

Wire Antenna Modelling with NEC-2

1 Numerical Electromagnetics Code (NEC)

The software *Numerical Electromagnetics Code* (NEC-2) has been developed in the 1970s in the Lawrence Livermore Laboratory in Livermore, California. It is based on a numerical solution of electromagnetic field integrals for thin, perfectly conducting wire segments using the Method of Moments (MoM). Such segments can be freely arranged in three-dimensional space and excited in different ways. To calculate the electromagnetic properties of antennas (e.g. input impedance, current distribution or radiation pattern) there are different analysis functions available.

The program has later been released as *Public Domain* and is available today in many different versions for almost all operating systems and CPU platforms. For the present tutorial, the software tool 4NEC2 will be used which, in addition to the NEC-kernel, offers a graphical user interface for creating geometries, displaying results and optimization tools. 4NEC2 is a completely free windows based antenna modelling tool developed by the dutch radio amateur Arie Voors [2].

1.1 Structure of NEC-2 Input Data

A NEC-2 input file consists of a number of commands (called “Cards” in remembrance of the good, old times of punch cards) specifying the geometry of a problem, the excitation and the output data to be calculated. The structure can be separated in three different blocks:

CM	Comments
⋮	
CE	End of Comment Blocks
GW/SP/...	Geometry Definition
⋮	
GE	End of Geometry Block
EX/GR/LD/FR/RP/...	Program Control
⋮	
EN	End of Program

The usage of the different commands and the different parameters is explained in a detailed handbook of which you have an excerpt of important commands. The complete NEC-2 Manual is available over the internet [3]. For entering dimensions the **standard units** m and MHz for frequencies are used. For wire geometries some **design criteria** have to be considered (s. section 1.2)!

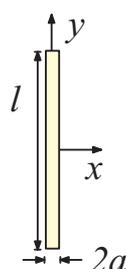
1.1.1 Simple Example

The structure of a NEC-2 program file and usage of “cards” shall be explained using the example of a half-wavelength dipole for the frequency of $f = 200$ MHz:

```

CM Example 1: Half-wavelength dipole
CE
GW 1 9 0 -0.2 0 0 0.2 0 .001
GE
EX 0 1 5 0 1 0
FR 0 1 0 0 200 0
EN

```

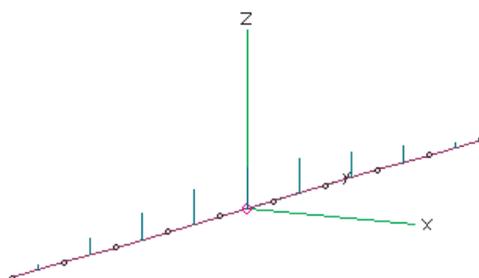


After the short command line, the geometry block consists of a single **GW** command and results in the creation of a wire of length $l = 40$ cm aligned along the y -axis. It is partitioned in 9 individual segments of equal length as shown in the above figure. The radius of the wire is $a = 1$ mm.

The subsequent **EX** command generates an impressed RF voltage current in the middle segment (no. 9) as excitation of the structure, the amplitude is set to 1 V per segment length. This is the common way of feeding wire antennas in NEC-2, for most single antenna problems one source of excitation will be sufficient but more impressed currents/voltages are also possible.

The last command in the example, **FR**, starts the computation of the problem at a single frequency of $f = 200$ MHz, as specified.

Before the execution of the program, the input file should be saved. Using the menu **Calculate**→**Generate** (or “calculator” menu button) the calculation is started, the wire input impedance $Z_a = R_a + jX_a$ and the line currents are shown as the calculated results. The representation of current amplitudes over each wire segment exhibits the expected sinusoidal current distribution.



The output of the NEC solver is a text file containing the numerical values required to obtain the results (e.g. geometry data, currents) and the desired target data (e.g. impedance, radiation pattern, gain etc.) which is stored in a “*.out”-file in the directory of program installation. For easier interpretation of the results, the 4NEC-2 program offers a number of different modules for the graphical representation of geometry, currents, impedance or radiation pattern.

