The STEREO/WAVES antenna calibration

Final Results

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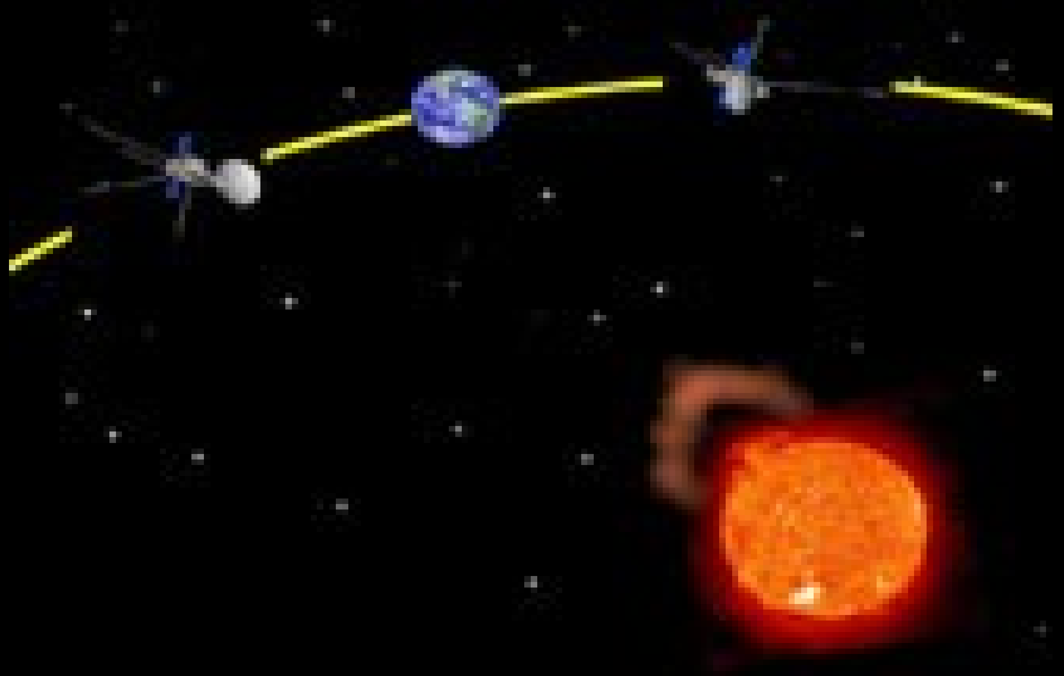
The STEREO mission

- Two spacecraft, one ahead and one behind earth,slowly drifting apart at a rate of 22 degrees by year
- To extend our knowledge about the physics of the solar system
- Research on space weather, CMEs and sun-earth-connection (SEC)
- For the first time stereoscopic methods are used which include remote and in-situ measurements of the same events

The STEREO mission



SWAVES

- Measures electric fields
- Frequency quasi-static-16MHz+2 fixed frequencies at 30.025 and 32.025MHz
- Measures electron density and temperature with quasi thermal noise analysis
- 3 orthogonal monopole-stacer-antennas, directed away from the sun, 6m length
- “Direction Finding” (DF) mode provides all auto- and cross correlation parameters
- 2 spacecraft render it possible to pinpoint the source of the EM radiation via triangulation
- The equipment on the 2 s/c will track those radio sources from less than 2 R_S to 1AU and beyond

SWAVES antennas

- The Goal: Correct data interpretation
- Influence of the spacecraft body
- Effective length vectors and impedance- or capacitance matrices
- These quantities were determined and analyzed numerically and experimentally

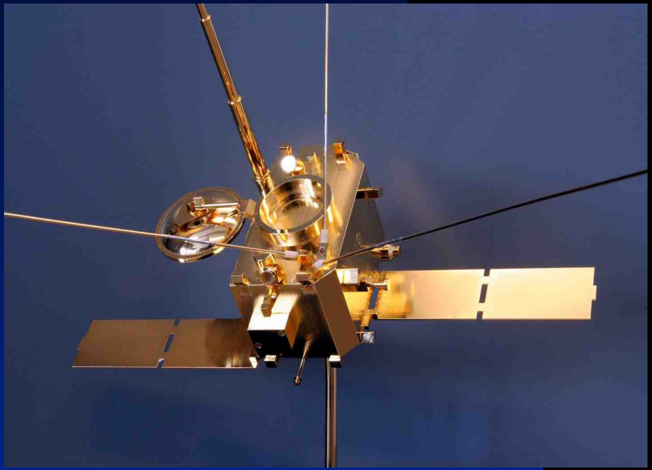
STATUS QUO

- We finished the ASAP project for the determination of the reception properties of the WAVES antennas on-board the two STEREO spacecraft.
- The numerical and experimental procedures are completed
- The interpretation of the results and the publication is not yet complete
- The capacitances have to be determined numerically

Methods to determine the effective length vector

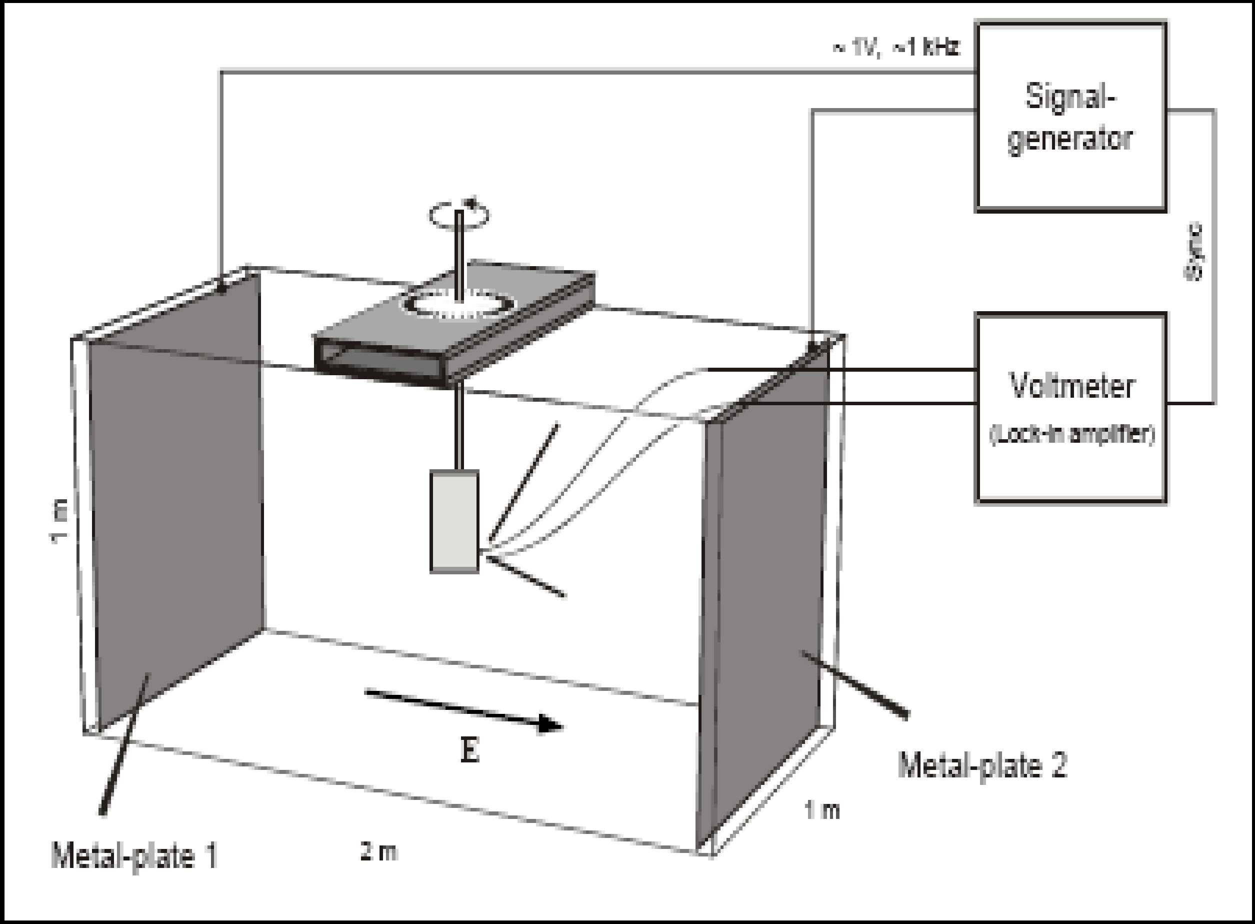
(1) Numerical electromagnetic code
(2) Rheometry
(3) The anechoic chamber
(4) In-flight Calibration

