is calculated as

$$X_A=\frac{-Z_M}{\tan(2\pi\frac{l}{\lambda})}+X_{korr}$$

X_{korr} is a correction quantity that can be approximated from the normalized antenna length l/λ:

$$X_{korr}[\Omega] \approx 276(\frac{l}{\lambda})^{1{,}85} \qquad \textit{für} \ \frac{l}{\lambda} \approx 0{,}14...0{,}25$$
$$X_{korr}[\Omega] \approx 78(\frac{l}{\lambda})^{1{,}22} \qquad \textit{für} \ \frac{l}{\lambda} < 0{,}14$$

The insertion of a coil at a distance b from the feed point corresponds to an electrical extension of the antenna, which corresponds to the auxiliary quantity

$$N = \frac{1}{\tan 2\pi \frac{l-b}{\lambda}} - \frac{X_L}{Z_M}$$

can be calculated as follows from line theory [1]:

$$l_v = \frac{\lambda}{2\pi} atan(\frac{1}{N}) - \frac{l-b}{\lambda}$$

X_L = reactance of the coil

The efficiency of the groundplane is given by:

$$\eta_{res} = \frac{1}{1 + \frac{R_{Vf} + R_{Ve}}{R_s}}$$

R_{vf} = Loss resistance transformed from the extension coil to the input
R_{Ve} = Earth loss resistance

Since the program also records the losses of the LC element required for the 50Ohm adjustment, the displayed overall efficiency is slightly lower than that calculated with the above formula.

The losses in the 50Ohm supply cable are not taken into account.
However, since this is terminated with 50Ohm on the antenna and transmitter side, there are no SWV-related additional losses and the losses are limited to the basic attenuation of the cable.

Remarks

I dispense with the derivatives required to determine input impedance and efficiency, because this has already been done at the required depth in [1].
In any case, this classic by OM Janzen, DF6SJ, underpinned by numerous diagrams, is recommended for all those who want to delve deeper into the demanding matter of short antennas.

In particular, I refer to the following formulas, which are directly implemented in the groundplane calculator:

(5.23)	Electrical extension of the antenna by inserting a coil
(5.24)	Reactance at the feed point of the antenna
(5.27)	Inductance of the coil to produce resonance
(5.32)	effective antenna length under constant current
(5.33)	Radiation resistance in general
(5.35)	Radiation resistance of the antenna extended to resonance
(5.41)	Extension coil loss resistance transformed to the input
(5.42)	loss resistance transformed to the input at resonance

Literature

[1] G. Janzen, DF6SJ: "Kurze Antennen", Franckh'sche Verlagshandlung W.Keller & Co., Stuttgart 1986