1.2 Design Rules

To obtain accurate and reliable results, certain rules for the dimensions and alignment of the wires must be observed.

Segment length	$l < \lambda/10$
Segment radius	$r < \lambda/100, r < l/8$
Segment connections	
$l_1 > l_2$	$l_1 < 5l_2$
$r_1 > r_2$	$r_1 < 5r_2$

Using the menu function **Show**→**VALIDATE**.. in the **Geometry-Window** these criteria may be checked one at a time or alltogether. In case the design rules have been broken, some segments are coloured grey (Warning) or red (Error) to mark the parts where the limits are exceeded.

References

- [1] “The unofficial Numerical Electromagnetic Code (NEC) Archives”,
<http://www.qsl.net/wb6tpu/swindex.html>
- [2] 4NEC2 antenna modeler and optimizer, <http://home.ict.nl/arivoors/>
- [3] NEC-2 User Manual, <ftp://ftp.qsl.net/pub/wb6tpu/NEC/nec2prt1.pdf>

1.3 Exercises

1.3.1 Half wavelength dipole

Calculate the wire length for a half wavelength dipole with a frequency of operation of $f = 300$ MHz using the rule-of-thumb ($l = \lambda_0/2$) and write a NEC-Program for the calculation. The dipole is fed at the center of the wire and the radius of the wire is $a = 1$ mm.

Calculate the input impedance at the frequency of operation and enter your result in the table in section 2.3.2! Why does the value differ from the value given in Literature of 73.2Ω ?

1.3.2 Resonance Frequency

Instead of single frequencies, a number of successive frequencies may be calculated (Sweep). Choose a suitable frequency range and make the required changes to the program. Determine the frequency of resonance and the input impedance (at this frequency) for your design. Note the results in the table!

1.3.3 Exact Wire Length

Try to find a length l of the wire such that the resonance will be **as close as possible** to the desired frequency of operation ($f_R = f_0 = 300$ MHz). Enter your results for wire length and input impedance in the table!

1.3.4 Radiation Pattern

Using the RP command in the control block of a NEC-2 program will output the antenna radiation pattern for the angular range defined in the command. The resulting antenna gain will be calculated.

Choose a suitable angular range and modify the program so that the radiation pattern of the dipole antenna will be calculated. The exact wire length determined **in the previous subsection** A1.3.3 should be kept. Enter in the table the values of maximum antenna gain G_{\max} , the directions of maximum radiation and the 3db-beam width!

1.3.5 Influence of Wire Diameter

To demonstrate the influence of wire diameter we will gradually reduce the wire radius a .

Using the optimum wire length from subsection A1.3.3, calculate for each given value of a the resulting resonance frequency and input impedance **at $f_0 = 300$ MHz**. Enter the values into the table!

2 Antenna Mutual Coupling

In the previous examples, only the properties of single wire dipole antennas have been considered. In the following exercises a second **passive** wire will be aligned parallel to the dipole axis, on which the effects of mutual coupling will excite linear currents. It should be observed how input impedance and radiation pattern of the dipole antenna are influenced by the mutual coupling.

2.1 Optimiser

In the standard version, NEC-2 can only calculate loops where the frequency is the varying parameter. For typical antenna problems such as impedance matching or finding appropriate dimensions, a variation of geometrical parameters is required. For such problems, an external optimiser is included in the 4NEC2 package and may be used in a very versatile way.

