Antenna system for the DTUsat

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1 Preface

It is the aim of this project to design the antenna system for the DTUsat.

The design of the DTUsat itself commenced in september 2001 where groups of students at DTU started to work on various parts of the satellite. The main purpose of the satellite was to develop a project in which students with various educational background could work together on an interdisciplinary and realistic engineering task.

It was decided to use the cubesat specifications as described on [8]. The reason being mainly that this concept offered a relatively low overall price and that it was a known concept.

As it is uncertain whether the attitude control works or not once the satellite is in orbit, the groups working on communication decided that communication should be possible no matter the orientation of the satellite. On this basis the requirements in section 2 was developed. For the same reason circular polarization was chosen due to the advantages when combined with an earth station capable of toggling between right and left hand circular polarization.

The report is intended partly as an evaluation of a special course at Ørsted DTU and partly as a documentation enabling others to continue/finish the work here presented. Because of this some sections are very thorough.

The report contains some theoretical sections, 4, 5, 6 and 7 to lay the foundation for discussing the antenna system. In section 9 two simulation programs are presented and discussed. Hereafter follows the simulations and discussions of these. The following section is devoted to feeding network. Finally the conclusion.

We would like to thank our instructor, Olav Breinbjerg, for his patience and his many man hours spend on the project.

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The key element in understanding antenna arrays is to realise that Maxwell's equations (see [Cheng, p. 244]) are all linear.

This means, that if there at a given positions, $\mathbf{X}_0$, in space, are some E-fields (the same goes for H-fields) $\mathbf{E}_1(\mathbf{X}_0), \mathbf{E}_2(\mathbf{X}_0) \ldots \mathbf{E}_n(\mathbf{X}_0)$ originating from different sources, then the total $\mathbf{E}$-field is

$$\mathbf{E} = \mathbf{E}_1(\mathbf{X_0}) + \mathbf{E}_2(\mathbf{X}_0) \ldots + \mathbf{E_n}(\mathbf{X_0}) \tag{1}$$

Where in general $\mathbf{E} = \mathbf{E}(t, \mathbf{X})$, where $\mathbf{X}$ is a position in space. This can be used to calculate the $\mathbf{E}$-field from multiple antennas at a given point in space. A number of examples are provided in [Cheng, chapter 10]. For briefty we will not provide any.

5 Polarization

It is the purpose of this section to develop a way of splitting a local plane and time harmonic electromagnetic wave up i two components, whose base vectors rotates in each direction in the θ,ϕ plane (in spherical coordinates).

The reason for doing so is, that a system, consisting of a transmitting and a receiving antenna, that uses circular polarization is less fragile with respect to the alignment of the transmitting and the receiving antenna, than a system using linear polarization. The reason is, that in the system using linear polarization the receiving antenna has to be aligned with the incoming E-field to function optimally. In the circular case there is no such demand[1]

In the far field of an antenna, that transmits a time harmonic signal, the **E**-field is a local plane wave. This means that it, for a given and sufficiently large R –needs to be in the far field (in spherical coordinates)– can be written in phasor notation as

$$\mathbf{E} = \mathbf{E}_\theta \widehat{\theta} + \mathbf{E}_\phi \widehat{\phi} \qquad \mathbf{E} = \mathbf{E}(\theta, \phi)$$

Where **E** is the phasor representation of the time harmonic E-field originating from the antenna. And $\widehat{\theta}$ and $\widehat{\phi}$ are base vectors in the spherical coordinate system.

We now define two new rotating (with time, as will be shown) base vectors $\widehat{L}$ and $\widehat{R}$, left and right hand circular polarization base vectors respectively. Henceforth we refer left and right hand circular polarization as *lhcp* and *rhcp*. We define $\widehat{L}$ and $\widehat{R}$ as:

$$\widehat{L} = \frac{1}{\sqrt{2}}\left(\widehat{\theta} + j\widehat{\phi}\right)$$

$$\widehat{R} = \frac{1}{\sqrt{2}}\left(\widehat{\theta} - j\widehat{\phi}\right)$$

Both are given on phasor form. As can be seen the two base vectors lies in the θ, ϕ plane and are not orthogonal.

To study the behaviour of $\widehat{L}$ and $\widehat{R}$ we write the two base vectors in the time domain:

$$\widehat{L}_T = Re\left\{\frac{1}{\sqrt{2}}\left(\widehat{\theta} + j\widehat{\phi}\right) e^{j\omega t}\right\}$$

$$= \cos(\omega t)\widehat{\theta} - \sin(\omega t)\widehat{\phi}$$

[1] In both cases the antennas are taken to be pointed correctly towards each other

The same can be done for $\widehat{R}$. The index T merely shows, that $\widehat{R}_T$ and $\widehat{L}_T$ are functions of the time, t.

$$\widehat{R}_T = \cos(\omega t)\widehat{\theta} + \sin(\omega t)\widehat{\phi}$$

When letting t run we see, that the two base vectors rotates. This is illustrated in Figure 1 As can be seen from the figure $\widehat{R}_T$ and $\widehat{L}_T$ will at some point

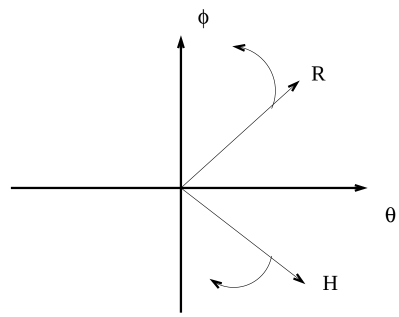

Figure 1: Illustration of how $\widehat{R}_T$ and $\widehat{L}_T$ varies with time

in time be parallel. It is therefor not obvious, that we can describe the **E**-field completely in these new base vectors. Returning to phasor notation we rewrite (5).

$$\begin{aligned}
\mathbf{E} &= E_\theta\widehat{\theta} + E_\phi\widehat{\phi} \\
&= E_\theta\left(\widehat{\theta}\cdot\widehat{L}\widehat{L} + \widehat{\theta}\cdot\widehat{R}\widehat{R}\right) + E_\phi\left(\widehat{\phi}\cdot\widehat{L}\widehat{L} + \widehat{\phi}\cdot\widehat{R}\widehat{R}\right) \\
&= \widehat{L}\left(E_\theta\widehat{\theta}\cdot\widehat{L} + E_\phi\widehat{\phi}\cdot\widehat{L}\right) + \widehat{R}\left(E_\theta\widehat{\theta}\cdot\widehat{R} + E_\phi\widehat{\phi}\cdot\widehat{R}\right) \\
&= \widehat{L}\left(\frac{1}{\sqrt{2}}E_\theta - \frac{j}{\sqrt{2}}E_\phi\right) + \widehat{R}\left(\frac{1}{\sqrt{2}}E_\theta + \frac{j}{\sqrt{2}}E_\phi\right)
\end{aligned}$$

Thus we have been able to completely write the **E**-field by help of $\widehat{R}$ and $\widehat{L}$. wherefore the **E**-field can be described completely with $\widehat{R}$ and $\widehat{L}$ as base vectors.

What we have shown is, that a time harmonic electromagnetic wave which is only polarized in the θ, ϕ-plane, can be written as

$$\mathbf{E} = E_{rhcp}\widehat{R} + E_{lhcp}\widehat{L}$$

Where

$$E_{rhcp} = \frac{1}{\sqrt{2}}\left(E_\theta + jE_\phi\right) \qquad E_{rhcp} = \frac{1}{\sqrt{2}}\left(E_\theta + jE_\phi\right)$$

6 Antenna arrays in our simulations

When considering an antenna array we are dealing with a linear circuit with n inputs (n antennas). From theory on linear circuits we know that the input voltages and currents can be written as

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \dots & Z_{1n} \\ Z_{21} & Z_{22} & \dots & Z_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ Z_{n1} & Z_{n2} & \dots & Z_{nn} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix}$$

As previously mentioned, neither of the programs can calculate the impedance of a given antenna, $R_x = \frac{V_x}{I_x}$, when more than one antenna is transmitting (more than one $I_x \neq 0 \quad x = 1..n$).

Of course the impedance of a given antenna can be found by combining the impedance matrix and the currents in the antennas. Both calculated by AWAS and WIPL[2]. When this is done a new simulation has to be performed in order to find the far field. As can be seen it requires quite some postprocessing to find the impedance of a single antenna in an array. The needed postprocessing is outside the scope of this report.

For the above reasons we have chosen to make the simulations of antenna arrays with antennas that are approximately $\lambda/4$ wavelengths long, and only make plots of the far field. It is known from literature that the radiation pattern barely change when the antenna lengths are changed symmetrically. Thus the radiation patterns obtained from these simulations will be practically identical with the radiation pattern of antennas, whos lengths have been tuned to achieve resonance at the transmitting frequency[3].

Of course all these problems could be accounted for if the mutual impedances were very small, that is $Z_{1x} \approx 0 \quad x \neq 1$ and $Z_{2x} \approx 0 \quad x \neq 2$. This however is not the case, as is evident from intuition, because the antennas are very close together and thus strongly coupled. This has been validated by simulations with both AWAS and WIPL.

[2]In the AWAS case it is very tedious to get the currents in the antennas, due to the format of the current output file, curr.dat

[3]Which is not know yet but is in the interval 435-438 MHz

7 Numerical solution of integro-differential equations

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8 Previous work

With the concept of a Cubesat Kit and the more manageable price of a such, one should think OSSS ([8]) has made it easier for universities to play an even greater role in construction of satellites. If this was the case, one would think it more likely to find information about these projects than for commercial ones, where it might not always in the interest of the companies to publish it. In addition, one would expect documentation and presentations presented by other students to be more easily understood, than something coming from the hands of professionals, which supposedly is intended for a higher level of knowledge.

This is why we first and foremost concentrated our search for information on previous projects carried out under the restrictions set by OSSS for a Cubesat. Another advantage in doing so could be, that the universities might be more willing to cooperate, with the prospect of getting something usable in return.

As expected, the mere word cubesat rendered thousands of links on the Internet. But a few of the projects, that seemed of immediate interest to us, are listed below along with their makers:

CUTE (see [4]). Tokyo Institute of Technology.

StenSat-2 (see [5]). A group of engineers.

MEROPE (see [6]). Montana State University.

As predicted by our instructor, there were an abundance of information to be found. But at the same time, also predicted by our instructor, very little was of any use to us. Most of the sites contained no more than a picture of the antenna system for the satellites, and data about placement of antennas, length and function are often let out.

Another problem with finding information on the Internet, is the lack of support on many home pages. Not only are people not updating frequently enough, but it is obvious that they often neglect putting out the final results, because their project is at an end, and the evaluation is over.

We did however get something out of our effort. The first of the above mentioned links, the CUTE, contained more information than the average cubesat home page, and at the same time it was, and still is at the time of writing, updated frequently. Still, the data was not overwhelming, but according to it, they expected to use something of the same frequency for downlink as we intended - something around the 430 MHz band. But it was the picture, that was the most intriguing M, having two antennas for downlink, looking kind of "wavy".

We started a dialog (see appendix L) with the leader of their antenna team, Hideto Okada. Our first idea was to find out more about the polarization of their antennas, especially for downlink, their estimate of the reflection coefficient, their feeding network and several other things. But, as it quickly can be seen by scanning through the letters, our goals and qualifications for the project were different from theirs.

After a while it became clear, or so they told us, that they were mainly in it for the mechanic part of it, at least in the beginning that is. The radio section was merely an extra benefit, or extra workload, which they had postponed as long as they could. Opposite to us, they did not plan the exact look of the antennas (e.g. as completely straight wires) but counted on a ground station to pick up the signal "sometimes", when the satellite would be in a favourable position to it. And also, they had not a clear understanding of polarization.

All in all we did not learn much from the correspondence. There is nevertheless some advice for other students who commence on projects of the same sort, people who picks this project up from where we leave it or our selves in similar projects later on. Though it may seem a bit naive or obvious, it is advisable to quickly get to know the background of the people with whom you are doing the correspondence. But with some more effort, there would definitely have been more learn from the other cubesat projects.

Another conclusion one can draw from this short survey of earlier work, is that our report should definitely be put on the Internet. And not only for the participants of the projects to be seen.

9 Simulation programs

From the beginning and throughout the project, we have done all our simulations on two different computer programs - WIPL and AWAS. Both presented to us by our instructor. To keep on using both of them, was a decision partly taken in the beginning, and a decision partly taken as the project progressed. Obviously it would be a waste of time using two programs parallel with one another, if one knew the results to be identical. But since it was the first time for any of us to participate in the design of an antenna system, neither of us had any knowledge about which program would suit this particular assignment best. At the same time we had no literature to previous projects, which could tell us anything about the agreement between the two.

However useful the programs turned out to be, they themselves were not enough. As is to be read in the following presentations of WIPL and AWAS, the data produced by the programs needed to be rearranged for the sake of clarity. Besides from that, the programs did not have all the functions one could wish. This is explained in 6. The tool we chose for the above mentioned problems, was Matlab.

9.1 WIPL

9.1.1 Introduction to WIPL

One of the two programs used in the process of determining the placement of the antennas on the DTUSat, was the program WIPL, Electromagnetic Modeling of Composite Wire and Plate Structures. Our version was published in 1995 by the company Artech House([7]) situated at that time in London.

As many other 5-year old programs today, WIPL does not need an especially powerful computer to run smoothly. In fact a IBM AT 286 is sufficient. And as for the platform, all that is necessary is DOS 3.3 or better. Hence todays powerful computers make computations much faster than estimated at the release of the program, and therefor makes it quite pleasant to work with.

WIPL is a simulation program primarily intended for use by professional engineers, but as it will be demonstrated in this project, it can also be used with success by students. With this said, it is necessary to emphasize the complexity of the program – that is, the theory behind the calculations of far-field vectors, admittance/impedance of antennas and current distribution. The manual (see [10], chpt.4) provides a section containing a brief introduction to electromagnetic modeling. Some of this theory is described in this report (see section 7) as well. Our use of the program has been mainly as a tool, where we have not focused on the theory, unless we had results on our hand, that did not correspond with what was to expect (see section 6). In such cases it was necessary to take the theory into consideration and then make some approximations in our calculations or the structure of the model.

9.1.2 Input data

A short description of the most simple procedure for a simulation is in place here. The modeling itself is made very easy by the user-interface provided by WIPL:

- At first one specifies the Cartesian coordinates for all the node points needed.
- From these, one defines the wires and at the same time their radii, and the plates.
- Then the junctions between wires and plates are specified.
- Then the placement of one or more generators are specified, including their amplitude and phase.
- The frequencies, for which the simulation is wanted, are defined.
- At last one defines for which values of θ and ϕ (spherical coordinates!) the far-field is wanted.

How easy and user friendly this might seem, the last item calls for some extra attention. For some reason, the designers of this early version of WIPL has decided, that θ is not to be used in the same way as in an ordinary spherical coordinate system([Cheng]). For example if θ was to be used in the yz-plane, it would normally go from the z-axes towards the y-axes. In WIPL it is just the opposite. In our further use of the data from WIPL, this has obviously been taken into consideration (see A.2).

Also one has to keep in mind, when working with complex and large structures, the limitations set by the maximum number of node points, elements (wires/plates) and excitations which are respectively 400, 200 and 900.

Apart from the above mentioned, very little input data is needed in addition to come up with exactly the simulations, which are presented in this report. When more than one generator is present, it is necessary to define whether WIPL should run the simulation one generator at a time or all generators simultaneously 6. In the first case WIPL will render only the admittance of each antenna, and in the second case only the far-field is the outcome.

9.1.3 Input file

The input data is stored in a file with the same name as that of the configuration, but with a different extension. For a configuration named “test”, the input data would be saved as:

test.OWP Contains the input-data. Ready to be used by WIPL for listing.

The input file has been of no interest in this project, since it has not been necessary at any point to change the input data after simulation.

9.1.4 Output files

As with the input data, all the output data from a simulation is saved in a file with the name of the configuration, but with a different extension. A list of the output data files for the above mentioned file would look like this:

test.AD1 Contains data for the admittance. Ready to be used by WIPL for plotting.

test.RA1 Contains data from the far-field evaluations. Ready to be used by WIPL for plotting.

test.CU1 Contains data for the current distribution. Ready to be used by WIPL for plotting.

test.ADM Contains data for the admittance. Ready to be used by WIPL for listing.

test.RAD Contains data from the far-field evaluations. Ready to be used by WIPL for listing.

test.CUR Contains data for the current distribution. Ready to be used by WIPL for listing.

In our further use of the data from WIPL, we found the files containing data for plotting the most convenient to work with. Hence the format of files with the extensions “.AD1” and “.RA1” is thoroughly described in appendix D.1 and appendix D.2 respectively.

9.1.5 Unused features

The possibilities with WIPL is, as can be seen in the above text, many. This also means, that we, in the past four months, only have had chance to utilize a fraction of the options offered by the program. Apart from calculating admittance and evaluating far-field for a given structure, it is also possible to evaluate a current distribution and to work with scatterers.

There are also some features, that can simplify or speed up the calculation time of WIPL:

- Symmetry planes (see [10], chpt.5). Can shorten time for computing considerably, and can also compensate for some of the limitations set by the maximum number of node points mentioned earlier.
- Integral accuracy (calculation time). Can be defined by the user. Very useful in the beginning of modeling, when all there is need for is approximations.
- Level of current expansion. Can also be defined by the user, and is usable for the same reasons as the integral accuracy.
- Display of structure. When modeling a structure, a 3D-drawing can be displayed.

Some more outdated features are the facilities intended for plotting. But for an survey, one can use the 2d-plots for the admittance or the 3d-plots for the radiation. The plots for admittance is acceptable, but due to the lack of axes, the 3d-plots can be used for no more than checking for symmetry in the pattern.

9.1.6 Advantages

An obvious advantage with WIPL in comparison to AWAS, is the possibility of simulating structures consisting of plates as well as wires. As it will be demonstrated in section 10.4, it has not been of great significance in our case. Though, if the proportion between the wavelength and the size of the structure had been different, this could be the point, that could decide which of the two programs to use.

The modeling itself is very easy. Existing node points can be moved easily and WIPL updates the input data when deleting a node point. This way one can reuse existing models for new simulations and quick alterations are possible. The 3D-drawing of the structure and its display of the names of node points is yet another thing, that makes modeling easy.

Another feature, or several actually, that makes WIPL pleasant to work with, is all the earlier mentioned possibilities to set the accuracy of the calculations. This way a user can have an influence on the execution time.

9.1.7 Disadvantages

Most of the disadvantages mentioned so far, are things that are easy to cope with and can be dealt with, if one keeps them in mind(e.g. definition of θ). But there are two things, which have been to great annoyance to us.

One of them is the missing calculation of the impedance. WIPL calculates the admittance, and of course the impedance is attainable from this (see A). But for the wholeness of the program, and the otherwise easy-to-use concept, one should think, that this was worth some extra lines of code.

The other thing that seem to actually be "missing", is the earlier mentioned simultaneous calculation of admittance and far-field evaluation of structures with several generators. This has to be done in two steps (see 6), very much complicating work for any users.

This is problems, that we have had with the version of WIPL dated 1995. On the home page of Artech House ([9]), one can find information about a new edition, WIPL-D. It is possible, that some of the issues mentioned above have been improved in this later version.

9.1.8 Summation, WIPL

Summing up the previous, WIPL is a useful and user friendly program and has been pretty much what was needed for this project.

9.2 AWAS

9.2.1 Introduction to AWAS

"AWAS for windows", Analysis of Wire Antennas and Scatterers, is an analysis and simulation program for wire structures and antennas. The version used is 1.0, published by Artech House, inc., in 1995 and is only available for Microsoft Windows. It requires as minimum a computer equipped with a 80386 processor together with a 80387 coprocessor and Microsoft Windows 3.0. Hence it runs flawlessly on modern pc's.

9.2.2 Input data

All input data are either loaded from a file or entered. If entered the following is to be defined.

- The structures and antennas, that are to be analysed. These are build by defining nodes and straight line segments[4]/wires. For limitations imposed on the number of nodes wires etc. see appendix F.

  Antennas are created by placing a voltage generator in a node. The program then automatically connects all wires connected to the specific node to the generator. The generators are all sinusoidal, but the amplitude and the phase can be defined as desired. The operating frequency is identical for all generators.

- The frequencies and angles where the analysis is to be done. The angles are given in spherical coordinates. These are defined as usual see [Cheng, p. 35].

All input data: Nodes, wires, impedances, generators etc. are entered in a common Windows like manner.

The program makes a validation of the input data. This means verifying that no logical errors (crossing wires, inconsistency in definition of: Generators, wires, nodes and so on) has been made while entering the geometry, voltages etc. This is done before any analysis/calculations is executed.

As a nice feature AWAS makes a real time 3d visualisation of the data that defines the structure (it draws the structure). Allowing for zooming and rotating hereof.

[4] which is the term used in the program

9.2.3 Input Files

All the entered data can be saved, for instance under the project name "test". The program then creates the following files

test.geo Containing operation mode, ground plan and the geometry of the structure, ex. nodes, wires, generators/ports, distributed loadings along the wires and generator amplitude, phase and the generators nominal impedance.

test.frq Contains the operating frequencies.

test.pwe Contains data defining the plane waves illuminating the structure

test.nfp Points where the near field is to be evaluated.

test.ffp Contains directions for which far fields are to be evaluated.

Of these only *test.geo*, *test.frq* and *test.ffp* are of interest to this project. Since test.frq and test.ffp are both well documented in the manual[1], and since it has not been necessary to alter them by hand, they will not be described further. However it was necessary to alter *test.geo* by hand in order to delete nodes from a structure. The reason for this being necessary is that all nodes has to be given consecutive numbers. And AWAS only allows for deleting a node, but offers no automatical adjustment of the following nodes. This problem can be partly bypassed by altering the test.geo file by hand. The format of test.geo is described in appendix C.3.

9.2.4 The analysis

The analysis is based on the moment method, as explained in section 7. It finds: Currents in all wires and antennas. Impedances and admittances of antennas and finally near and far field of the radiated E-field. There is two different modes of operation when more more than one generator/antenna is present. Either all or one generator is excitated at a time. In the first case the impedance for the various antennas is not calculated, that is the impedance matrix is not found, whereas in the later the near and far field is not calculated. All calculations can be done at a specified frequency and specified angles or over a range of frequencies and angles.

AWAS allows for plotting of the calculated data, though this feature is quite primitive (see section 9.2.7, Disadvantages). Finally it is possible to view all the calculated data from within the program.

9.2.5 Output files

The calculated data is not, as one would expect, saved to files with names given by the user. Rather it is always saved to the following files:

SPAR.DAT Contains passive portions of port scattering parameters

YPAR.DAT The port admittances matrix.

ZPAR.DAT The port impedance matrix.

CURR.DAT Currents in all wires.

NFLD.DAT The near field and the points and frequency, where it is evaluated.

FFLD.DAT The far field and the directions and frequency, where it is evaluated.

WIREOUT.DAT The main output file. Here the content of most of the above files is gathered along with information on polynomial coefficients(see section 7) and radiated and fed power to the generators/ports.

Of these files only *zpar.dat* and *ffld.dat* are used. Both of these files are rather poorly described in the manual[1]. For this reason a clear overview is given in appendix C.1 and C.2

9.2.6 Advantages

AWAS is clearly an easy program to start using. It is well documented, with exception of the output files where the documentation is somewhat loose. It comes with a tutorial –though this is not very needed– that quickly enables one to build structures and antennas. The created structure is shown as a 3d model in real time in another window, where it is possible to zoom and rotate the structure. This is a great help in building and modifying structures. Further, the quick validation of the input files saves time. The program, being build for an 80386 PC, runs quite easily on modern computers, though defining even a modest number of wires (100 or thereabouts[5]) is perceptible when simulating at multiple frequencies.

[5] Which has been done i some cases in our simulations

9.2.7 Disadvantages

The major drawback – as with WIPL– is the inability of the program to calculate the impedance of an antenna, when more than one antenna/generator is present.

The second major drawback of AWAS is, that when entering nodes these has to be given consecutively numbers. If one wants to delete a node it is thus necessary to alter all the following node numbers by hand, as AWAS offers no such option. The option AWAS offers, is merely to delete the line which defines the node, but not to alter the following numbers and the nodes numbers to which wires are attached. The demand on consecutive numbers also makes the building of structures quite awkward, because it disables the possibility to add new nodes at random places in the list of nodes. Which is often nice when altering an existing structure. Both of these problems can be bypassed by making changes to the .geo file by hand. This on the other hand, can make dramatical changes to the structure, because the wires are defined to start and end at special nodes identified by there node number. All this makes it rather unpleasant and tedious to alter an existing structure.

The last major drawback is, that AWAS is unable to split the far field into right and left hand circular polarised fields, *rhcp* and *lhcp*. This has to be done by the user.

It should also be mentioned, that the plotting facilities are very limited. Only 2d-plots are possible and these cannot be exported to any useful graphical file format. Thus it is necessary with external programs to make plots for reports, presentations etc.

These are all drawbacks that makes the program somewhat incomplete. There are some small issues as well. For instance, the filenames are limited to $8+3$ characters –as all filenames are in old Windows versions.

The output file for the calculated far field is very loosely documented. But when using the documentation in appendix C.1 and C.2 this should be no problem.

9.2.8 Summation, AWAS

Summing up the previous: AWAS is a useful, though far from perfect program for our task. Not perfect, due to its lack of calculating the impedance of a single antenna in an array. This and the inability of AWAS to split the far field into *lhcp* and *rhcp* calls for quite some postprocessing. The other drawbacks are all possible to overcome without very great difficulties.

9.3 Summing up on AWAS and WIPL

Both AWAS and WIPL are unable to split the far field into left and right hand circular polarized fields. They are also unable to calculate the impedance of a single antenna in an array, when all antennas in the array are transmitting at the same time. As is to be seen in section 10.4, they (AWAS and WIPL) yields the same results[6] (within a small margin). Thus there is no reason to prefer one of the program from a feature or correctness perspective. However WIPL is far more comfortable to work with because it works with plates, and due to its possibility to delete and insert nodes without the same difficulties as in AWAS.

[6]This might not be the case, if the size of the structures buildt in the program are not significantly smaller than the wavelength

10 Simulations

10.1 Definitions for simulations

When working with arrangements such as the ones presented in this report, firstly one has the specify the coordinate system, in which the simulations is to take place. Since WIPL and AWAS works with Cartesian coordinates for the construction of configurations, we decided for that as well. Hereafter we defined the side of the satellite with the antennas to be in the xy-plane, its center situated in origo and with the body bellow $z = 0$. This is demonstrated in the following figure:

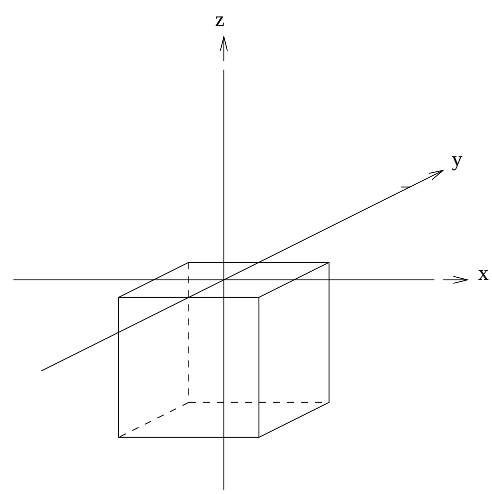


Figure 2: Coordinate system

The second decision to be made, was in which coordinates the evaluation of the far-field should be described. WIPL and AWAS use spherical coordinates for this purpose, so it was natural to use the same in our presentations as well. To cover the entire space evenly, but at the same time keeping the number of output plots manageable, we decided for the following values to plot for:

ϕ : 0^o, 45^o, 90^o and 135^o.

θ : $0^o ... 360^o$.

As can be seen in section 10.2, a plot is generated for every of the above mentioned value of ϕ. That is, the choice of values for ϕ as defined above, results in four plots with a resolution of θ decided by the simulation, thus giving a coverage of the entire space as desired.

The resolution mentioned above is decided by the values entered in simulation program. The values used in WIPL and AWAS differs from one another, because of different resources on the computers where the simulations were performed.

The simulations run by WIPL has a resolution of θ of 5^o, whereas the simulations run on AWAS has a resolution of θ of 3.6^o. As can be seen later, this is of no significance.

10.2 Description of presentations

A very important issue in a project, where one is dealing with several almost similar versions of a specific arrangement, is consistency. It is crucial that the presentations of the different arrangements can be compared with one another, so even small variations can be spotted immediately.

Despite the fact that we started using WIPL and AWAS at a early stage in the project, we did not have a clear idea of the final appearance of our presentations. The format of the presentations was decided as the project progressed, the configurations developed and as it became clear to us what was needed. Also some small alterations was necessary in some of the presentations (see later in this section) due to limitations in WIPL and AWAS (see 9.3).

A presentation, as the one following shortly, can be divided into 5 points:

Page 1

1. A sketch of the arrangement along with a data box
2. Plots of impedance and the reflection coefficient
3. A short description of the antenna(s) orientation and placement

Page 2

1. Plots of the gain.
2. An analysis of the radiation pattern.

The short description of the specific configuration of the antenna(s) is due to the fact, that the sketches does display exactly where the antennas are fastened and in what direction they point.

The analysis has two main goals:

- To validate that the plots agree with what is expected according to the theory we know.
- To decide whether this is a configuration that matches the demands for the antenna system.

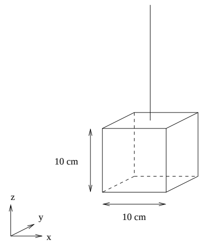
However the presentations of configurations with more than one antenna differs from the others. It is limited to one page with the following points:

Page 1

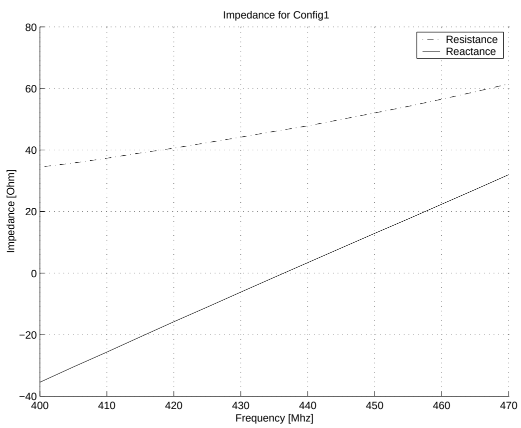
1. A sketch of the arrangement along with a data box
2. A short description of the antenna(s) orientation and placement
3. Plots of the gain.
4. An analysis of the radiation pattern.

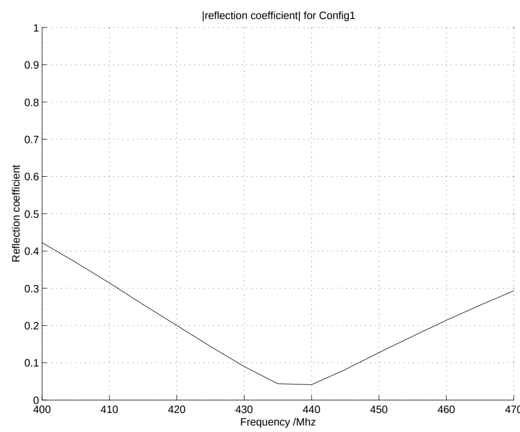
Some of the analysis in the presentations of configurations with more than one generator might be placed above the plots along with the descriptions.

A precise idea of the presentations is necessary before we start examining the results. Hence an example of how a presentation may look. It is to be found on the next page, just as the real presentations will be placed at new pages for a clear overview.

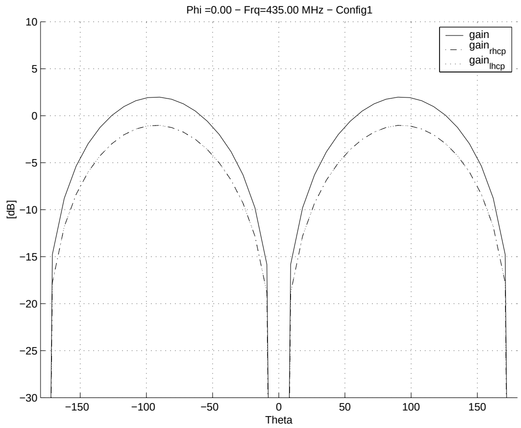


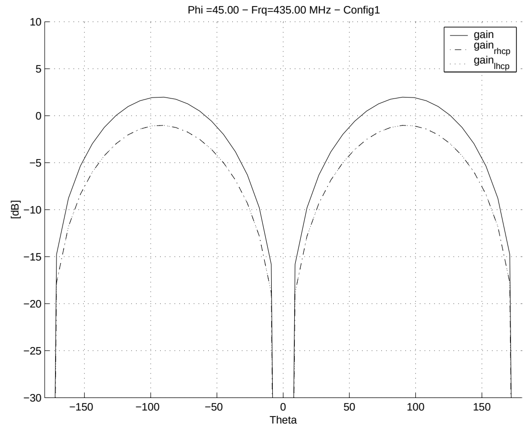
Config1	
Program	WIPL
Resonans frq.	4.3500e+002
Resistance.	46.04 Ω
Reaktance	-1.36 Ω
Reflections coe.	0.044
Length of antenna	$\frac{\lambda}{4} = 172.0$ mm
Wire radius	1mm

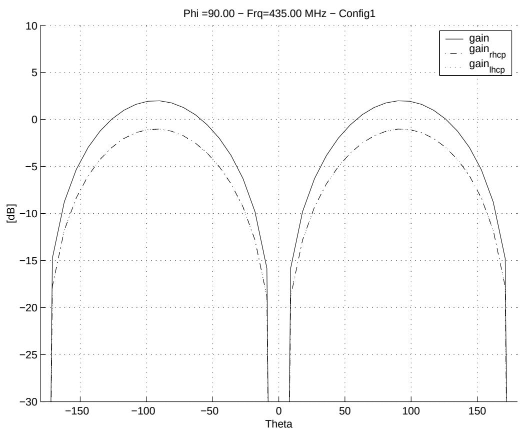


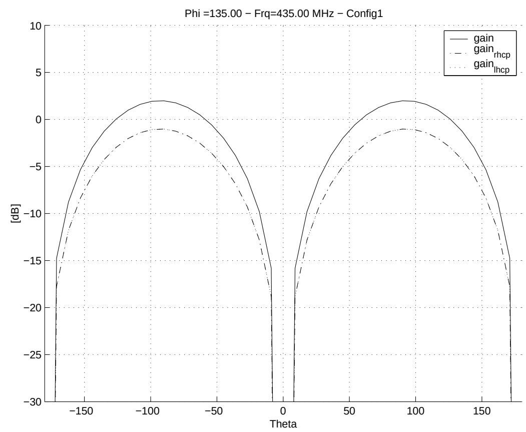


Description of the antenna(s) placement and orientation









Analysis of the plots

10.3 Validation of WIPL and AWAS

In this section the outcome of the simulations for a dipole antenna in WIPL and AWAS is compared to the results obtained by theoretical considerations. This is done to confirm the reliability of the two programs. For the theoretical results we refer to [Cheng, chapter 10] and to section 4 in this report.

As can be seen on the following pages, the far field tends to 0 ($-\infty$ on the dB scale used in the plots), as θ tends to either 0^o or 180^o. This is what to expect. The far field reaches a maximum whenever $\theta = 90^o$ or $\theta = 270^o$. Again this harmonize with the theory. If plots were made for all ϕ values with $\theta = 90^o$ we would get (a) in FIGURE 10-4 in [Cheng]. Only our plots are in Cartesian coordinates(this is due to the way we makes the plot).

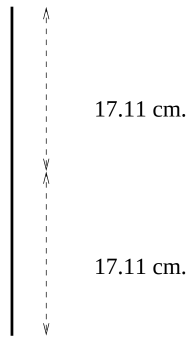
The antenna impedance when the dipole antenna is resonant, is seen from the data box to be 67.65. Again this agrees nicely with theory[7].

The partial gains for *lhcp* and *rhcp* are identical and 3dB below the gain. This will always be the case when the two partial gains are identical because $lhcp + rhcp = gain$ on the normal scale (non dB). When *rhcp* and *lhcp* are identical we thus have $2 \cdot rhcp = gain$. In the dB scale this is very close to $3 + rhcp = gain$, where now *rhcp* and *gain* are in the dB scale.

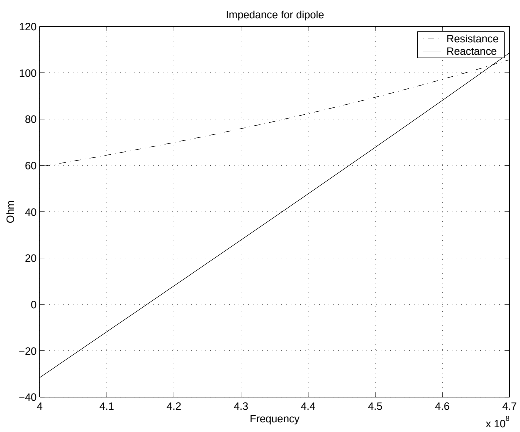
From the graphs of the simulations from AWAS and WIPL we see that they are identical[8]. Thus we have shown that the outcome of the simulation of a dipole antenna, in both AWAS and WIPL, agrees with theory and each other.