The experimental method : Rheometry



- A gold-plated model of the spacecraft is submerged into a water tank
- A low-frequency electric field is applied
- The response (induced voltage) of the antennas is measured as a function of spacecraft orientation
- The effective length vectors and the antenna impedances can be computed from the data
- Rheometry is only applicable to the quasi-static limit

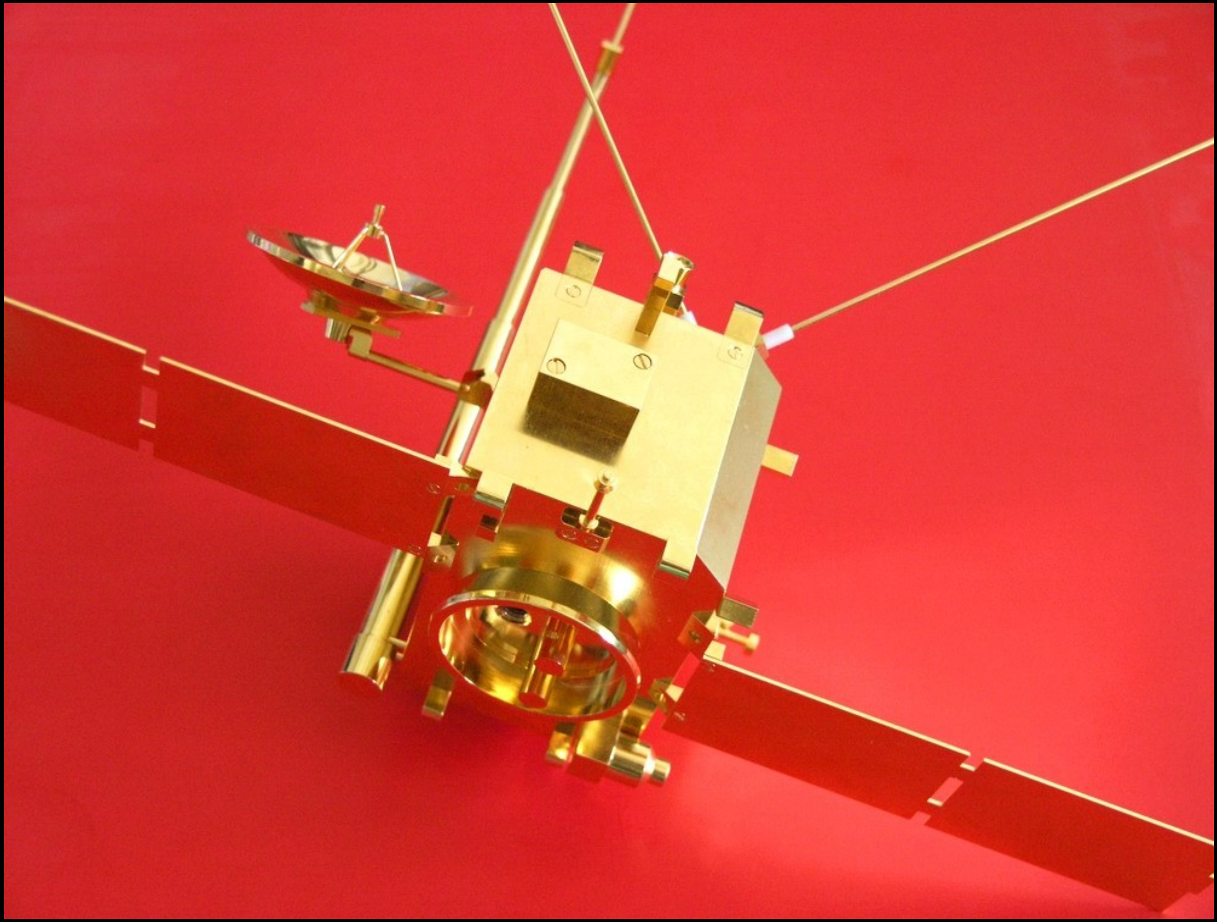
Rheometry



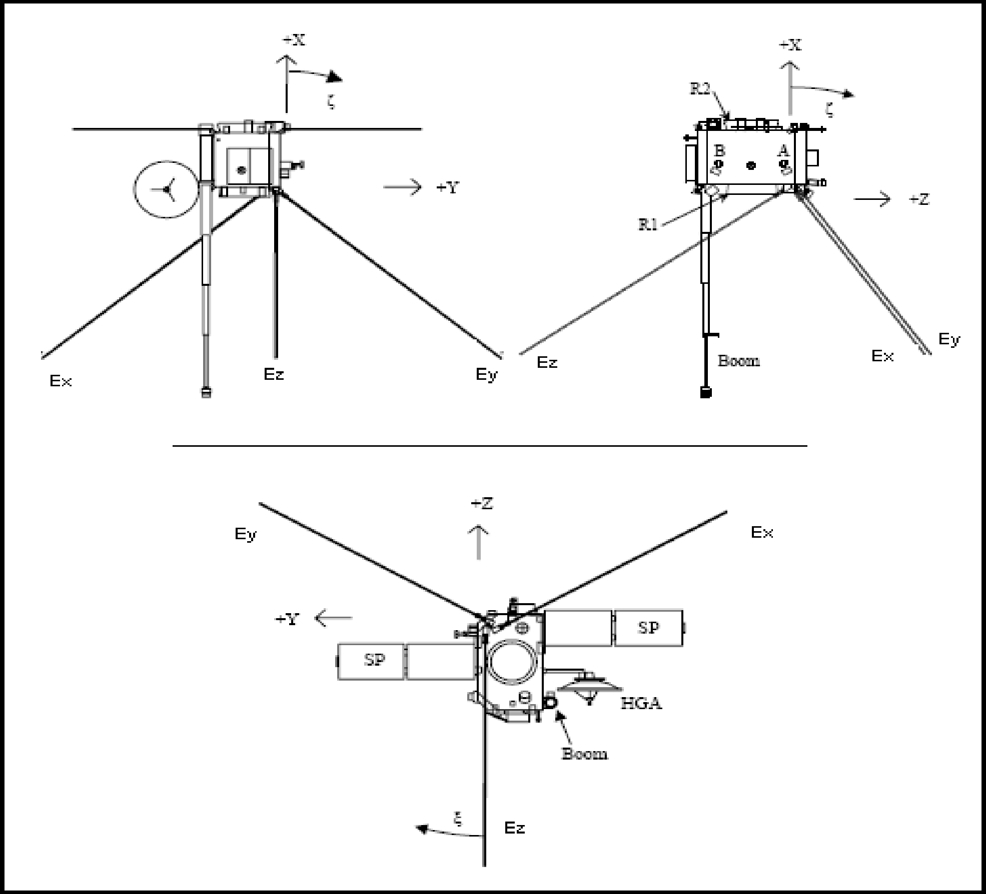
~ 1V, ~1 kHz
Signal-generator
Sync
Voltmeter
(Lock-in amplifier)
1 m
E
Metal-plate 1
2 m
1 m
Metal-plate 2