First, some parameters (variables) need to be declared and be applied in suitable commands. These parameters may be modified automatically by optimiser later when it is started. The parameters may be declared using a special **SY**-command: The cards in the following example

```
SY d=0.01
GW 1 9 0 -0.25 0 0 0.25 0 d
```

will create the variable d with an initial value of 0.01 [m], it is used subsequently to specify the radius of a wire. Parameters may also be calculated using simple formulas, e.g. $2 * (d + 1)$. In a 'normal' run of NEC-2 (**Calculate**→**Generate**) the pre-defined initial value is used to calculate the dimensions while the optimiser is tries to modify these values for best fit. The usage of multiple variables at different points in a NEC-program is possible, also for optimisation.

The optimiser is started using the menu **Calculate**→**Optimize** and offers different modes of operation:

- In the **Evaluate**-mode the value of one or more parameters is altered step-by-step around the starting value. This can be used to realise loops for sweeping parameters other than frequency.
- The **Optimize**-mode offers a variety of different output data for definition of a design quality ("goal functions"):

SWR	Standing Wave Ratio
Gain	Antenna Gain
F/B, F/R	Front-to-Back Ratio of Field Magnitude
R-a	Input Resistance
X-a	Input Reactance
Eff.	Antenna Efficiency

One or more values can be combined in goal function by weighting the different criteria (entering percentages in the appropriate fields). If, for example, only the standing wave ratio is to be optimised, a value of "100" is to be entered in the SWR-field. Should also other fields be included, different percentages may be added in other boxes. If the far field is addressed (e.g. gain or front-to-back-ratio), it is sometimes required to specify a particular direction (in Theta/Phi-angles) for the calculation. In the **Optimize**-mode selected parameters are made larger or smaller until each new variation leads to worse results considering the desired design goal function and a (local) optimum has been found.

It has to be noted that this optimisation process does not always lead to an **absolute** minimum bzw. maximum, depending on the starting values of the different parameters. Therefore it is sometimes advisable to start with an initial run of **Evaluate** with a coarse grid of points for determining a finer range of starting values in the parameter space for a subsequent run.

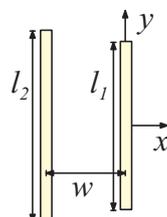
2.2 Exercises

2.2.1 Initial Example

First, just like in the previous example, a single wire with a radius of $a=1$ mm should be designed as a half wavelength dipole antenna for a resonance frequency of $f_0=500$ MHz. Enter your values for wire length l_1 , input impedance and reflection coefficient in table 2.3.2.

2.2.2 Additional Wire / Reflector

A second linear wire antenna with identical dimensions ($l_2 = l_1$) in a distance w should be aligned parallel to the first dipole as shown in the following figure. The second antenna will remain passive, i.e. only the middle segment of the first wire (right hand side) will be excited.



Set the distance between the two wires to $w = \lambda_0/4$ and evaluate the influence of mutual coupling on resonance frequency, antenna input impedance and gain **in the direction of the x -axis** at $f = 500$ MHz using 4NEC2.

2.2.3 Optimum Input Impedance

Find a suitable distance w between the two wires using the optimiser, so that the antenna has a **real** input impedance at $f_0 = 500$ MHz ($Z_a = R_a$, $X_a = 0$).

2.2.4 Optimum Antenna Gain

Find a suitable distance w using the optimiser, so that the gain of the antenna at $f_0 = 500$ MHz reaches a maximum.

2.2.5 Multi-Parameter Optimisation

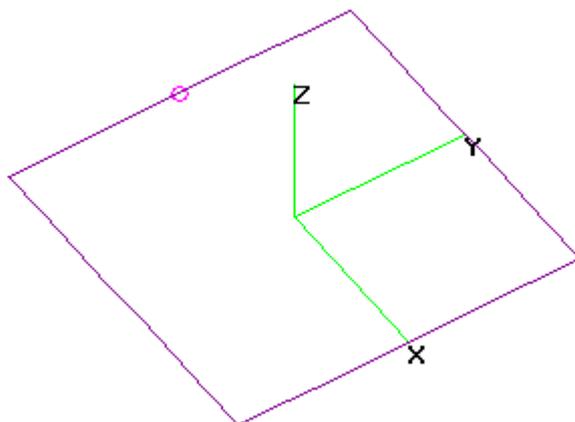
In addition to the distance w between the two wires, now also the reflector wire length l_2 is variable. Start the optimiser with one or both variables and try to find a good compromise between input impedance and antenna gain. Write down the results in the table.