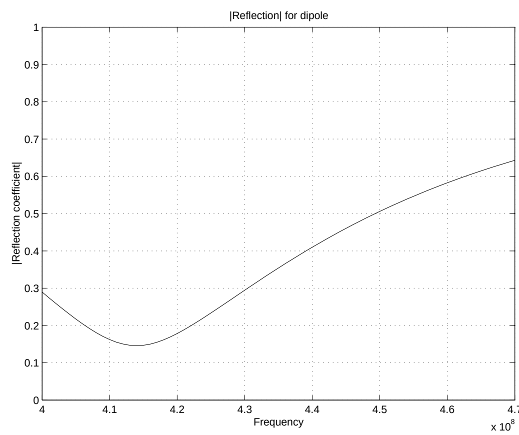
[7] The resistance found in [Cheng, p. 439], 73.1 Ω is a bit higher. This is because the resistance here is taken at exactly a half wavelength, where the antenna is not resonant. The antenna is resonant, when the length of the antenna a bit shorten than half a wavelength. Here the resistance is (as can be seen from the plots) a bit lower. When studying the impedance plots more thoroughly we see, that at 436 MHz –where the antenna is $\lambda/2$ long, the resistance is about 73 Ω

[8] The small derivations comes from different resolutions when doing the plots

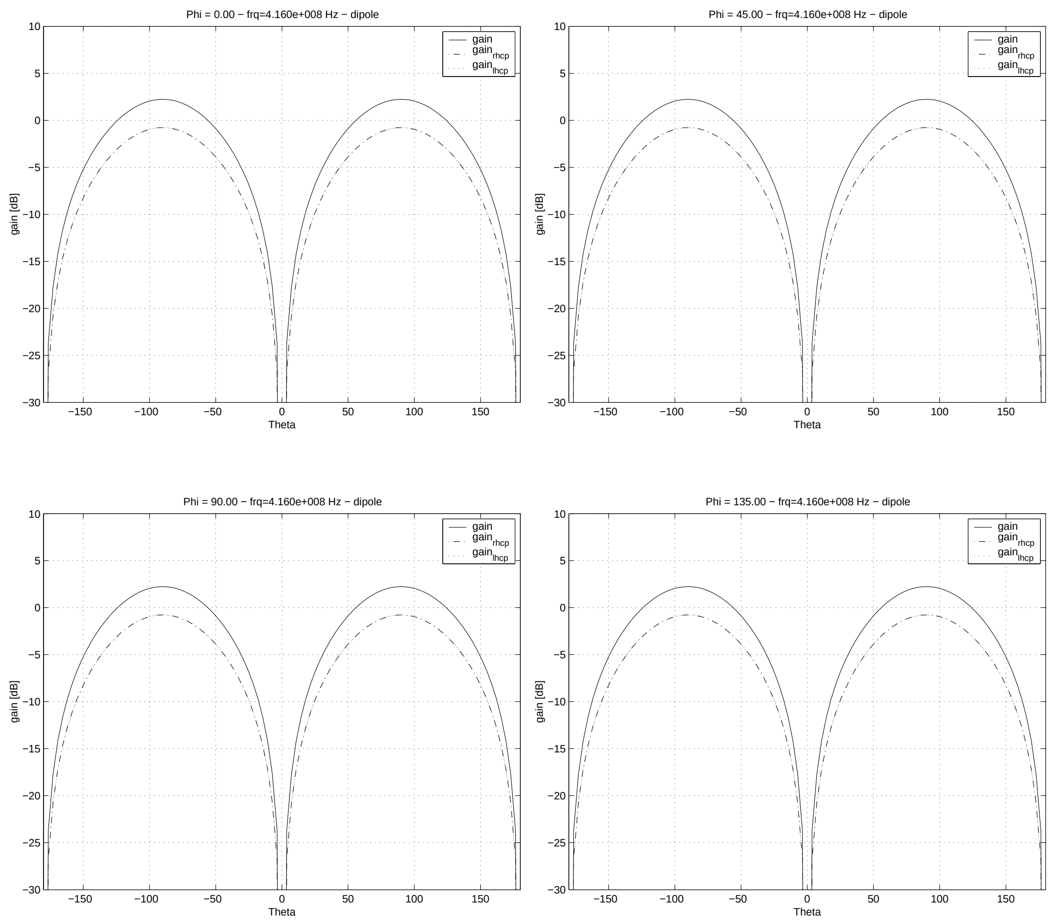


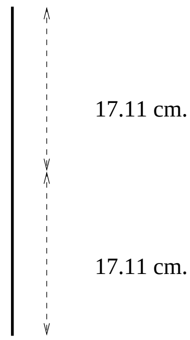
dipole	
Program	AWAS
Resonans frq.	4.1600e+008
Resistance.	67.65 Ω
Reaktance	0.04 Ω
Reflections coe.	0.150
Length of antenna	cm
Wire radius	1mm



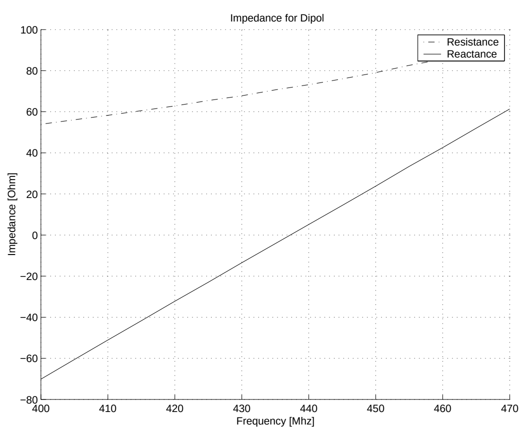


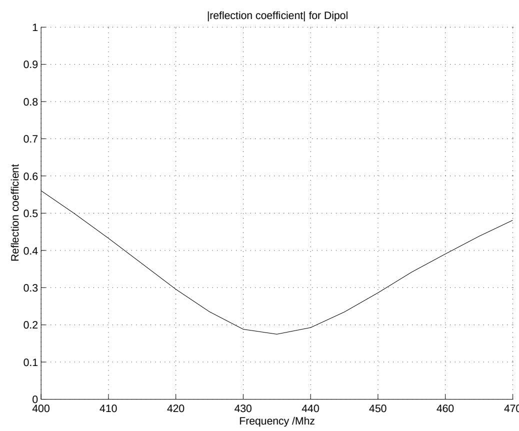
A dipole antenna aligned with the z-axis


Phi = 0.00 − frq=4.160e+008 Hz − dipole
Phi = 45.00 − frq=4.160e+008 Hz − dipole
Phi = 90.00 − frq=4.160e+008 Hz − dipole
Phi = 135.00 − frq=4.160e+008 Hz − dipole
gain
gain$_{rhcp}$
gain$_{lhcp}$
gain [dB]
Theta
10
5
0
−5
−10
−15
−20
−25
−30
−150
−100
−50
0
50
100
150

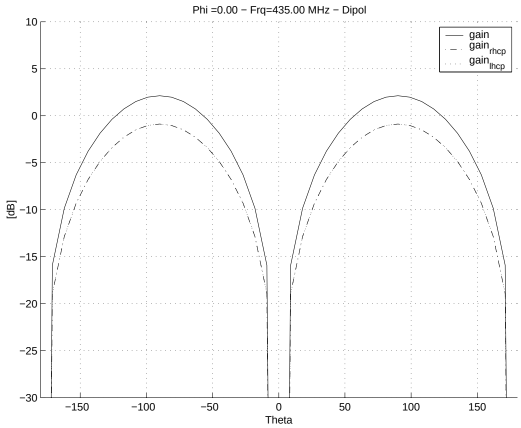


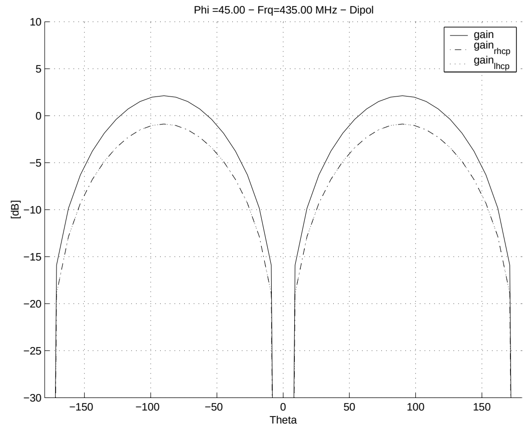
Dipol	
Program	WIPL
Resonans frq.	4.3500e+002
Resistance.	70.67 Ω
Reaktance	-4.20 Ω
Reflections coe.	0.175
Length of antenna	$\frac{\lambda}{4} = 163.0$ mm
Wire radius	1mm

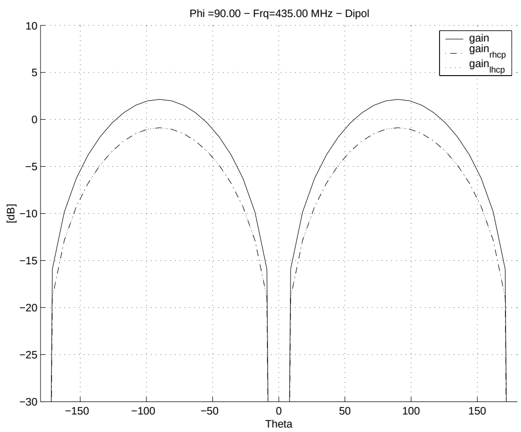


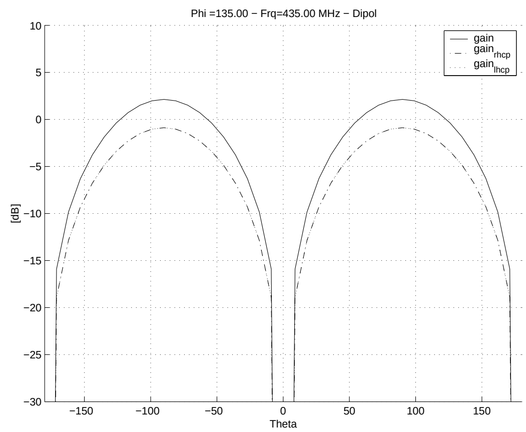


A dipole antenna aligned with the z-axis


Phi =0.00 − Frq=435.00 MHz − Dipol
gain
gain$_{rhcp}$
gain$_{lhcp}$
[dB]
Theta


Phi =45.00 − Frq=435.00 MHz − Dipol
gain
gain$_{rhcp}$
gain$_{lhcp}$
[dB]
Theta


Phi =90.00 − Frq=435.00 MHz − Dipol
gain
gain$_{rhcp}$
gain$_{lhcp}$
[dB]
Theta


Phi =135.00 − Frq=435.00 MHz − Dipol
gain
gain$_{rhcp}$
gain$_{lhcp}$
[dB]
Theta

10.4 Agreement between WIPL and AWAS

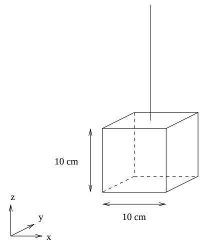
Earlier in the report an advantage with WIPL compared to AWAS was mentioned (see 9.1.8). It was the ability of WIPL to simulate structures consisting of plates as well as wires. This is not of crucial importance in our case. It nevertheless eases work considerably if only one program is needed, cutting the number of plots down to the half. However we did not feel properly assured of the agreement between the programs until the end of the project, which is why every simulation has been conducted with WIPL as well as AWAS.

Nevertheless we have decided to omit the AWAS results from here on for the sake of clarity. Instead one can consult appendix B to confirm the agreement between WIPL and AWAS, or one can consult appendix H, where AWAS presentations are to be found for all configurations.

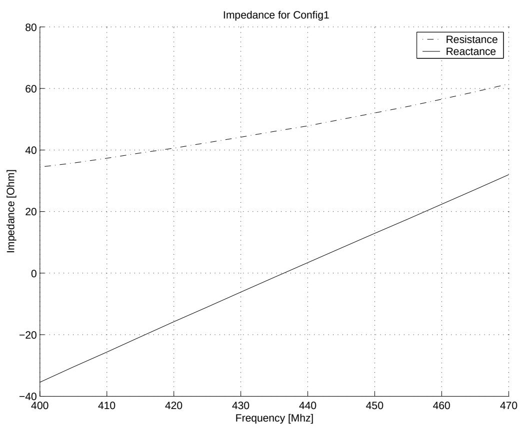
This way the reader will not be bother twice with configurations we have selected for agreement, but only once when we present our configurations.

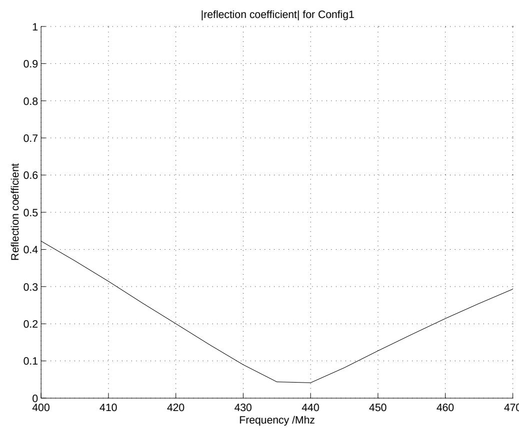
10.5 Presentation of simulations

Followingly are all our simulations as described in section 10.2. An important remark is, that the missing Config6 is not an error, but is due to the fact that this configuration name was used for variations of other configurations.

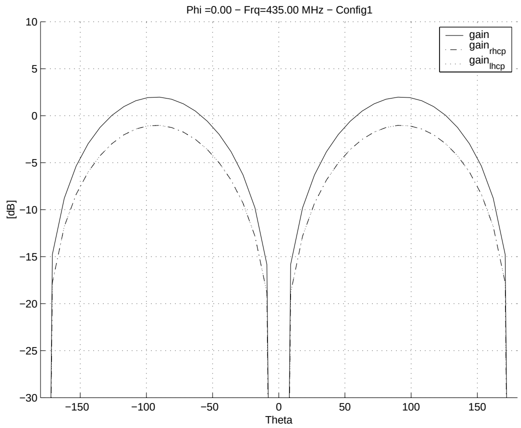


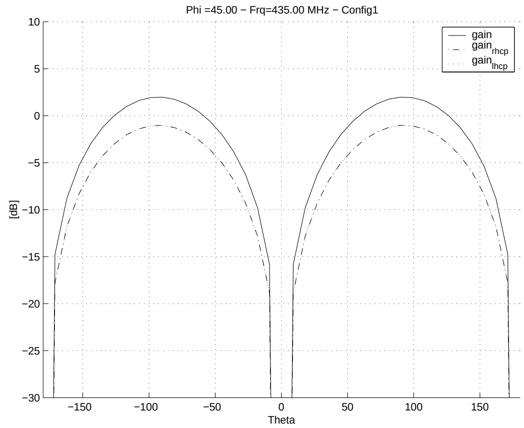
Config1	
Program	WIPL
Resonans frq.	4.3500e+002
Resistance.	46.04 Ω
Reaktance	-1.36 Ω
Reflections coe.	0.044
Length of antenna	$\frac{\lambda}{4} = 172.0$ mm
Wire radius	1mm

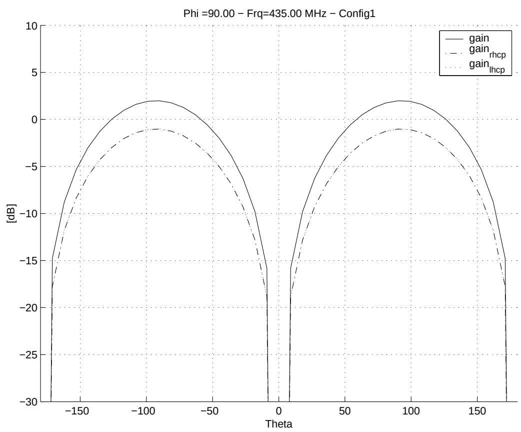


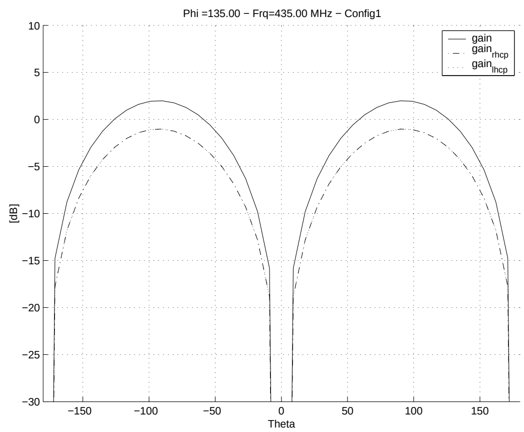


The antenna is fixed at the center of the satellite, and is oriented along the z-axis.







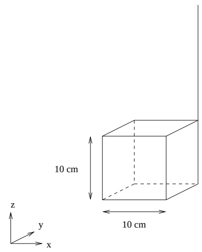


The radiation patterns looks very much like that of a dipole antenna. However the directivity is a little larger and the impedance at the resonans frequency is somewhat lower than that of the dipole. That the antenna behaves much like a dipole is quite understandable, since the structure rather is symmetrical around the antenna, when taking the wavelength into consideration.

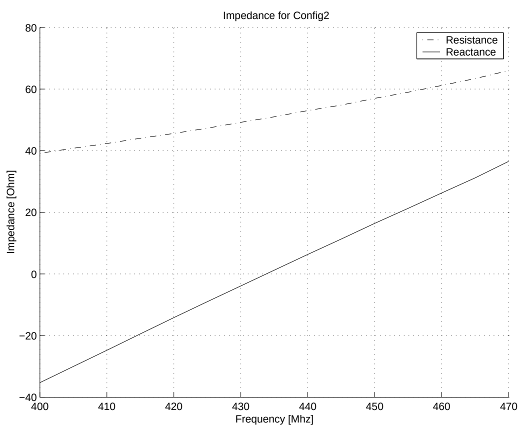
That the gain is 0 in $\theta = 0^o$ is to be expected, because no (time varying)currents in the antenna can generate a **E**-field here. Also this explains for $gain = 0^o$ when $\theta = \pm 180^o$. From the symmetry of the structure we see, that the $\mathbf{E} - field$ created by the induced current on the top or bottom of the structure cancel out at $\theta = 0^o$ and $\theta = \pm 180^o$.

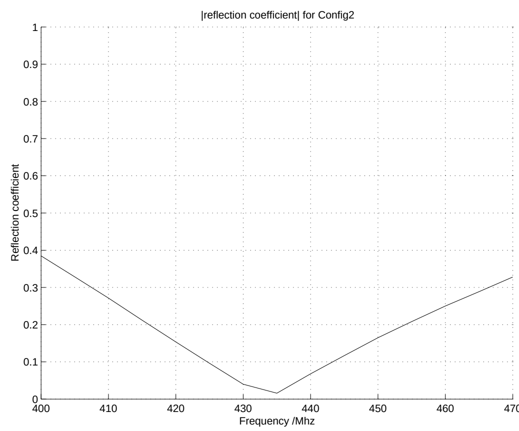
Because the gain[9] tends to zero (-∞ in the plots) for certain angles, this antenna can not be used.

[9] not in dB as in the plots

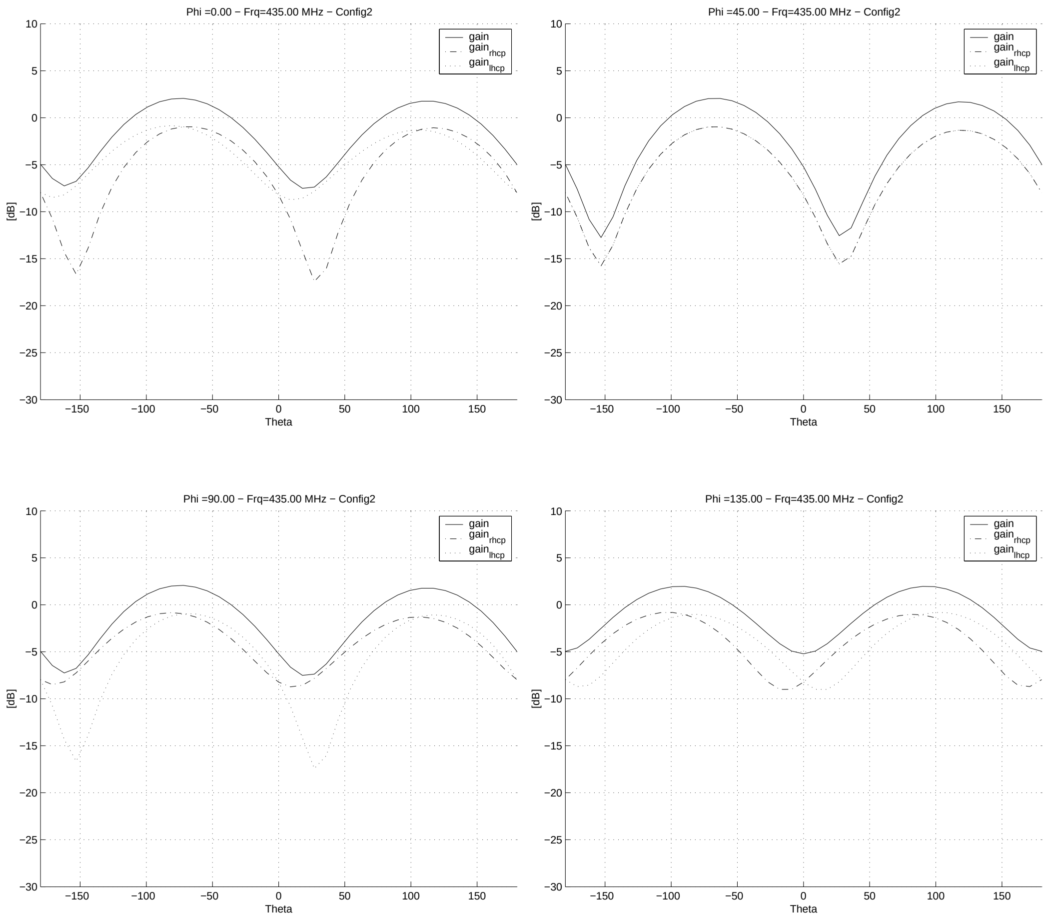


Config2	
Program	WIPL
Resonans frq.	4.3500e+002
Resistance.	50.99 Ω
Reaktance	1.24 Ω
Reflections coe.	0.016
Length of antenna	$\frac{\lambda}{4} = 162.0$ mm
Wire radius	1mm



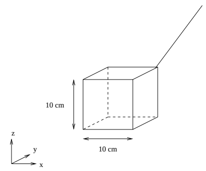


The antenna is fixed at the corner of the satellite and is oriented along the z-axis.

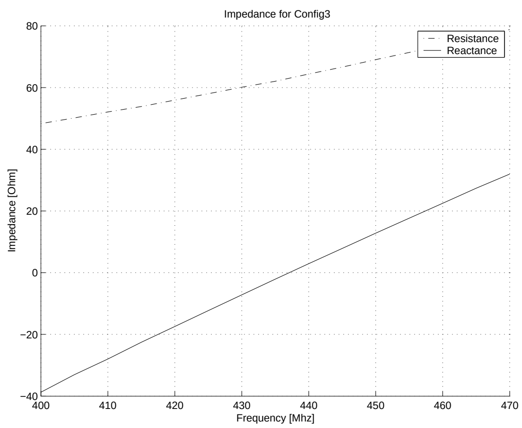


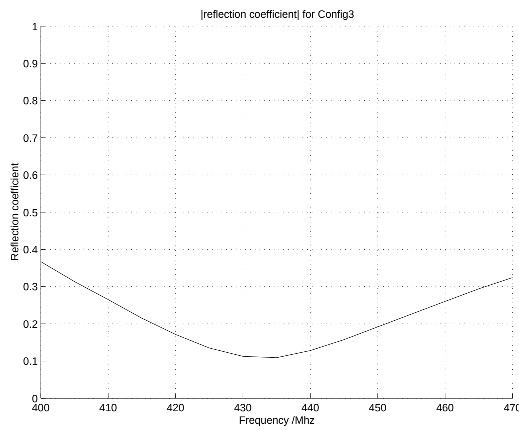
In this configuration one would expect symmetry around $\phi = 45^o$. This is validated by looking at the plots for $\phi = 0^o$ and $\phi = 90^o$ where the expected symmetry appears. A thing that further assures one of the reliability of the plots is the plot for $\phi = 45^o$, where one finds the expected 3 dB between the gain and each of the partial circularly polarized gains.

As a matter of fact this is not a very bad candidate for an antenna. If one assumes that the earth station can toggle between *lhcp* and *rpch* there are very few places where it is not possible to receive a signal over -10 dB. Actually it is only around $\phi = 45$, there is a risk of not receiving a signal. However this is still enough to discard it as a candidate.

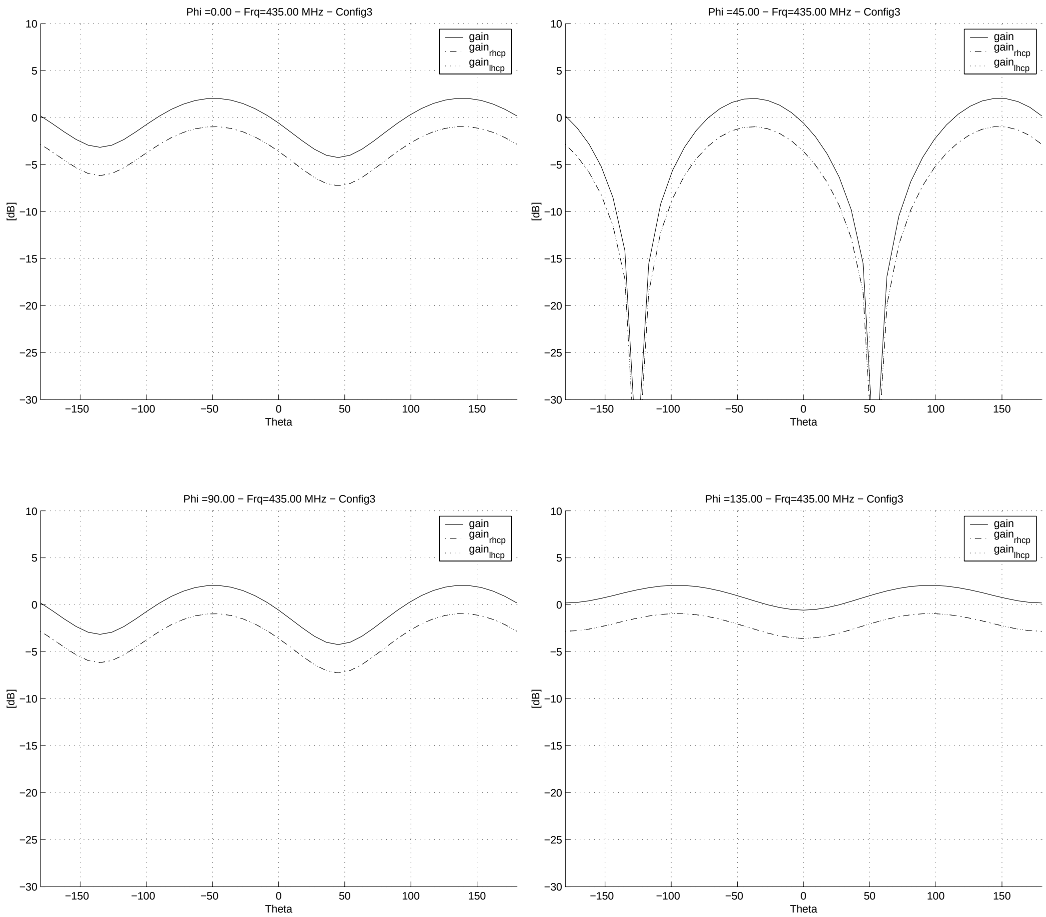


Config3	
Program	WIPL
Resonans frq.	4.3500e+002
Resistance.	62.04 Ω
Reaktance	-2.09 Ω
Reflections coe.	0.109
Length of antenna	$\frac{\lambda}{4}$ = 155.9 mm
Wire radius	1mm



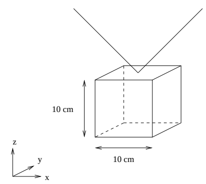


The antenna is fixed at the corner of the satellite. It makes an angle of 45^o with the z-axis, the xy-plane, the x-plane and the yz-plane. That is, θ is 45^o and ϕ is 45^o.

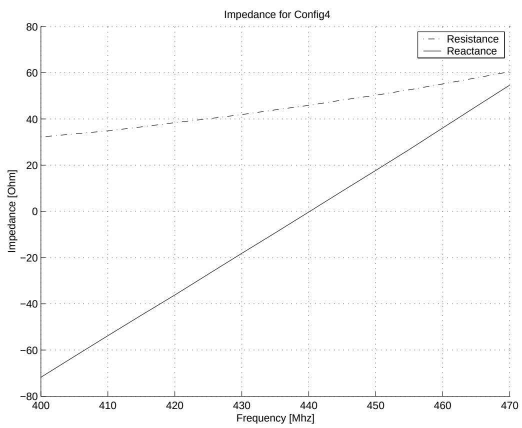


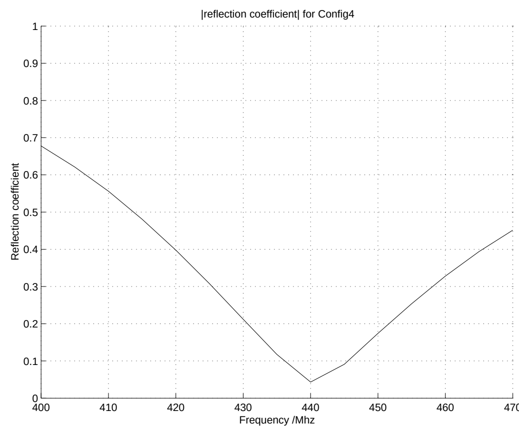
The most interesting is that the $gain = 0$ in the $\phi = 45$ plane when $\theta \approx 50$ and $\theta \approx 125$ and not when $\theta \approx 45$, which is the angle between the antenna and the z-axis. It is also notable that in all the other planes (than $\phi = 45$) the partial gains, $rhcp$ and $lhcp$, are identical and 3dB below the total gain –as would be expected.

Because the gain tends to zero (-∞ in the plots) for certain angles, this antenna can not be used.

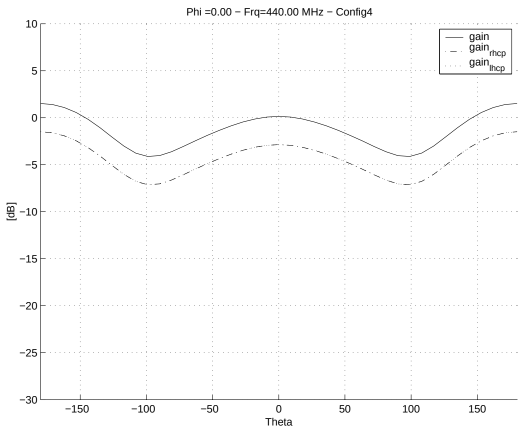


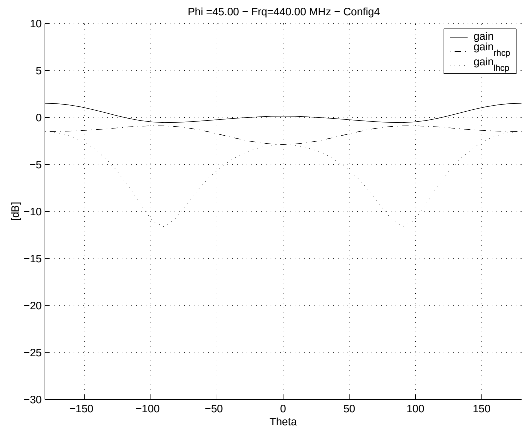
Config4	
Program	WIPL
Resonans frq.	4.4000e+002
Resistance.	45.87 Ω
Reaktance	-0.28 Ω
Reflections coe.	0.043
Length of antenna	$\frac{\lambda}{4}$ = 171.1 mm
Wire radius	1mm

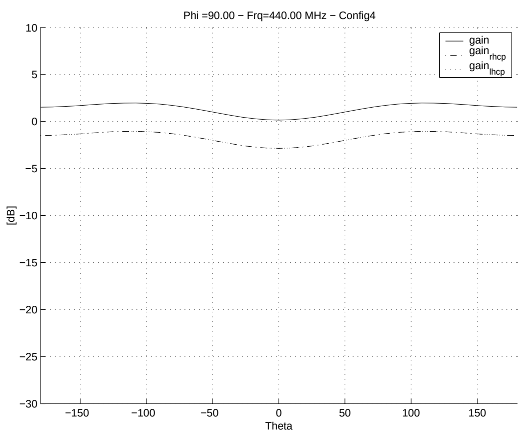


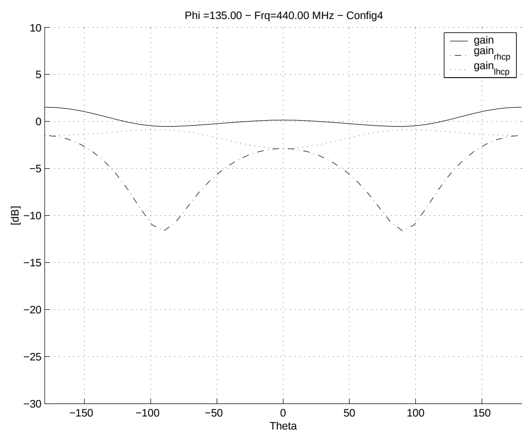


The antenna is fixed at the center of the satellite having an angle of 45^o to the z-axis and lying in the xz-plane.



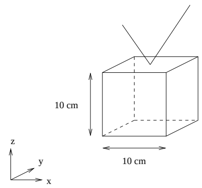




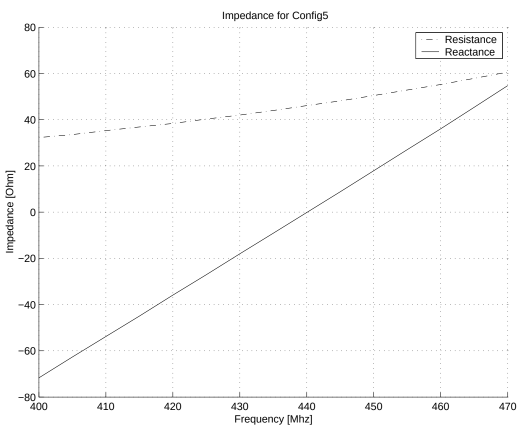


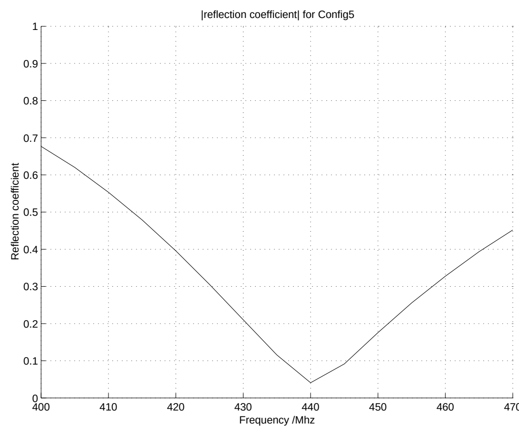
The symmetry for the xz-plane is obvious, since the plots for $\phi = 45^o$ are $\phi = 135^o$ are identical except for the expected shift of the polarized signals. The plots actually have similarities with those of Config1, and thus with a dipole, which could be expected when regarding the symmetry around the antenna. However these plots are much more pleasant, considering the specifications.

Keeping in mind the toggling earth station, there are no real problems. Though for $\phi = 0^o$ there are some gaps where the signal slips below -7 dB. But not a bad candidate.

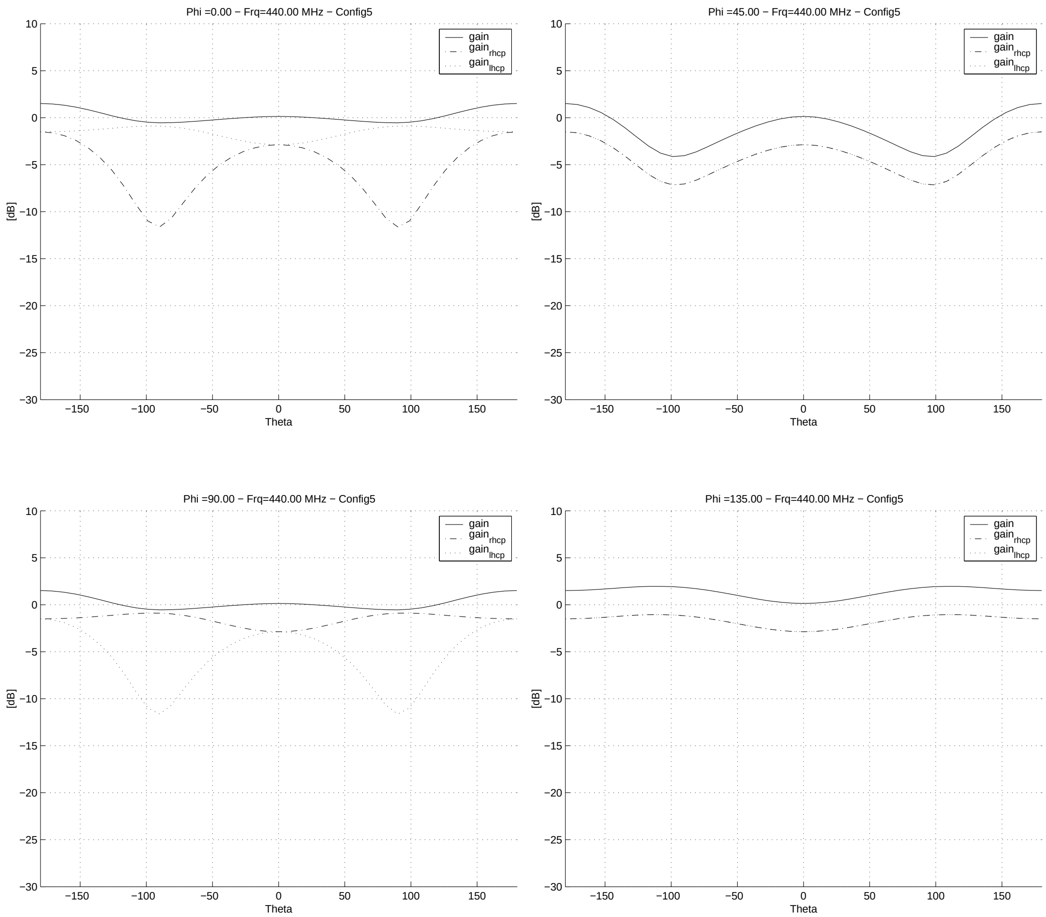


Config5	
Program	WIPL
Resonans frq.	4.4000e+002
Resistance.	46.08 Ω
Reaktance	-0.17 Ω
Reflections coe.	0.041
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Wire radius	1mm



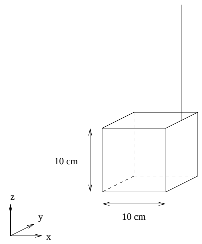


The antenna is fixed at the center of the satellite each antenna arm forming an angle of 45^o with the z-axis. One arm with $\phi = 45^o$ and one with $\phi = 225^o$.

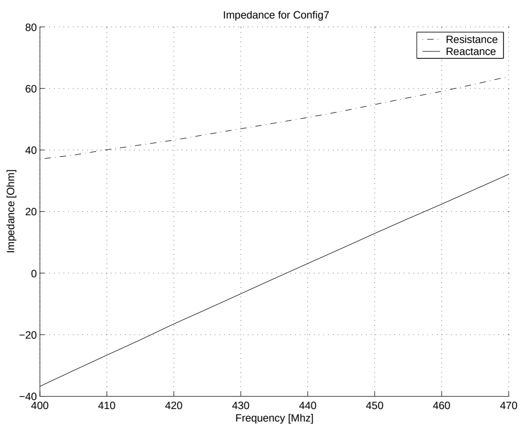


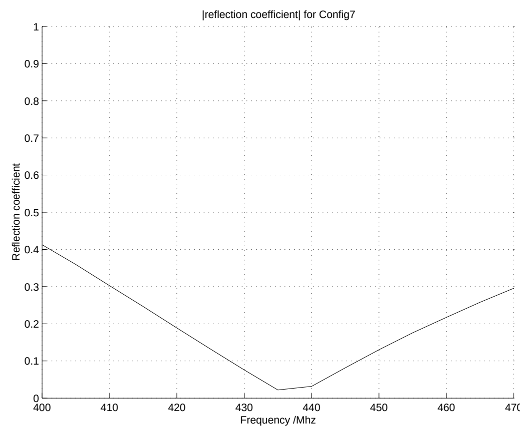
Once again our expectations on symmetry are fulfilled. As can be seen from the figure (of the satellite), symmetry should be found around $\phi = 45^o$. And so it is. Actually these plots are almost identical with those of Config4, keeping in mind the different placements of the antennas. This necessarily means, that whatever symmetry is connected with the currents in Config4 does not depend on whether the antennas are placed at the sides or in the corners.

Just as good a candidate as Config4 with the same reservation on the gaps, where the signal slips below -7 dB.

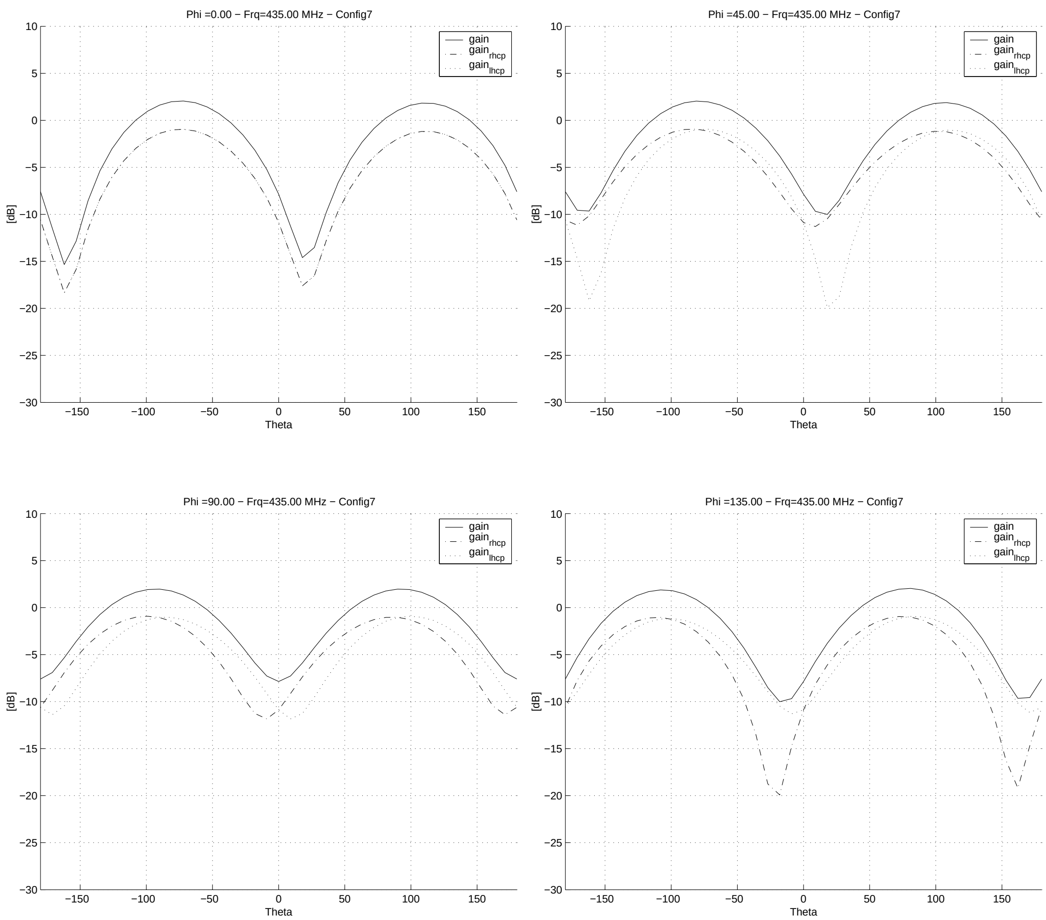


Config7	
Program	WIPL
Resonans frq.	4.3500e+002
Resistance.	48.72 Ω
Reaktance	-1.75 Ω
Reflections coe.	0.022
Length of antenna	$\frac{\lambda}{4} = 167.0$ mm
Wire radius	1mm





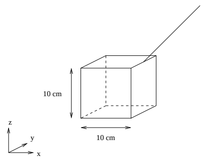
The antenna is fixed at the side of the satellite. It lies in the xz-plane and is parallel to the z-axis.