Rheometry

Our model

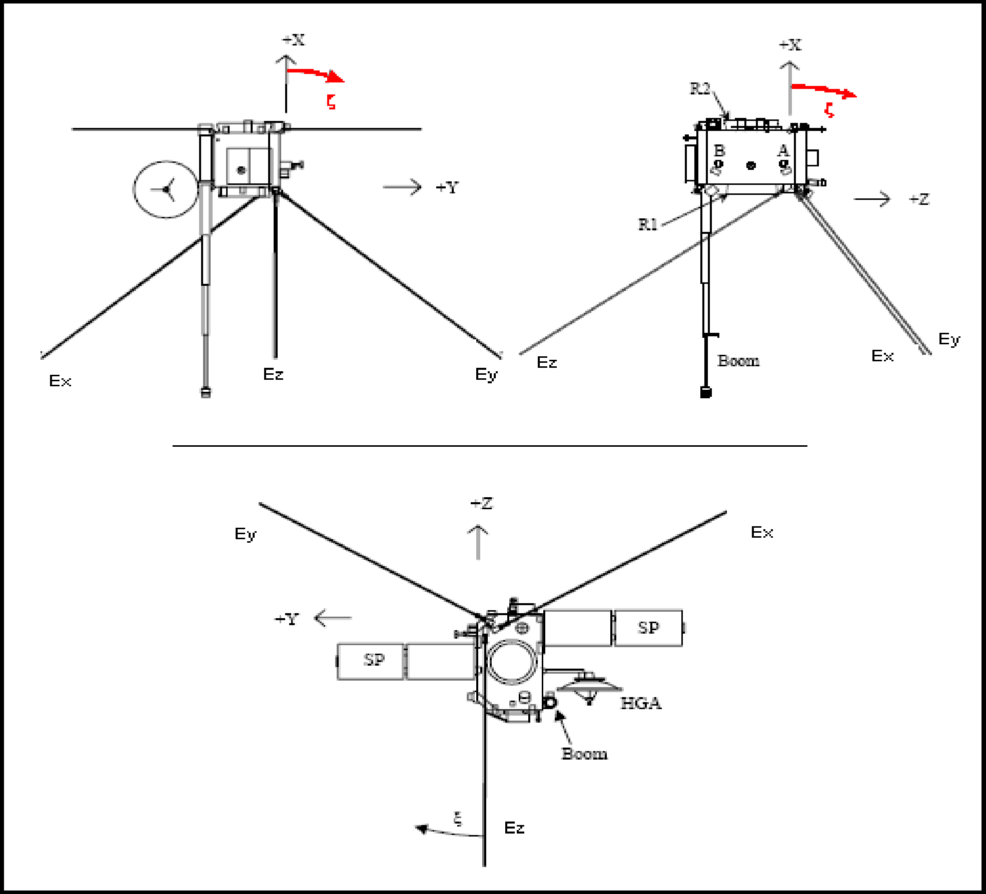


The coordinate system



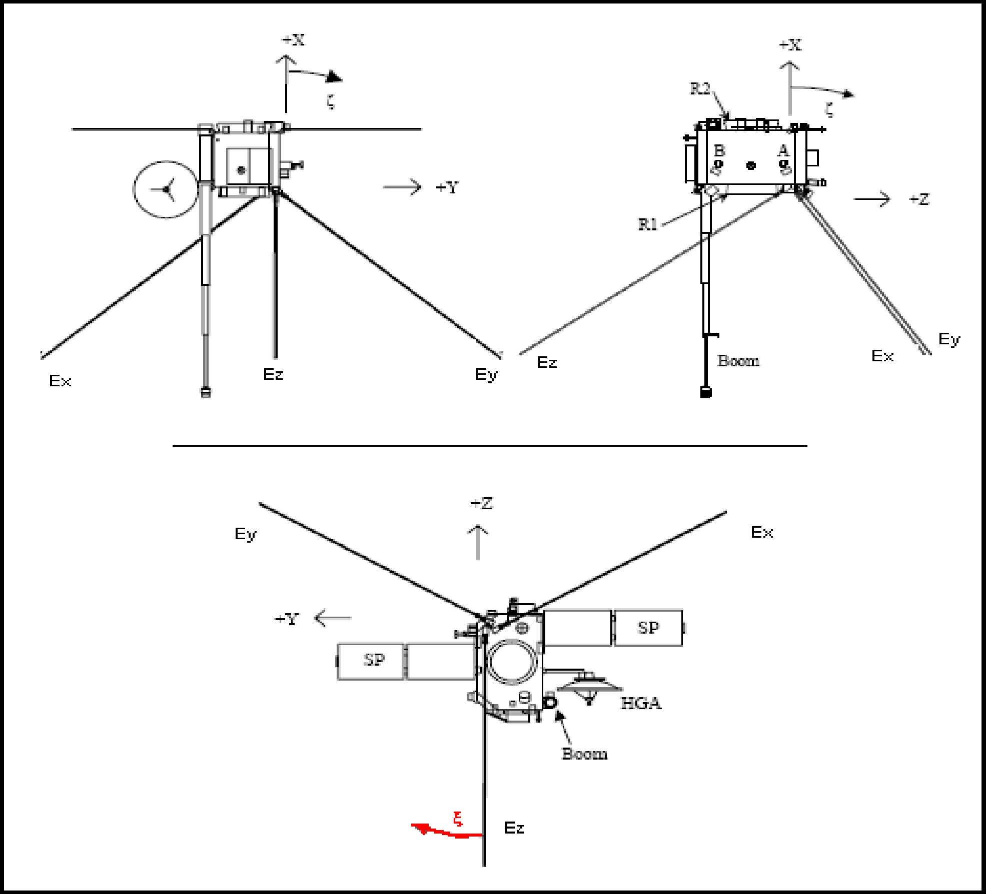
Antenna	h^m [m]	ζ^m [deg]	ξ^m [deg]
E_x	6.00	125.3	-120.0
E_y	6.00	125.3	120.0
E_z	6.00	125.3	0.0

The coordinate system



Antenna	h^m [m]	ζ^m [deg]	ξ^m [deg]
E_x	6.00	125.3	-120.0
E_y	6.00	125.3	120.0
E_z	6.00	125.3	0.0

The coordinate system



Antenna	h^m [m]	ζ^m [deg]	ξ^m [deg]
E_x	6.00	125.3	-120.0
E_y	6.00	125.3	120.0
E_z	6.00	125.3	0.0

Rheometry results

HGA orientation	Antenna	STEREO A			STEREO B		
		h^o [m]	ζ^o [deg]	ξ^o [deg]	h^o [m]	ζ^o [deg]	ξ^o [deg]
-90 deg	E_x	2.89	126.5	-140.2	2.93	126.2	-140.8
	E_y	3.83	118.9	127.8	3.86	118.8	127.7
	E_z	2.37	132.2	21.1	2.36	132.4	20.0
0 deg	**E_x**	**2.89**	**126.2**	**-140.7**	**2.92**	**126.0**	**-141.2**
	E_y	**3.84**	**118.7**	**127.9**	**3.87**	**118.8**	**127.6**
	E_z	**2.36**	**132.2**	**21.6**	**2.36**	**132.8**	**20.6**
+90 deg	E_x	2.85	126.2	-140.8	2.89	125.8	-141.3
	E_y	3.84	118.6	128.1	3.86	118.6	127.2
	E_z	2.36	131.7	21.6	2.36	132.5	20.8

Antenna	h^m [m]	ζ^m [deg]	ξ^m [deg]
E_x	6.00	125.3	-120.0
E_y	6.00	125.3	120.0
E_z	6.00	125.3	0.0

