Dr.-Ing.habil. Walter Doberenz DL1JWD

Input impedance of Dipole and Groundplan antennas

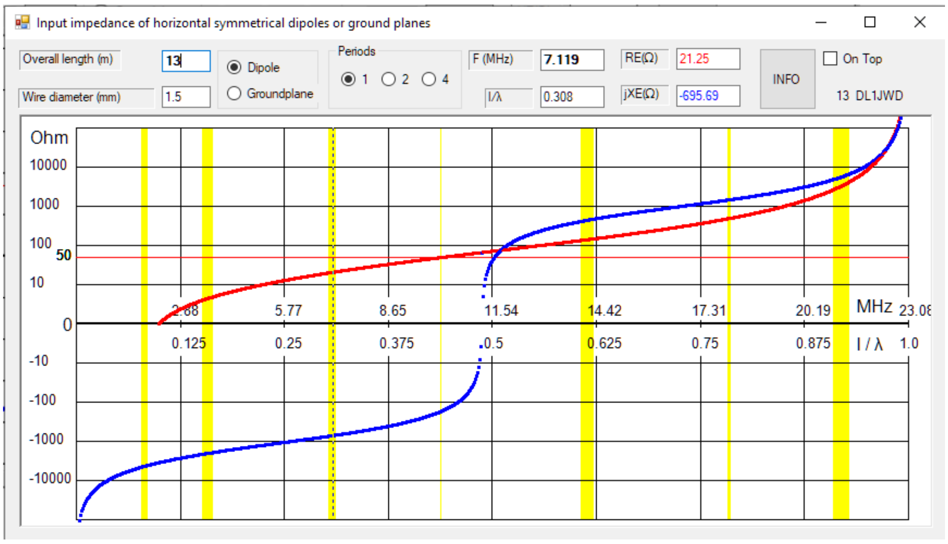
The program calculates the input or base impedance of a horizontal center-feeded dipole or a ground plane under idealized conditions based on integrals of antenna theory and is well suited for initial estimates.
The wide-band frequency axis shows at a glance which amateur radio bands work particularly well with a given antenna length and which bands can be adjusted poorly or not at all.
Once you have determined the base impedance of the antenna, you can use the "Cable Calculator" program to determine the input impedance of the feed line and then calculate a suitable matching circuit (e.g. with my "*Pi vs. T-Coupler*" tool).

Example 1

Center-fed dipoles are particularly popular because of their favorable properties. In multi-band operation, they are usually also operated outside of their resonant frequency. The best-known example is the Doppelzepp.

What is the input impedance of a 2x6.5m dipole on the 40m band?

All you have to do is enter the wire diameter (1.5mm) and the total length of the dipole (13m) and finish with the ENTER key (or click on the diagram):



The program sweeps the dipole's input impedance from 0 to the frequency of the first full-wave resonance, this is the frequency at which a full wavelength fits exactly on the dipole.

You can immediately see the course of the real (red) and reactive (blue) components of the input impedance as a function of the normalized dipole length l/λ or the frequency.

The areas of the amateur radio bands are highlighted in yellow.

Drag the mouse on the right or bottom edge of the window and enlarge or reduce the diagram in order to easily adapt it to the screen resolution of your PC.

If you move the frequency ruler along the scale with the mouse, the current frequency, the normalized length and the real and reactive components of the base impedance are continuously displayed at the top of the window.

For the 40m band one reads a value of about **Ze(Ohm) = 21.25 - j695.7**.

The normalized dipole length $l/\lambda = 0.5$ (half-wave dipole) is in the middle of the diagram.
If you look closely, however, you will see that the corresponding frequency (11.54MHz) is not yet the resonant frequency of the dipole, because it is a little lower, why?

As you can see from the course of the blue line, the input impedance Ze(Ohm) ~ 73 +j42 still has an inductive reactive component at this point.
Only by shortening the half-wave dipole by about 5% can it be made resonant /2/.

Because the input impedance varies from a few ohms to tens of thousands of ohms depending on the frequency, I divided the vertical axis logarithmically, i.e. the values appear extremely compressed towards the top. You can see this from the course of the red 50 ohm line, among other things.
It should be clear that input impedances greater than 5000 ohms are only of theoretical interest and are significantly lower in practice, as confirmed by VNA measurements or a comparison with the results of the antenna simulation program MMANA.

You can also enter a specific frequency directly from the keyboard.
After you have completed the entry with the ENTER key, this frequency is marked with a vertical red line and the corresponding input impedance can be read in the display fields for RE and jXE.
After clicking on the diagram, the red line disappears again.