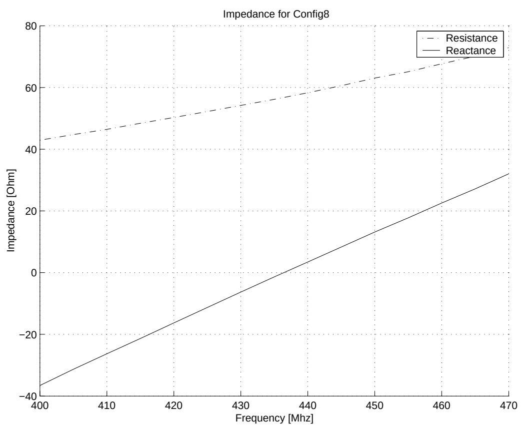
The most exciting thing here is that the gain does not tend to zero anywhere ($-\infty$ in the dB scale). Not even in the directions parallel to the antenna. This is quite different from Config1. The reason is, that the **E**-fields that are created by the induced currents on the structure, does not cancel out as they did in config1. This is because we do not have the same symmetry of the structure around the antenna. This shows that the box functions as a scatter eventhough it is very small compared to the wavelength.

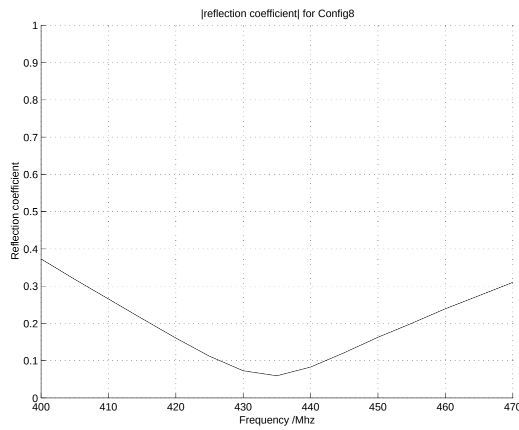
We also notice that the $\phi = 45^o$ and $\phi = 135^o$ planes are identical, except that *lhcp* and *rhcp* have changed place. This is accountable for because of the symmetry around the antenna in these angles.

The configuration is not usable as the partial gains of *rhcp* and *lhcp* for some directions are very low.

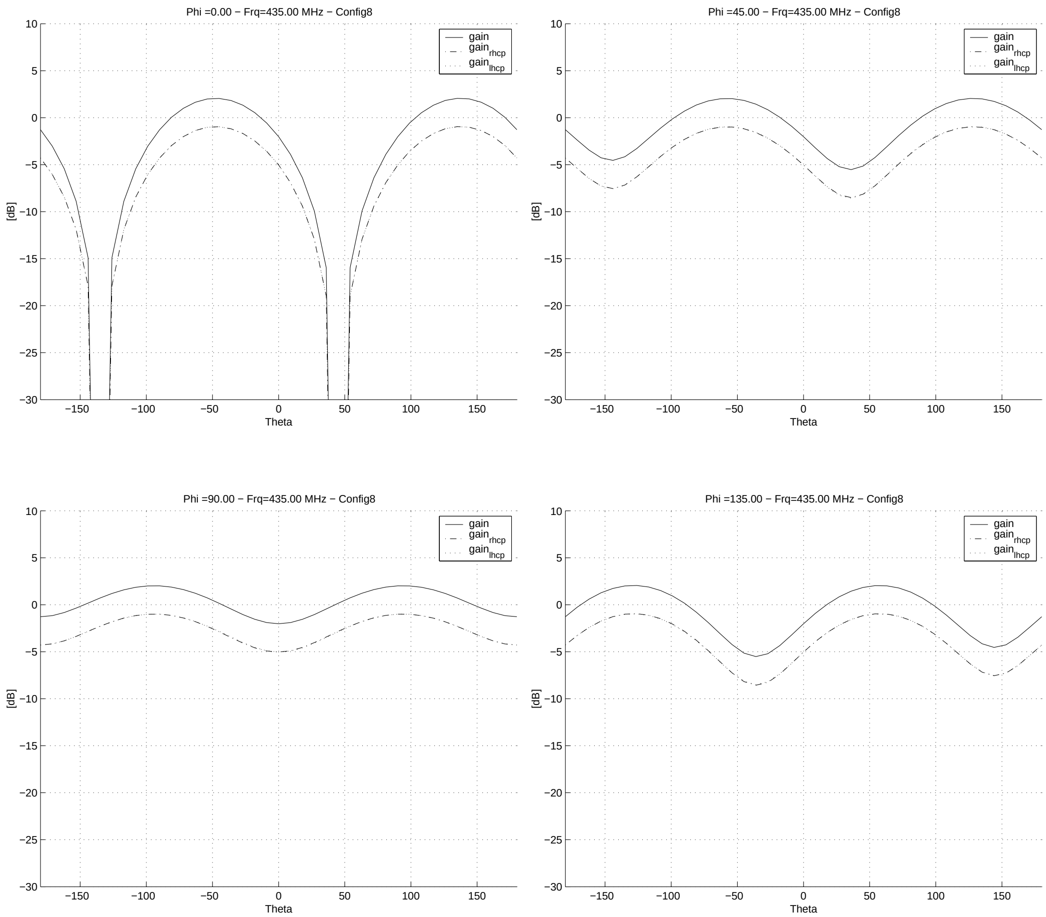


Config8	
Program	WIPL
Resonans frq.	4.3500e+002
Resistance.	56.14 Ω
Reaktance	-1.40 Ω
Reflections coe.	0.059
Length of antenna	$\frac{\lambda}{4} = 164.8$ mm
Wire radius	1mm



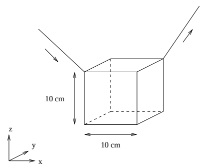


The antenna is fixed at the side of the satellite. It lies in the xz-plane and the angle to the z-axis is 45^o. That is, $\theta = 45^o$ and $\phi = 0^o$.



In the $\phi = 0$ plane the gain tends to 0 when θ is around 45^o and 135^o. This is understandable, because in these angles the structure is symmetric with respect to the antenna so that the **E**-fields that are created by the induced currents on the structure cancels out. Where the partial gain of *rhcp* and *lhcp* are identical they are both 3dB below the gain.

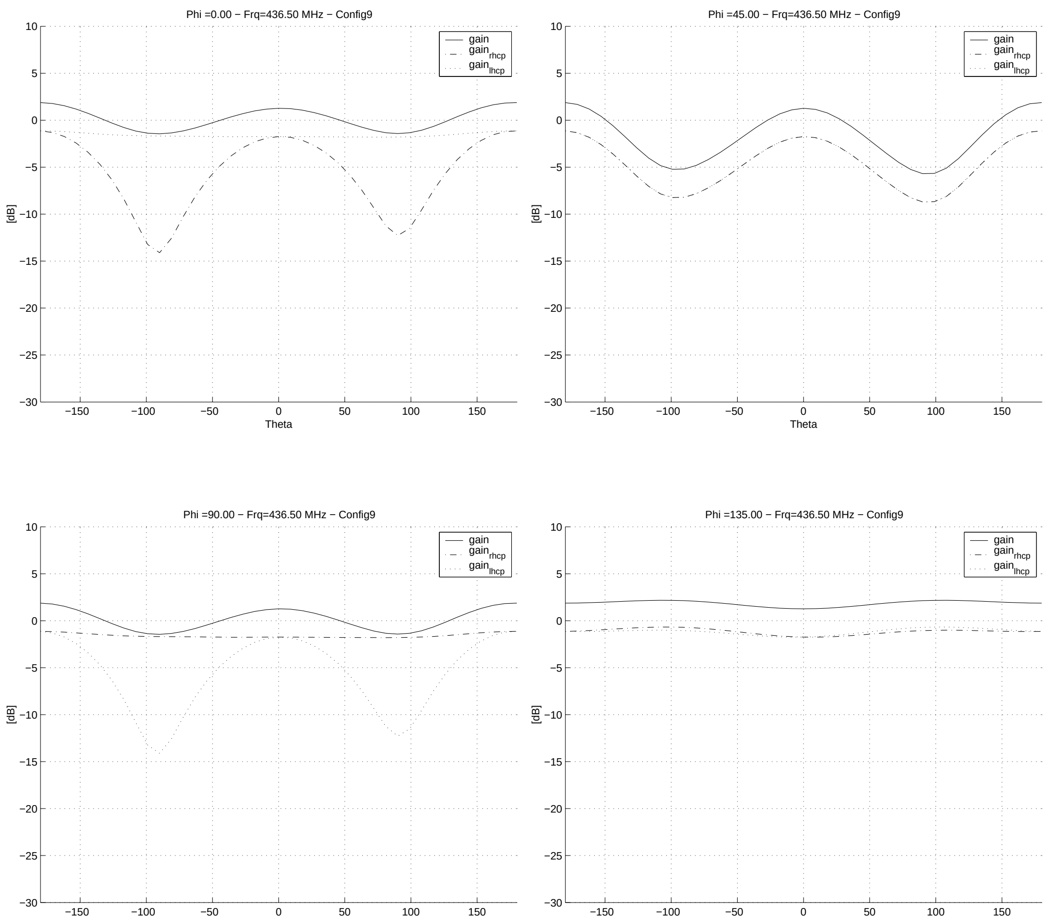
The configuration is not usable because it has zeros in the radiation pattern.



Config9	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

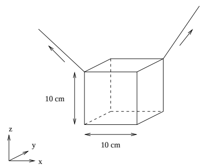
The antennas are fixed in the corners of the satellite, each with $\theta = 45^o$, $\phi = 45^o$ for one of them and $\phi = 225^o$ for the other. The generators are defined, so the phase is 0^o as illustrated on the figure.

Once again the expected symmetry is fulfilled. This time for $\phi = 0^o$ and



$\phi = 90^o$.

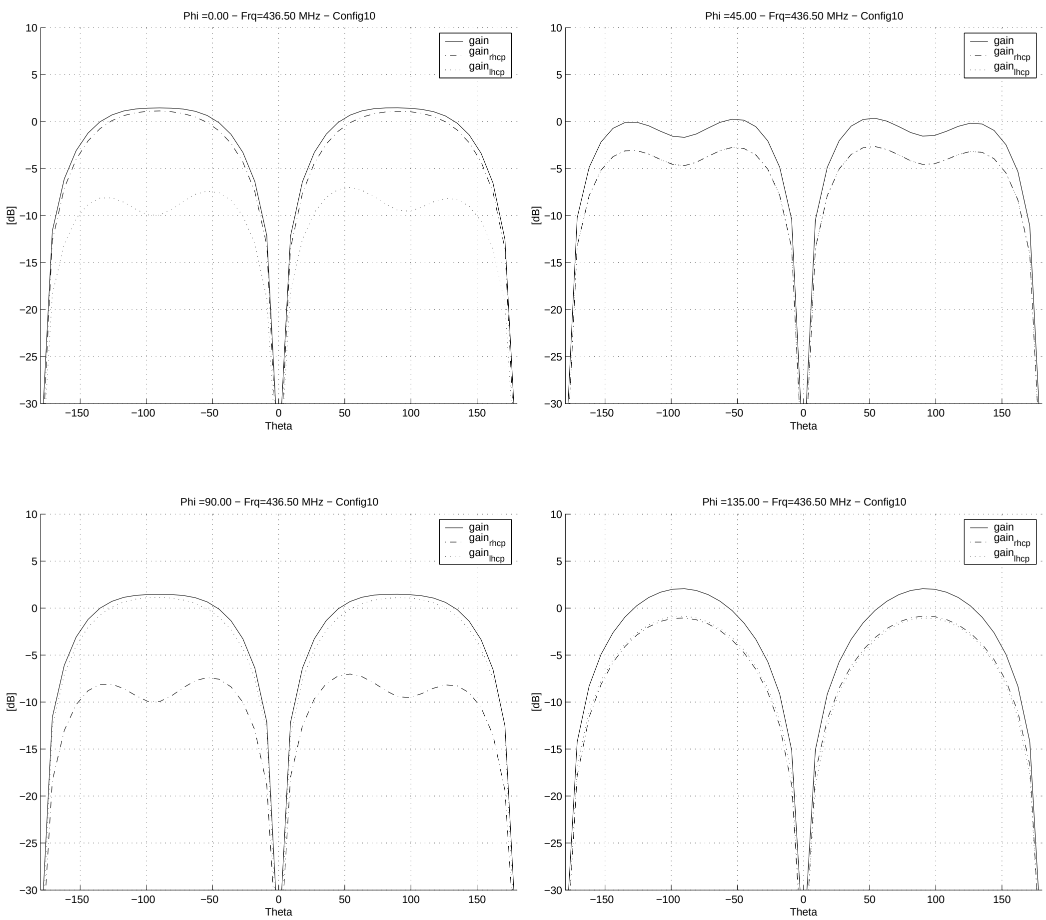
If it were not for the gaps for $\phi = 45^o$ where the partial gains drops to -8 dB, it would not be a very bad candidate.



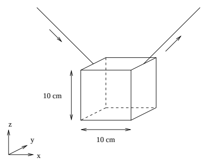
Config10	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are fixed in the corners of the satellite, each with $\theta = 45^o$, $\phi = 45^o$ for one of the antennas and 225^o for the other. The generators are defined, so that the phase is 180^o as illustrated on the figure.

The expected symmetry is once again fulfilled. But the plots themselves



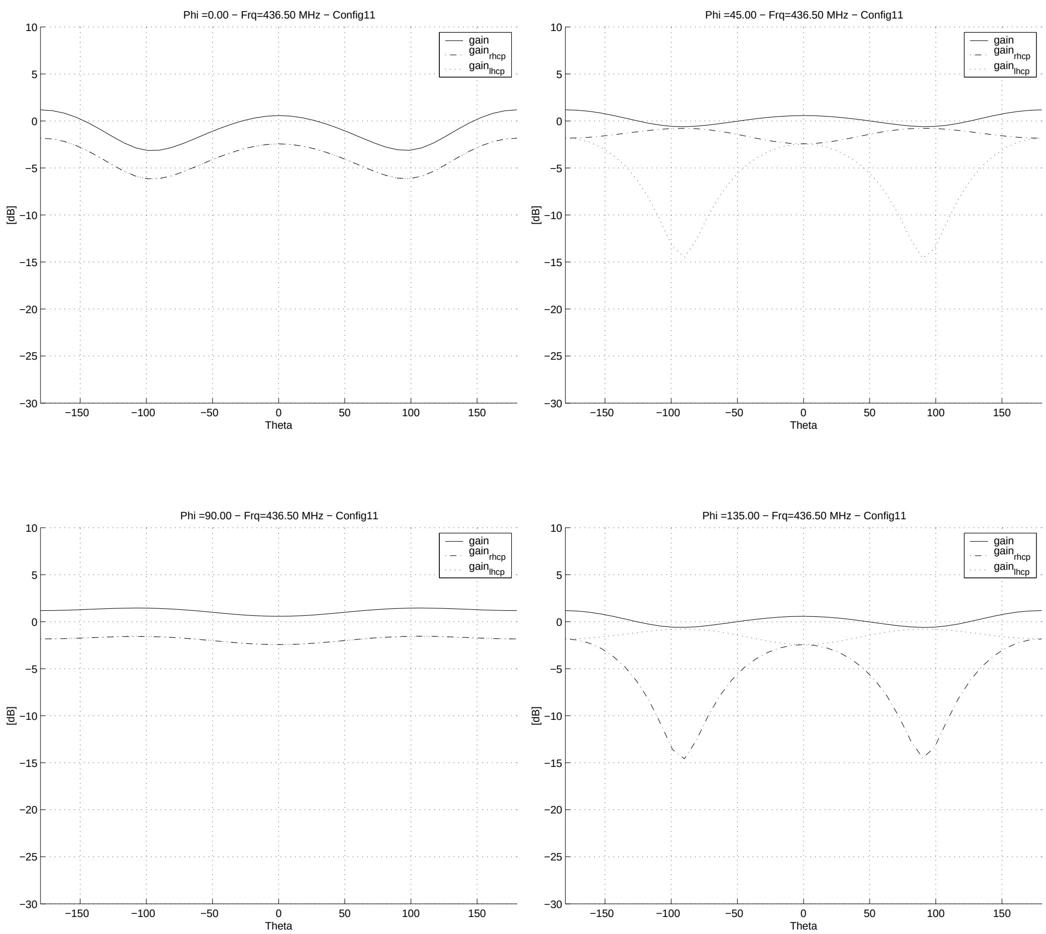
are a bit more interesting this time due to the phase of the currents. This results in horizontal currents neutralizing one another and vertical currents strengthen one another, thus giving rise to currents reminding of that of a dipole. This, we assume, is the reason for the fatal gaps in the plots, and so it rules out this configuration as a candidate.



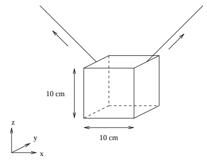
Config11	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are fixed at each side of the satellite in the xz-plane. Θ is 45^o for both. The generators are defined so that the phase is 0^o as illustrated on the figure.

The plots for this configuration almost matches those of Config9, and hence

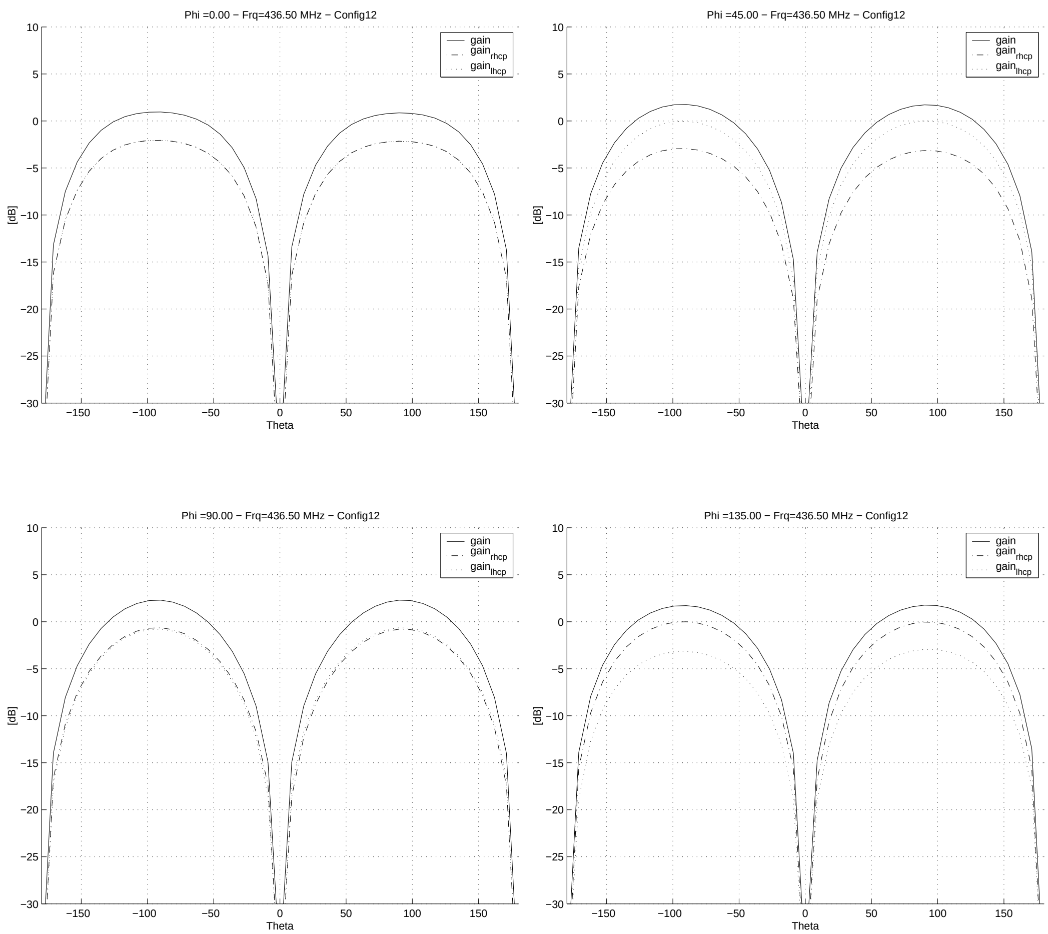


gives rise to the same conclusions. Aside from this, one can conclude that the position of the antennas themselves are not the very important.

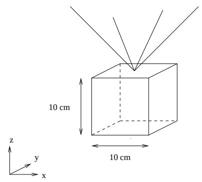


Config12	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are fixed at each side of the satellite in the x-plane. Theta is 45^o for both. The generators are defined, so the phase of the currents is 180^o as illustrated on the figure.
As expected, considering Config11, these plots are almost similar to the ones

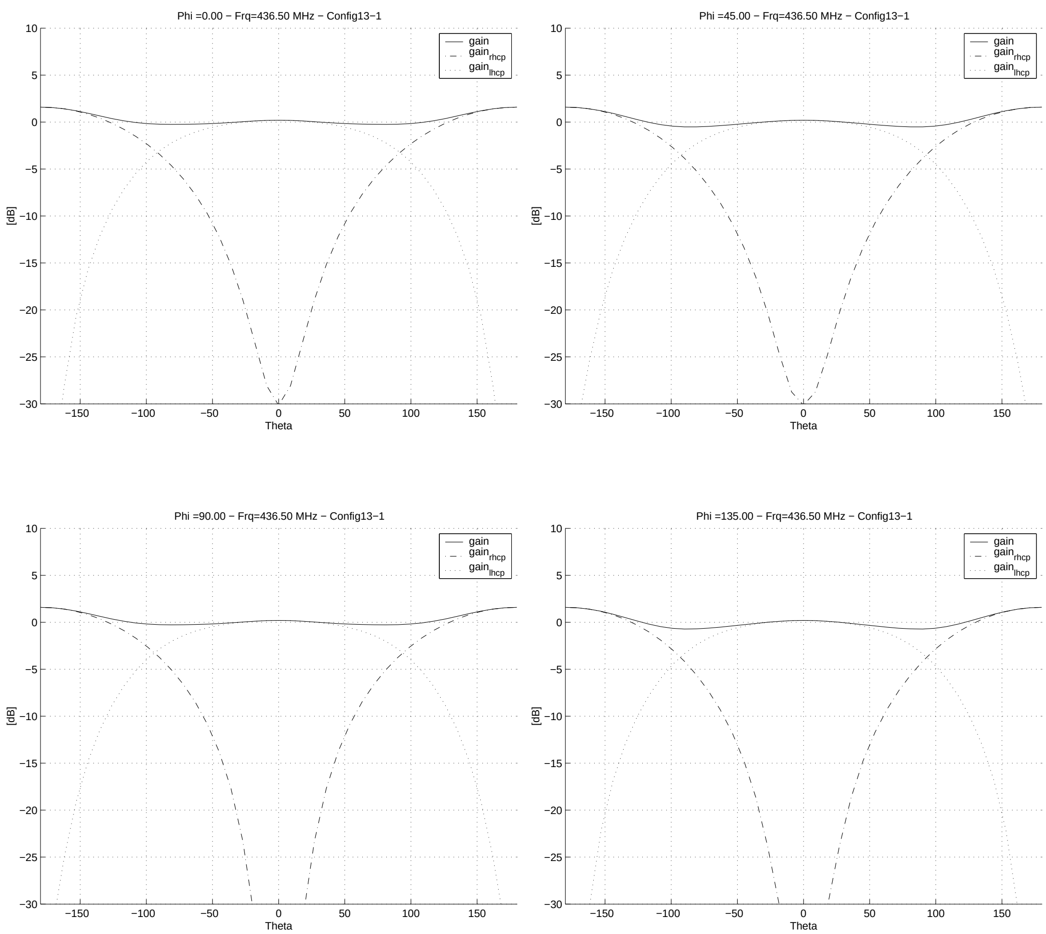


from Config10, and therefor calls for no further explanation. One should just consult the analysis of Config10.



Config13-1	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

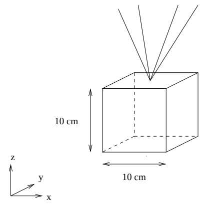
The two antennas are fixed at the center of the satellite, each with an angle of 45^o to the z-axis. The time harmonic generator for each of the two antennas are given by (1,0) for the antenna in the xz-plane. And (0,1) in the yz-plane. That the **E**-field is strictly *lhcp* for $\theta = 0$ is due to the currents, when seen



from this angle (the projection onto the xy-plane), is shifted in phase as described above. This shifting entails, that the **E**-field in the $\theta = 0^o$ direction is *lhcp*

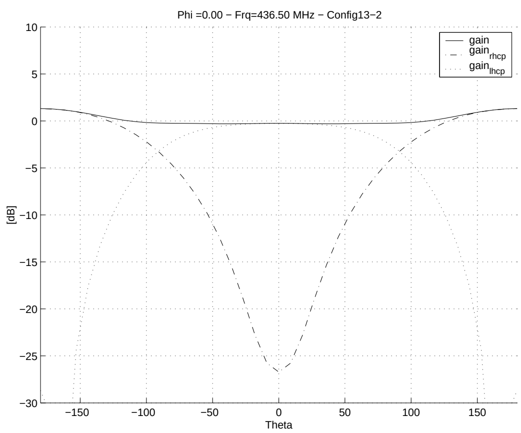
When $\theta = 180^o$ the field is purely $rhcp$ (same reason as above) and the partial gain hereof is somewhat higher than the partial gain of $lhcp$ at $\theta = 0^o$. This must be due to the box acting as a scatter, because it does not origin from the antenna configuration itself, as can be seen from Config16.

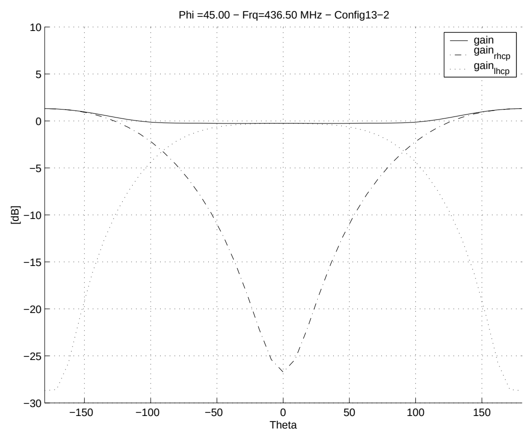
The configuration is usable because at least one of the partial gains, $rhcp$ and $lhcp$, is greater than $-4dB$. From a radio perspective it would be prefereable to have the "bottom" of the satellite towards the receiver, which means that the antennas would be pointing out in space. This is nevertheless not of current interest to us, because the restrictions set up by the mechanical team. They define the antennas to be place on the side of the satellite, which is directed towards the earth

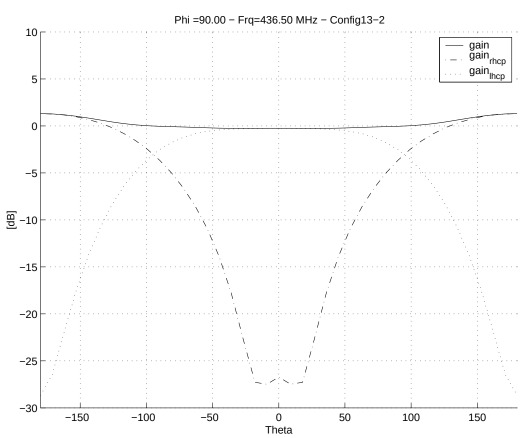


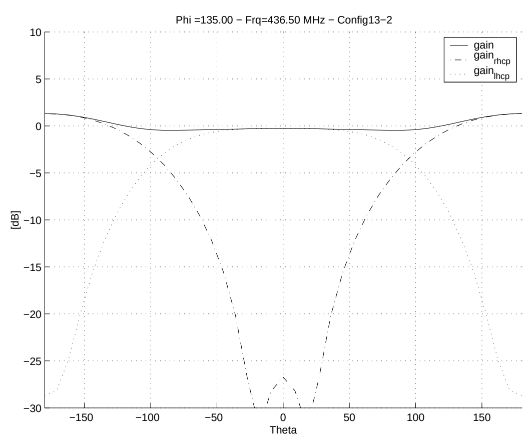
Config13-2	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

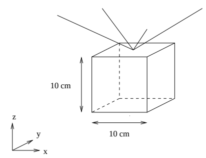
The two antennas are fixed at the center of the satellite, each with an angle of 33^o to the z-axis. The time harmonic generator for each of the two antennas are given by (1,0) for the antenna in the xz-plane. And (0,1) in the yz-plane. Very much the same as config13-1





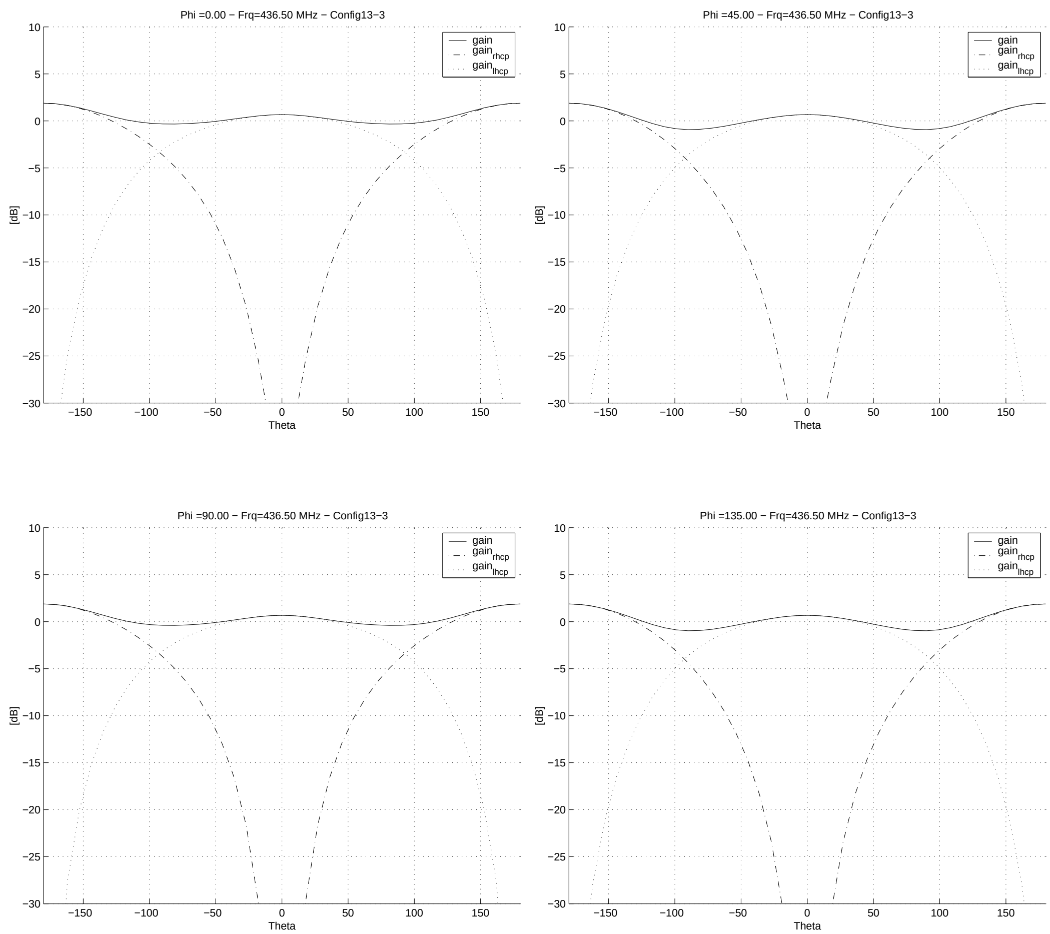




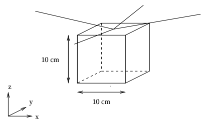


Config13-3	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The two antennas are fixed at the center of the satellite, each with an angle of 66^o to the z-axis. The time harmonic generator for each of the two antennas are given by (1,0) for the antenna in the xz-plane. And (0,1) in the yz-plane. Almost the same as config13-1 with a deviation of no more than 1 dB (for

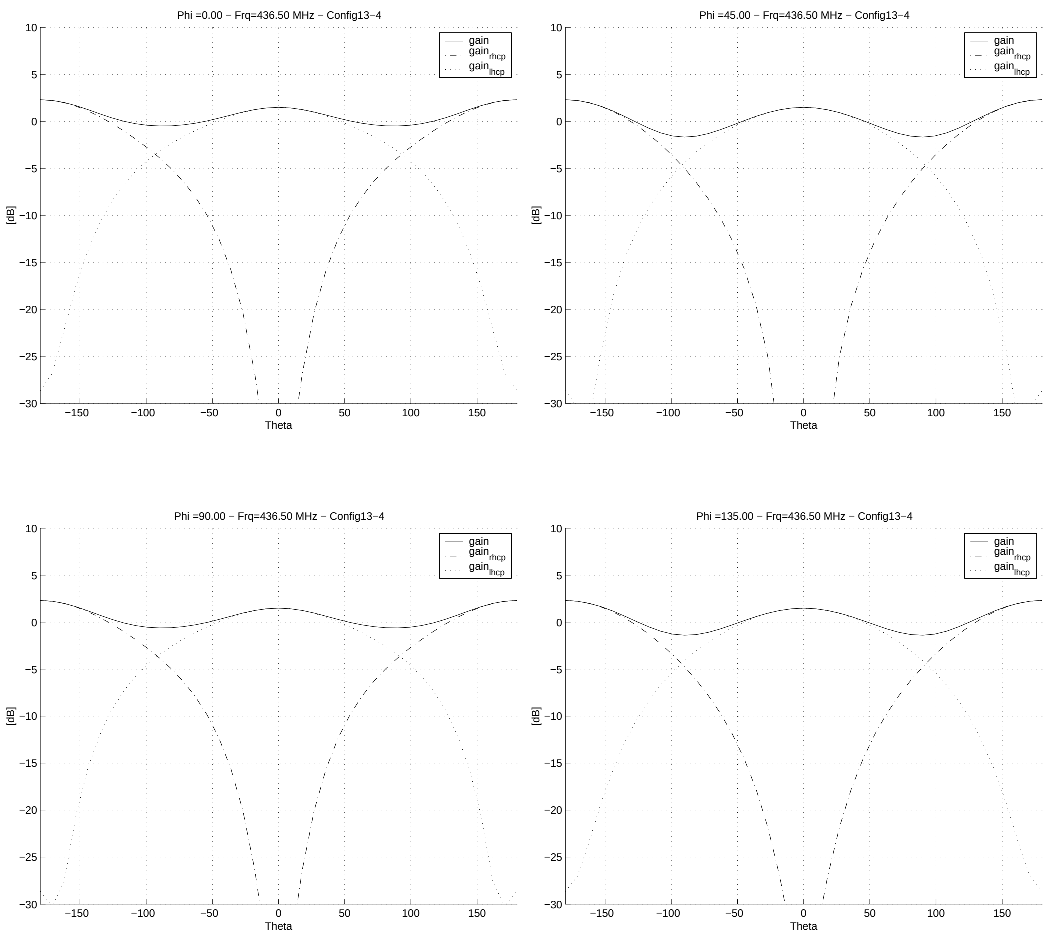


the gain).

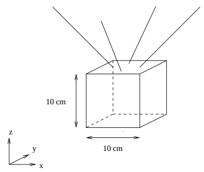


Config13-4	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The two antennas are fixed at the center of the satellite, each with an angle of 80^o to the z-axis. The time harmonic generator for each of the two antennas are given by (1,0) for the antenna in the xz-plane. And (0,1) in the yz-plane Overall it appears much like config13-1 however it is more curved, but not



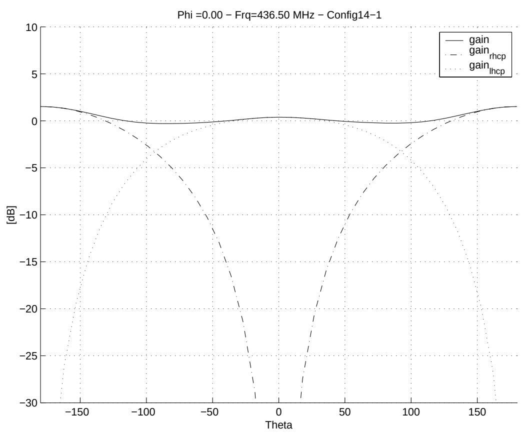
much considering that the angle between the antennas and the satellite surface are only 10^o.

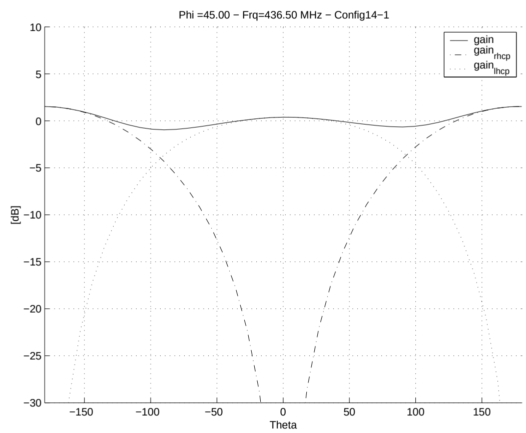


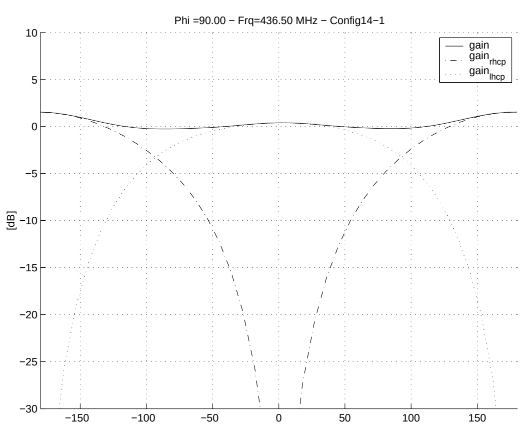
Config14-1	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

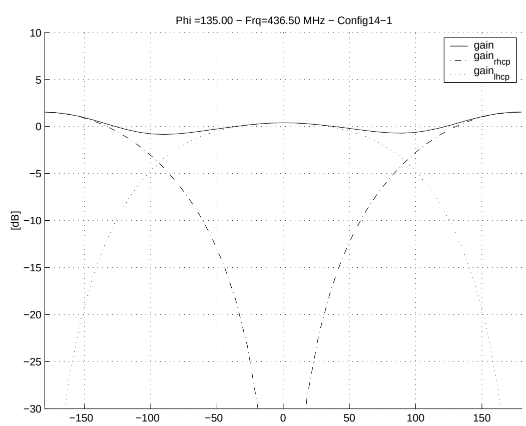
The antennas are each fixed halv-way between the center of the satellite and the four sides, each having a θ of 45^o. The time harmonic generator for each, starting with the one for $\phi = 0^o$ and proceeding counter clockwise, is (1,0), (0,1), (-1,0) and (0,-1).