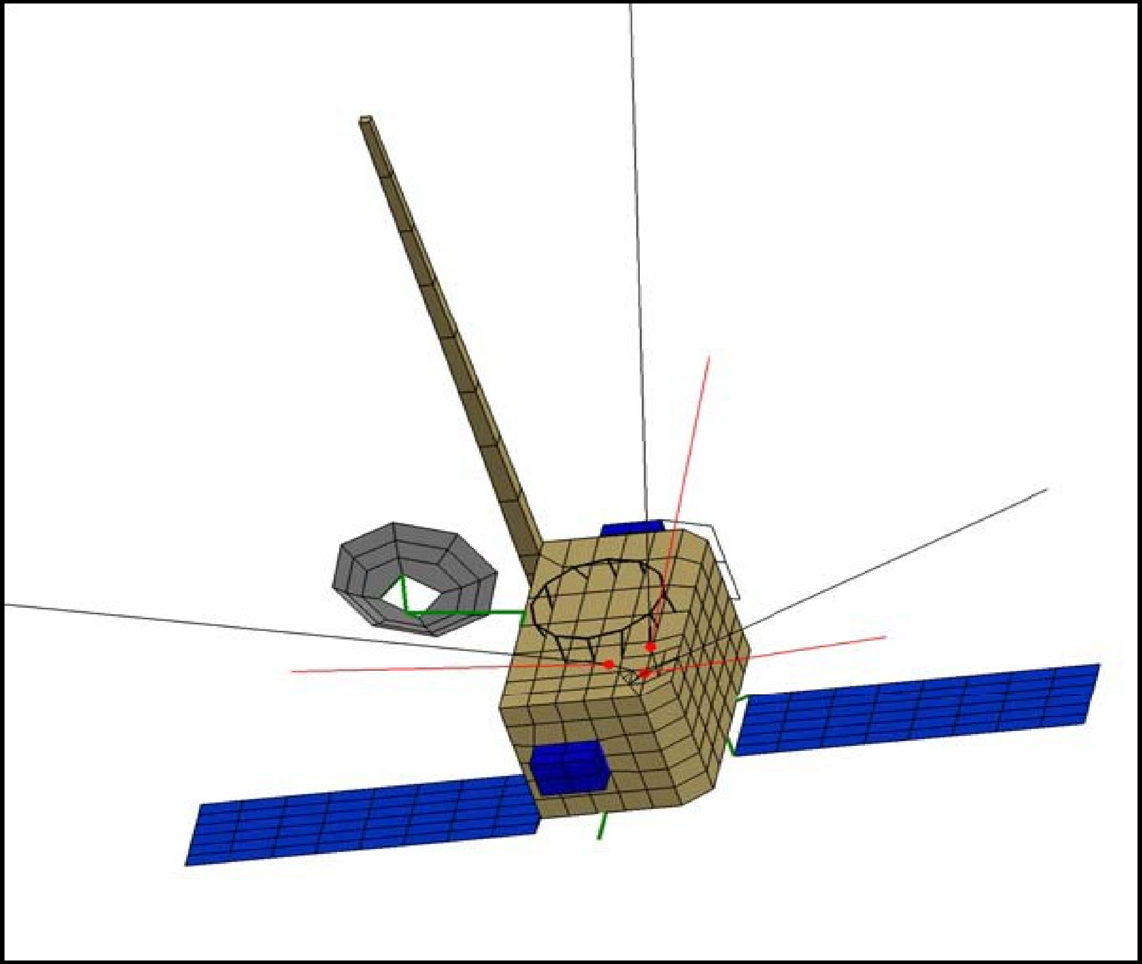
Rheometry results

open feeds

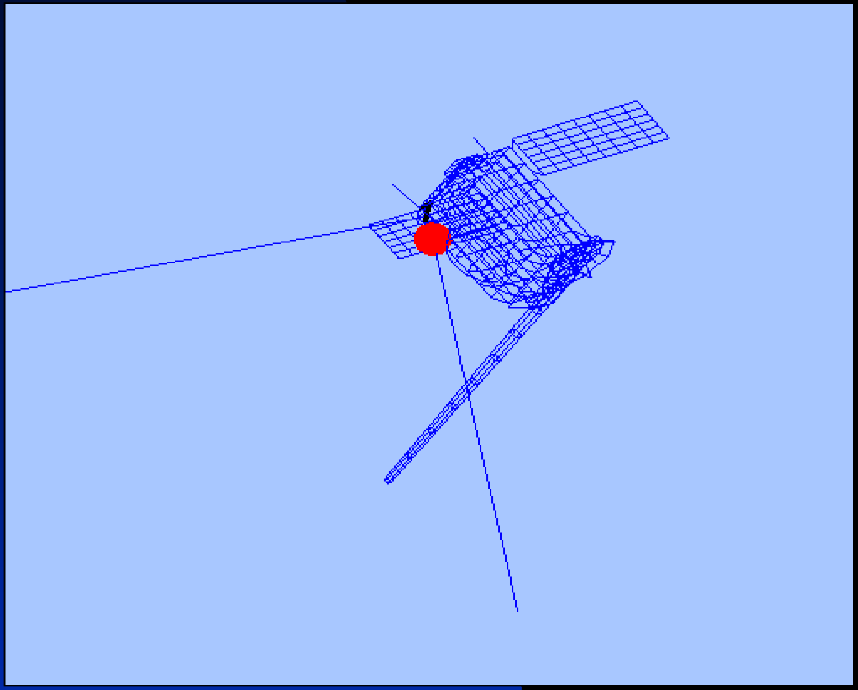
loaded feeds

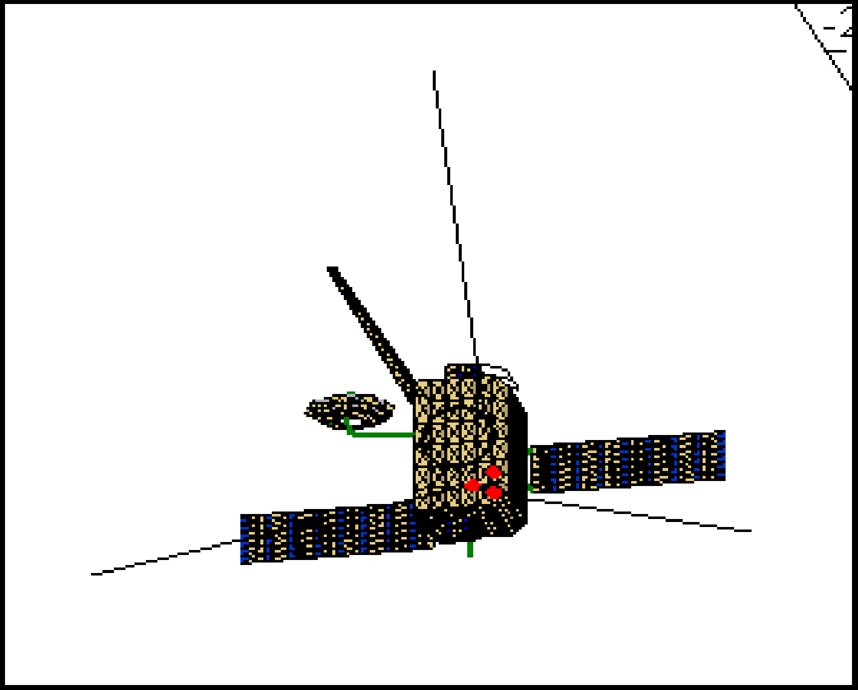
HGA orientation	Antenna	STEREO A			STEREO B		
		h^o [m]	ζ^o [deg]	ξ^o [deg]	h^o [m]	ζ^o [deg]	ξ^o [deg]
-90 deg	E_x	2.89	126.5	-140.2	2.93	126.2	-140.8
	E_y	3.83	118.9	127.8	3.86	118.8	127.7
	E_z	2.37	132.2	21.1	2.36	132.4	20.0
0 deg	**E_x**	**2.89**	**126.2**	**-140.7**	**2.92**	**126.0**	**-141.2**
	E_y	**3.84**	**118.7**	**127.9**	**3.87**	**118.8**	**127.6**
	E_z	**2.36**	**132.2**	**21.6**	**2.36**	**132.8**	**20.6**
+90 deg	E_x	2.85	126.2	-140.8	2.89	125.8	-141.3
	E_y	3.84	118.6	128.1	3.86	118.6	127.2
	E_z	2.36	131.7	21.6	2.36	132.5	20.8
		h [m]	ζ [deg]	ξ [deg]	h [m]	ζ [deg]	ξ [deg]
-90 deg	E_x	1.17	121.0	-134.5	1.17	120.8	-135.0
	E_y	1.46	114.9	126.6	1.46	114.8	126.4
	E_z	0.99	124.6	15.5	0.98	124.6	14.4
0 deg	**E_x**	**1.16**	**120.8**	**-134.9**	**1.18**	**120.6**	**-135.4**
	E_y	**1.46**	**114.7**	**126.7**	**1.47**	**114.8**	**126.3**
	E_z	**0.99**	**124.6**	**15.9**	**0.98**	**125.0**	**14.9**
+90 deg	E_x	1.15	120.8	-135.0	1.16	120.5	-135.5
	E_y	1.45	114.7	127.0	1.47	114.7	126.0
	E_z	0.98	124.3	15.9	0.98	124.9	15.0