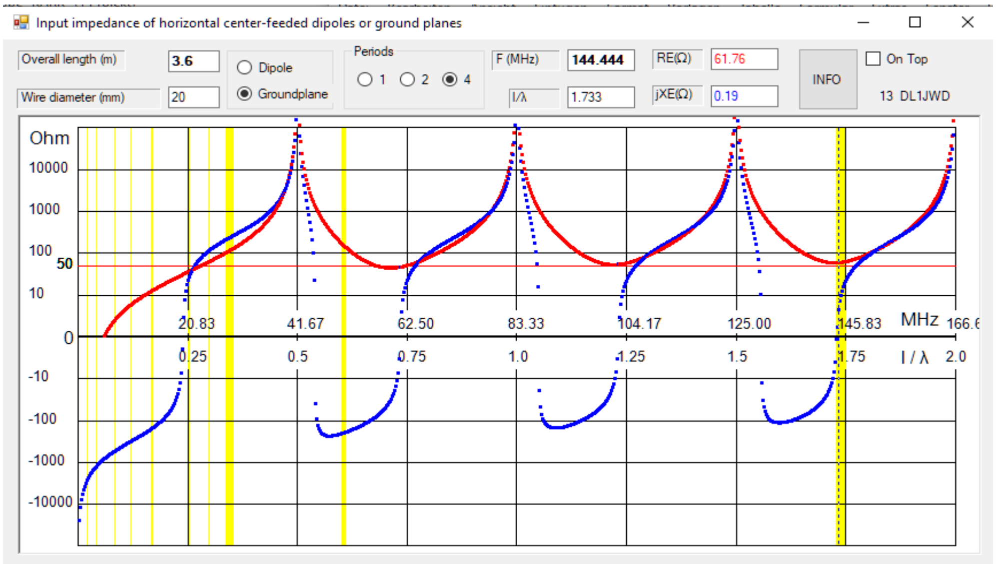
Example 2

The input impedance of vertical radiators can also be calculated with this program according to the same principle as with dipole antennas, assuming an ideal earth.

For the 2m band I would like to build a groundplane, whereby max. 4m aluminum tube with a diameter of 2cm is available.
The base point impedance should be as close as possible to 50 ohms, so that an adjustment element can be dispensed with.
How long does the spotlight have to be?

First enter 4m as total length and also the wire thickness (20mm).
Now click the "Groundplane" button.
Then increase the number of periods to 4 so that the 2m band also appears at the right edge of the frequency scale.

As you can see, it is still slightly above a current resonance, so you have to successively shorten the total length of the radiator until RE has reached the lowest possible value (approx. 62Ohm) with simultaneous zero crossing of the blank component (jXE approx. 0.2Ohm).
This is approximately the case with a construction height of 3.6m:

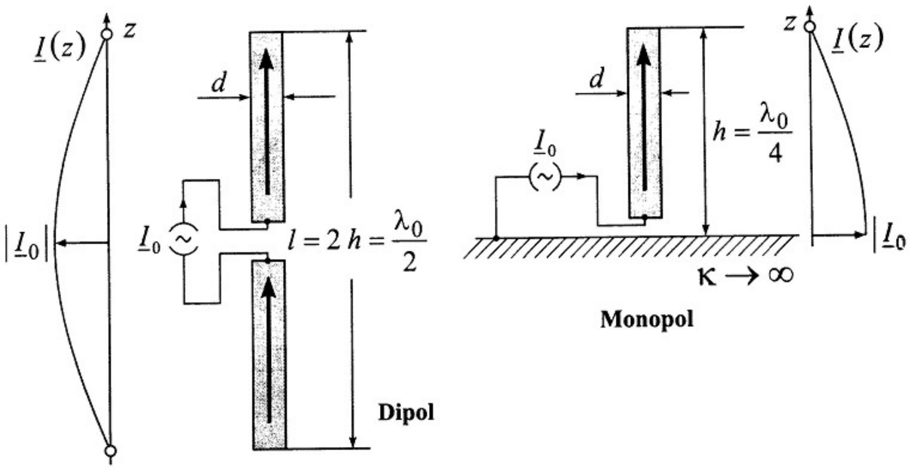


As you can easily verify with my *Adjustment Losses* tool, the best possible SWV = 1.26 and the losses due to mismatch are negligible (0.06dB).

For comparison: The simulation of this 3.6m GP with the "big" program MMANA-GAL comes to an input impedance Ze(Ohm) = 72.86 + j4.5 at 145MHz.
This deviation is therefore within reasonable limits, at least for the average demands of an amateur radio operator.

Theory

The so-called "linear antenna" is one of the most common radiator shapes, it consists in its simplest form of a stretched cylindrical conductor, which is usually excited in the middle (dipole) or at the base point against earth (monopole or ground plane).
Both antenna shapes have the same radiation pattern in the upper half-space, since the Earth's surface lies in a plane of symmetry of the electric field.
With the same source current Io, the monopole emits only half the radiant power of the dipole, real or blind part of its input impedance are also exactly half as large.



The theory of radiation fields and antennas is mathematically highly complex, usually based on the current distribution on the antenna surface, which is clearly linked to the radiation field (the mantra "current radiates" should be familiar to every OM).

As a rule, these surface currents have to be determined with complex numerical methods.

If the current is known at all points according to magnitude and phase, the field strength can be determined from the superposition (superposition) of the individual current elements, whereby phase and distance differences between the respective source and destination points must be taken into account.
In practice, however, simple approximations are often sufficient, from which the radiation fields can be obtained in a second step by integration over the radiating surfaces.