Comparing these plots with the ones from Config13-1, we can see that it does

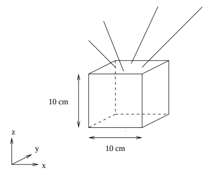






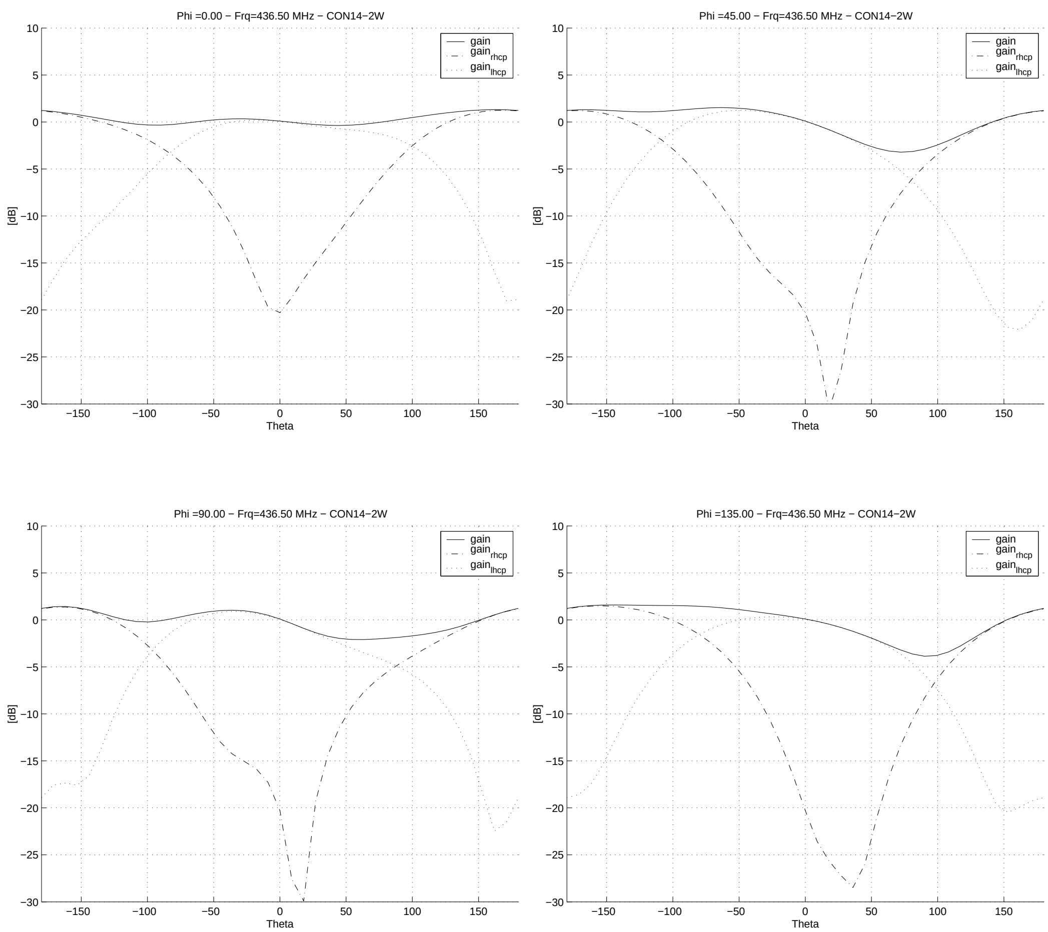


not change the radiation pattern significantly to move the antennas apart.

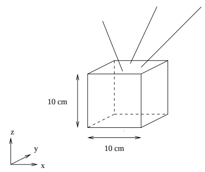


Config14-2	
Program	WIPL
Length of antennas	$\frac{\lambda}{4} = 171.1$ mm
(Length of broken antenna	$\frac{\lambda}{4} = 61.0$ mm)
Frequency	436,5 MHz
Wire radius	1mm

Same antenna placement as in Config14-1 apart from the antenna arm that is fastened in $(x, y, z) = (-25, 0, 0)mm$ is only half the length of the others. As would be expected the symmetry that we saw in Config14 has gone in all

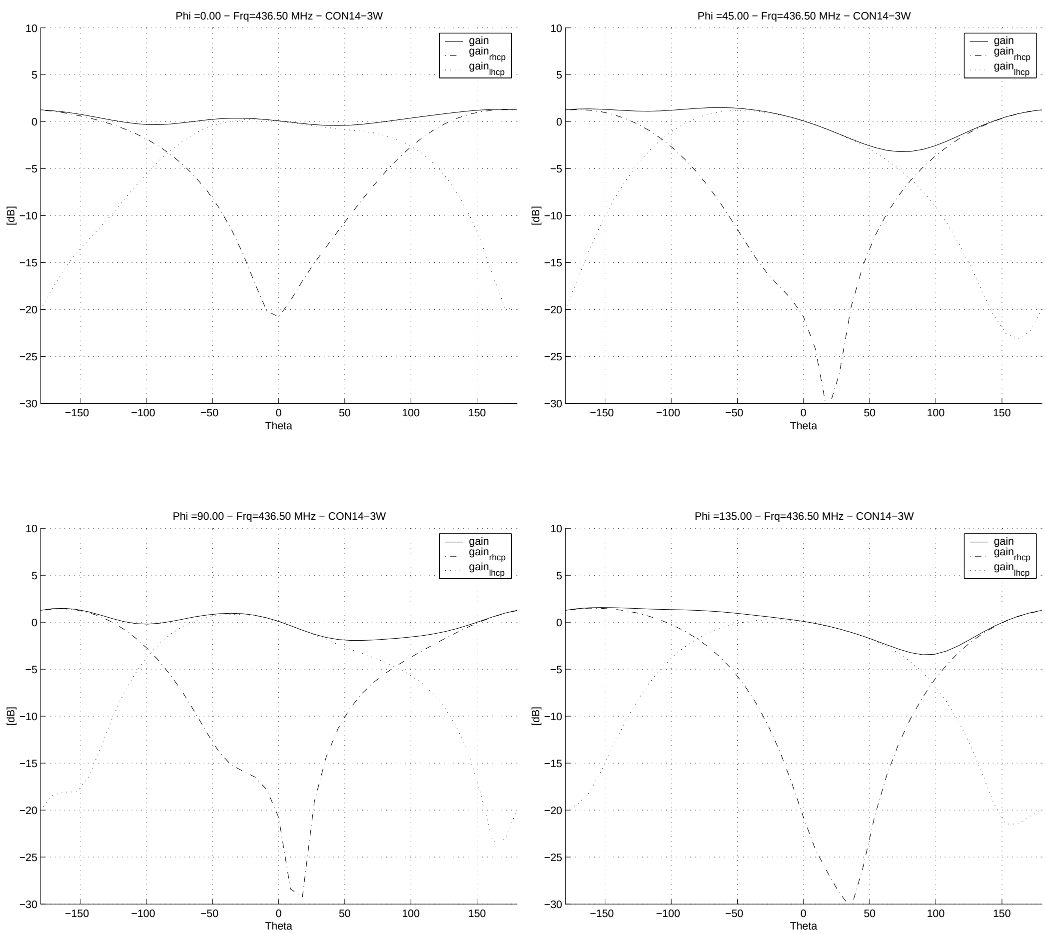


ϕ-planes. What is of interest is that at least one of the partial gains is still larger than -12dB. It is thus possible to communicate with the satellite even if one antenna is only half the length of the others. When this simulation was made we expected that the antennas were to be shot out of the satellite body. It was therefore interesting to see how the radiation would be affected in the event of one antenna only being half deployed. However the idea of shooting the antennas out has later been abandon because the firing mechanism would be to heavy. A new deployment method has not been decided on yet, but we believe that the antennas will be made of tape measure and then bend around on one side of the satellite fixed with some sort of device. When the satellite is deployed the device fixing the antennas will open and the antennas will unfold to there ideal position. Because of this new deployment method this configuration is not very likely to occur.

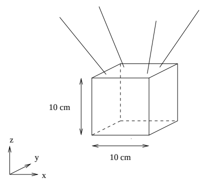


Config14-3	
Program	WIPL
Length of antennas	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

Same antenna placement as in Config 14-1 apart from the antenna arm that were fastened in $(x, y, z) = (-25, 0, 0)mm$ is missing.
As would be expected the symmetry that we saw in Config14 has gone in all



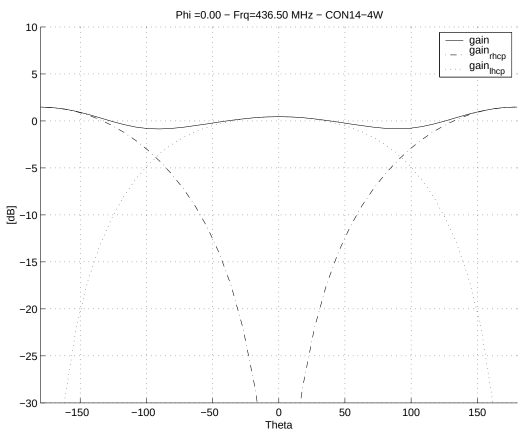
ϕ-planes. What is of interest is that at least one of the partial gains is still larger than -12dB. It is thus possible to communicate with the satellite even if one antenna is missing (has fallen of).

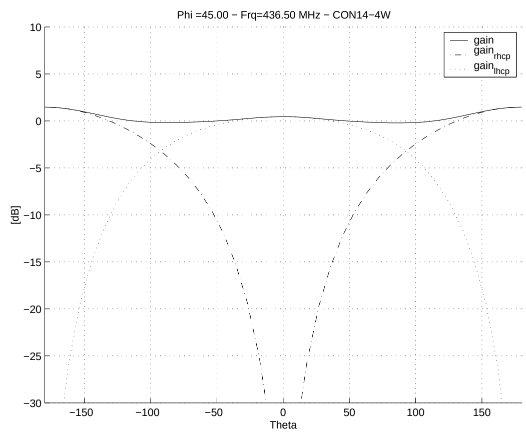


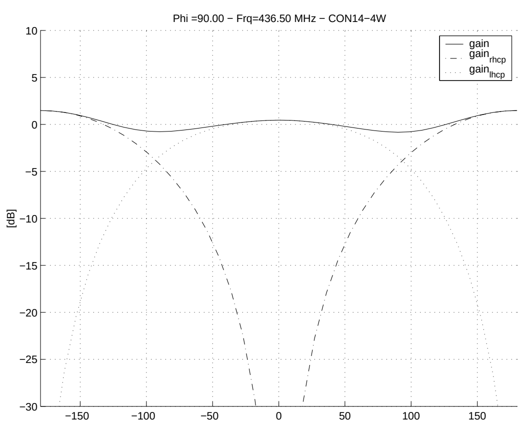
Config14-4	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

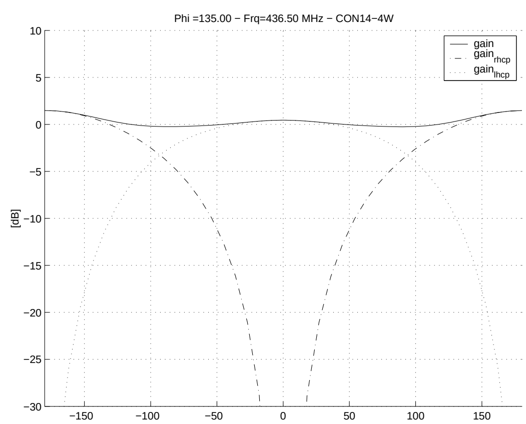
The antennas have the same length as those in Config14-1, only they are "rotated" 45^o counter clockwise. This means that the antenna fastened in $(x, y, z) = (25, 0, 0)$ in Config14-1 is now fastened in $(x, y, z) = (25, 25, 0)$ and so on

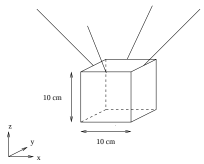
The plots are almost identical to those of Config14-4





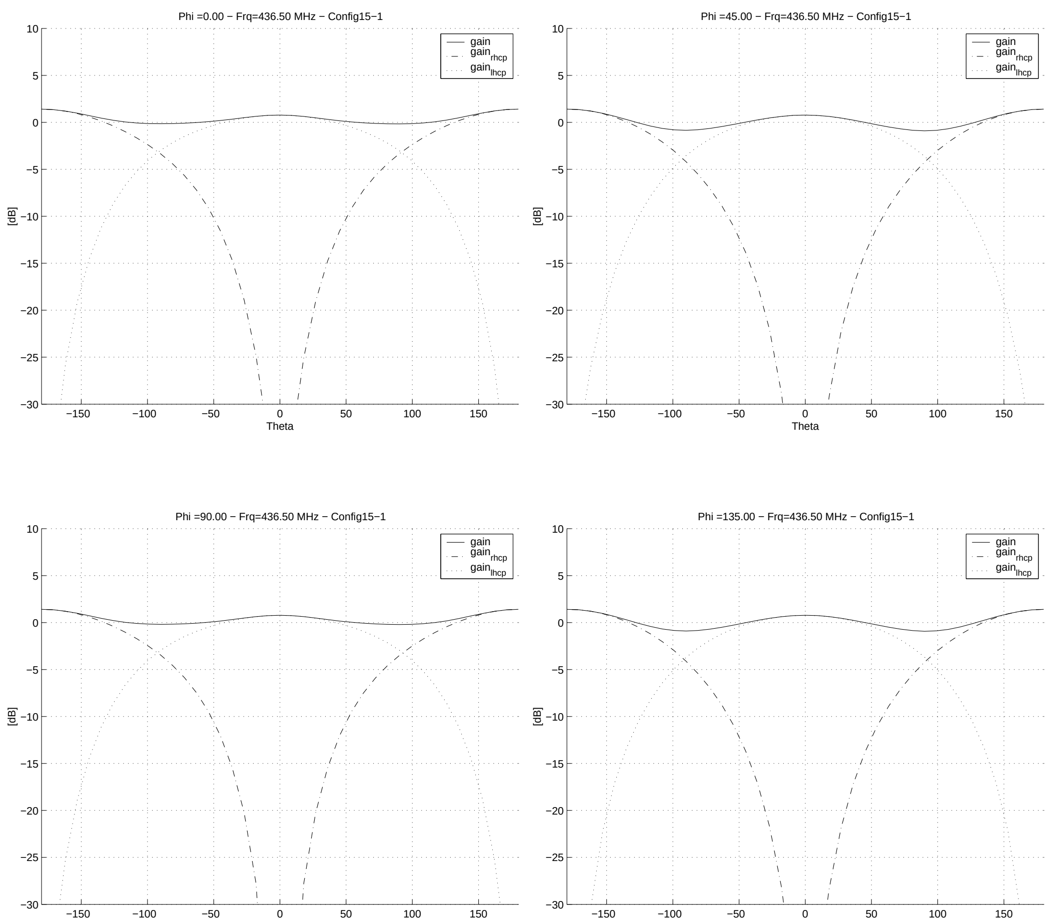




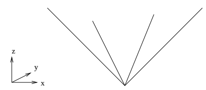


Config15-1	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are each fixed at the sides of the satellite, each having $\theta = 45^o$. The time harmonic generator for each, starting with the one for $\phi = 0^o$ and proceeding counter clockwise, is (1,0), (0,1), (-1,0) and (0,-1).
Comparing these plots with the ones from Config13-1, we can see that it does



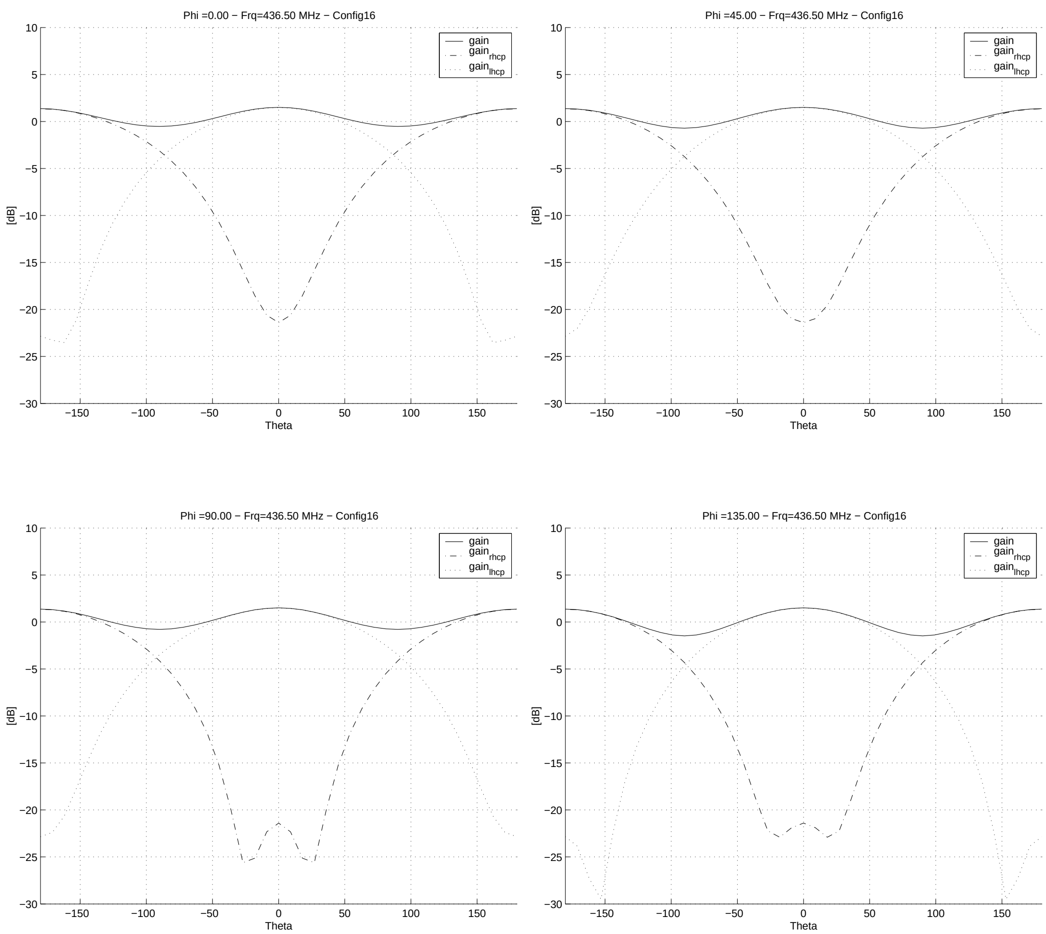
not change the radiation pattern significantly to move the antennas apart.



Config16	
Program	WIPL
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antenna configuration is the same as in config13-1, but without the satellite body. This is know as a canted turnsyle antenna

These plots reminds of those from config13-1, which was to be expected, the



missing body of the satellite kept in mind. The theory behind the results is analogue to those in Config13-1, but confirms the idea of the satellite body being the reason for the difference between the gain in $\theta = 0^o$ and $\theta = 180^o$ in Config13-1. As expected there is no difference in the signal for the different values of θ for Config16.

11 Discussion of possible candidates

There are several things to take into consideration when evaluating which is the best solution for the antenna system. Some of these can only be described and kept in mind, as they depend on future decisions in the satellite project. Examples of such issues are the placement of the antennas, the deployment mechanism, the complexity of the feeding network required for the given configuration and several others.

Following below is a further discussion or analysis of two groups of configurations that are possible candidates.

11.1 Discussion of Config4 and Config5

As can be seen from the presentations in section 10.5 Config4 and Config5 radiates in a similar manner. It can also be seen that at least one of the two partial gains *lhcp* and *rhcp*, is always above the specified minimum of -12dB. However the margin is not as large as in Config13 to Config15, see below. If the attitude of the satellite can be controlled within a modest 50^o in each direction and the antenna is mounted on the side of the satellite pointing towards or away from the earth, these configurations are well suited.

The two configurations are rather easy to construct, in that they do not need a complex feeding circuit. They only need a circuit that ensures that the same current runs on both antenna arms – a ballun. Further it is easier and lighter to place two antennas instead of four.

Another drawback, apart from the demands to the satellite attitude, is that it is uncertain whether the antenna can actually be placed at the center of the side pointing towards or away from earth. This is due to the physical design of the satellite, not the antenna.

All in all this is a good candidate if the satellite has a fairly good attitude control. As can be seen from Config6-1 to 6-7 in appendix H it is possible to change the angle of the antennas with the z-axis in order to either focus or flatten the radiation pattern. A large angle with the z-axis makes flat pattern whereas a small angle gives a more focused radiation pattern. The angle with the z-axis can thus be adapted to the expected precision of the attitude control.

11.2 Discussion of Config13 to Config15

The most important in summing up on these eight configurations, is the similarity in their partial gains. Taken into consideration the ability of the earth station to toggle between *lhcp* and *rhcp*, the intensity of the signal is evenly for any value of θ and ϕ. That is, the power (total gain) is evenly distributed over the entire sphere surrounding the satellite.

Comparing the four variations of Config13, one is assured that the angle θ between the antennas and the z-axis has no major influence on the radiation. This can be considered an asset for a configuration, since it gives the mechanics team greater freedom on how to fasten the antennas. This can make the deployment safer and more smooth.

Further comparison of Config13-1, Config14-1 and Config15-1 convinces us, that the exact placement of the antennas from the center towards the borders of the side (on the x- and y-axis) has no great influence on the signal. This has the same advantages as mentioned above.

As it is in the time of writing, the mechanical team has informed of us the placement of the antennas so far. They are likely to be place in the diagonal as in Config14-4. This configuration shows no serious deviation from the configurations with the antennas fastened on the axes of the coordinate system. This leads us to believe that all the configurations in this section can be placed on the diagonals without changing the radiation significantly.

These configurations, having an evenly distributed signal, are candidates for a satellite with little or no attitude control.

11.3 Further analysis

So far all our plots of the far field has covered only a fraction of the space. As described in section 10.1 the decision of which values of ϕ to plot for, defines four planes. These give a good idea of the radiation, but leaves much of the space uncovered. The following section presents a solution of this problem. Due to lack of time and the already proven agreement between WIPL and AWAS (see section B), the extra simulations necessary has only been conducted using WIPL.

There are two methods, quite analogue to one another, which can be used to solve the problem. Both methods are based on the assumption, that when the number of divisions of θ and ϕ reach a certain number, the plots will change no further. For a division to cover space satisfactorily, our instructor suggested 5 degrees for ϕ as well as for θ. Due to some restrictions in the processing of the data from WIPL, the divisions has instead been set to 5 degrees for ϕ and 2.5 degrees for θ, which only makes the results more reliable.

As mentioned before there are two solutions for the stated problem. These are: The coverage quality factor, Q, or a 3D-plot of the gain, *rhcp* and *lhcp*. These are described below.

11.3.1 Coverage quality factor

The coverage quality factor is a number which tell how large a percentage of space meets a certain requirement to the gain, be it the total gain or the partial gains *rhcp* or *lhcp*. For example, if the factor $Q_{gain,-5dB}$ had the value 66 (percent) for a given structure, this means that 66 % of the space has a gain above -5 dB – or that 34 percent has a gain less than -5 dB.

The formula for the coverage quality factor is:

$$Q_{gain,req\_val} = \frac{\int_0^{\pi}\int_0^{2\pi} x sin\theta d\theta d\phi}{4\pi}$$

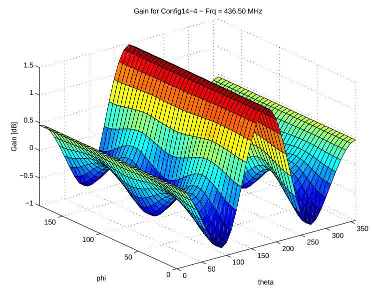
where $x = 1$ when the gain is over the required value, req_val, and $x = 0$ when this condition is not satisfied.

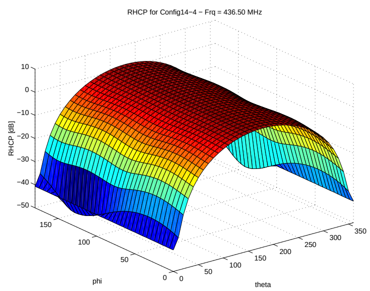
11.3.2 3d-plot

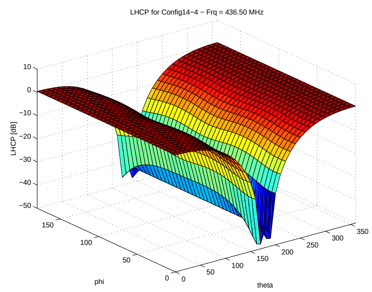
A clear 3d-plot of the gain, with ϕ and θ on the x-axis and y-axis, could give some of the same information as the Q-factor gives, though it may not be quite as specific. In Matlab it is possible to leave it to the program to set the boundaries of the z-axis, thus making it easy for the user to read the minimum gain from the plot.

Obviously this is not as specific as the Q-factor, where one can define for exactly which value of the gain the coverage is to be determined. Nevertheless the 3d-plots has, considering the lack of time again, showed itself sufficient for this last investigation of our candidates for the antenna system. The Matlab program for the 3d-plotting of WIPL data is described in appendix A.3.

All the 3d-plots of the candidates discussed above are placec in appendix G. Comparing them with the 2d-plots in section 10.5 one will find the plots to be concordant with one another. That is, the 2d-plots are extracts from the 3d-plots for specific values of ϕ. Below the 3d-plots for Config14-4 is presented:







Not only will one find that the 3d-plots and 2d-plots agree with one another. They also show, that the divisions of ϕ (see section 10.1), that is the number of plots, were sufficient to describe the radiation. In the 3d-plots there are no unexpected sharp declines between the values of ϕ for which we decided to plot. Besides, all the 3d-plots for the variations over Config13-1 and Config14-1 illustrate beautifully how the *lhcp* and *rhcp* compensate for one another.

12 Feeding network to the antenna system

12.1 Using a hybrid

12.2 Power divider + coax cables

12.3 Using descrete passive components

a

13 Conclusion and further work

Taking the discussion in section 11 and the 3D-plots in section 11.3.2 into consideration, we have found two different configuration groups filling the needs of either a stabilized or a tumbling satellite.

13.1 Antenna for a stabilized satellite

A version over Config4 or Config5 is the best of our configurations for this situation.

13.2 Antenna for a unstabilized satellite

A variation over the configurations ranging from Config13-1 to 15-1 is the best of our configurations for this situation. Taken into consideration the present restrictions for the placement of the antenna we recommend Config14-4.

13.3 Further work

A number of issues remains unaddressed

- It is still uncertain how to fasten and deploy the antennas. The most likely is that the antennas are to be made of tape measure and soldered onto some sort of connector on the satellite surface. This enables the antennas to be somewhat self deploying so that they can be bend around the satellite body during launch and unfold once in space.
- A computer program that can calculate the impedances of each antenna in an array when all antennas are transmitting would be comfortable to have.
- A feeding circuit needs to be designed, no matter which configuration is chosen.
- A prototype (a test model has been made) still remains to be crafted of both the tape measure antennas and the satellite itself. Radiation and impedance measurements has to be done hereof.

References

[1] *AWAS for Windows: Analysis of Wire Antennas and Scatterers, Software and User's Manual*: Artech House, INC. Boston. London (1995)

[Cheng] *Fundamentals of Engineering Eloctromagnetics*: David K. Cheng, Addison-Wesley (April 1994)

[2] *MMIC design* edited by I.D Robertson.

[3] *A Short note on integral equation techniques in electromagnetics*: Erik Jœrgensen and Jens Troelsen. Department of electromagnetic systems, Technical University of Denmark.(April 28,2000)

[4] *http://horse.mes.titech.ac.jp/srtlssp/cubesat/index.html*, january 2002

[5] *http://www.stensat.org/index.html*, january 2002

[6] *http://www.ssel.montana.edu/merope*, january 2002

[7] *Artech House, INC.*Portland House, Stag Place,London,SW1E 5XA. UK.

[8] *http://www.osss.com/*, january 2002

[9] *http://web.syr.edu/ tksarkar/softw.html*, january 2002

[10] *WIPL manual*, edition 1995.

A Matlab programs

A.1 Introduction to Matlab programs

As described earlier in the report, the data rendered by WIPL and AWAS calls for postprocessing due to lacks in the simulation programs. First and foremost we found the plotting facilities to be insufficient in both programs. Later on we also discovered, that both programs did not have enough facilities when simulating structures with more than one antenna (see section 6). The tool chosen for this processing was Matlab.

A point to emphasize is that none of the participants in the project had any previous experience with the program. This justifies the possible first impression of the Matlab scripts as being immediate solutions and partly incomplete – meaning, some things could have been made more elegantly. Here it is once again important to emphasize the use of Matlab as the use of a tool. We trusted the correctness of Matlab, and validate our own programs by checking that the plots agreed with the theory we know.

This justifies that we have decided to leave out any tests of programming code, this being beyond the scope of this project. Instead an instruction to future users follows below for each of the simulation programs. Due to the different output from WIPL and AWAS, the Matlab programs are also divided into two sections – one for each. Also an instruction follows for the Matlab scripts designed to make 3D plots for WIPL simulations.

A.2 Matlab scripts for WIPL

As mentioned above, one of the reasons for postprocessing, is that WIPL can not evaluate the far field of a structure with more than one antenna, and calculate the admittance of the antennas at the same time. This is the reason why we have decided for two different procedures, when plotting the results for WIPL. The procedures, which developed as the analysis progressed, are to be described shortly. First a description of the four functions used in the two procedures.

A.2.1 Functions for Matlab scripts for WIPL

plot_imp.m Enters the WIPL file with the extension ".AD1" (see appendix D.1) containing the data for the admittance, and converts these data to obtain the impedance instead. The frequency with the lowest reactance is found. This frequency is then set to be the frequency, where the antenna is resonant. The real and imaginary part of the impedance for every frequency are plotted. The reflection coefficient is calculated, and the absolute value of this is then plotted. Both plots are saved. Finally the function data_1gen() is activated to create a data box for the configuration. The data box is used in the presentations.

plot_gain.m If the structure only has one antenna, the function plot_imp() is called to decide for which frequency the antenna is resonant. This way, the frequency for which the far field is to be plotted, is found. If there is more than one antenna, this frequency is defined by the user, and the function data_2gen() is invoked to create a data box. The function reads through the datafile with the extension ".RA1" (see appendix D), and picks out the data for the specified frequency. Then some lines of codes follows, which ensures that θ runs in the interval $[-180^o, 180^o]$, which we decided to use for our plots. After this the $rhcp$ and $lhcp$ is calculated and are plotted along with the gain. Finally the plots are saved. One of the forces of this function is, that the resolution of θ and ϕ is of no matter. It figures out by itself how many plots are needed, that is for each division of ϕ (see section 10.2. As an example, this allow the user to quickly run another evaluation of the far-field for the configuration, but for different places in space.

data_1gen.m Used for configurations with only one antenna. Creates a file with the same name as that of the configuration and with the extension ".tex". When included in Latex documents (see section J.1), this file generates a data box containing the data for the configuration, and is to be used in the presentations.

data_2gen.m Used for configurations with more than one antenna. Creates a file with the same name as that of the configuration and with the extension ".tex". When used in Latex, this file generates a data box containing the data for the configuration.

The two very simple procedures, and their use of plot_imp() and plot_gain(), are described below.

A.2.2 User guide for WIPL Matlab scripts

For only one antenna:

1. Enter the file plot_gain.m.

2. Enter the name of the configuration in line 1, as in the example in line 2.
3. Remove the "comment-operator" from line 9, if this is not done already.
4. Assure that line 12 and 13 is not activated.
5. Save and run the program.

For more than one antenna:

1. Enter the file plot_gain.m.
2. Enter the name of the configuration in line 1, as in the example in line 2.
3. Assure that line 9 is not activated.
4. Remove the "comment-operator" from line 12 and 13, if this is not done already.
5. Save and run the program.

A.3 Matlab scripts for 3D-plotting with WIPL

As with the other Matlab programs so far, it is important to remember that this program is only intended as a tool. Nevertheless the program for 3d-plotting is very easy to use. Prior to the user guide, we present a short description of the only function in the program.

A.3.1 Functions for 3D Matlab to WIPL

plot_gain3d.m This function works in a manner similar to that of plot_gain(). First it opens the file with the name of the configuration and the extension ".RA1" (see section D.2). Then it reads through the data until it encounters the data for the frequency specified by the user. It extracts the data for the gain and plot this in a 3d plot, which it saves. After this the *rhcp* and the *lhcp* is calculated, plotted and saved in a file each of their own.

A.3.2 user guide for 3D Matlab to WIPL

1. Enter the file plot_gain3d.m.
2. Enter the name of the configuration in line 1.
3. Save and run the program

A.4 Matlab scripts for AWAS

The Matlab scripts used for visualising the AWAS simulations consists of four files *pGain.m*, *plotZparFRQ.m*, *plotall.m* and *plotgain.m*. These files are to be placed in the same directory as the AWAS output files *ffld.dat* and *zpar.dat*. The four Matlab files have been used for making all the plots and the data boxes in the presentation of the simulations in AWAS in appendix H. The directory where the files resides is used as naming on all plots and in the data boxes. The scripts produces the following files that are all saved in the working directory.

radiation(1...n).eps n plots of the far field. All in .eps format. Where n is the number of far field groups.

karakteristik.tex contains the data box for the configuration. It is written as a LaTeX table (in ANSI format) ready to be included in a document.

impedanse1.eps is the impedance plot.

reflection1.eps is the plot depicting the magnitude of the reflection coefficient as a function of frequency.

A.4.1 The scripts

Here follows a description of the four Matlab scripts/functions:

plotZparfrq.m is only used in conjunction with a single antenna. It finds the frequency where $abs(reactance)$ is minimal. It returns this frequency, the reactance here and the number of frequencies before this frequency +1. (the frequency step+1). It also makes and saves a data box and plots for reflection and impedance. It reads *zpar.dat* for data.

pGain.m makes as many far field plots (saved to the files *radiation(1..n)*) as there are far field groups (see appendix C.1) defined in *ffld.dat*. Each far field group should be defined as a θ interval and a ϕ value, which is displayed in the plot title. The function takes as parameters the resonans frequency (only used to make nice titles), the frequency step, where the antenna is most resonant ($\min abs(reactance)$) and the reactance(not used) at that frequency. All data is read from *ffld.dat*.

plotAll.m is used with single antenna configurations to make the data box, the impedance, reflection coefficient and far field plots. It uses the two functions *pGain.m* and *plotZparfrq.m* to achieve this.

plotgain.m is used with antenna arrays to plot the far field and make the data boxes as seen in the last configurations in appendix H. It uses only *pGain.m*.

A.4.2 Additional programs

A bat-script has been written to ease the organisation of the files. The file is called *copyall.bat*. Its sole purpose is to copy all AWAS output files and Matlab scripts(both from a fixed location) to the directory where it resides.

The following illustrates how the directories can be organized to obtain the same naming as in the presentations

```
\satellite
     |
     +->config1\
         | Matlab scrips and AWAS output files and bat-script
     +->config13-2\
         | Matlab scrips and AWAS output files and bat-script
     +->config4\
         | Matlab scrips and AWAS output files and bat-script
     |
```

A.4.3 User guide for AWAS Matlab scripts

This is very simple. Copy the scripts to a directory along with the AWAS output files *zpar.dat* and *ffld.dat*, ex. using the bat-script. Start Matlab. Go to the directory from before and run either *plotall* or *plotgain*. Thats all.

B Plots for agreement between simulation programs

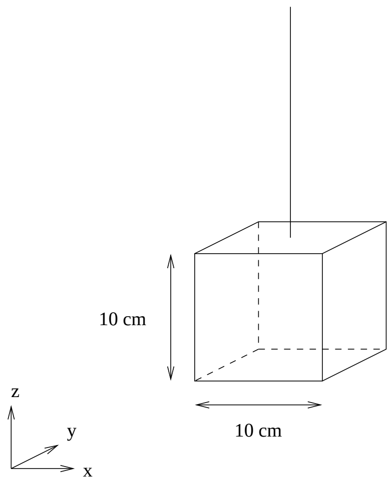
We have chosen three different configurations, in addition to the dipole (see section 10.3, to validate the agreement between AWAS and WIPL. It is presumed that the reader is familiar with the section 10.2, which is why we omit any description of the antennas placement on the satellite.

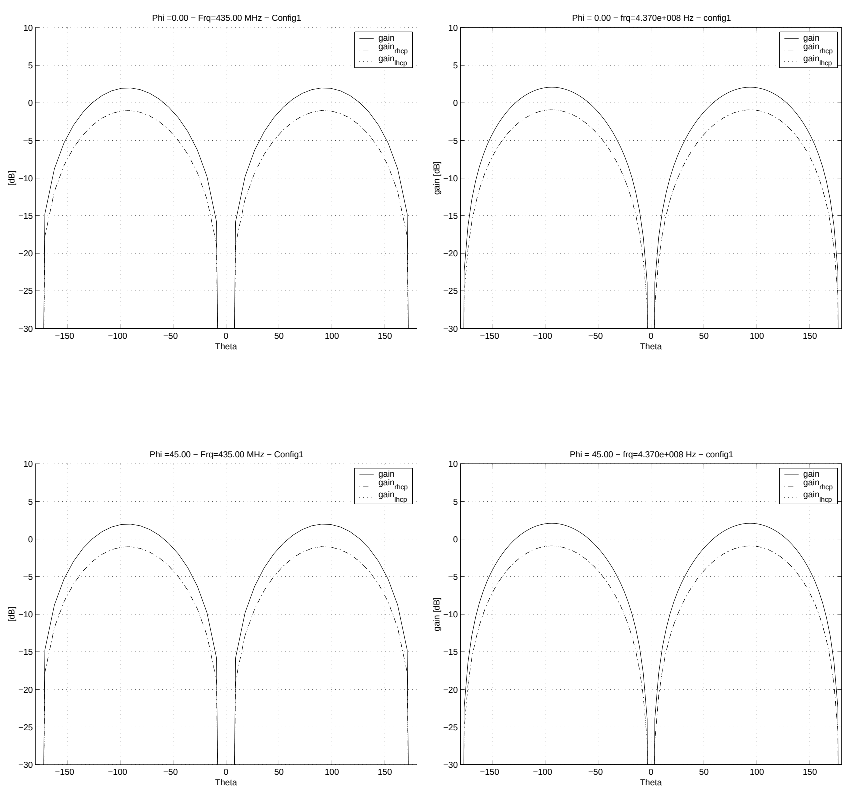
The three configurations are Config1, Config5 and Config 13-1. The difference between them being quite obvious.

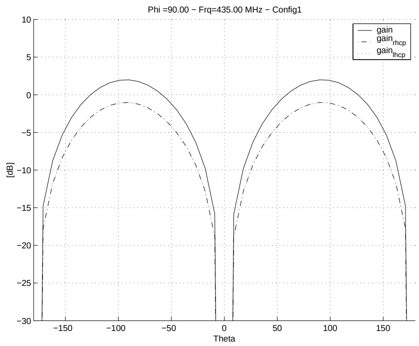
Before each comparison a picture of the configuration is shown. Followingly comes the plots for the four different values of ϕ. On the left side the plots for WIPL is placed and on the right side the plots for AWAS, allowing for easy comparison.

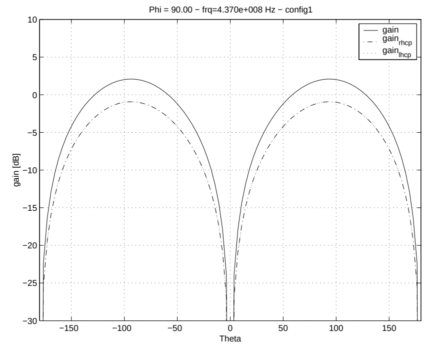
There are three remarks to be made before commencing the comparisons. Due to lack of time, a minor difference between WIPL and AWAS in the headlines of the plots has not been taken care of. This can be consider a slight blemish. On the other hand, it could at first seem like something of a big error that some of the frequencies are not the same for WIPL and AWAS, although the differences are very small. This is due to the procedure of adjusting the antenna until resonance occurs. However it is not of crucial importance, as the evaluation of the far field is hardly affected by the small differences. The final thing one has to keep in mind comparing the following plots, is that some might have been conducted for different resolution of the frequency, resulting in different grade of smoothness.