2.2.6 Additional Wire / Director

The usage of additional passive wires parallel to the active wire can also increase the antenna gain in the forward direction (so called “directors”). Try to add one or more wires to your model as directors and experiment with different configurations (no. of wires, lengths, distances etc.)

2.3 Quad-Antenna

Another example of a simple wire antenna is the so-called “Quad Antenna” shown in the following figure. It is built of 4 linear wires forming a square with an edge length of $\lambda/4$.



2.3.1 Resonance Frequency

Build a model of a Quad antenna using 4NEC2 and find a suitable wire (edge) length l , so that the resulting frequency of resonance will be $f_R = 40$ MHz. Take into account the wire radius a : Which wire length will be used for a very thin wire ($a = 0.01\text{mm}$), which length will be required for a wire with a radius of $a = 5\text{mm}$? What is the input impedance Z_a in both cases?

2.3.2 Antenna Radiation Pattern

The far field radiation pattern of a Quad antenna differs from that of a half-wavelength dipole. Draw the shape of the E_θ and E_ϕ components of the Quad antenna's far field (as shown above) in the different planes:

Results

Enter your results for wire geometry and resulting antenna parameters in the following tables:

Half-wavelength Dipole

E1.3.1 Half wavelength dipole, $a = 1$ mm, $f_0 = 300$ MHz

$l =$	$R_a =$	$X_a =$
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E1.3.2 Resonance Frequency

$f_R =$	$R_a =$	$X_a =$
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E1.3.2 Exact Wire Length, $f_R = f_0 = 300$ MHz

$l =$	$R_a =$	$X_a =$
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E1.3.4 Radiation Pattern

$G_{\max} =$	$(\vartheta, \varphi)_{\max} =$	$\alpha_{3\text{dB}} =$
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E1.3.5 Influence of Wire Diameter

	at $f_0 = 300$ MHz:		
$a=0,1$ mm	$R_a =$	$X_a =$	$f_R =$
$a=0,01$ mm	$R_a =$	$X_a =$	$f_R =$
$a=0,001$ mm	$R_a =$	$X_a =$	$f_R =$

Antenna Mutual Coupling

E2.2.1 Single Wire as Dipole Antenna, $f_0 = 500$ MHz

$l_1 =$	$R_a =$	$X_a =$	$G_{\max} =$
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E2.2.2 Second Wire with Identical Length, $w = \lambda_0/4$

new resonance frequency:		$f_R =$	
at $f_0 = 500$ MHz	$R_a =$	$X_a =$	$G_{\max} =$

E2.2.3 Optimum Input Impedance

new wire distance:		$w =$	
at $f_0 = 500$ MHz	$R_a =$	$X_a =$	$G_{\max} =$

E2.2.4 Optimum Antenna Gain

new wire distance:		$w =$	
new resonance frequency:		$f_R =$	
at $f_0 = 500$ MHz	$R_a =$	$X_a =$	$G_{\max} =$

E2.2.5 Multi-Parameter Optimisation

new wire distance:		$w =$	
new wire length:		$l_2 =$	
at $f_0 = 500$ MHz	$R_a =$	$X_a =$	$G_{\max} =$

Quad Antenna

E2.3.1 Resonance Frequency

	at $f_R = 40$ MHz:		
$a = 0,01$ mm	$l =$	$R_a =$	$X_a = 0$
$a = 5$ mm	$l =$	$R_a =$	$X_a = 0$

E2.3.2 Antenna Radiation Pattern

Max. Gain: $G(\vartheta = \quad, \varphi = \quad) = \quad$ dBi