The numerical method



The numerical method





The numerical method

- The spacecraft is modeled as a grid of wires or patches
- Then the currents along these wires/patches are computed
- This calculation is done with ASAP (wires) and CONCEPT II (wires and patches)
- On base of the current distribution, all other antenna properties (effective length vectors, impedances) can be calculated with MATLAB routines

Computation of the current distribution

- The equation governing the current distribution is the electric field integral equation (EFIE. CONCEPT), or the reaction integral equation (RIE, ASAP)
- For patches, the magnetic field integral equation (MFIE, CONCEPT) is used
- The antenna is excited at the feed
- Due to reciprocity, the receiving antenna results in the same current distribution as the transmitting

Computation of the antenna properties

- Calculations were performed for open feeds and base capacitances of 90pF
- A correction for the real antenna diameters has to be applied on the ASAP results. CONCEPT can deal with real antenna diameters.

Numerical Results:

The quasi-static limit (ASAP)

HGA orientation	Antenna	STEREO A			STEREO B		
		h^o [m]	ζ^o [deg]	ξ^o [deg]	h^o [m]	ζ^o [deg]	ξ^o [deg]
-90 deg	E_x	3.03	126.3	-141.1	3.03	126.4	-141.1
	E_y	3.81	119.3	129.2	3.82	119.4	129.2
	E_z	2.32	133.8	20.8	2.32	133.9	20.8
0 deg	E_x	3.03	126.0	-141.6	3.03	126.1	-141.6
	E_y	3.82	119.1	129.3	3.83	119.2	129.3
	E_z	2.30	133.7	21.4	2.31	133.8	21.4
+90 deg	E_x	2.98	126.0	-141.6	2.99	126.0	-141.6
	E_y	3.81	118.9	129.0	3.81	119.0	129.0
	E_z	2.31	133.1	21.4	2.31	133.2	21.4
		h [m]	ζ [deg]	ξ [deg]	h [m]	ζ [deg]	ξ [deg]
-90 deg	E_x	1.19	120.5	-134.9	1.19	120.6	-134.9
	E_y	1.43	114.8	127.4	1.43	114.9	127.4
	E_z	0.96	125.0	14.9	0.97	125.1	15.0
0 deg	E_x	1.19	120.3	-135.3	1.19	120.4	-135.3
	E_y	1.43	114.7	127.5	1.43	114.8	127.5
	E_z	0.96	124.9	15.4	0.96	125.0	15.4
+90 deg	E_x	1.17	120.3	-135.4	1.18	120.4	-135.4
	E_y	1.43	114.5	127.3	1.43	114.6	127.3
	E_z	0.96	124.6	15.4	0.96	124.7	15.4

Numerical Results:

The quasi-static limit (CONCEPT)

HGA orientation	Antenna	STEREO A			STEREO B		
		h^o [m]	ζ^o [deg]	ξ^o [deg]	h^o [m]	ζ^o [deg]	ξ^o [deg]
-90 deg	E_x	3.07	125.9	-141.1	3.07	126.0	-141.1
	E_y	3.87	118.9	129.2	3.87	119.0	129.2
	E_z	2.35	133.6	20.9	2.35	133.7	20.9
0 deg	E_x	3.07	125.6	-141.6	3.07	125.7	-141.6
	E_y	3.88	118.6	129.2	3.88	118.7	129.2
	E_z	2.34	133.5	21.5	2.34	133.6	21.5
+90 deg	E_x	3.02	125.5	-141.7	3.02	125.6	-141.7
	E_y	3.86	118.4	128.9	3.87	118.5	128.9
	E_z	2.34	132.9	21.5	2.34	133.0	21.5
		h [m]	ζ [deg]	ξ [deg]	h [m]	ζ [deg]	ξ [deg]
-90 deg	E_x	1.17	119.5	-134.4	1.17	119.6	-134.4
	E_y	1.42	114.1	127.3	1.42	114.2	127.3
	E_z	0.96	123.9	14.5	0.96	124.0	14.5
0 deg	E_x	1.17	119.3	-134.8	1.17	119.4	-134.8
	E_y	1.42	113.9	127.3	1.42	114.0	127.3
	E_z	0.96	123.9	15.0	0.96	124.0	15.0
+90 deg	E_x	1.16	119.3	-134.9	1.16	119.4	-134.9
	E_y	1.42	113.8	127.1	1.42	113.9	127.1
	E_z	0.96	123.5	15.0	0.96	123.6	15.0

Experimental Results

HGA orientation	Antenna	STEREO A			STEREO B		
		h^o [m]	ζ^o [deg]	ξ^o [deg]	h^o [m]	ζ^o [deg]	ξ^o [deg]
-90 deg	E_x	2.89	126.5	-140.2	2.93	126.2	-140.8
	E_y	3.83	118.9	127.8	3.86	118.8	127.7
	E_z	2.37	132.2	21.1	2.36	132.4	20.0
0 deg	E_x	2.89	126.2	-140.7	2.92	126.0	-141.2
	E_y	3.84	118.7	127.9	3.87	118.8	127.6
	E_z	2.36	132.2	21.6	2.36	132.8	20.6
+90 deg	E_x	2.85	126.2	-140.8	2.89	125.8	-141.3
	E_y	3.84	118.6	128.1	3.86	118.6	127.2
	E_z	2.36	131.7	21.6	2.36	132.5	20.8
		h [m]	ζ [deg]	ξ [deg]	h [m]	ζ [deg]	ξ [deg]
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	E_y	1.46	114.9	126.6	1.46	114.8	126.4
	E_z	0.99	124.6	15.5	0.98	124.6	14.4
0 deg	E_x	1.16	120.8	-134.9	1.18	120.6	-135.4
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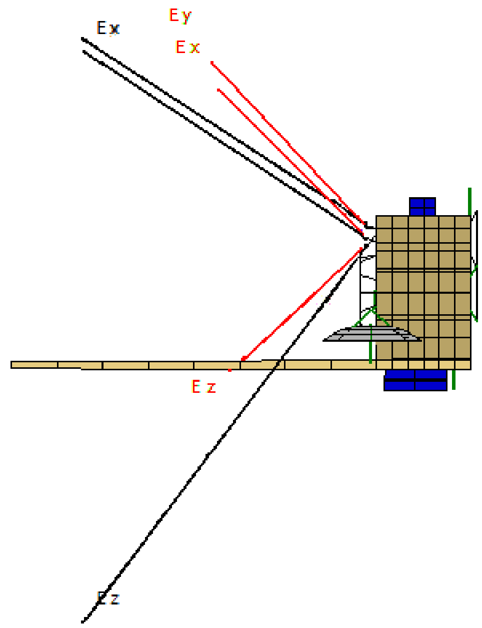
	E_z	0.99	124.6	15.9	0.98	125.0	14.9
+90 deg	E_x	1.15	120.8	-135.0	1.16	120.5	-135.5
	E_y	1.45	114.7	127.0	1.47	114.7	126.0
	E_z	0.98	124.3	15.9	0.98	124.9	15.0