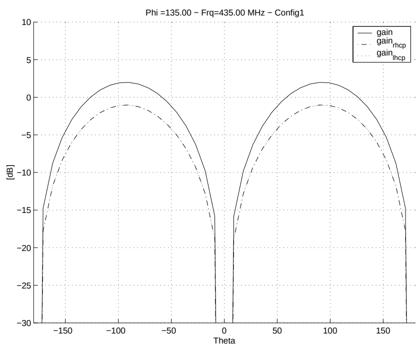
B.1 Comparison of Config1

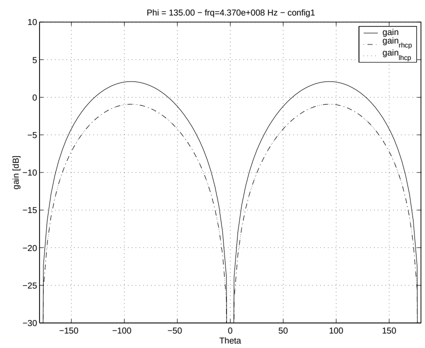




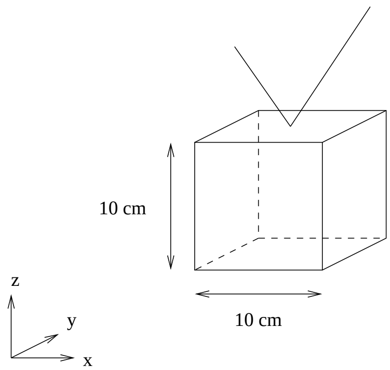

Phi =90.00 − Frq=435.00 MHz − Config1
gain
gain_rhcp
gain_lhcp
[dB]
Theta

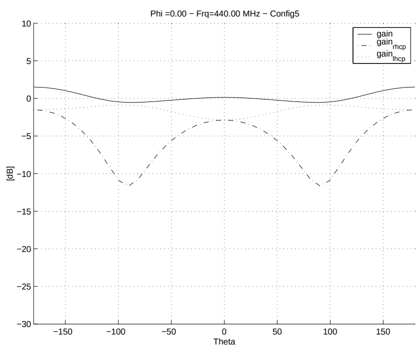

Phi = 90.00 − frq=4.370e+008 Hz − config1
gain
gain_rhcp
gain_lhcp
gain [dB]
Theta

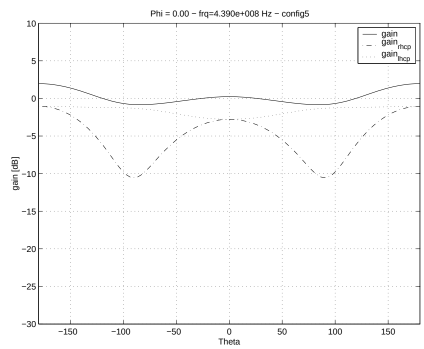

Phi =135.00 − Frq=435.00 MHz − Config1
gain
gain_rhcp
gain_lhcp
[dB]
Theta

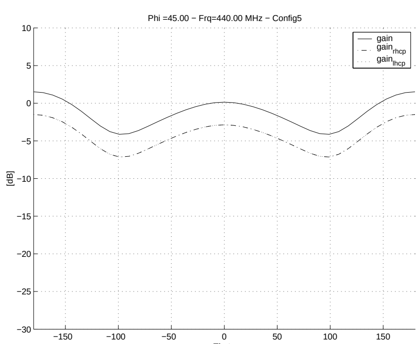

Phi = 135.00 − frq=4.370e+008 Hz − config1
gain
gain_rhcp
gain_lhcp
gain [dB]
Theta

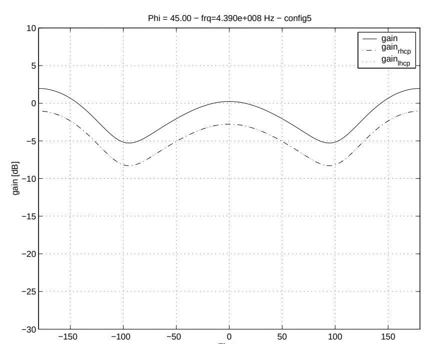
B.2 Comparison of Config5

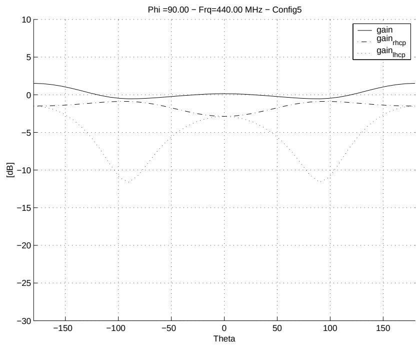


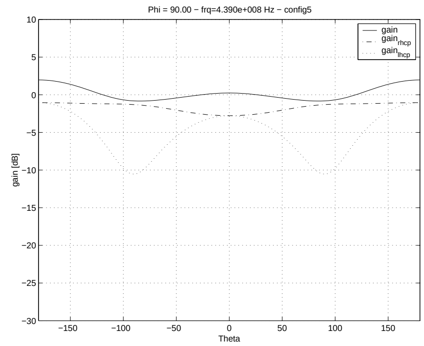


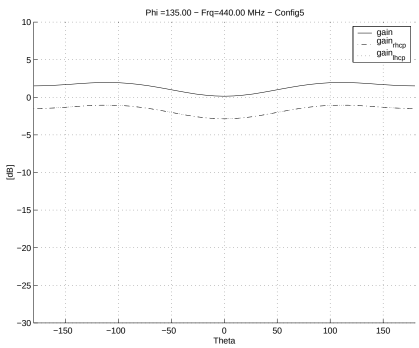


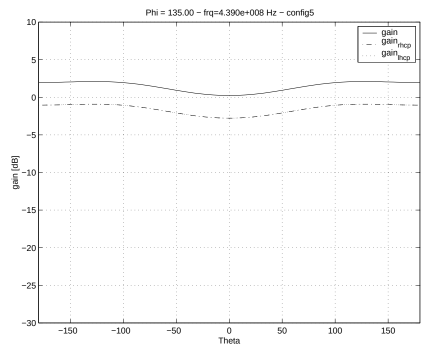




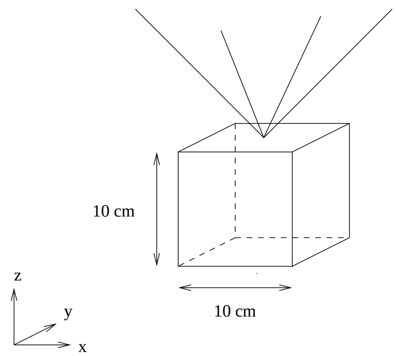

Phi =90.00 − Frq=440.00 MHz − Config5
gain
gain rhcp
gain lhcp
[dB]
Theta

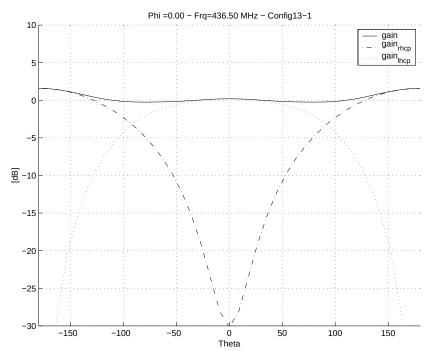

Phi = 90.00 − frq=4.390e+008 Hz − config5
gain
gain rhcp
gain lhcp
gain [dB]
Theta

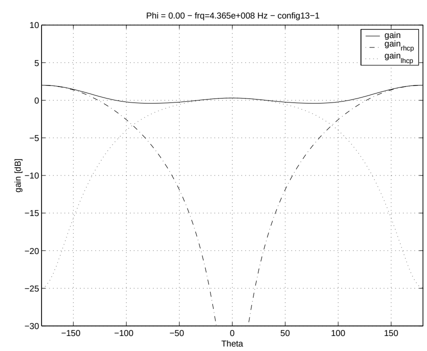

Phi =135.00 − Frq=440.00 MHz − Config5
gain
gain rhcp
gain lhcp
[dB]
Theta

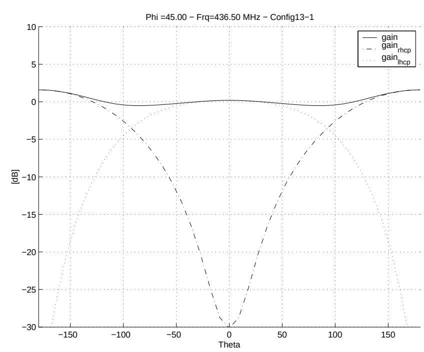

Phi = 135.00 − frq=4.390e+008 Hz − config5
gain
gain rhcp
gain lhcp
gain [dB]
Theta

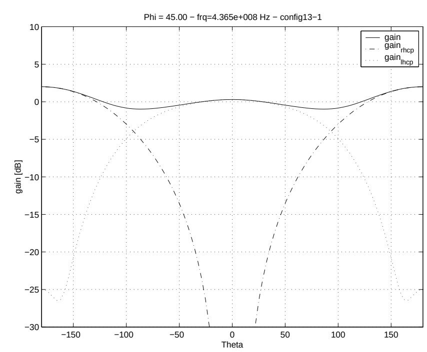
B.3 Comparison of Config13-1

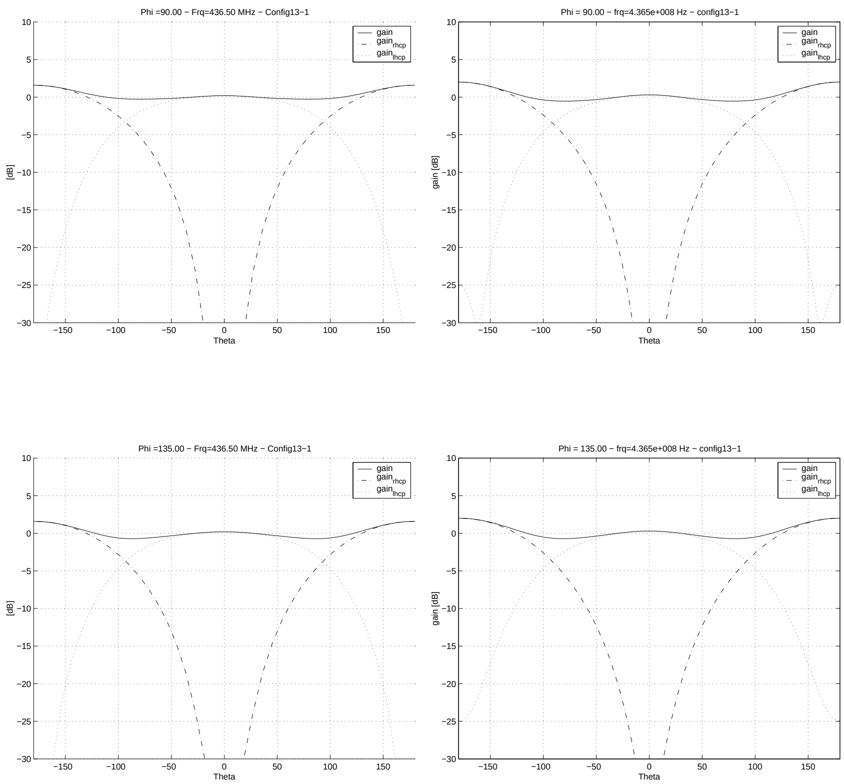












Just comparing each pair of the above figures should be sufficient to convince one of the agreement between AWAS and WIPL. That is, at least for the level of precision required in this project.

C Format of AWAS out- and input files

In this section the format of various in- and output files for AWAS is presented. This is done due to the lack of a clear and thorough description in the AWAS manual[1].

C.1 FFLD.dat

When having calculated the far field AWAS saves the data in the default file, *ffld.dat*, residing in the same directory as the AWAS executables. The format of the file is presented in Table 1.

Each line in the blocks in the matrix from Table 1, consists actually of two lines containing the following data:

line	column 1	column 2	column 3	column 4
1	$Re(E_\theta)$	$Im(E_\theta)$	$Re(E_\phi)$	$Im(E_\phi)$
2	Gain			

The gain in a given direction is calculated from:

$$G_p = \frac{|\mathbf{p}|}{p_{fed}} \cdot 4\pi r^2 \tag{2}$$

Where $\mathbf{P}$ is Poyntings vector, $\mathbf{P} = \mathbf{E} \times \mathbf{H}^*$. Because we are in the far field we know, that $\mathbf{H} = \frac{\mathbf{u}_r \times \mathbf{E}}{\eta_0}$, where $\mathbf{u}_r$ is the direction of propagation. Putting this into (2) we get

$$G_p = \frac{|\mathbf{E}|^2}{\eta_0 p_{fed}} 4\pi r^2 = \frac{\mathbf{E} \cdot \mathbf{E}^*}{\eta_0 p_{fed}} 4\pi r^2 \tag{3}$$

which is the formula used in the Matlab scripts. In the WIPL case divided by 2.

line no.	Description
1	A number showing the number of far field groups.
2	The frequency range for which the structure is to be analysed. The format of the line is: start frequency. stop frequency and number of steps in between. They are separated by spaces(blank character).
3	A number indicating operating mode of the structure. The numbers 1, all ports excitated at the same time, and -1, one port excitated at a time, where the only two used in this project.
4	A number showing the number of ports/generators.
5	A number indicating the number of plane wave groups (not used in our simulations) . If any groups three lines per group will follow this line. These we will omit to describe, because plane wave groups have not been used in this project.
6	The line number is provided that the number of plane wave groups is zero, as is the case in our simulations. If there were plane wave groups, the correct number of this line, instead of 6, is $5 + 3 \cdot noplanewavegroups$ –from line 5–). The format of this line is: θ_{start} θ_{stop} and steps between the two. The numbers are separated by a blank.
7	ϕ_{start} ϕ_{stop} steps between the two
8	Blank line. Hereafter follows a sequence of blocks in which the data is organized in the following manner:

Frq_{start}	$farfield1$	$\phi_{start_{f1}}$	$\theta_{startf1}$
...	...	...	$\theta_{startf1+1}$
...	...	...	...
...	...	...	θ_{stopf1}
...	...	$\phi_{start_{f1}+1}$	$\theta_{startf1}$
...	...	...	$\theta_{startf1+1}$
...	...	...	...
...	...	...	θ_{stopf1}
...	...	$\phi_{stop_{f1}}$	$\theta_{startf1}$
...	...	...	$\theta_{startf1+1}$
...	...	...	...
...	...	...	θ_{stopf1}
...	$farfield2$	$\phi_{start_{f2}}$	$\theta_{startf2}$
...	...	...	$\theta_{startf2+1}$
...	...	...	...
...	...	...	θ_{stopf2}
...	...	$\phi_{start_{f2}+1}$	$\theta_{startf2}$
...	...	...	$\theta_{startf2+1}$
...	...	...	...
...	...	...	θ_{stopf2}
...	...	$\phi_{stop_{f21}}$	$\theta_{startf2}$
...	...	...	$\theta_{startf2+1}$
...	...	...	...
...	...	...	θ_{stopf2}
$Frq_{start+1}$	...	...	...
...	...	...	...
...	...	...	...
Frq_{stop}	...	...	...

Table 1: The format of the far field output file, ffld.dat.

C.2 ZPAR.DAT

The calculated impedances are written to the file *zpar.dat*. With n generators, the impedance matrix:

$$\begin{bmatrix} Z_{11} & Z_{12} & \dots & Z_{1n} \\ Z_{21} & Z_{22} & \dots & Z_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ Z_{n1} & Z_{n2} & \dots & Z_{nn} \end{bmatrix}$$

is written to the file in the following format:

if n odd		if n even	
Z_{11}	Z_{12}	Z_{11}	Z_{12}
Z_{13}	Z_{14}	Z_{13}	Z_{14}
$\vdots$	$\vdots$	$\vdots$	$\vdots$
Z_{1n}		$\vdots$	Z_{1n}
Z_{21}	Z_{22}	Z_{21}	Z_{22}
Z_{23}	Z_{24}	Z_{23}	Z_{24}
$\vdots$	$\vdots$	$\vdots$	$\vdots$
Z_{2n}		$\vdots$	Z_{2n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$
Z_{n1}	Z_{n2}	Z_{n1}	Z_{n2}
$\vdots$	$\vdots$	$\vdots$	$\vdots$

If the analysis is done with multiple frequencies an empty line follows after the impedance matrix. Afterwards the impedance matrix for the next frequency is written. Each number in the impedance matrix is written as a complex number, meaning that Z_{11} is actually $real(Z_{11}) \quad imag(Z_{11})$. The two numbers are separated by a blank character.

C.3 .geo files

The files that contains the geometry of the structure has the extension .geo. The format of the file is fairly easy and well described in the AWAS manual[1]. Therefore it is only presented here in brief for consistency. For details, consult the manual[1].

line no.	description
1 - 3	Optional comments to the structure. Each line must be 76 characters (excluding the carriage return and line feed characters).
4	A number indicating operating mode of the structure. The numbers 1, all ports excitated at the same time, and -1 one port excitated at a time, where the only two used in this project
5	A number indicating whether a ground plane is present. 0 means no and 1 yes.
6	Is the number of nodes,n_n. This entry needs to be edited when manually changing the number of nodes on the structure
7	Is the number of wires, n_w on the structure. This to sometimes needs to be edited.
8	Number of ports.
9	Empty line.
10 - $10 + n_n$	lines defining all the nodes by their x, y and z coordinate. Each coordinate is separated by a space.
10+$n_n + 1$	empty line.
next n_w	Definitions of all the wires.
next	empty line
rest	Defining the generators. [The wire where the generator is connected. A positive number indicates the origin of the wire, whereas a negative number indicates that the generator is places at the terminal of the wire. Then follows a space character and $(real(V), imag(V))$, where V is the generator voltage. Followed by yet another space character and at last the nominal impedance of the generator]

Table 2: Format of the geometry input file (.geo)

D Format of WIPL out- and input files

In this section the format of the output files for WIPL is described. The reason for this is, that such a description is nowhere to be found in the manual. This section might ease work up a little for people who, like ourselves, are determined to use the data from WIPL. In addition this might make the Matlab scripts, see appendix A, more understandable.

D.1 filename.AD1

When the simulation has terminated, the admittance of the antenna is saved in a file with the same name as that of the simulation. It has the extension ".AD1" and resides in the same directory as WIPL itself. The format of this file is

line no.	Description			
1	Unimportant line. Can be skipped without further notice			
2	Hereafter follows a sequence of lines with 5 columns, in which the data is placed:			
Frq_{start}	gen_{ref}	gen_{source}	$admittance_{real}$	$admittance_{imag}$
$Frq_{start+1}$	gen_{ref}	gen_{source}	$admittance_{real}$	$admittance_{imag}$
...	...	...		
...	...	...		
Frq_{end}	gen_{ref}	gen_{source}	$admittance_{real}$	$admittance_{imag}$

For a explanation of why there is two generator fields, one should consult section 6.

The situation, which has been used in this project, is when one is dealing with a structure with only one antenna. Then it should be obvious that both generator fields have the value 1.

D.2 filename.RA1

Just as for the data for the admittance, the data from the evaluation of the far-field is stored in a file with the same name as that of the configuration. Only this has the extension ".RA1"

The format of this file is as follows:

The data is put in blocks for every frequency for which the evaluation is conducted. Every block starts with a headline, containing:

1. Frequency
2. ϕ_{steps}
3. θ_{steps}

After this the data is presented in 8 columns as described below:

Column no.	Description
1	Angle of ϕ
2	Angle of θ
3	ϕ_{real} part of the E-field in volts
4	ϕ_{imag} part of the E-field in volts
5	θ_{real} part of the E-field in volts
6	θ_{imag} part of the E-field in volts
7	The gain in the specific direction
8	The gain again, but in dB

E Wire models in AWAS

As can be seen from the presentation of the AWAS simulations in appendix H the antennas are always connected to the satellite body with some wires. This has been done because we from the following considerations are lead to suspect, that the induced currents are likely to run towards or away from the antenna.

If we take a dipole in the z-direction and place a thin conduction plane around its middle as show in figure 3 there will be an induced H- and E-field on the plane as shown.

The directions are found by building the dipole from Hertzian dipoles. For the dipole in the center of plane the direction of the H-field and E-field can readily be seen from [Cheng, equation (10-7)] and [Cheng, equation (10-8a) - (10-8c)] when setting $\theta = \pi/2$. It is seen that there is no field in other directions (then the ones drawn on the plane in the figure) because the contribution in any such direction from a Hertzian dipole on one side of the plane is canceled out by a dipole on the other side. Thus we know the direction of the fields on the plane.

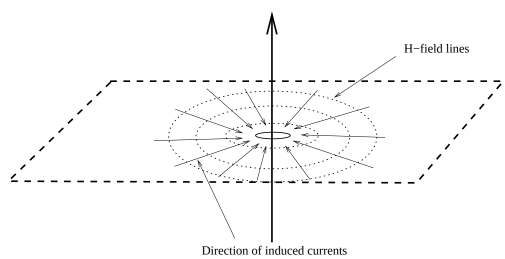


Figure 3: A thin conduction plane crossing the middle of a thin dipole antenna

The figure shows that there will be induced an E-field pointing towards or away from the antenna. This might cause currents to flow. To enable these currents to run in the AWAS simulations we connected the generator with the satellite body with wires. Of course the antennas placed on the satellite model in AWAS was often monopoles. However if we place a monopole on an infinite plane we can use the method of images to make this problem look like the one above. Now the satellite is not infinite, but from the above speculation it can be suspect that the induced currents will behave in much the same way as described here. Therefore all models have been build with some wires between the generator of the antenna and the satellite body.

As is to bee seen by comparing Config1 and Config1-2 in appendix H and

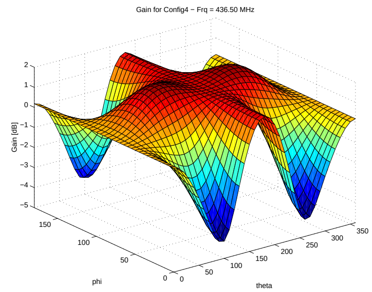
Config7 and Config7-1 it has some influence whether there are many or few wires.

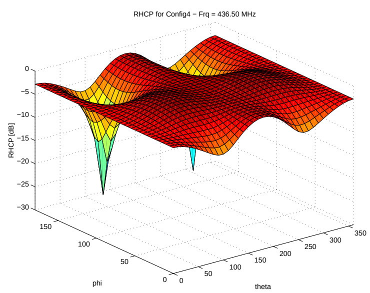
F Program restrictions

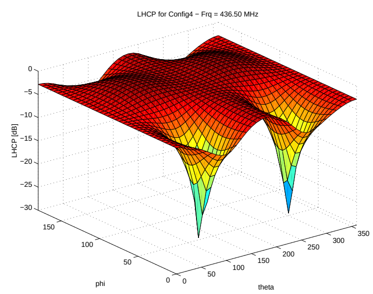
As can be seen bellow, the program allows for plenty of wires and nodes considering that the most detailed structures used in this project had less than 100 nodes and wires.

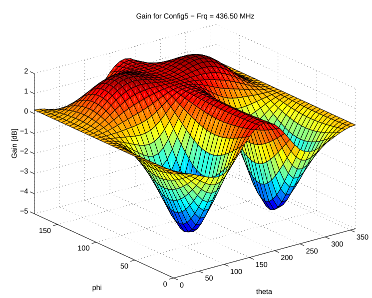
- Maximal number of nodes 500
- Maximal number of segments/wires 320
- Maximal number of ports/generators 16

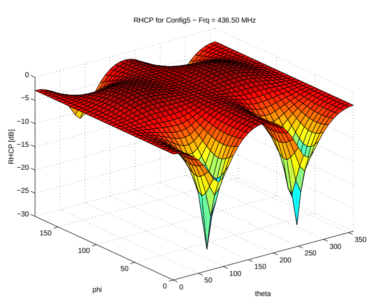
G 3D-plots of selected configurations

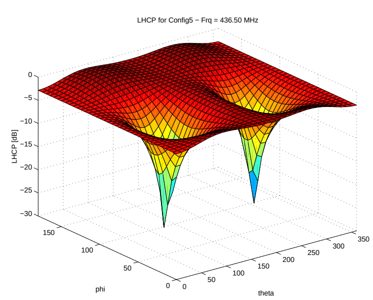


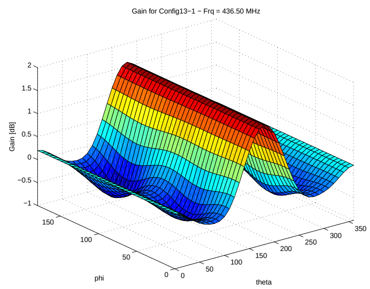


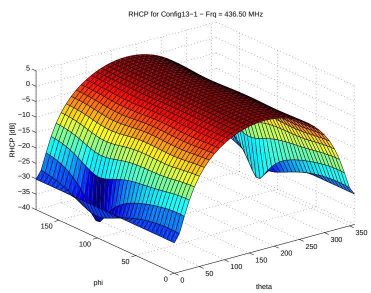


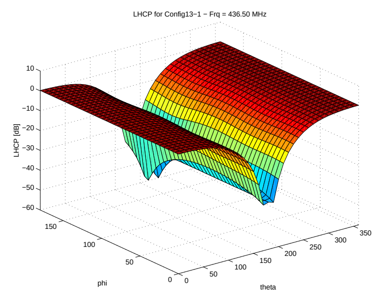


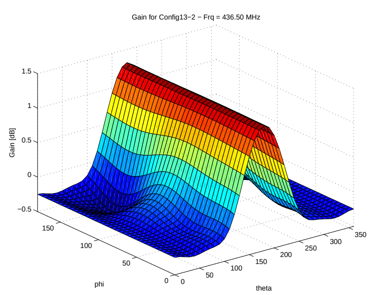


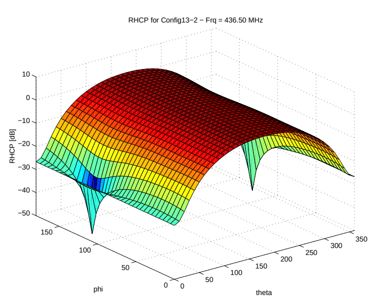


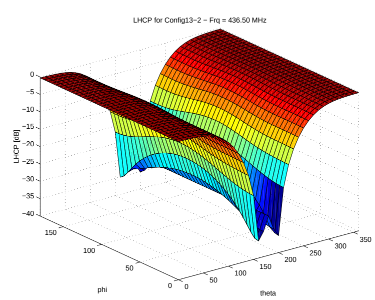

Gain for Config13−1 − Frq = 436.50 MHz
Gain [dB]
phi
theta

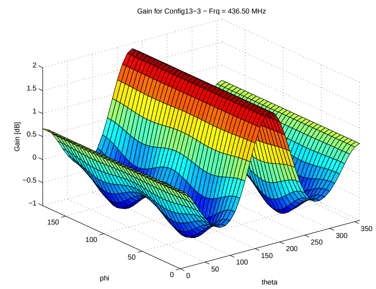

RHCP for Config13−1 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

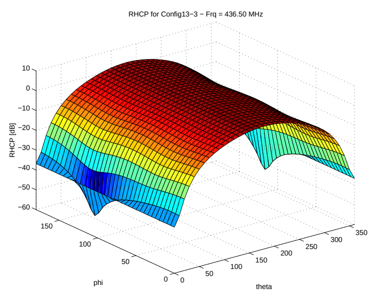

LHCP for Config13−1 − Frq = 436.50 MHz
LHCP [dB]
phi
theta

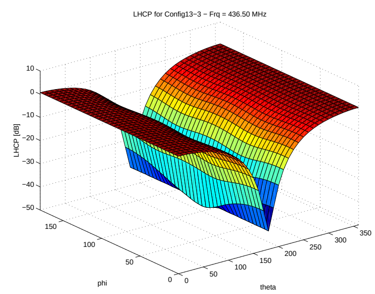

Gain for Config13−2 − Frq = 436.50 MHz
Gain [dB]
phi
theta

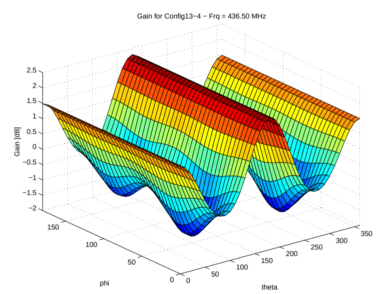

RHCP for Config13−2 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

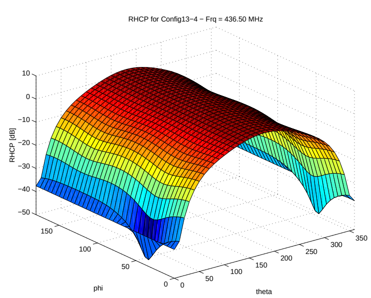

LHCP for Config13−2 − Frq = 436.50 MHz
LHCP [dB]
phi
theta

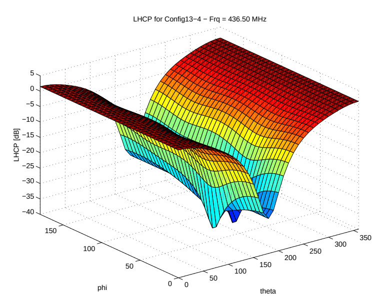

Gain for Config13−3 − Frq = 436.50 MHz
Gain [dB]
phi
theta

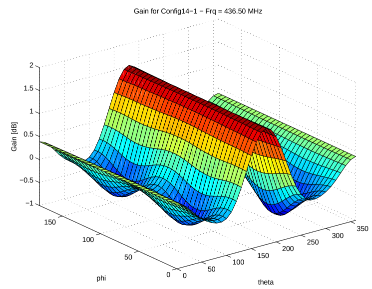

RHCP for Config13−3 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

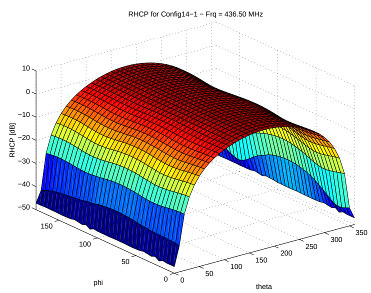

LHCP for Config13−3 − Frq = 436.50 MHz
LHCP [dB]
phi
theta

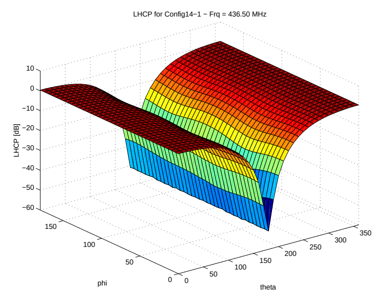

Gain for Config13−4 − Frq = 436.50 MHz
Gain [dB]
phi
theta

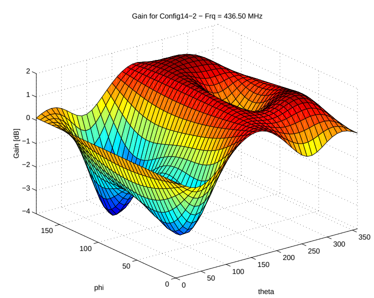

RHCP for Config13−4 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

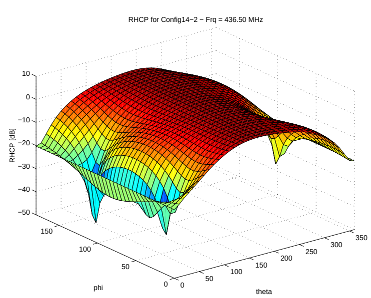

LHCP for Config13−4 − Frq = 436.50 MHz
LHCP [dB]
phi
theta

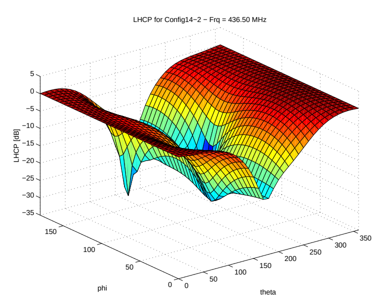

Gain for Config14−1 − Frq = 436.50 MHz
Gain [dB]
phi
theta

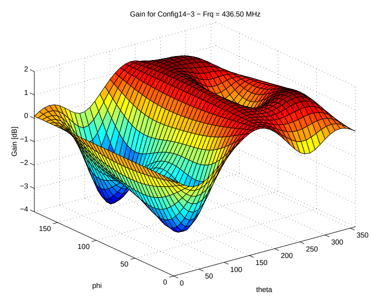

RHCP for Config14−1 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

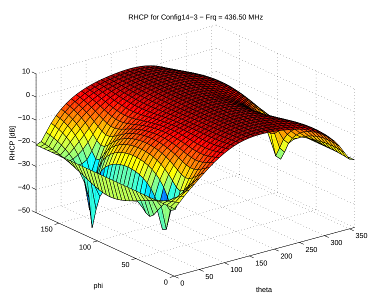

LHCP for Config14−1 − Frq = 436.50 MHz
LHCP [dB]
phi
theta

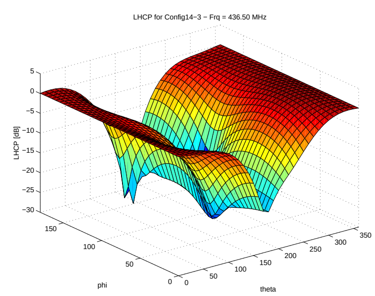

Gain for Config14−2 − Frq = 436.50 MHz
Gain [dB]
phi
theta

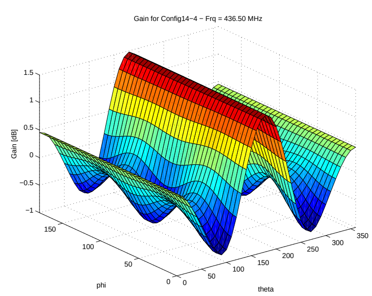

RHCP for Config14−2 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

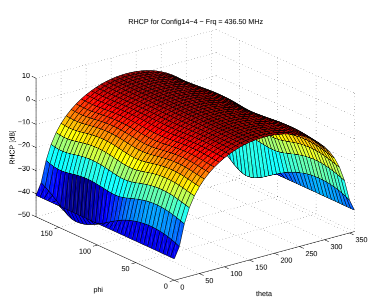

LHCP for Config14−2 − Frq = 436.50 MHz
LHCP [dB]
phi
theta

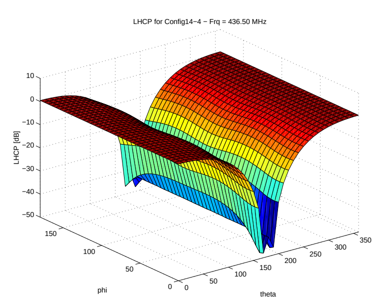

Gain for Config14−3 − Frq = 436.50 MHz
Gain [dB]
phi
theta

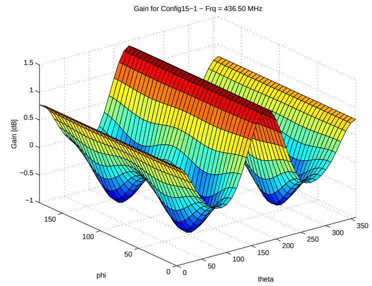

RHCP for Config14−3 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

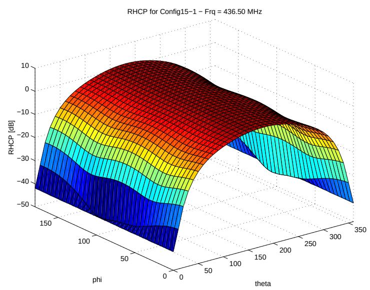

LHCP for Config14−3 − Frq = 436.50 MHz
LHCP [dB]
phi
theta

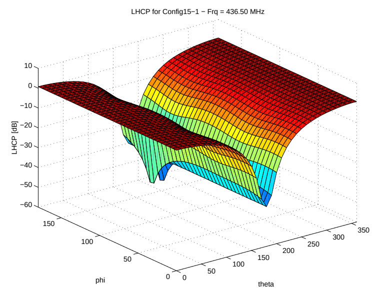

Gain for Config14−4 − Frq = 436.50 MHz
Gain [dB]
phi
theta


RHCP for Config14−4 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

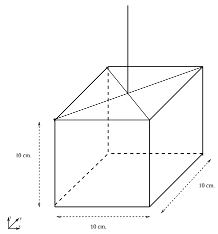

LHCP for Config14−4 − Frq = 436.50 MHz
LHCP [dB]
phi
theta


Gain for Config15−1 − Frq = 436.50 MHz
Gain [dB]
phi
theta

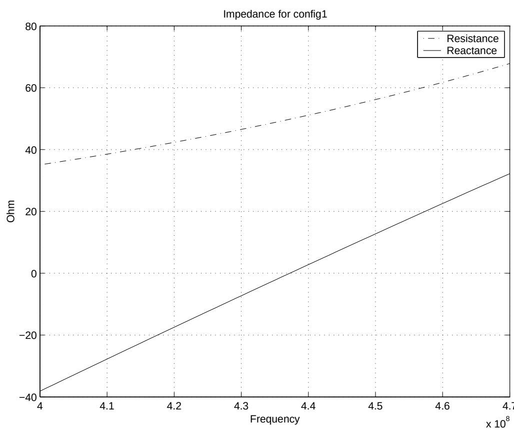

RHCP for Config15−1 − Frq = 436.50 MHz
RHCP [dB]
phi
theta

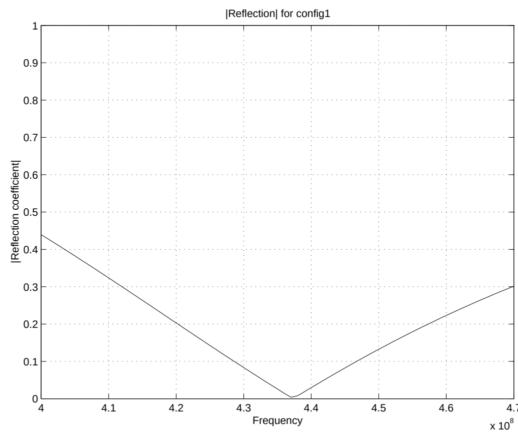

LHCP for Config15−1 − Frq = 436.50 MHz
LHCP [dB]
phi
theta

H Presentation of simulations from AWAS

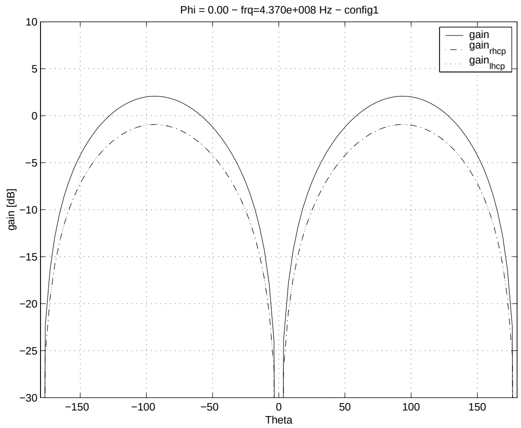


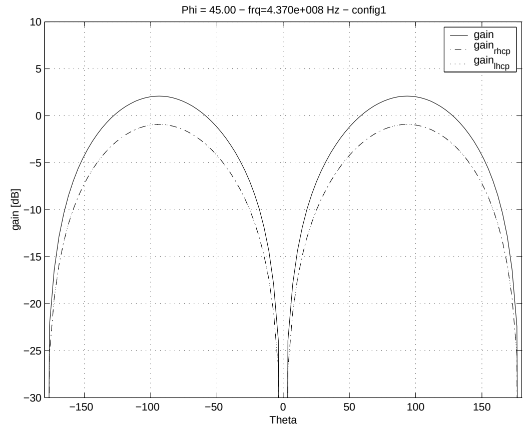
config1	
Program	AWAS
Resonans frq.	4.3700e+008
Resistance.	49.70 Ω
Reaktance	-0.22 Ω
Reflections coe.	0.004
Length of antenna	16.7 cm
Wire radius	1mm

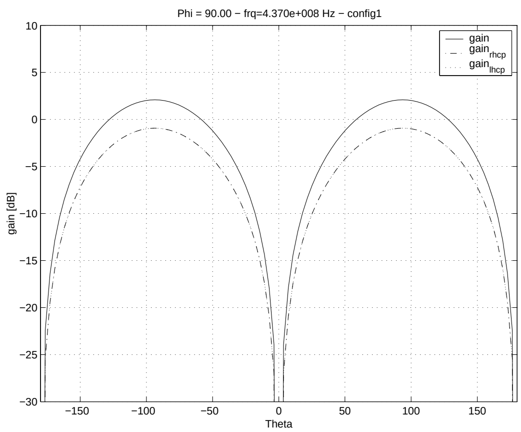


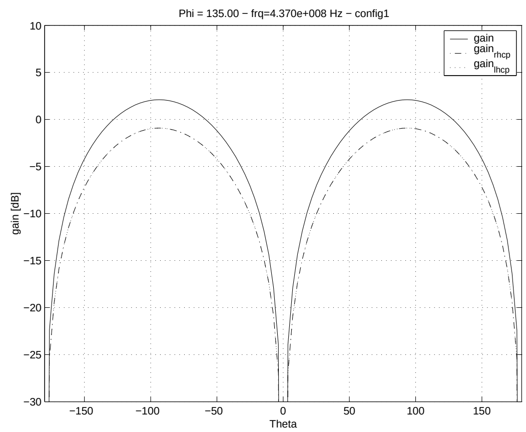


The wires are placed as in the figure. Only crossing wires on one side.