However, for the calculation of the input impedance, in particular of its blank part, which describes the energy storage in the near field, a more precise knowledge of the current distribution on the antenna is required.

How does the program work?

I developed the program with Visual C#, this software is tremendously powerful, comfortable to use and relatively easy to learn /3/.

First, I calculate the active power radiated by a thin linear antenna, which is proportional to the so-called radiation resistance Rs.

The sticking point is then the solution of the integral form of the complex radiation resistance Zs, which leads to higher mathematical functions such as integral sine and integral cosine, which in turn can only be determined numerically.

The input impedance Ze (the complex input resistance), on the other hand, can be easily calculated from the radiation impedance Zs.
Zs and Ze are identical for the current resonances $l=(2n-1)\ \lambda/2$ (current belly at the feed point).
A slim half-wave dipole therefore has an input impedance

$$\mathbf{Ze} = \mathbf{Zs} = (73{,}1+j42{,}5)\text{Ohm}.$$

Ze has for dipole lengths $l = \lambda * n$ n pole points, a whole wave dipole must therefore be fed with a voltage and not with a current source.
For these voltage resonances there is a current node in the feed point, so that the input resistance is seemingly infinitely large.
These singularities have their cause in the mathematical model of the thin linear antenna, in which the symmetrical current distribution is approximated by a standing sine wave, they disappear in technically real dipoles with finite thickness and taking into account the radiation attenuation.

The deviations of the mathematical model from practice are increasingly evident in the area of pole positions, as can be determined, for example, by measurements or comparison with an antenna simulation program.
Thus, values of about 10kOhm will be achieved for input impedances at most, while the mathematical model spits out astronomically high numbers.

Mathematically interested OMs can take the formulas I use, for example, from the classic by Klaus Kark /1/ (chapter 10, linear antennas).
Important suggestions can also be found in the well-known book by OM Gerd Janzen, DF6SJ, although only "short" antennas, i.e. below the dimensions of a half-wave dipole, are discussed there.

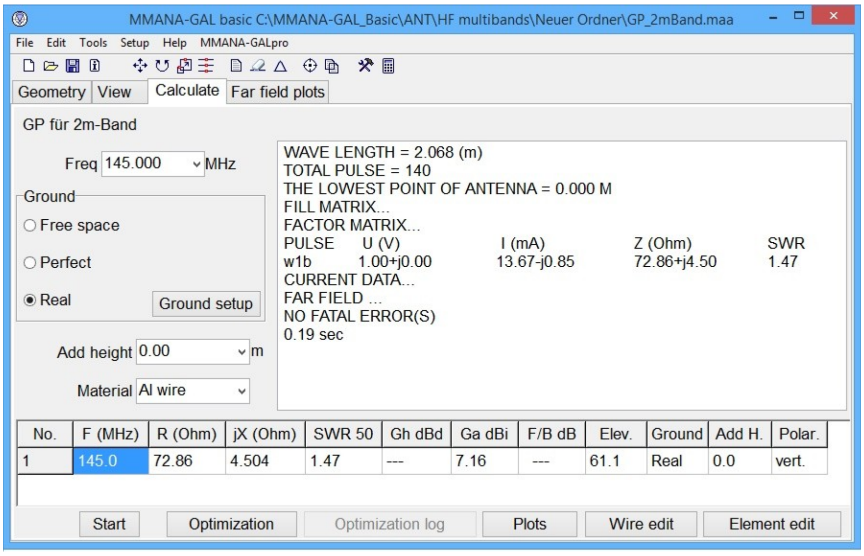
A word about EZNEC & Co

More complex antenna structures can only be meaningfully analyzed with computer support, whereby the antenna is "disassembled" into individual wire pieces, whose far and near-field components are determined individually taking into account environmental factors and finally "assembled" again.

The most important programs for Hams are 4nec2, EZNEC and MMANA-GAL.
I prefer the latter because it strictly follows the familiar Windows interface, but is otherwise based on the same solution algorithm (nec kernel) as its siblings.
The calculation kernel was programmed many years ago by the staff of the Lawrence Livermoore Laboratory in the then current language Fortran, this demanding numerical calculation of the antenna properties based on complex differential equation systems was and is the real outstanding achievement!

The developers of EZNEC, MMANA etc. had to deal "only" with the programming of an easy-to-use user interface, whereby the input of the antenna geometry takes place in the form of a strictly formatted table.
After the calculation in the kernel, its result data is converted e.g. in radiation diagrams and impedance tables.

A calculation of the input impedance of the 3.6m high GP for the 2m band with MMANA shows that the results of the antenna theory (see example 2) do not differ so much from those of the "big" programs under the given simplifying conditions:



Literature

/1/ Kark, K.: Antennen und Strahlungsfelder.
Friedr. Vieweg & Sohn Verlag, Wiesbaden 2004

/2/ Janzen, G., DF6SJ: Kurze Antennen. 1.Aufl.
Franckh'sche Verlagshandlung W.Keller & Co., Stuttgart 1986

/3/ Doberenz,W., Gewinnus,Th. : Visual C# 2015, Grundlagen, Profiwissenund Rezepte.
Carl Hanser Verlag, München 2015