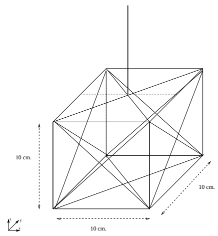


The radiation patterns looks very much like that of a dipole antenna. However the directivity is a little larger and the impedance at the resonans frequency is somewhat lower than that of the dipole. That the antenna behaves much like a dipole is quite understandable, since the structure rather is symmetrical around the antenna, when taking the wavelength into consideration.

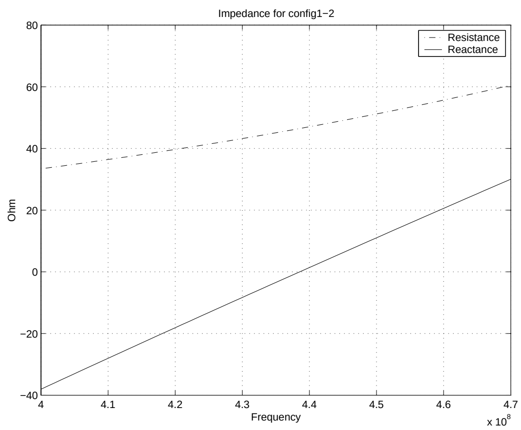
That the gain is 0 in $\theta = 0^o$ is to be expected, because no (time varying)currents in the antenna can generate a **E**-field here. Also this explains for $gain = 0^o$ when $\theta = \pm 180^o$. From the symmetry of the structure we see, that the $\mathbf{E} - field$ created by the induced current on the top or bottom of the structure cancel out at $\theta = 0^o$ and $\theta = \pm 180^o$.

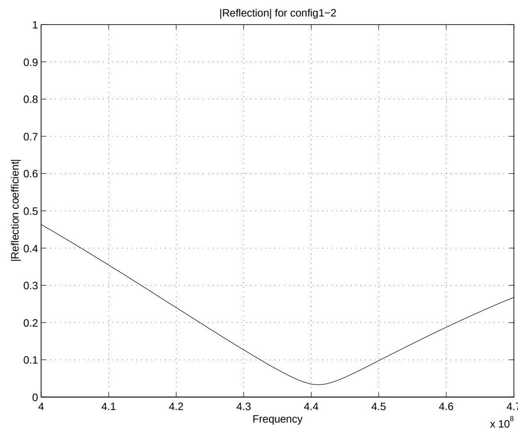
Because the gain[10] tends to zero (-∞ in the plots) for certain angles, this antenna can not be used.

[10]not in dB as in the plots

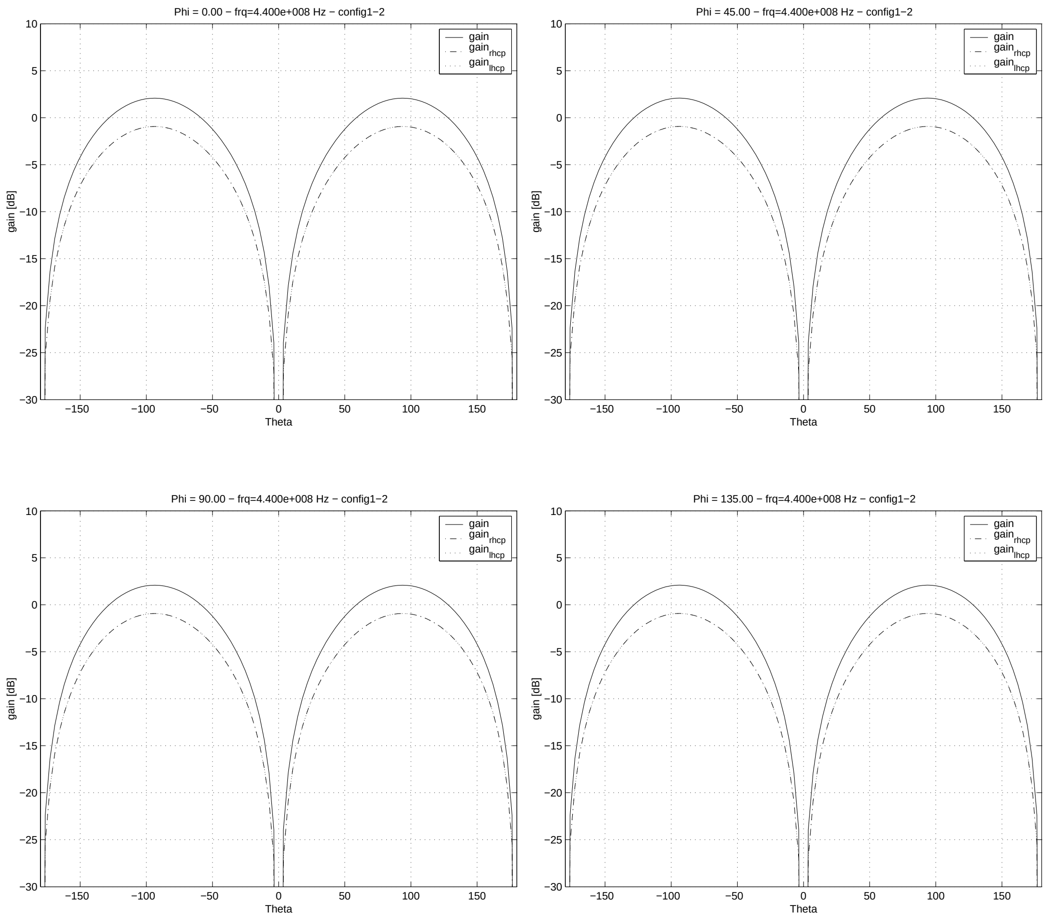


config1-2	
Program	AWAS
Resonans frq.	4.3900e+008
Resistance.	46.64 Ω
Reaktance	0.44 Ω
Reflections coe.	0.035
Length of antenna	16.7cm
Wire radius	1mm

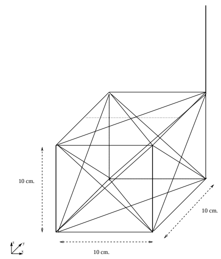




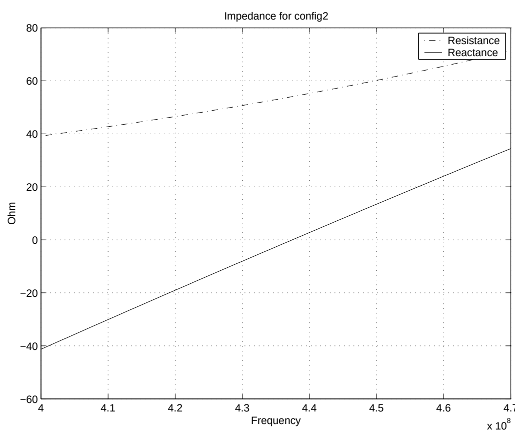
We have now placed wires on all sides of the satellite

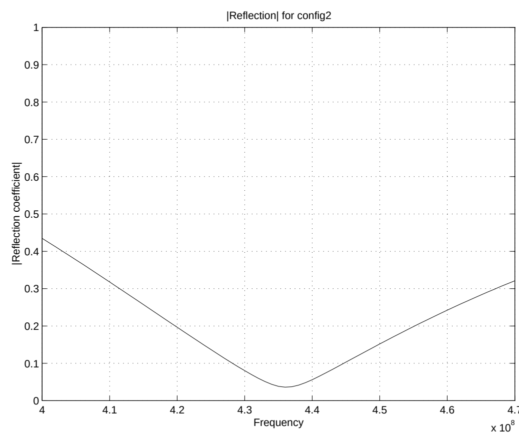


We see that the increased number of wires makes a small change in the resonce frequency and the impedance.

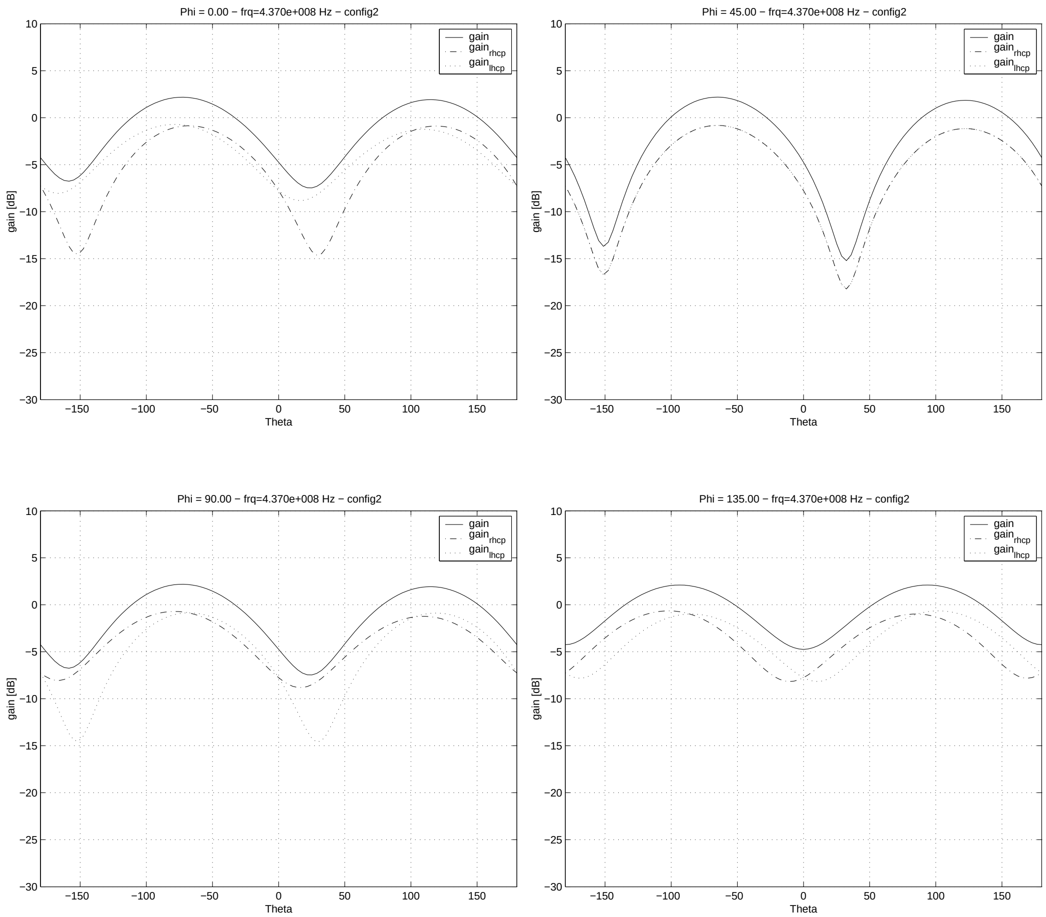


config2	
Program	AWAS
Resonans frq.	4.3700e+008
Resistance.	53.83 Ω
Reaktance	-0.49 Ω
Reflections coe.	0.037
Length of antenna	15.65cm
Wire radius	1mm



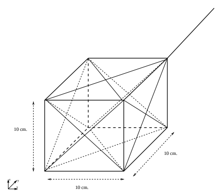


The antenna is fixed at the corner of the satellite and is oriented along the z-axis.

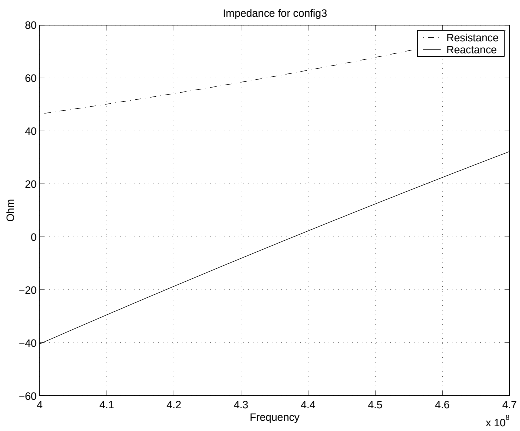


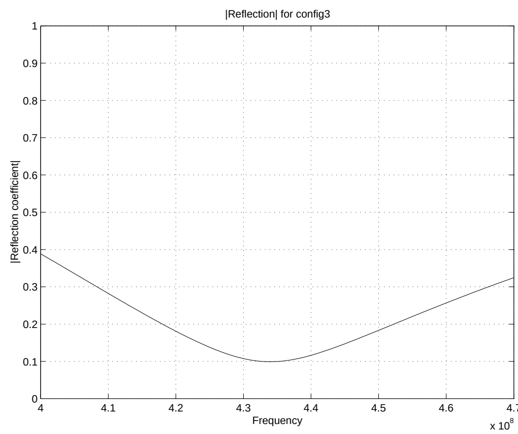
In this configuration one would expect symmetry around $\phi = 45^o$. This is validated by looking at the plots for $\phi = 0^o$ and $\phi = 90^o$ where the expected symmetry appears. A thing that further assures one of the reliability of the plots is the plot for $\phi = 45^o$, where one finds the expected 3 dB between the gain and each of the partial circularly polarized gains.

As a matter of fact this is not a very bad candidate for an antenna. If one assumes that the earth station can toggle between *lhcp* and *rpch* there are very few places where it is not possible to receive a signal over -10 dB. Actually it is only around $\phi = 45$, there is a risk of not receiving a signal. However this is still enough to discard it as a candidate.

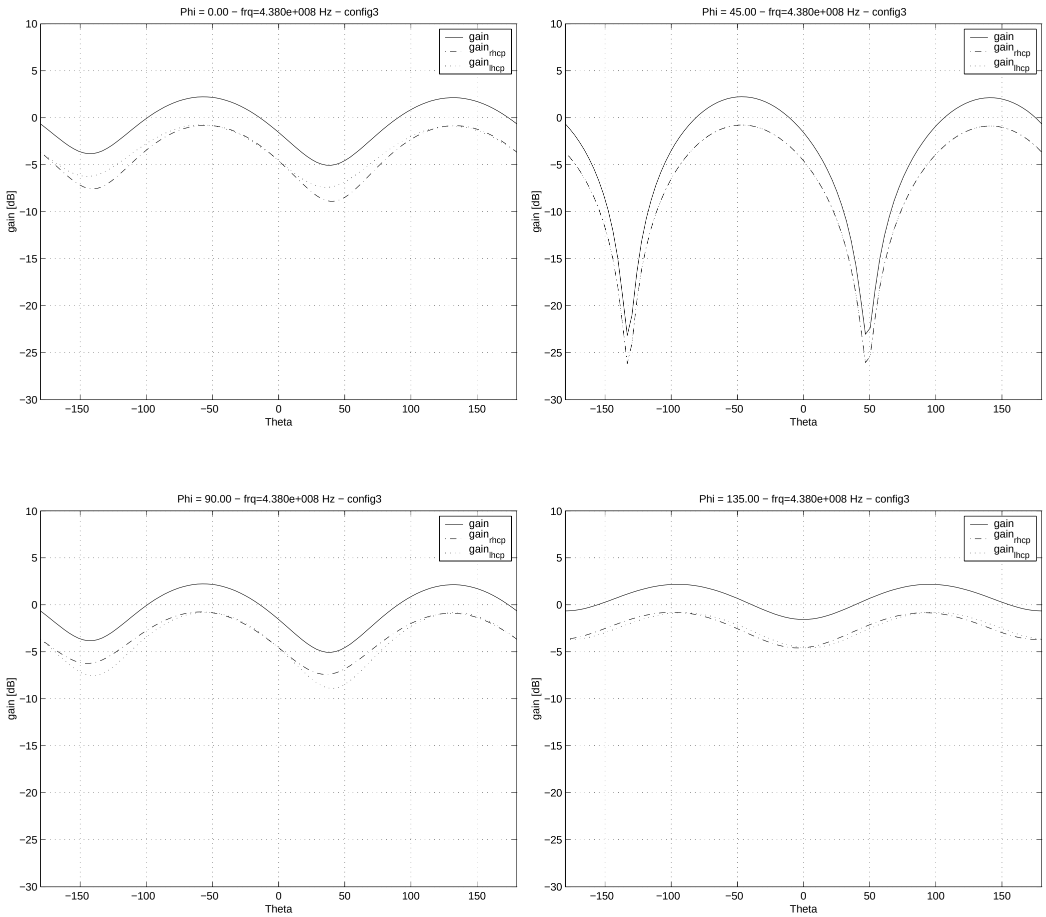


config3	
Program	AWAS
Resonans frq.	4.3800e+008
Resistance.	62.01 Ω
Reaktance	0.19 Ω
Reflections coe.	0.107
Length of antenna	15.07cm
Wire radius	1mm



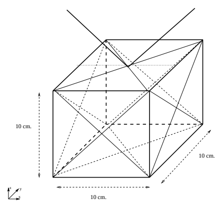


The antenna is fixed at the corner of the satellite. It makes an angle of 45^o with the z-axis, the xy-plane, the x-plane and the yz-plane. That is, θ is 45^o and ϕ is 45^o.

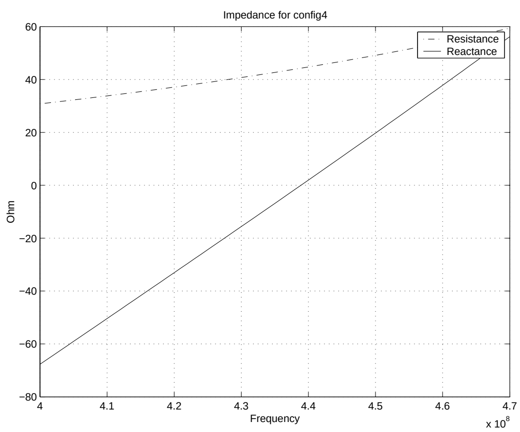


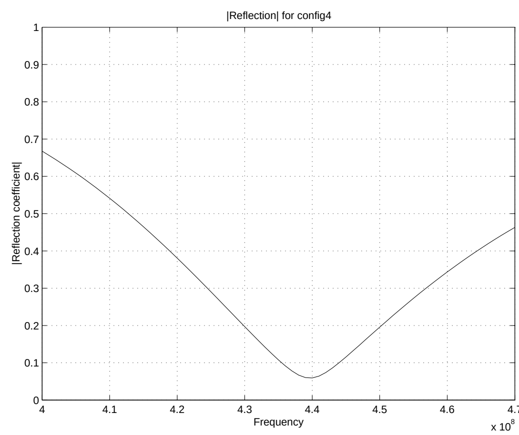
The most interesting is that the $gain = 0$ in the $\phi = 45$ plane when $\theta \approx 50$ and $\theta \approx 125$ and not when $\theta \approx 45$, which is the angle between the antenna and the z-axis. It is also notable that in all the other planes (than $\phi = 45$) the partial gains, $rhcp$ and $lhcp$, are identical and 3dB below the total gain –as would be expected.

Because the gain tends to zero (-∞ in the plots) for certain angles, this antenna can not be used.

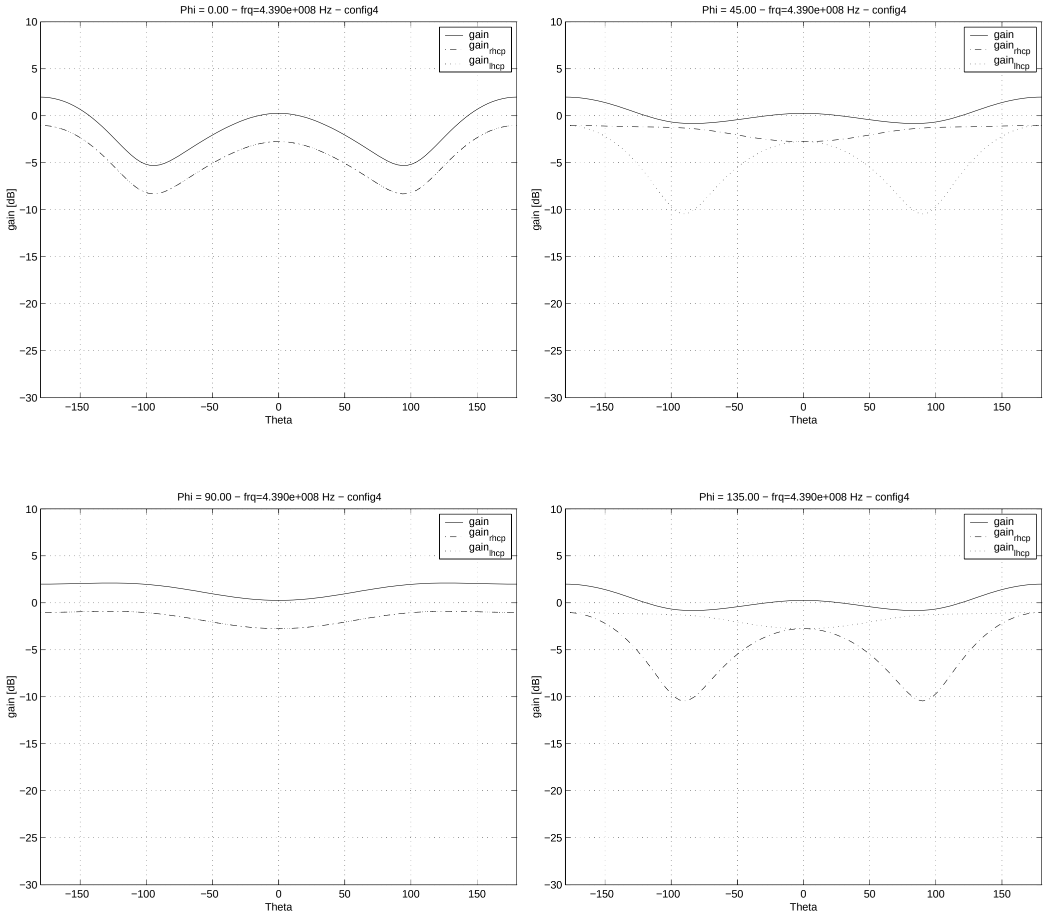


config4	
Program	AWAS
Resonans frq.	4.3900e+008
Resistance.	44.33 Ω
Reaktance	0.21 Ω
Reflections coe.	0.060
Length of antenna	17.42cm
Wire radius	1mm



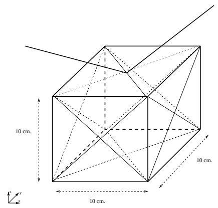


The antenna is fixed at the center of the satellite having an angle of 45^o to the z-axis and lying in the xz-plane.

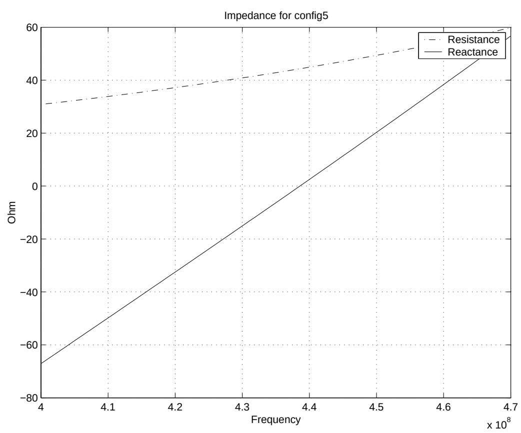


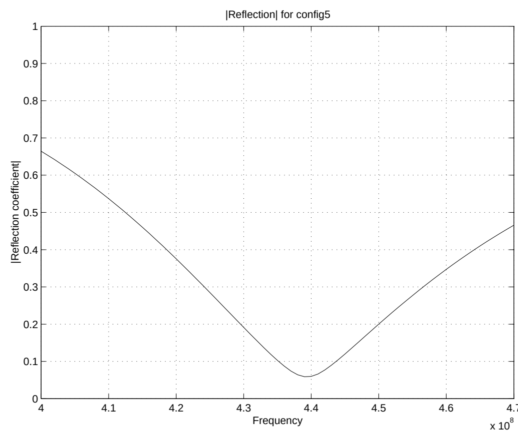
The symmetry for the xz-plane is obvious, since the plots for $\phi = 45^o$ are $\phi = 135^o$ are identical except for the expected shift of the polarized signals. The plots actually have similarities with those of Config1, and thus with a dipole, which could be expected when regarding the symmetry around the antenna. However these plots are much more pleasant, considering the specifications.

Keeping in mind the toggling earth station, there are no real problems. Though for $\phi = 0^o$ there are some gaps where the signal slips below -7 dB. But not a bad candidate.

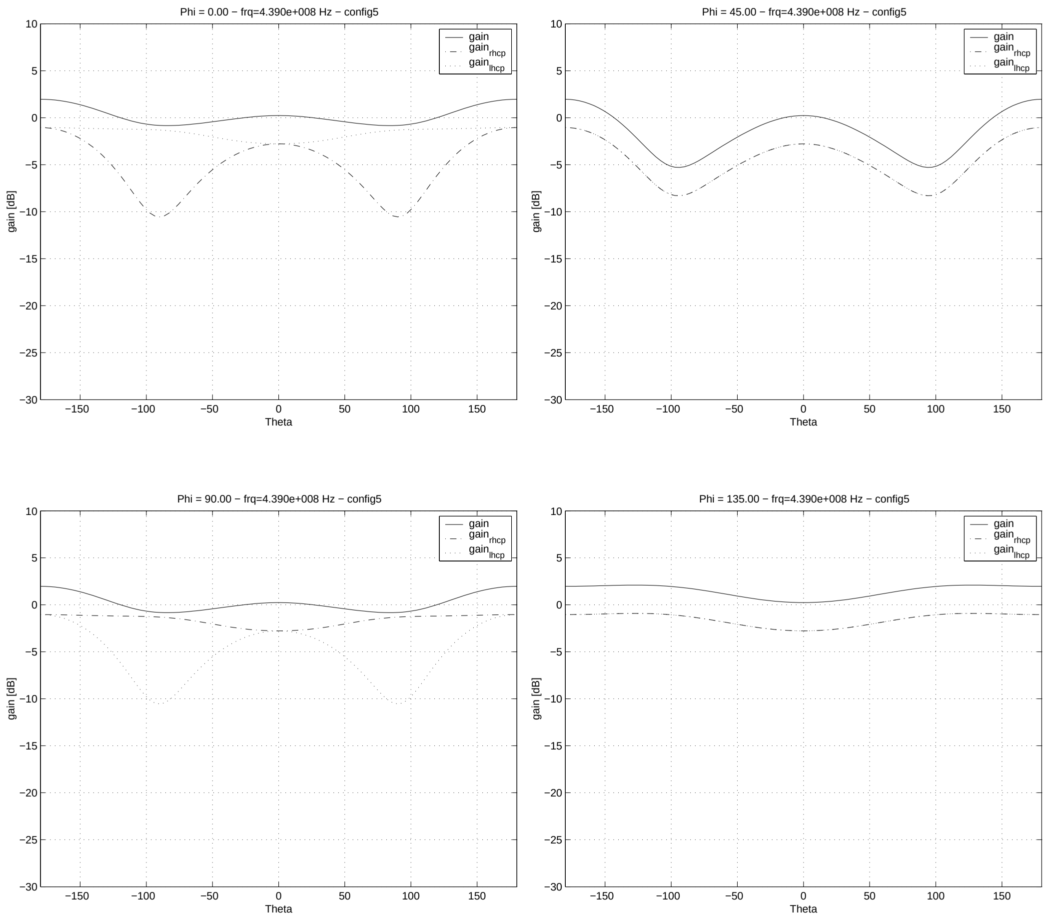


config5	
Program	AWAS
Resonans frq.	4.3900e+008
Resistance.	44.48 Ω
Reaktance	0.73 Ω
Reflections coe.	0.059
Length of antenna	17.68 cm
Wire radius	1mm



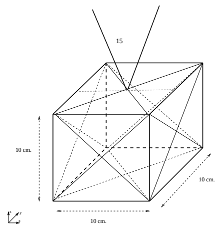


The antenna is fixed at the center of the satellite each antenna arm forming an angle of 45^o with the z-axis. One arm with $\phi = 45^o$ and one with $\phi = 225^o$.

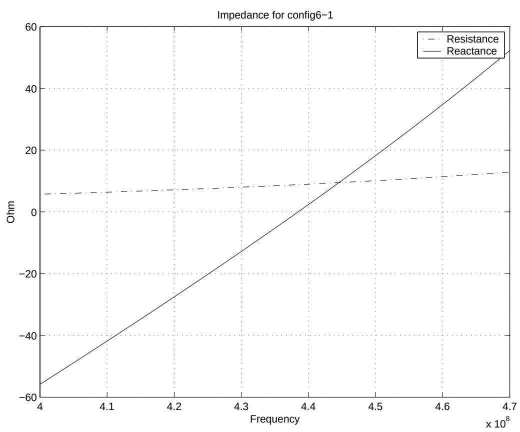


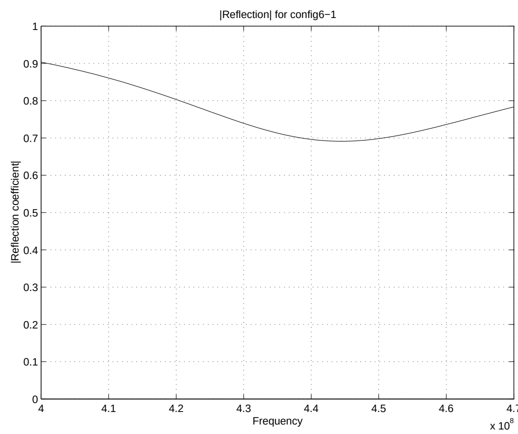
Once again our expectations on symmetry are fulfilled. As can be seen from the figure (of the satellite), symmetry should be found around $\phi = 45^o$. And so it is. Actually these plots are almost identical with those of Config4, keeping in mind the different placements of the antennas. This necessarily means, that whatever symmetry is connected with the currents in Config4 does not depend on whether the antennas are placed at the sides or in the corners.

Just as good a candidate as Config4 with the same reservation on the gaps, where the signal slips below -7 dB.

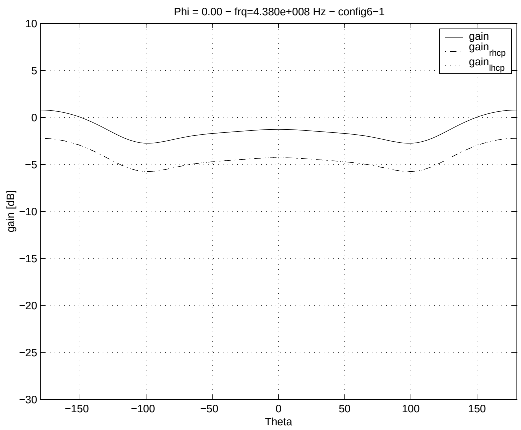


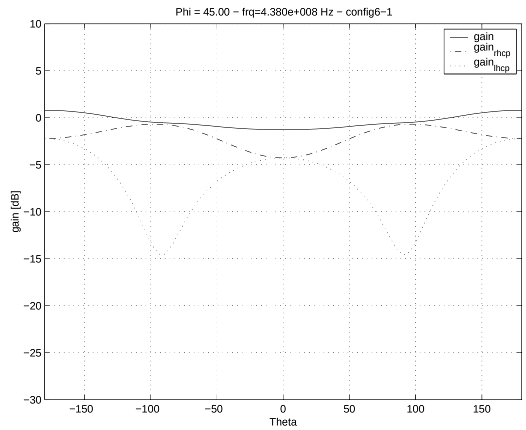
config6-1	
Program	AWAS
Resonans frq.	4.3800e+008
Resistance.	8.77 Ω
Reaktance	-0.71 Ω
Reflections coe.	0.702
Length of antenna	19.56cm
Wire radius	1mm

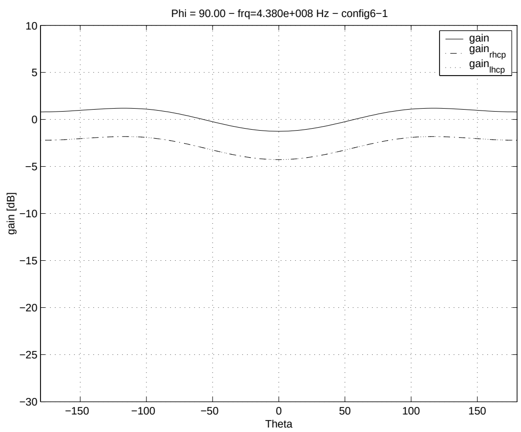


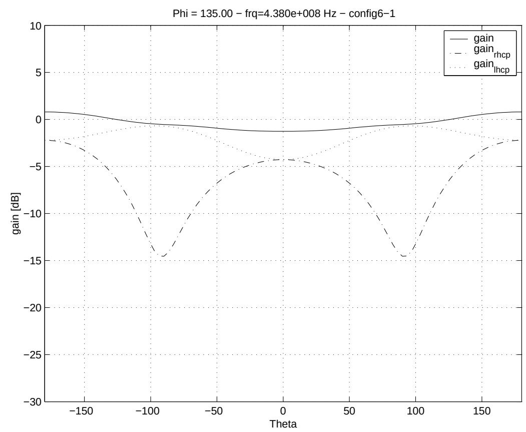


Variations over Config4. The angle between the antennas and the z-axis is $\theta = 15^0$

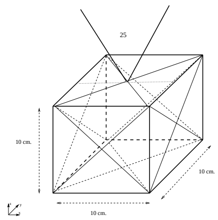




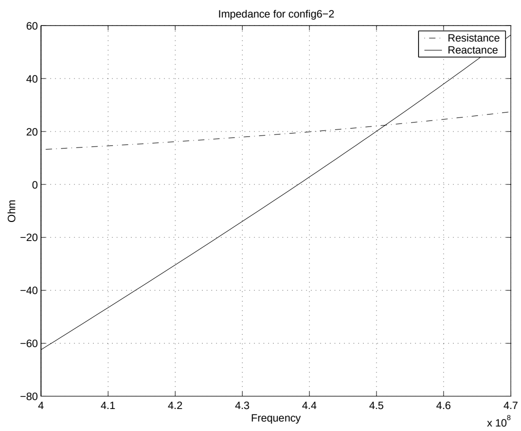


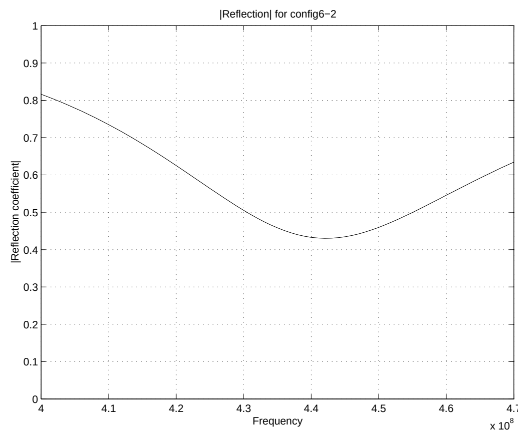


The radiation is more evenly distributed than in Config4

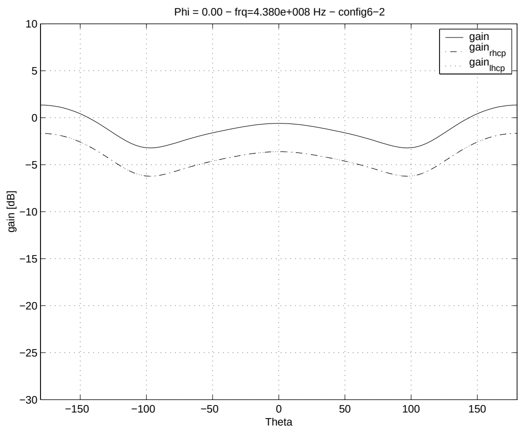


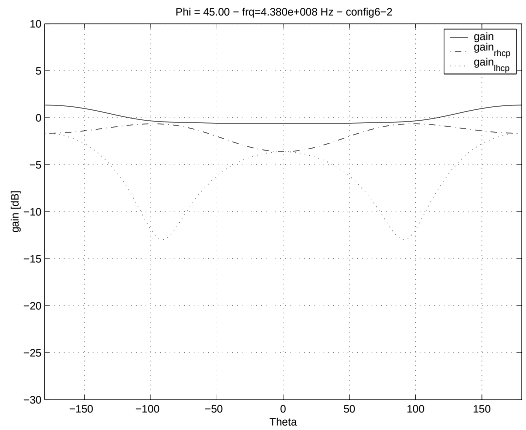
config6-2	
Program	AWAS
Resonans frq.	4.3800e+008
Resistance.	19.45 Ω
Reaktance	-0.58 Ω
Reflections coe.	0.440
Length of antenna	18.67cm
Wire radius	1mm

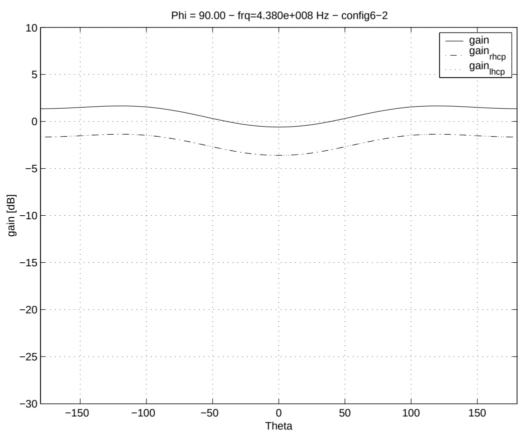


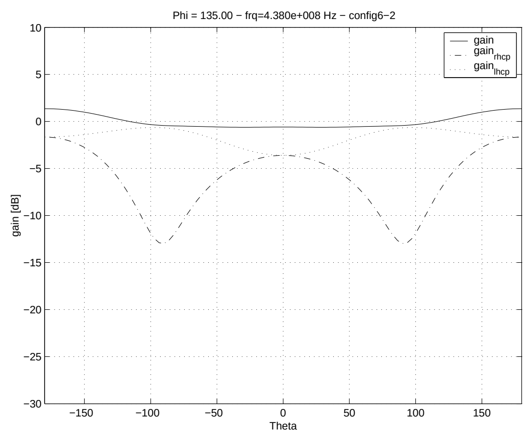


Variations over Config4. The angle between the antennas and the z-axis is $\theta = 25^0$

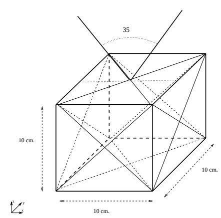




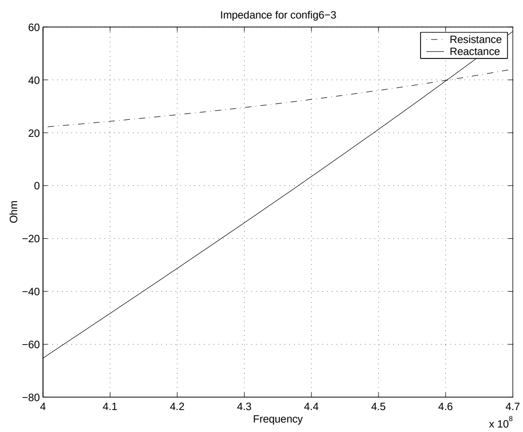


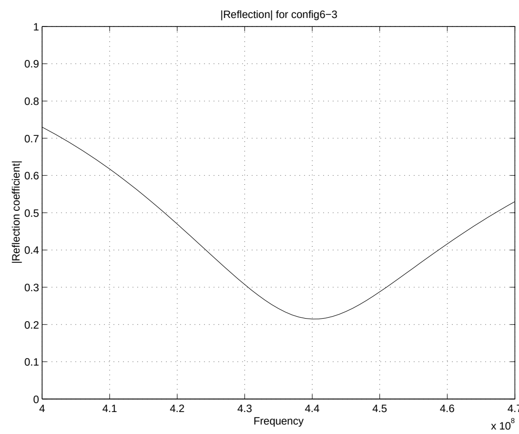


More variation in the radiation than in Config6-2

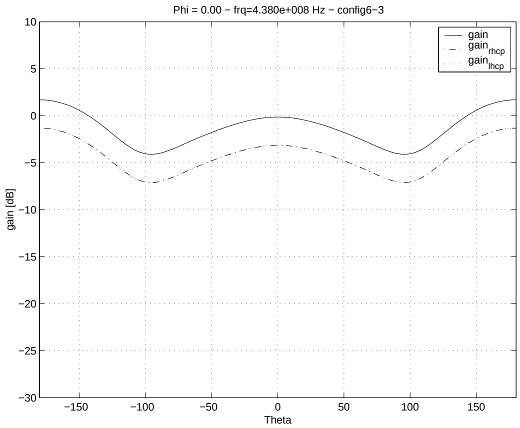


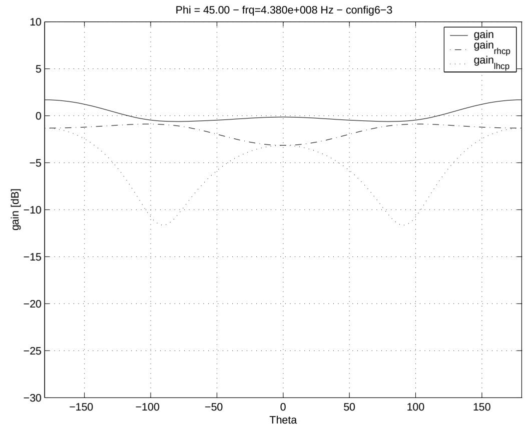
config6-3	
Program	AWAS
Resonans frq.	4.3800e+008
Resistance.	31.96 Ω
Reaktance	-0.08 Ω
Reflections coe.	0.220
Length of antenna	18.08cm
Wire radius	1mm

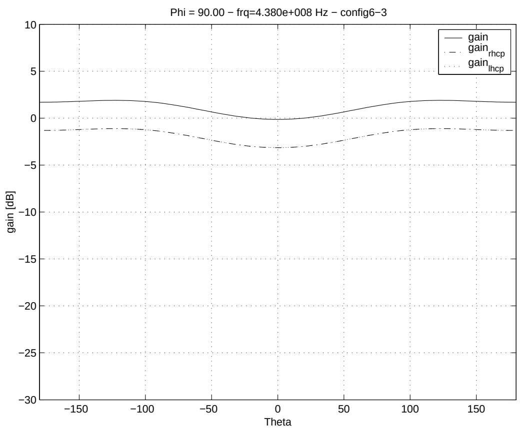


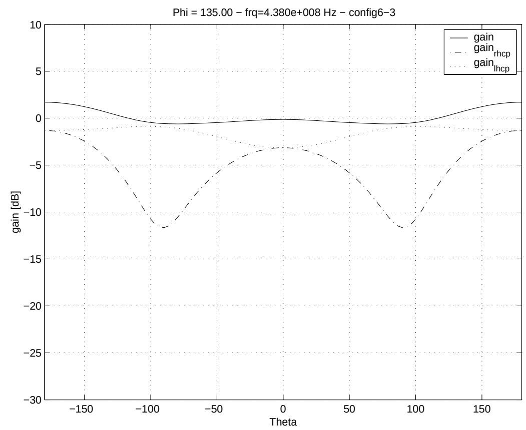


Variations over Config4. The angle between the antennas and the z-axis is $\theta = 35^0$

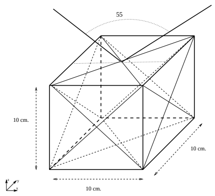




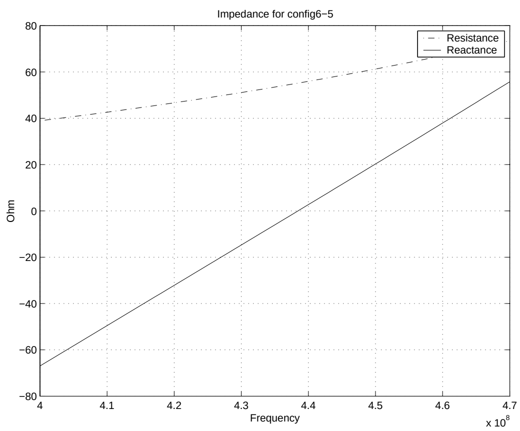


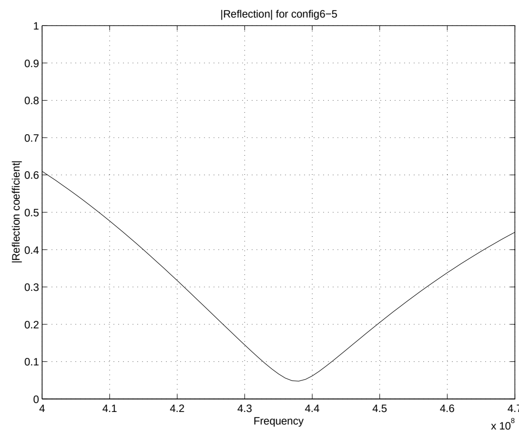


Even more variation

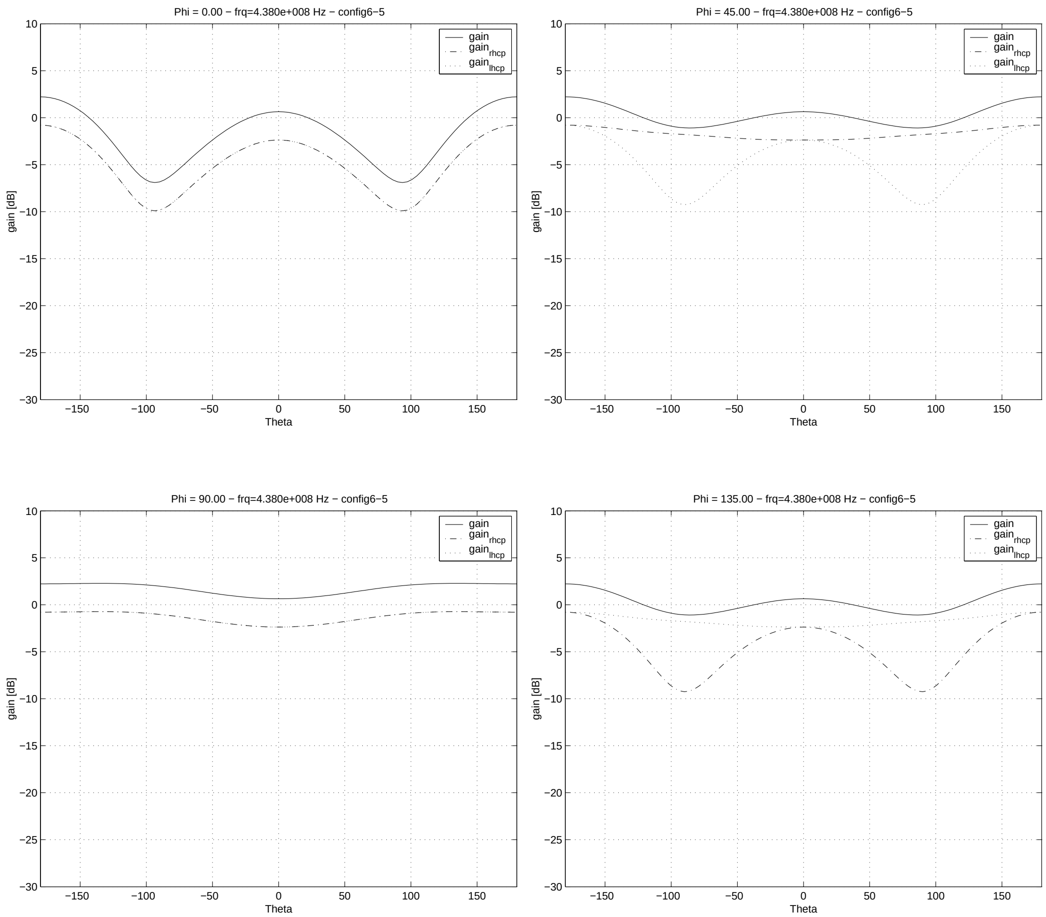


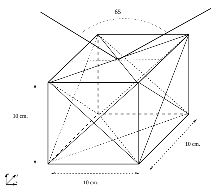
config6-5	
Program	AWAS
Resonans frq.	4.3800e+008
Resistance.	54.94 Ω
Reaktance	-0.78 Ω
Reflections coe.	0.048
Length of antenna	17.38cm
Wire radius	1mm



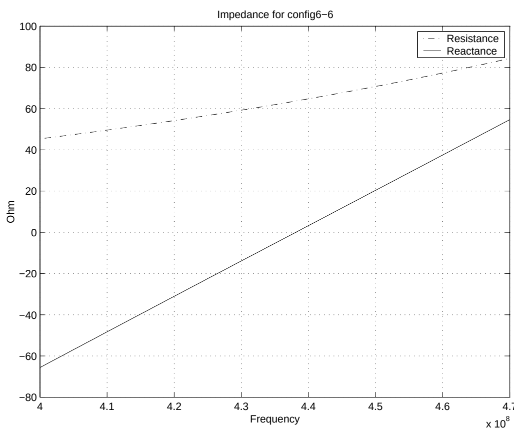


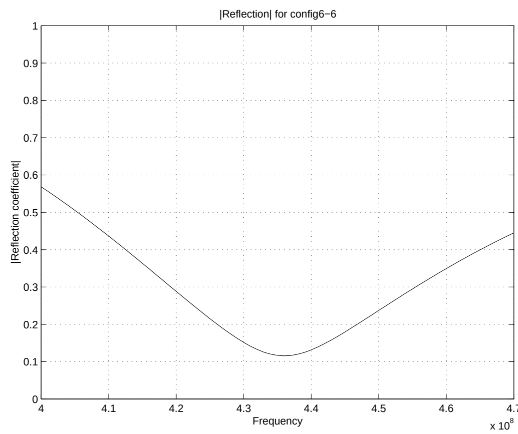
Variations over Config4. The angle between the antennas and the z-axis is $\theta = 55^0$


Phi = 0.00 − frq=4.380e+008 Hz − config6−5
Phi = 45.00 − frq=4.380e+008 Hz − config6−5
Phi = 90.00 − frq=4.380e+008 Hz − config6−5
Phi = 135.00 − frq=4.380e+008 Hz − config6−5
gain
gain rhcp
gain lhcp
gain [dB]
Theta

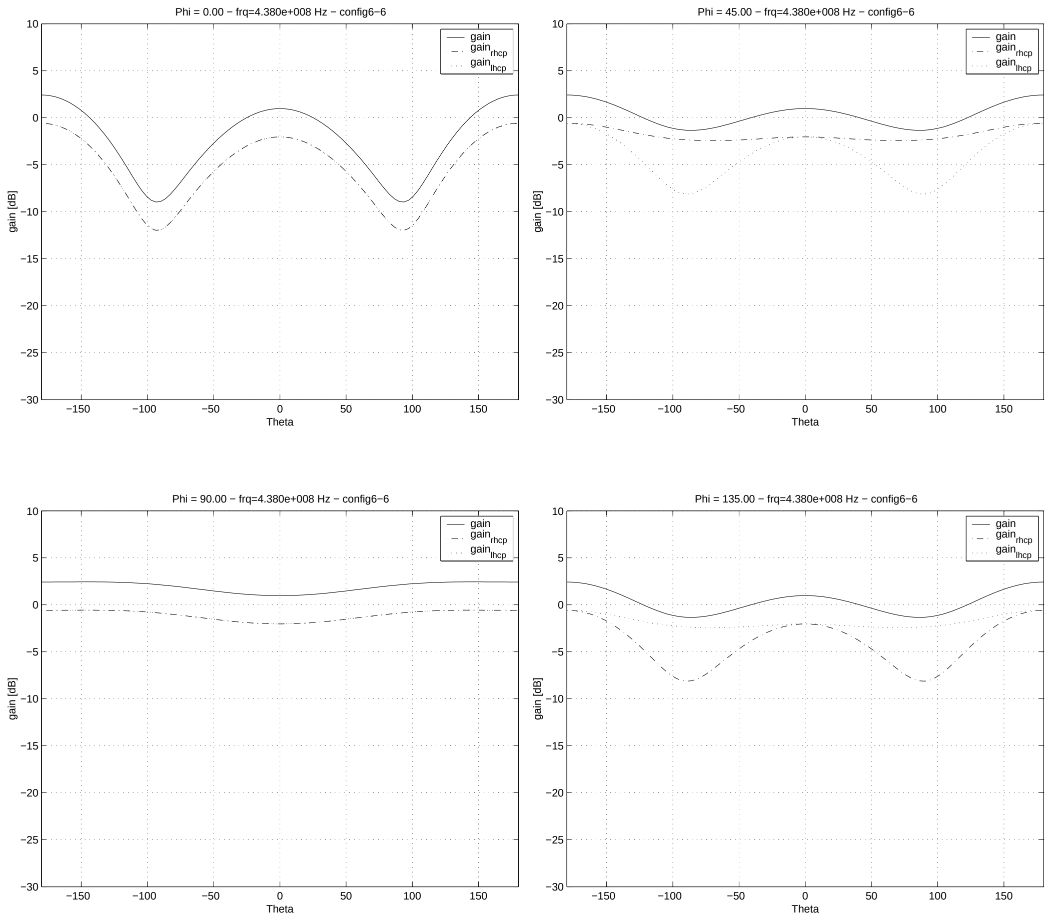


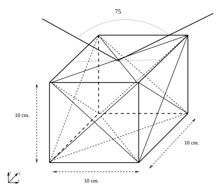
config6-6	
Program	AWAS
Resonans frq.	4.3800e+008
Resistance.	63.61 Ω
Reaktance	-0.20 Ω
Reflections coe.	0.120
Length of antenna	17.23cm
Wire radius	1mm



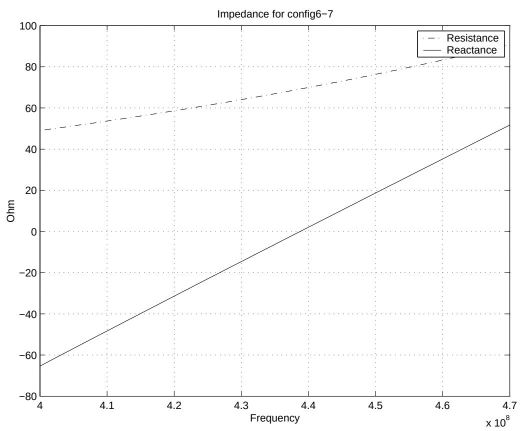


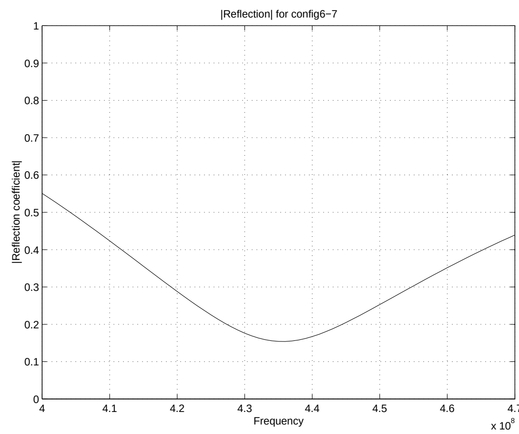
Variations over Config4. The angle between the antennas and the z-axis is $\theta = 65^o$


Phi = 0.00 − frq=4.380e+008 Hz − config6−6
Phi = 45.00 − frq=4.380e+008 Hz − config6−6
Phi = 90.00 − frq=4.380e+008 Hz − config6−6
Phi = 135.00 − frq=4.380e+008 Hz − config6−6
gain
gain rhcp
gain lhcp
gain [dB]
Theta
10
5
0
−5
−10
−15
−20
−25
−30
−150
−100
−50
0
50
100
150

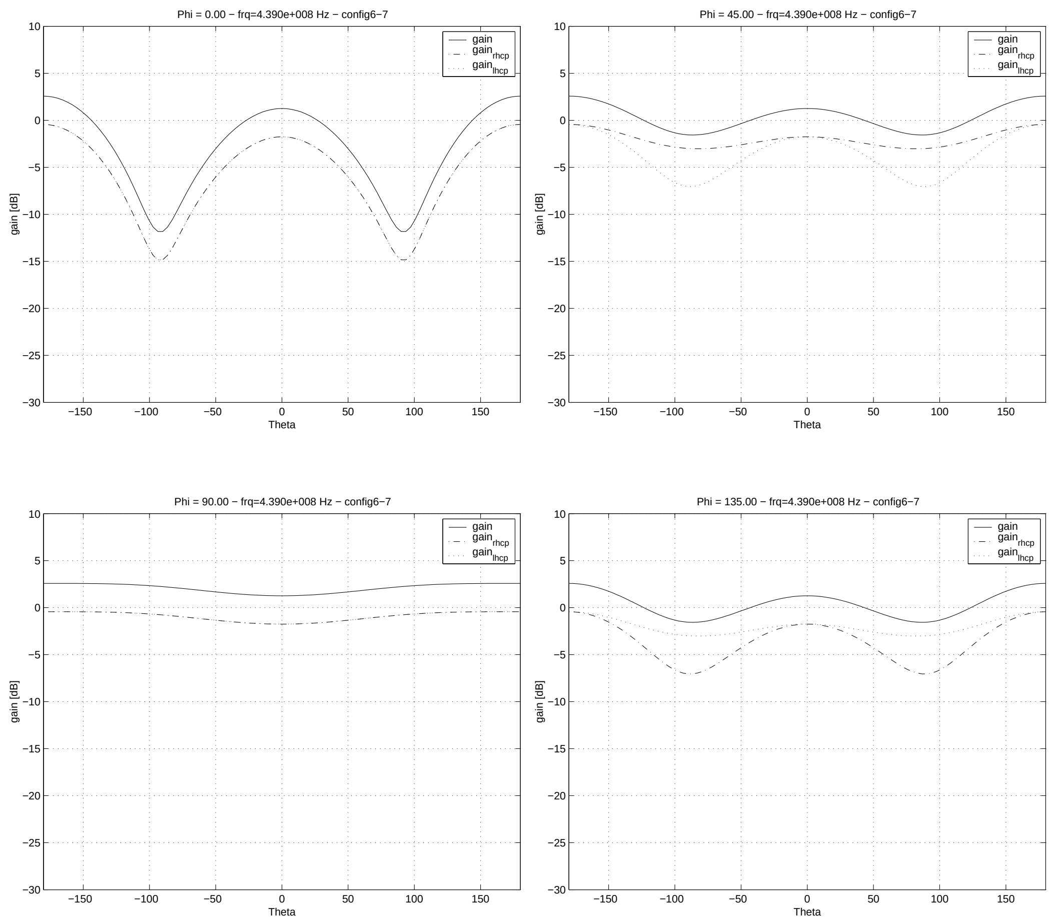


config6-7	
Program	AWAS
Resonans frq.	4.3900e+008
Resistance.	69.33 Ω
Reaktance	0.41 Ω
Reflections coe.	0.162
Length of antenna	17.13cm
Wire radius	1mm

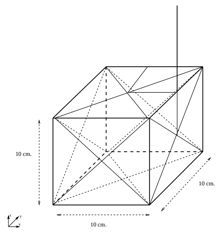




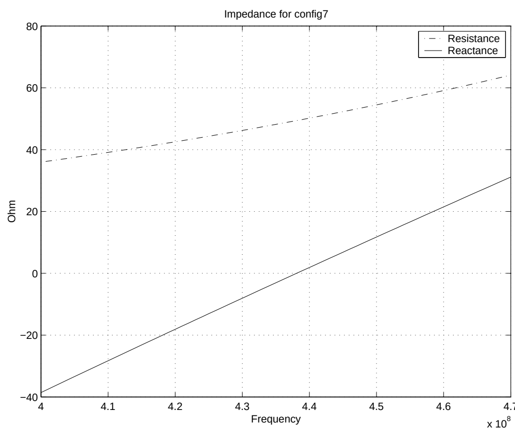
Variations over Config4. The angle between the antennas and the z-axis is $\theta = 75^0$

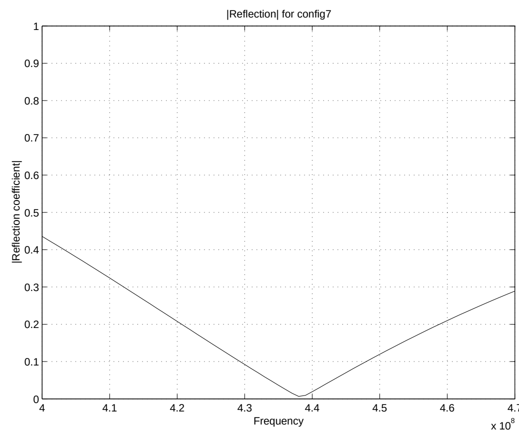


Generally we have seen from the Config6 series that a small angle with the z-axis results in a more flat radiation pattern especially in the $\phi = 0^o$ plane

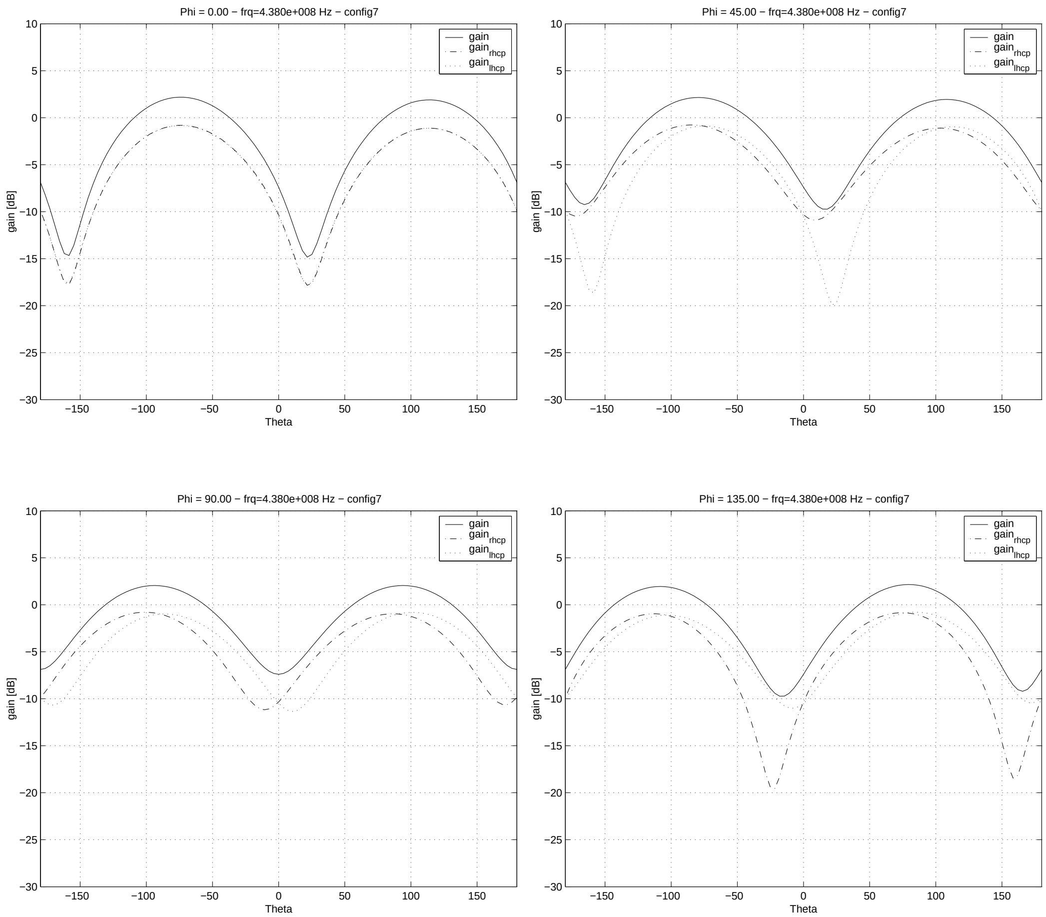


config7	
Program	AWAS
Resonans frq.	4.3800e+008
Resistance.	49.37 Ω
Reaktance	-0.09 Ω
Reflections coe.	0.006
Length of antenna	16.3 cm
Wire radius	1mm





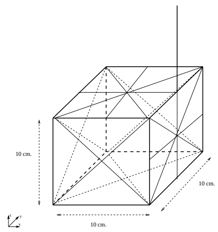
The antenna is fixed at the side of the satellite. It lies in the xz-plane and is parallel to the z-axis.



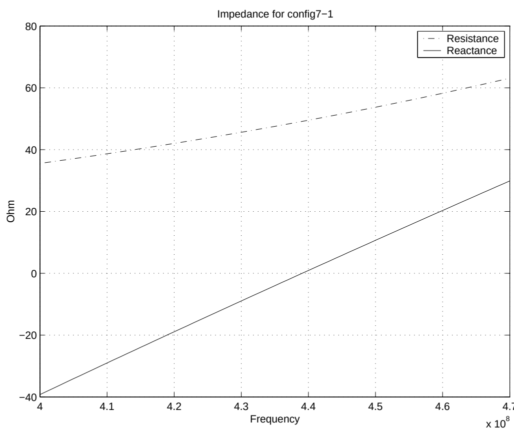
The most exciting thing here is that the gain does not tend to zero anywhere ($-\infty$ in the dB scale). Not even in the directions parallel to the antenna. This is quite different from Config1. The reason is, that the **E**-fields that are created by the induced currents on the structure, does not cancel out as they did in config1. This is because we do not have the same symmetry of the structure around the antenna. This shows that the box functions as a scatter eventhough it is very small compared to the wavelength.

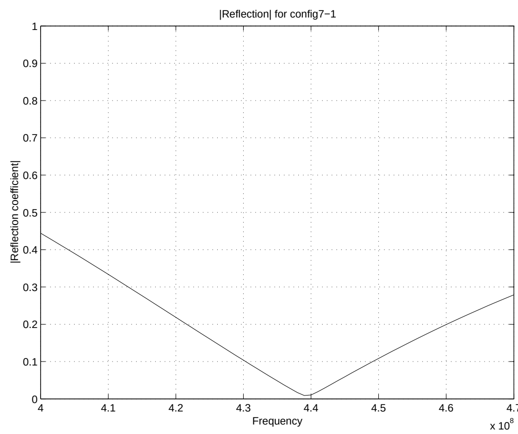
We also notice that the $\phi = 45^o$ and $\phi = 135^o$ planes are identical, except that *lhcp* and *rhcp* have changed place. This is accountable for because of the symmetry around the antenna in these angles.

The configuration is not usable as the partial gains of *rhcp* and *lhcp* for some directions are very low.

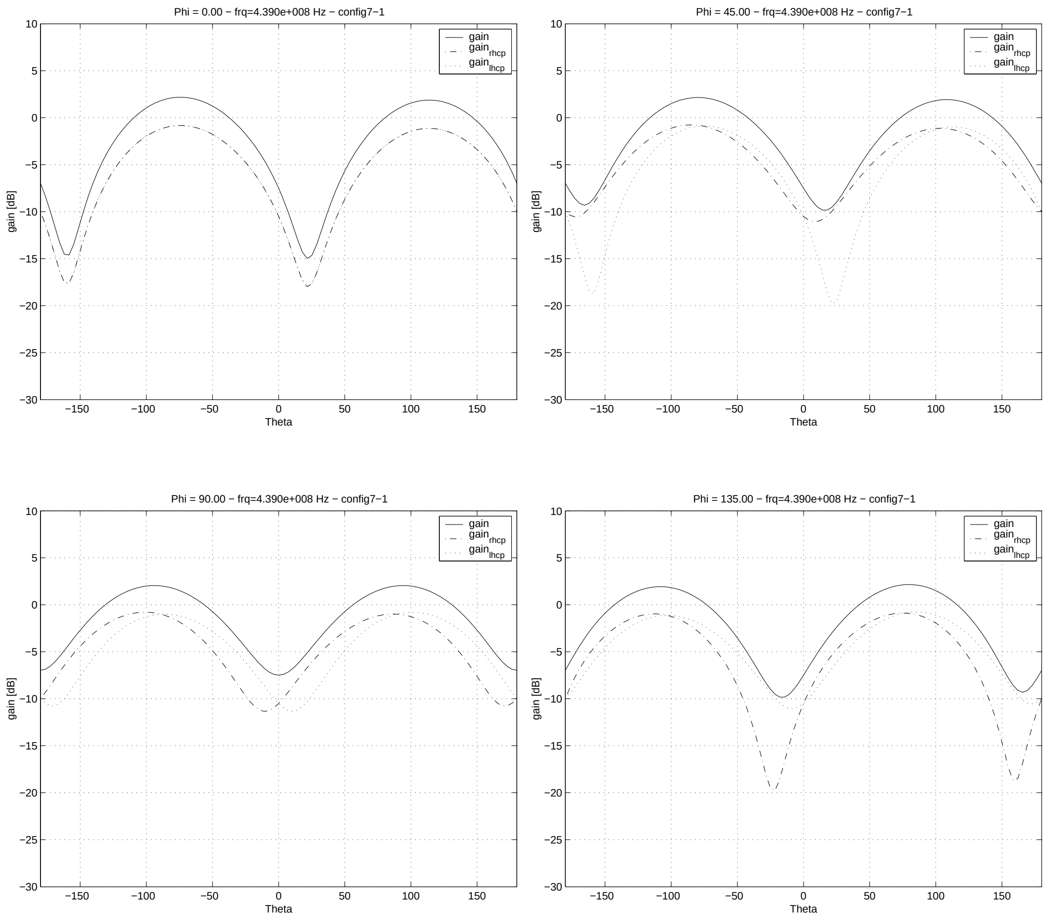


config7-1	
Program	AWAS
Resonans frq.	4.3900e+008
Resistance.	49.12 Ω
Reaktance	-0.07 Ω
Reflections coe.	0.009
Length of antenna	16.3cm
Wire radius	1mm

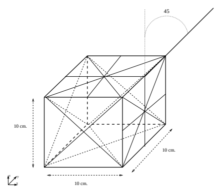




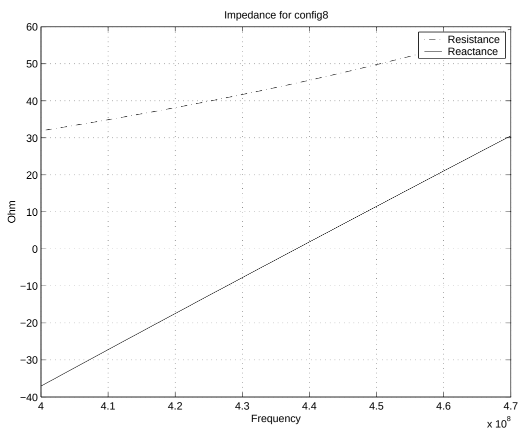
The same as Config7 only with more wires added

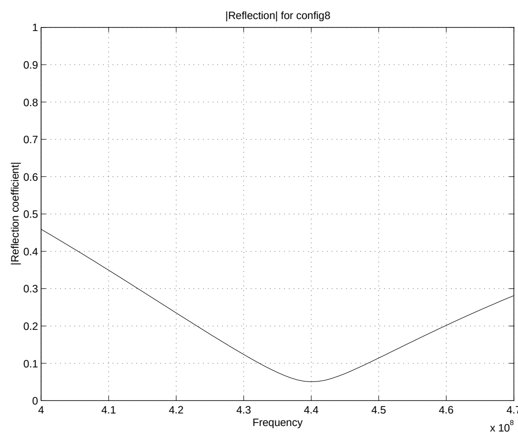


A small difference between this and Config7 is seen, but not enough to excuse the troubles of adding more wires to all the following configurations

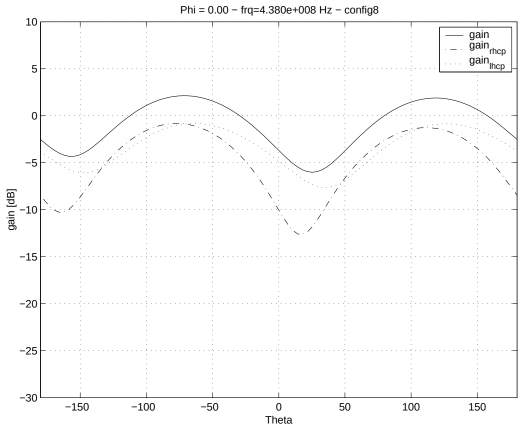


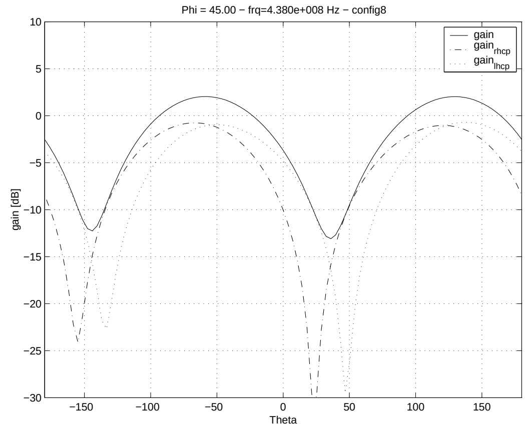
config8	
Program	AWAS
Resonans frq.	4.3800e+008
Resistance.	44.76 Ω
Reaktance	-0.05 Ω
Reflections coe.	0.055
Length of antenna	16.86cm
Wire radius	1mm

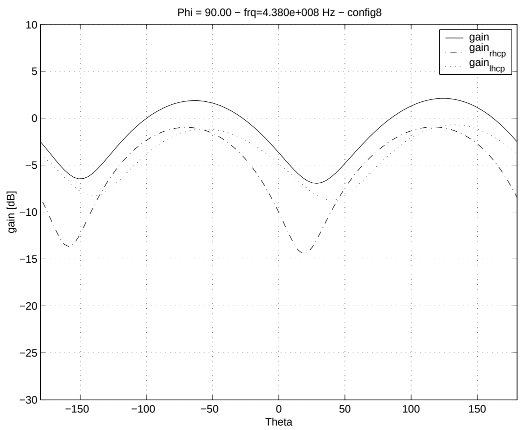


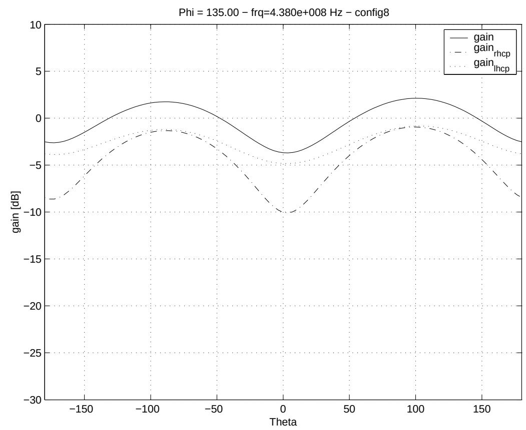


The antenna is fixed at the side of the satellite. It lies in the xz-plane and the angle to the z-axis is 45^o. That is, $\theta = 45^o$ and $\phi = 0^o$.



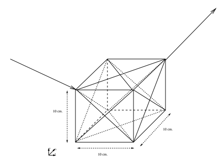






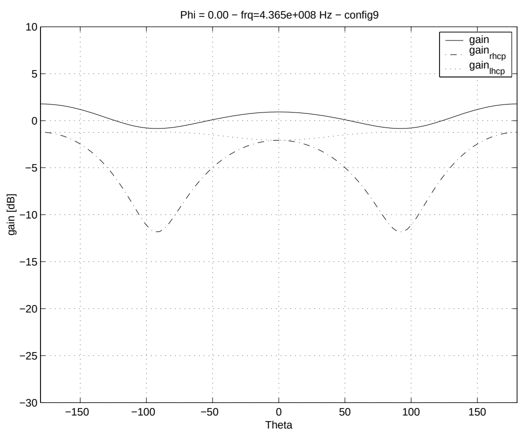
In the $\phi = 0$ plane the gain tends to 0 when θ is around 45^o and 135^o. This is understandable, because in these angles the structure is symmetric with respect to the antenna so that the **E**-fields that are created by the induced currents on the structure cancels out. Where the partial gain of *rhcp* and *lhcp* are identical they are both 3dB below the gain.

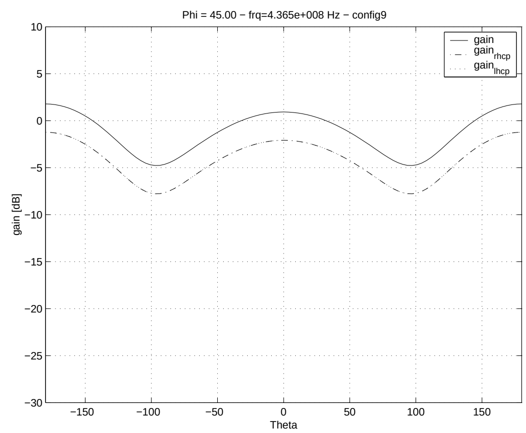
The configuration is not usable because it has zeros in the radiation pattern.

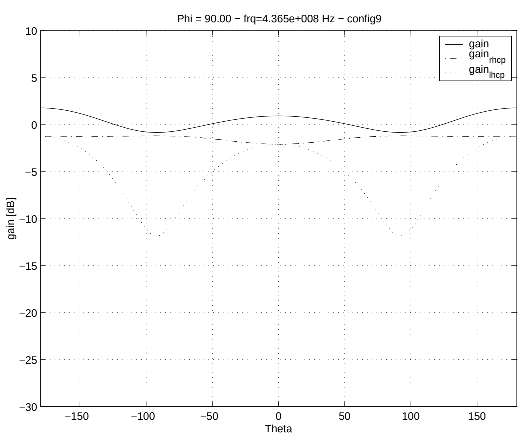


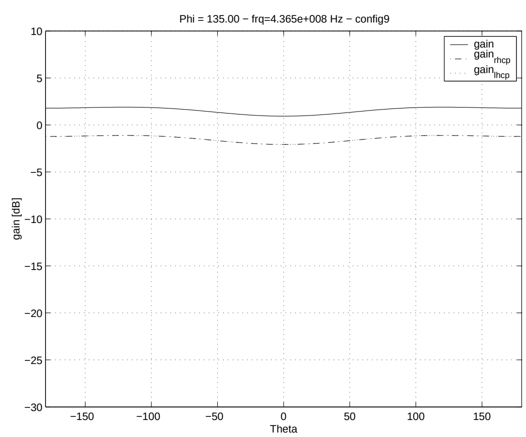
config9	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are fixed in the corners of the satellite, each with $\theta = 45^o$, $\phi = 45^o$ for one of them and $\phi = 225^o$ for the other. The generators are defined, so the phase is 0^o as illustrated on the figure.



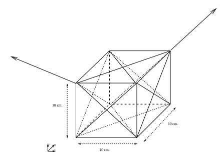






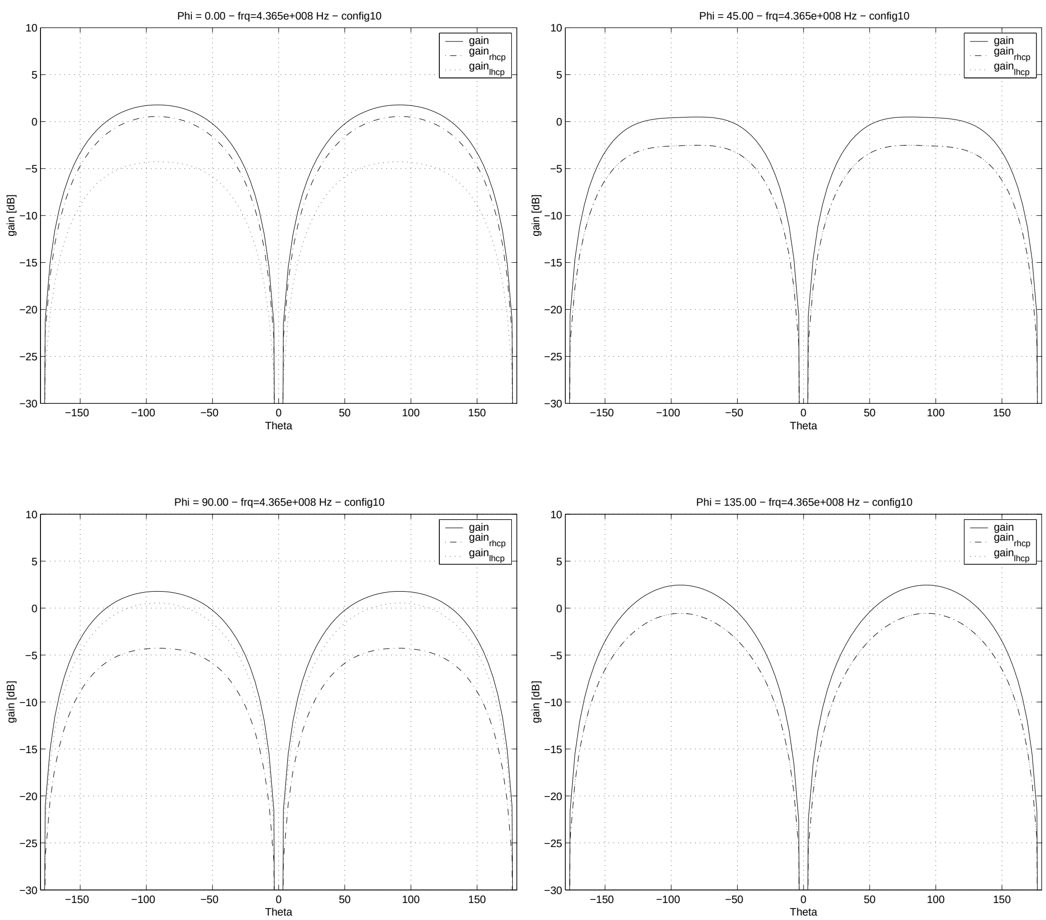
Once again the expected symmetry is fulfilled. This time for $\phi = 0^o$ and $\phi = 90^o$.

If it were not for the gaps for $\phi = 45^o$ where the partial gains drops to -8 dB, it would not be a very bad candidate.

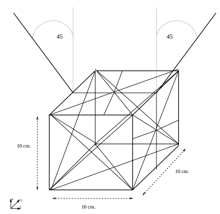


config10	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are fixed in the corners of the satellite, each with $\theta = 45^o$, $\phi = 45^o$ for one of the antennas and 225^o for the other. The generators are defined, so that the phase is 180^o as illustrated on the figure.

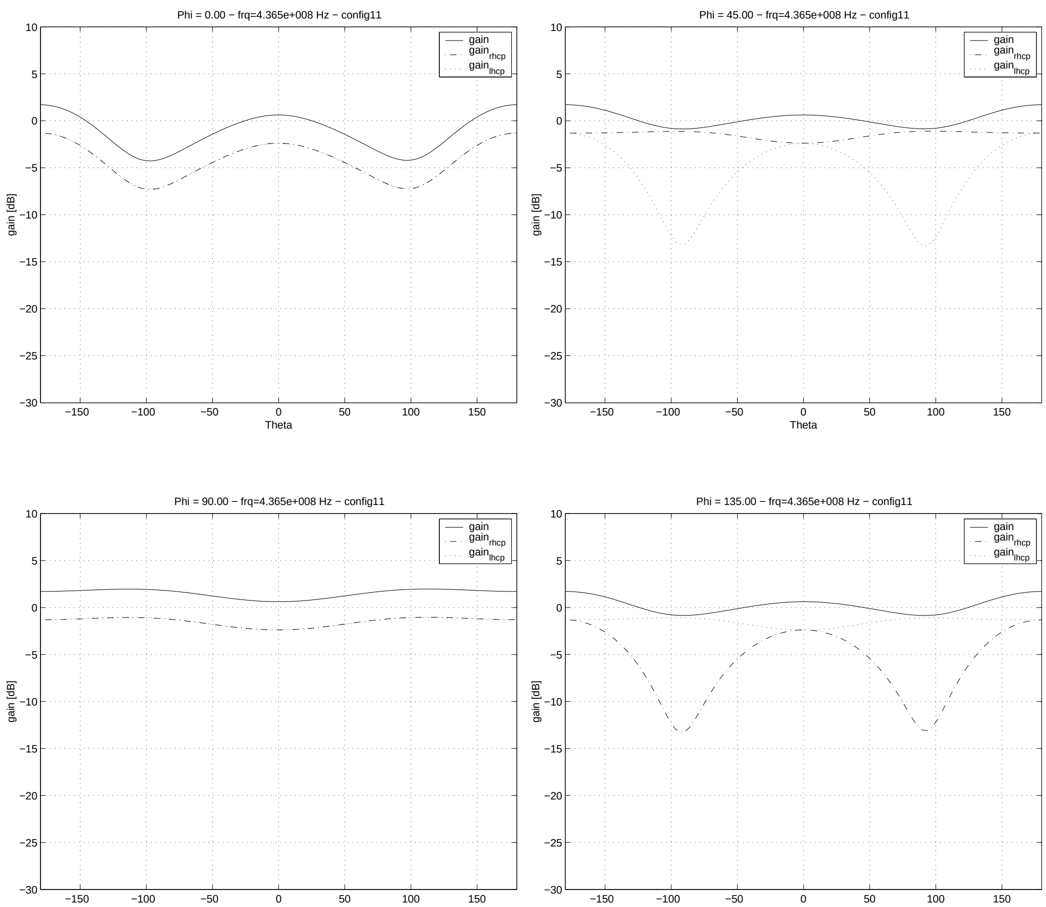


The expected symmetry is once again fulfilled. But the plots themselves are a bit more interesting this time due to the phase of the currents. This results in horizontal currents neutralizing one another and vertical currents strengthen one another, thus giving rise to currents reminding of that of a dipole. This, we assume, is the reason for the fatal gaps in the plots, and so it rules out this configuration as a candidate.

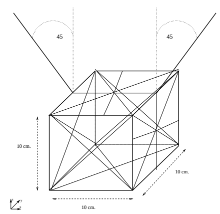


config11	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are fixed at each side of the satellite in the xz-plane. Θ is 45^o for both. The generators are defined so that the phase is 0^o as illustrated on the figure.

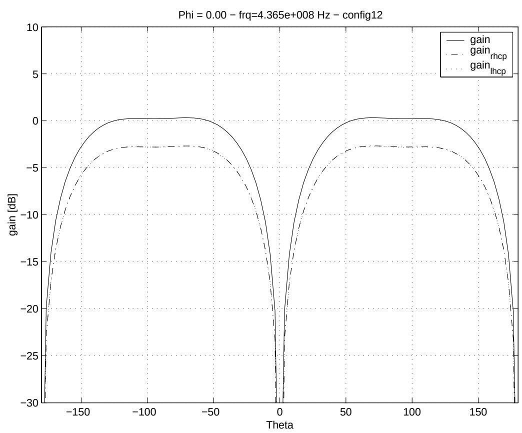


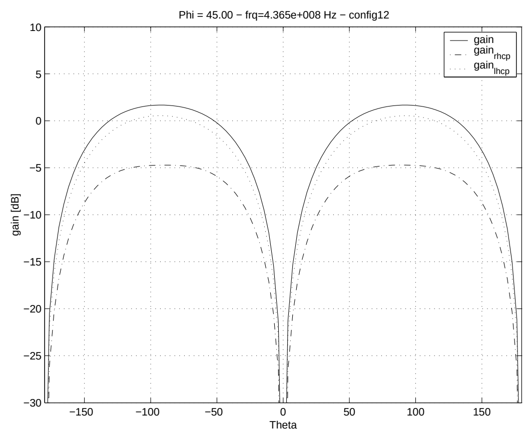
The plots for this configuration almost matches those of Config9, and hence gives rise to the same conclusions. Aside from this, one can conclude that the position of the antennas themselves are not the very important.

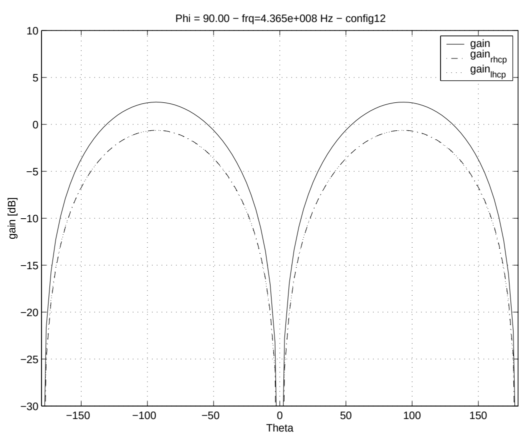


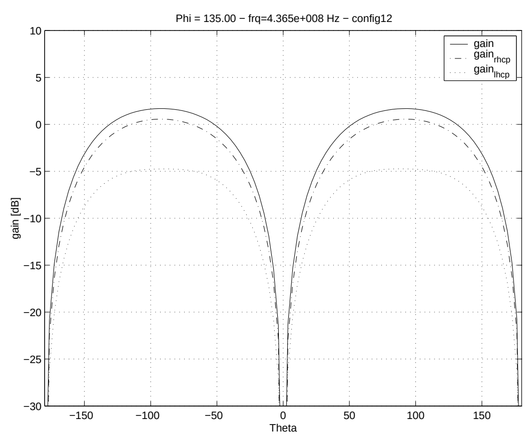
config12	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are fixed at each side of the satellite in the x-plane. Theta is 45^o for both. The generators are defined, so the phase of the currents is 180^o as illustrated on the figure.

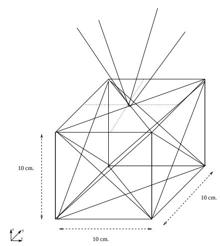






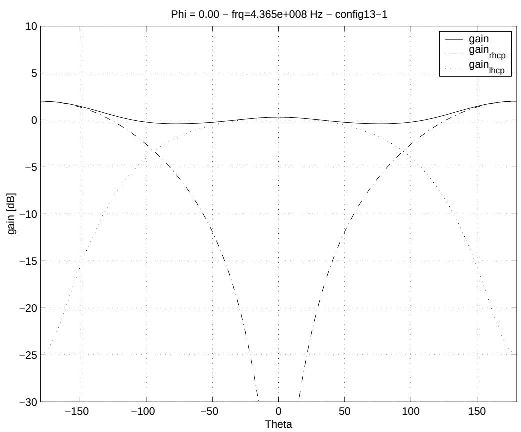


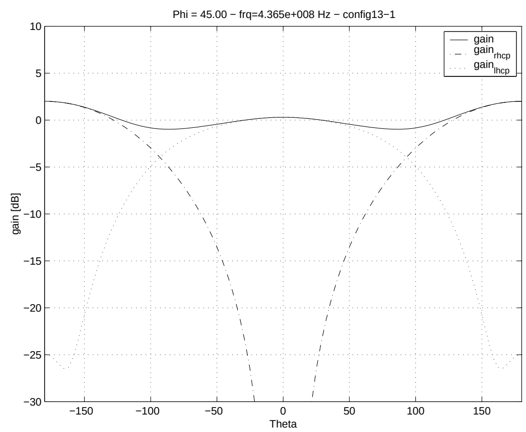
As expected, considering Config11, these plots are almost similar to the ones from Config10, and therefor calls for no further explanation. One should just consult the analysis of Config10.

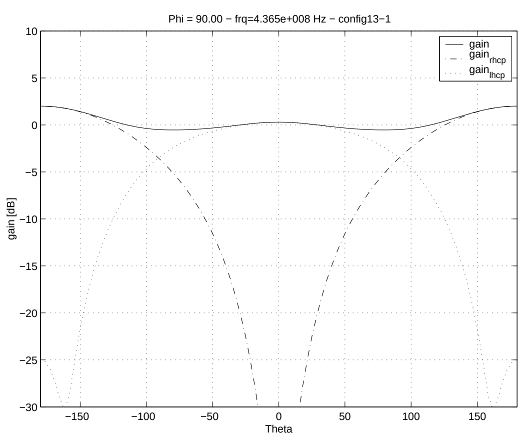


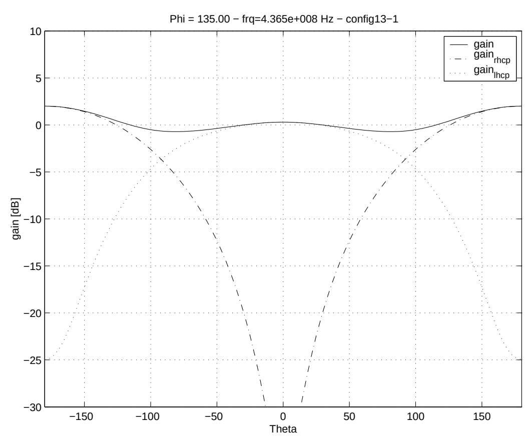
config13-1	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The two antennas are fixed at the center of the satellite, each with an angle of 45^o to the z-axis. The time harmonic generator for each of the two antennas are given by (1,0) for the antenna in the xz-plane. And (0,1) in the yz-plane.





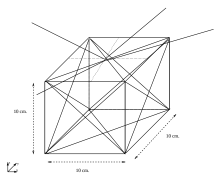




That the **E**-field is strictly *lhcp* for $\theta = 0$ is due to the currents, when seen from this angle (the projection onto the xy-plane), is shifted in phase as described above. This shifting entails, that the **E**-field in the $\theta = 0^o$ direction is *lhcp*

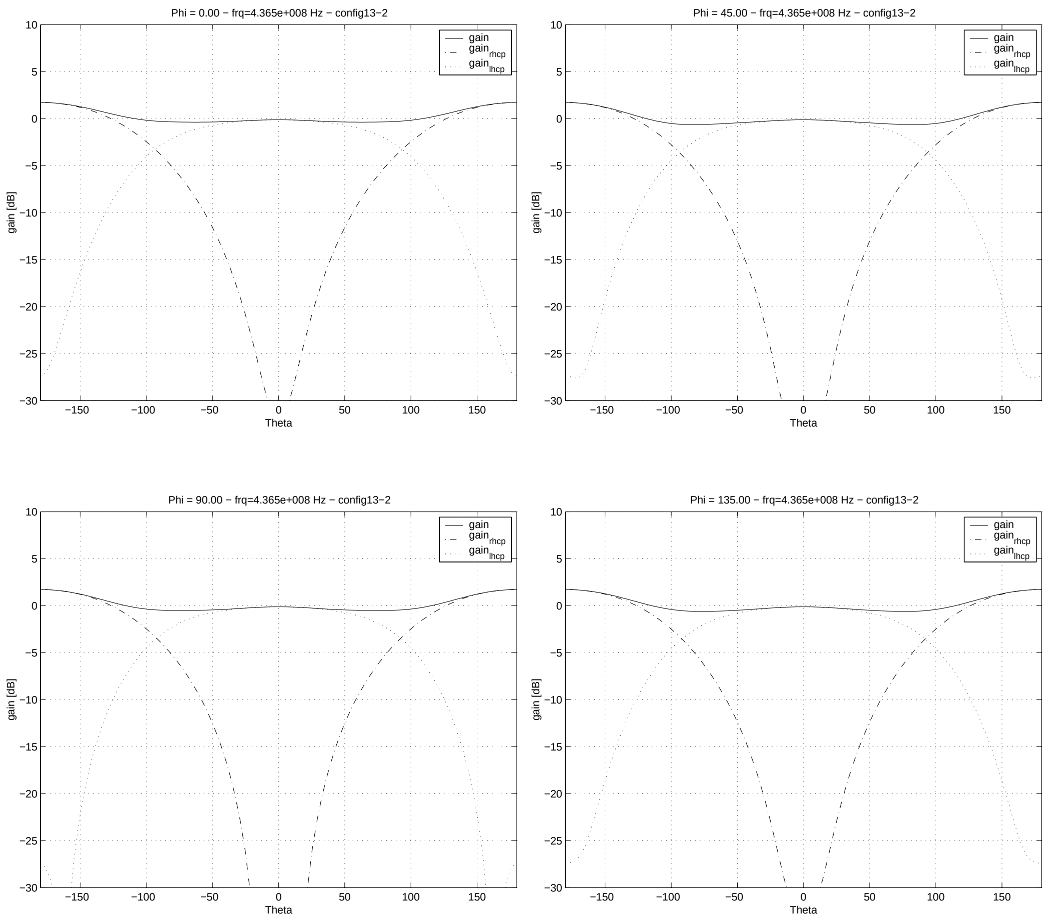
When $\theta = 180^o$ the field is purely $rhcp$ (same reason as above) and the partial gain hereof is somewhat higher than the partial gain of $lhcp$ at $\theta = 0^o$. This must be due to the box acting as a scatter, because it does not origin from the antenna configuration itself, as can be seen from Config16.

The configuration is usable because at least one of the partial gains, $rhcp$ and $lhcp$, is greater than $-4dB$. From a radio perspective it would be prefereable to have the "bottom" of the satellite towards the receiver, which means that the antennas would be pointing out in space. This is nevertheless not of current interest to us, because the restrictions set up by the mechanical team. They define the antennas to be place on the side of the satellite, which is directed towards the earth

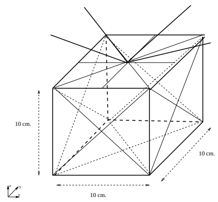


config13-2	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The two antennas are fixed at the center of the satellite, each with an angle of 33^o to the z-axis. The time harmonic generator for each of the two antennas are given by (1,0) for the antenna in the xz-plane. And (0,1) in the yz-plane.

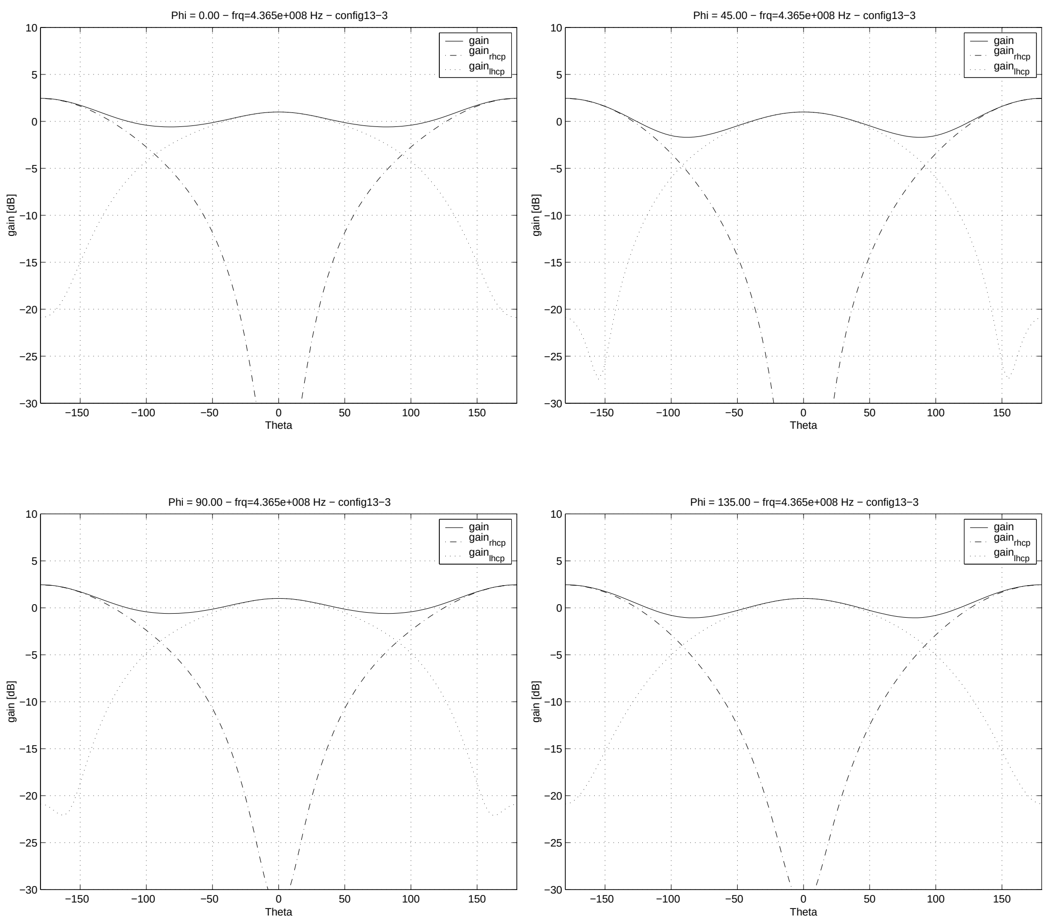


Very much the same as config13-1

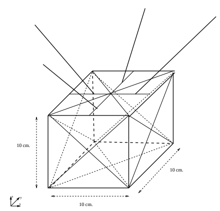


config13-3	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The two antennas are fixed at the center of the satellite, each with an angle of 66^o to the z-axis. The time harmonic generator for each of the two antennas are given by (1,0) for the antenna in the xz-plane. And (0,1) in the yz-plane.

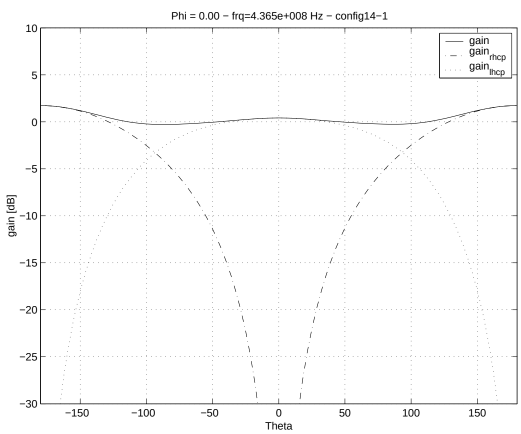


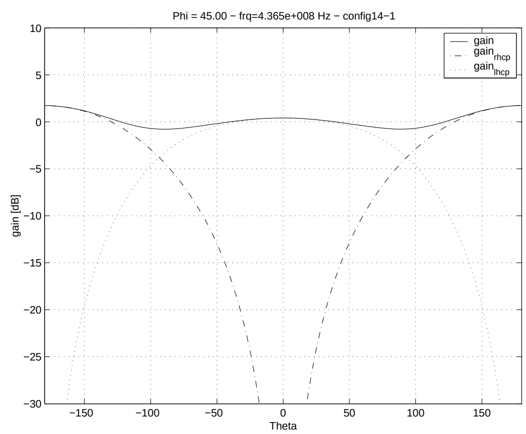
Almost the same as config13-1 with a deviation of no more than 1 dB (for the gain).

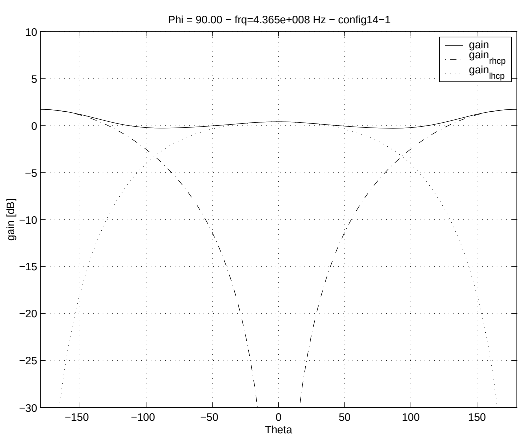


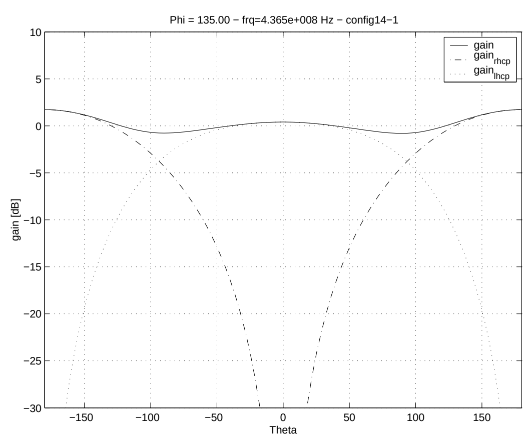
config14-1	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are each fixed halv-way between the center of the satellite and the four sides, each having a θ of 45^o. The time harmonic generator for each, starting with the one for $\phi = 0^o$ and proceeding counter clockwise, is (1,0), (0,1), (-1,0) and (0,-1).

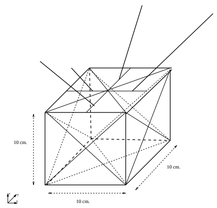






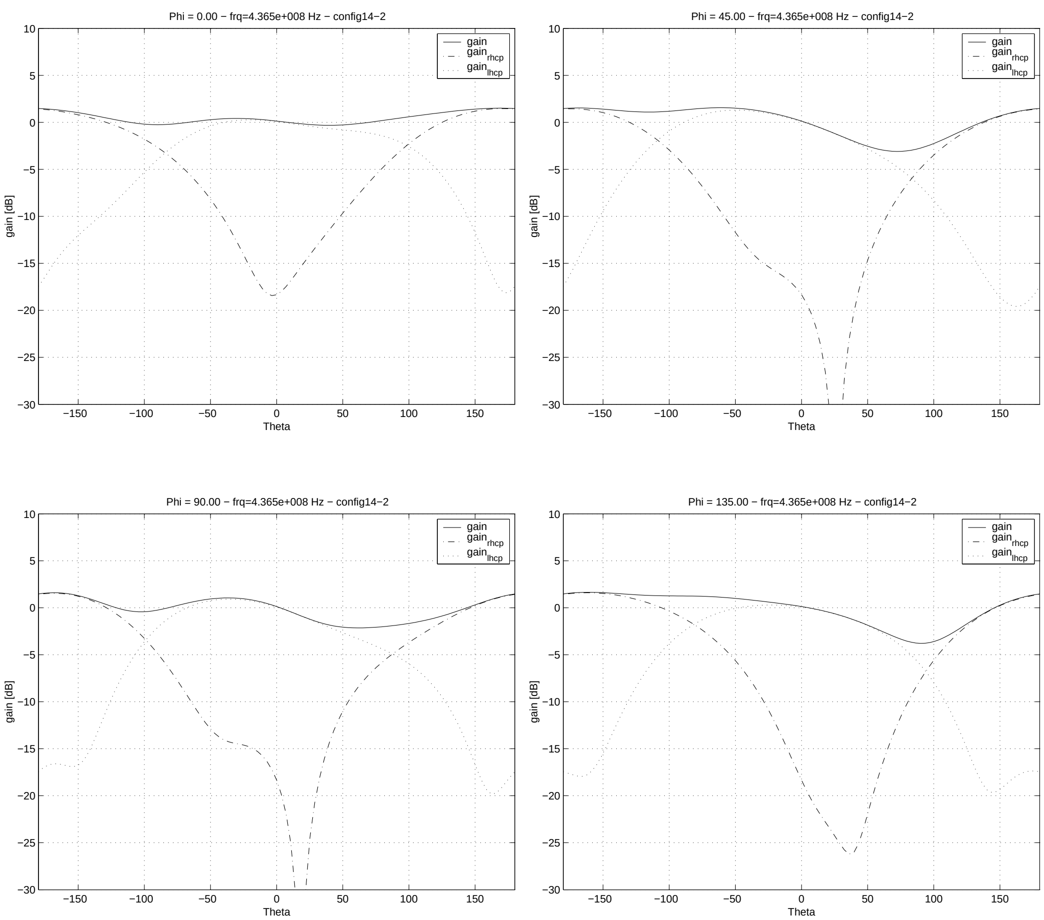


Comparing these plots with the ones from Config13-1, we can see that it does not change the radiation pattern significantly to move the antennas apart.

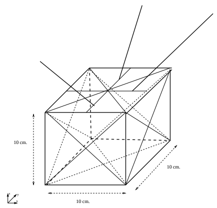


config14-2	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

Same antenna placement as in Config14-1 apart from the antenna arm that is fastened in $(x, y, z) = (-25, 0, 0)mm$ is only half the length of the others.

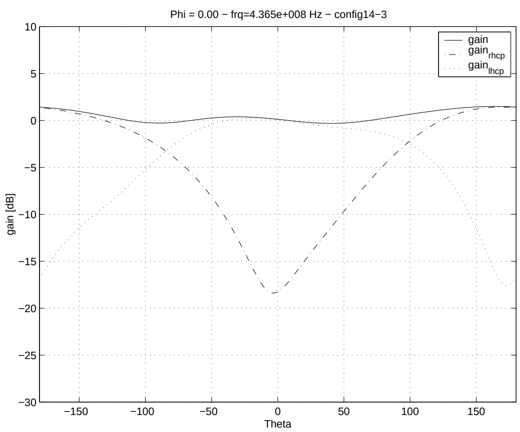


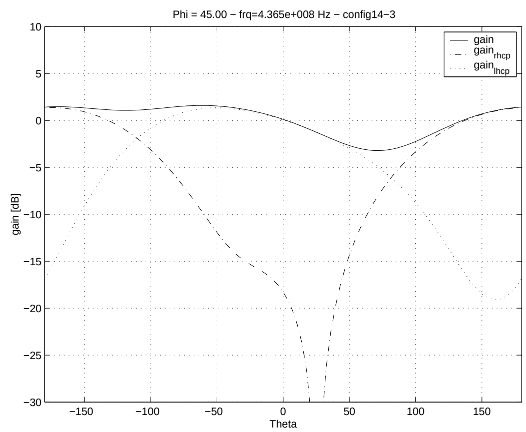
As would be expected the symmetry that we saw in Config14 has gone in all ϕ-planes. What is of interest is that at least one of the partial gains is still larger than -12dB. It is thus possible to communicate with the satellite even if one antenna is only half the length of the others. When this simulation was made we expected that the antennas were to be shot out of the satellite body. It was therefore interesting to see how the radiation would be affected in the event of one antenna only being half deployed. However the idea of shooting the antennas out has later been abandon because the firing mechanism would be to heavy. A new deployment method has not been decided on yet, but we believe that the antennas will be made of tape measure and then bend around on one side of the satellite fixed with some sort of device. When the satellite is deployed the device fixing the antennas will open and the antennas will unfold to there ideal position. Because of this new deployment method this configuration is not very likely to occur.

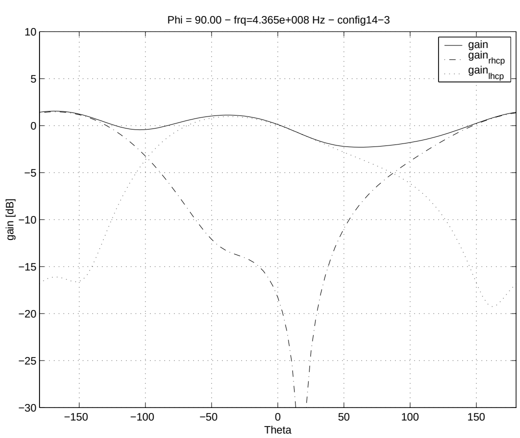


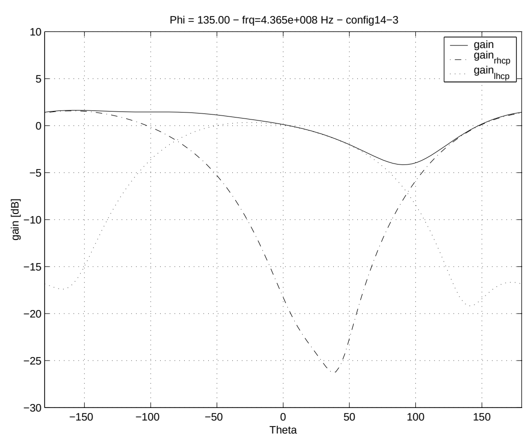
config14-3	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

Same antenna placement as in Config 14-1 apart from the antenna arm that were fastened in $(x, y, z) = (-25, 0, 0)mm$ is missing.

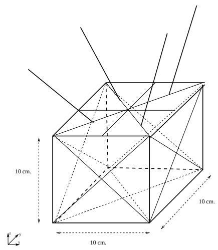






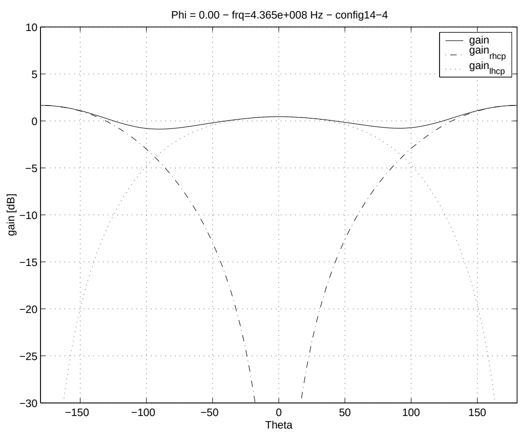


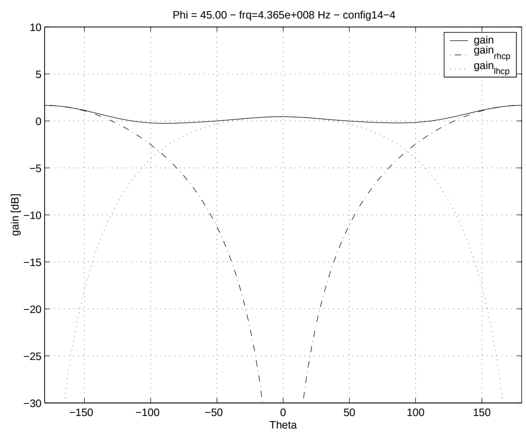
As would be expected the symmetry that we saw in Config14 has gone in all ϕ-planes. What is of interest is that at least one of the partial gains is still larger than -12dB. It is thus possible to communicate with the satellite even if one antenna is missing (has fallen of).

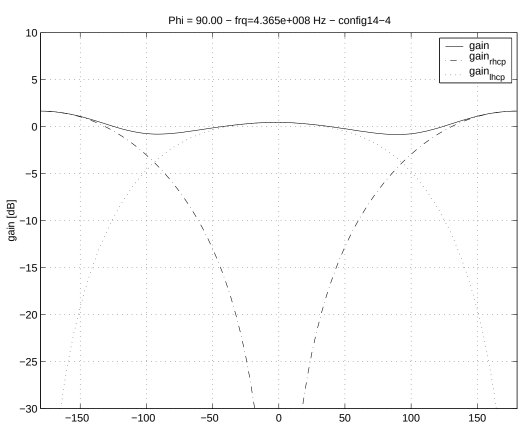


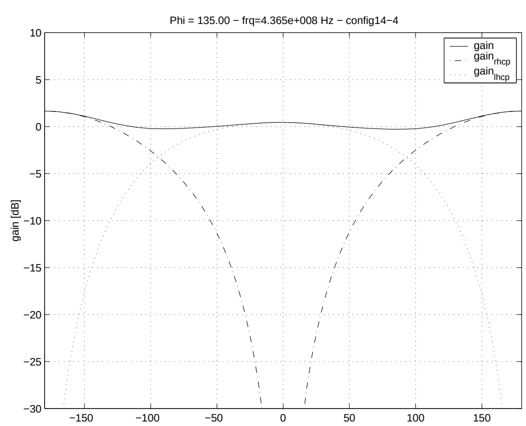
config14-4	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas have the same length as those in Config14-1, only they are "rotated" 45^o counter clockwise. This means that the antenna fastened in $(x, y, z) = (25, 0, 0)$ in Config14-1 is now fastened in $(x, y, z) = (25, 25, 0)$ and so on

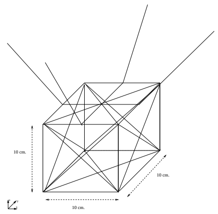






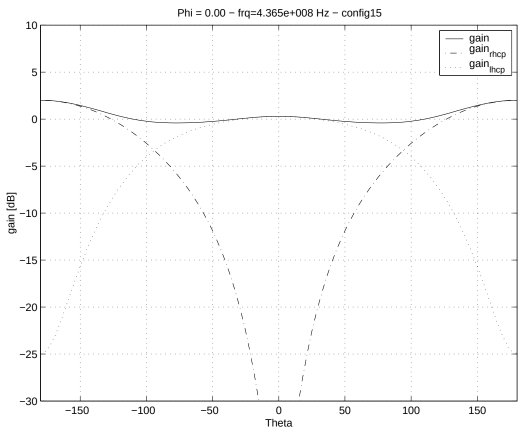


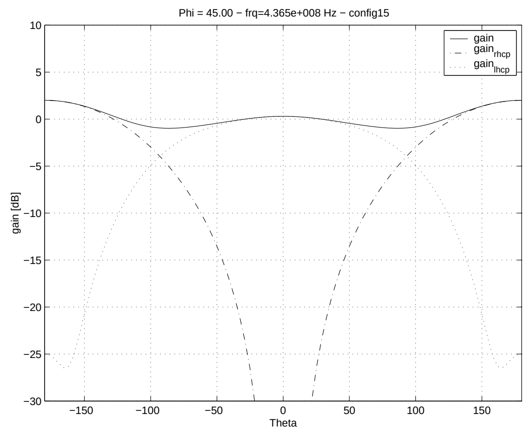
The plots are almost identical to those of Config14-4

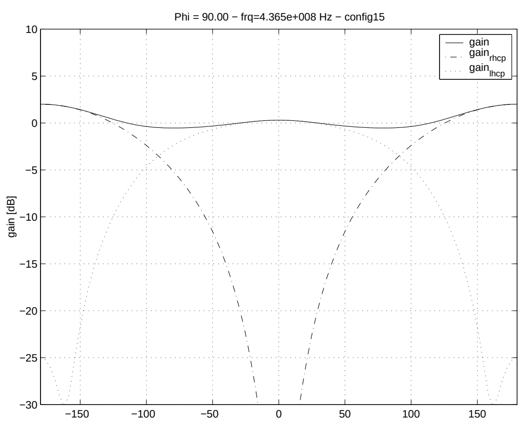


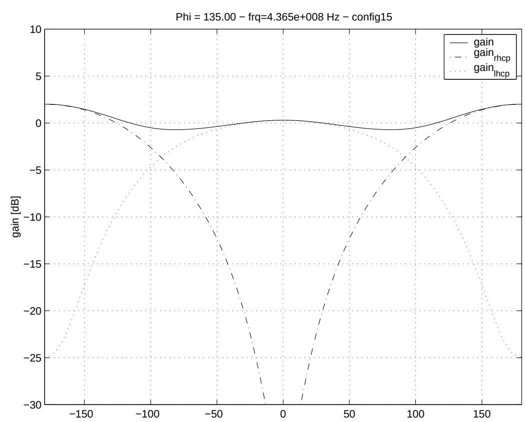
config15	
Program	AWAS
Length of antenna	$\frac{\lambda}{4} = 171.1$ mm
Frequency	436,5 MHz
Wire radius	1mm

The antennas are each fixed at the sides of the satellite, each having $\theta = 45^o$. The time harmonic generator for each, starting with the one for $\phi = 0^o$ and proceeding counter clockwise, is (1,0), (0,1), (-1,0) and (0,-1).









Comparing these plots with the ones from Config13-1, we can see that it does not change the radiation pattern significantly to move the antennas apart.

I Link budget from radio group

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J Data sheets for power splitters

J.1 How the presentations were done

For actually making the presentations some LaTeX functions were made. These are quite simple, readable and functional, wherefor a description is ommited. We only mention it for the sake of completeness.

K Drawings for model of cubesat

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L Letter correspondence

The letters for the correspondence with the leader of the antenna team for the CUTE, are to be found on the following pages.

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M Picture of CUTE