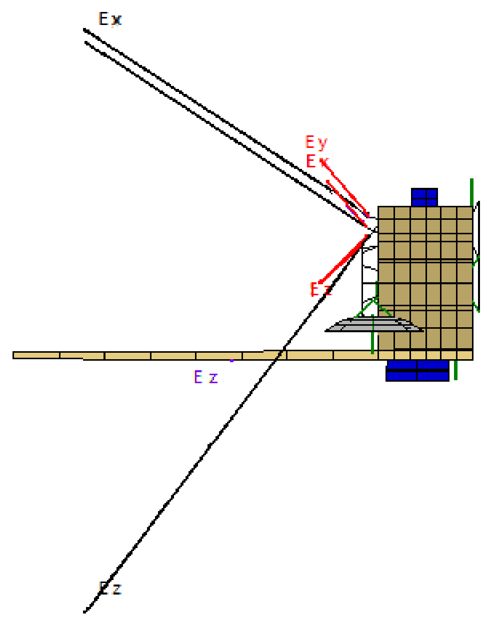
Numerical Results:

The quasi-static limit



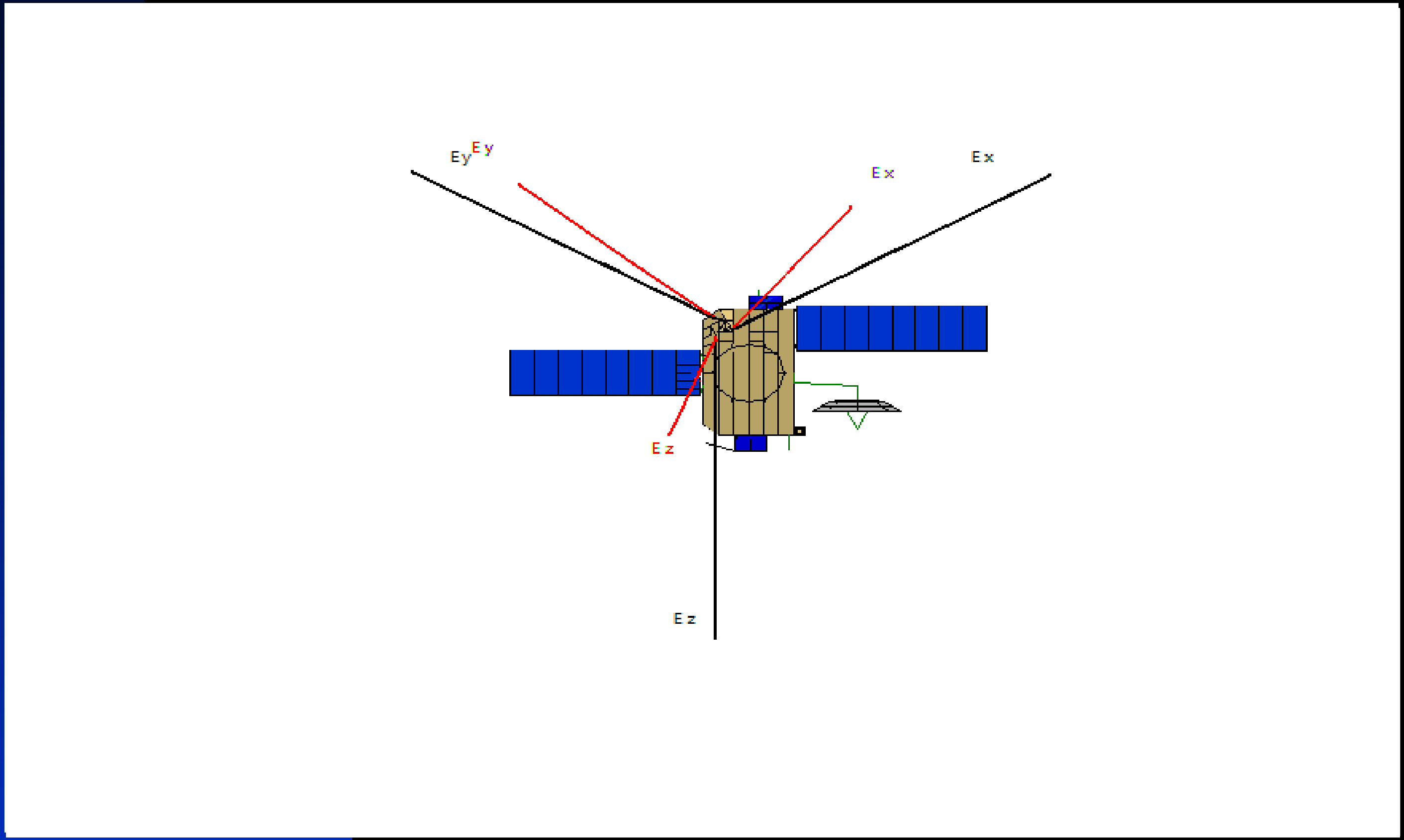
Numerical Results:

The quasi-static limit



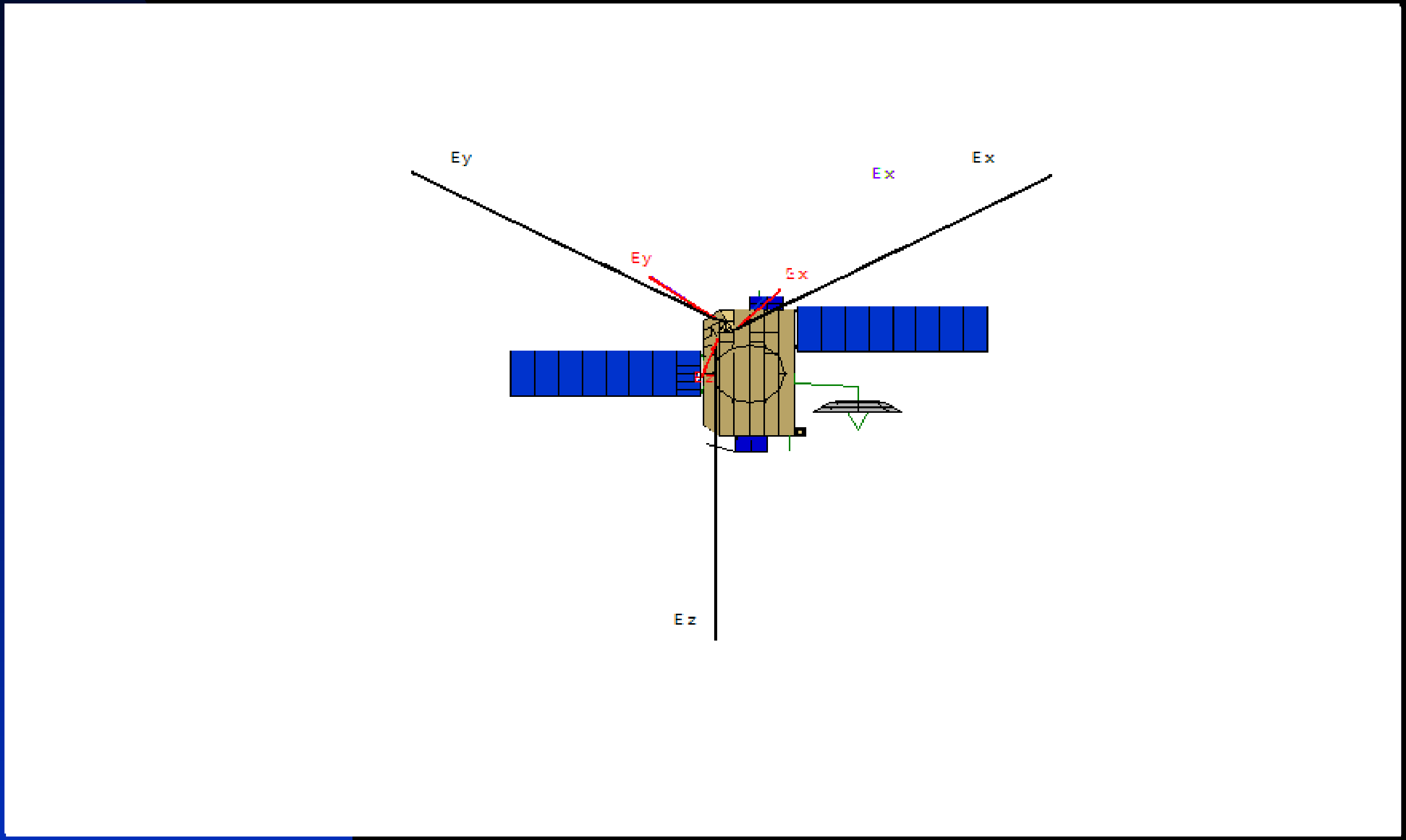
Numerical Results:

The quasi-static limit



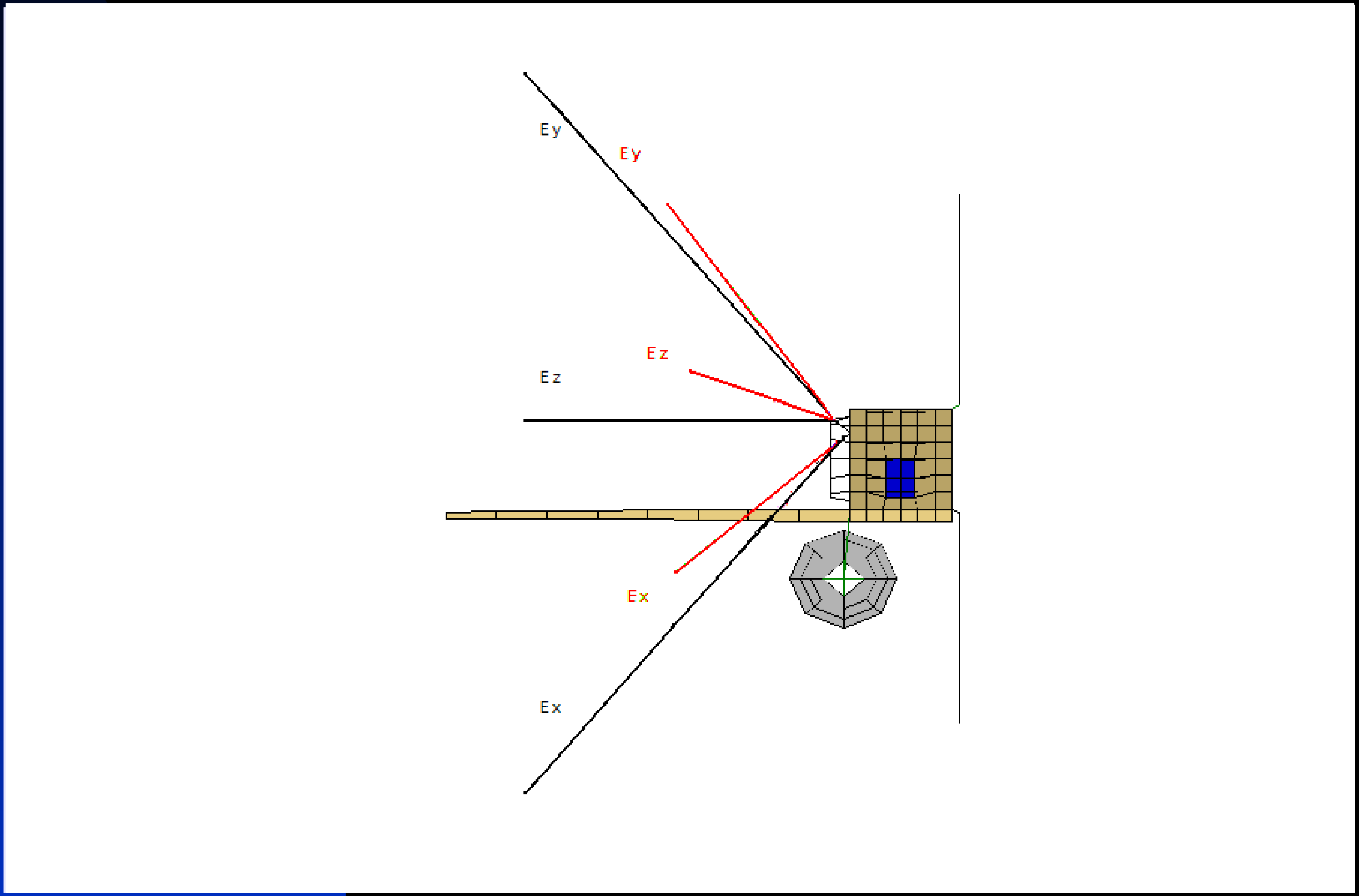
Numerical Results:

The quasi-static limit



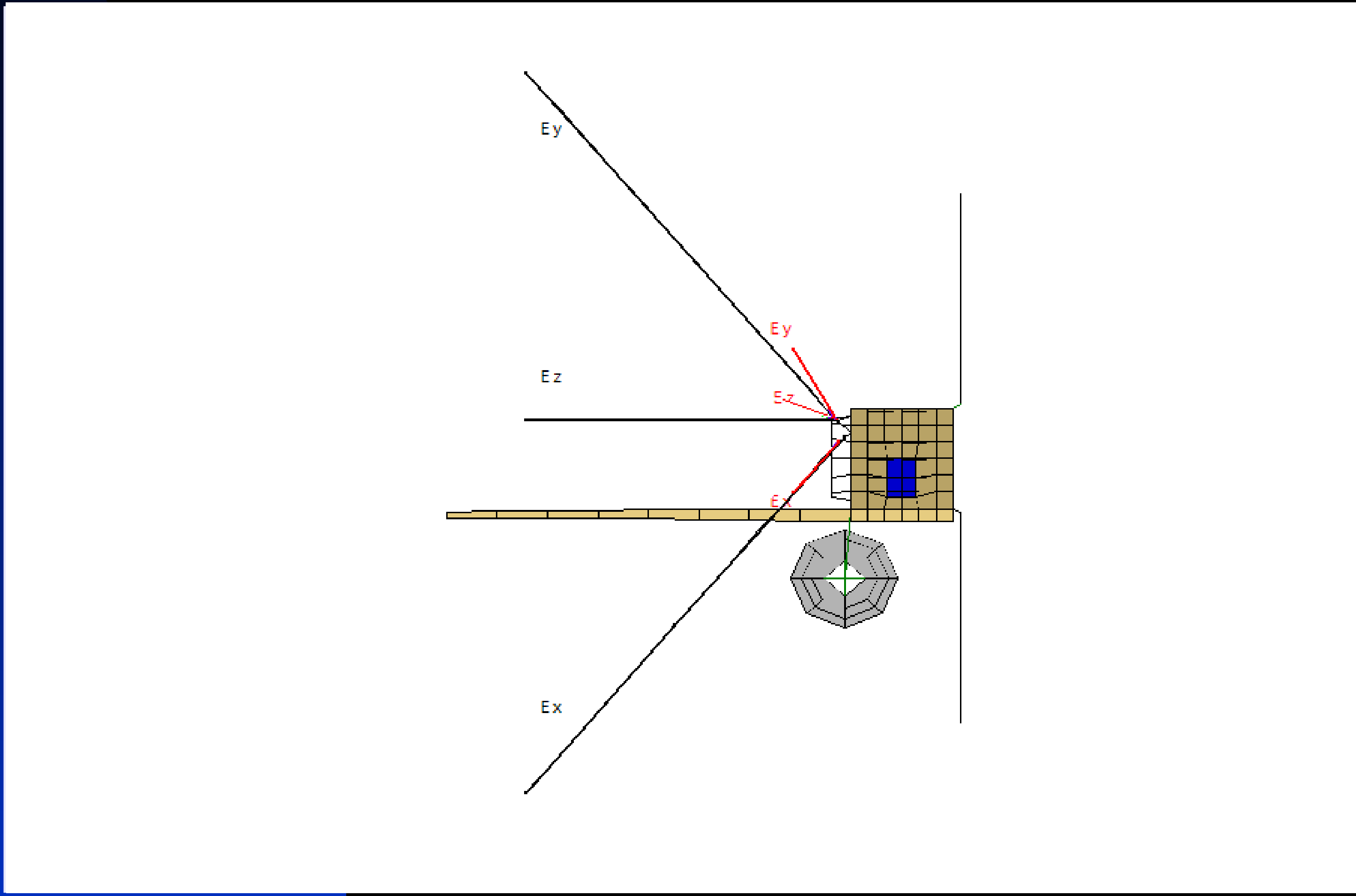
Numerical Results:

The quasi-static limit



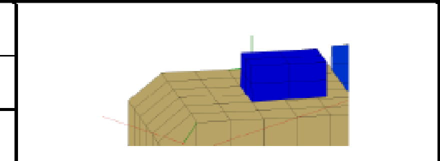
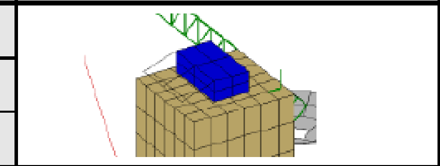
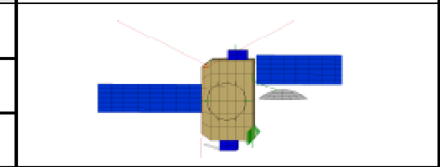
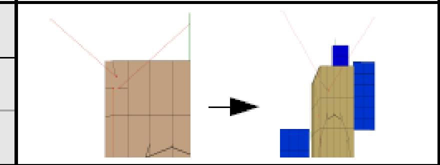
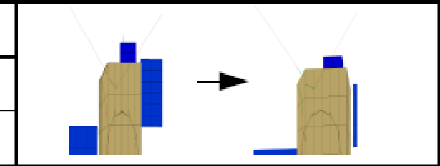
Numerical Results:

The quasi-static limit



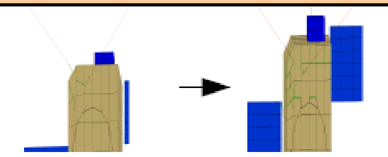
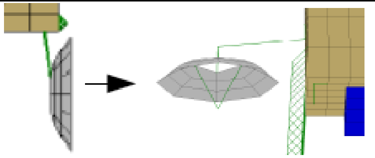
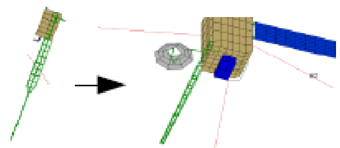
Numerical Results:

The Effect of changing the model 1

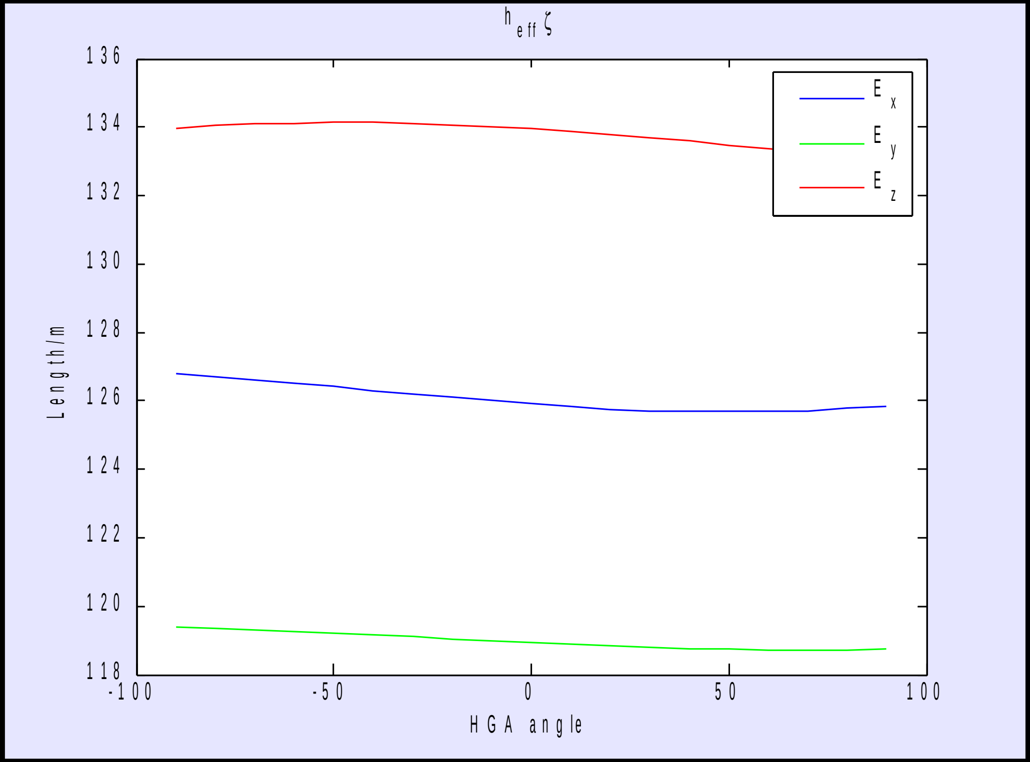
Component	Antenna	δh^{o} [m]	$\delta \zeta^{o}$ [deg]	$\delta \xi^{o}$ [deg]	Illustration
1. Battery	E_x	0.01	0.1	0.2	
	E_y	0.00	0.0	0.2	
	E_z	0.00	0.1	0.0	
2. SECCHI (HI)	E_x	0.00	0.0	0.1	
	E_y	0.00	0.0	0.1	
	E_z	0.00	0.1	0.0	
3. Beveling of hull edges	E_x	0.01	0.0	0.2	
	E_y	0.02	0.0	0.0	
	E_z	0.01	0.0	0.3	
4. Change of antenna connections	E_x	0.08	1.3	6.6	
	E_y	0.02	0.2	0.1	
	E_z	0.13	3.8	0.1	
5. Change of feed positions	E_x	0.11	0.0	0.1	
	E_x	0.12	0.1	0.1	
	E_z	0.09	0.1	0.3	

Numerical Results:

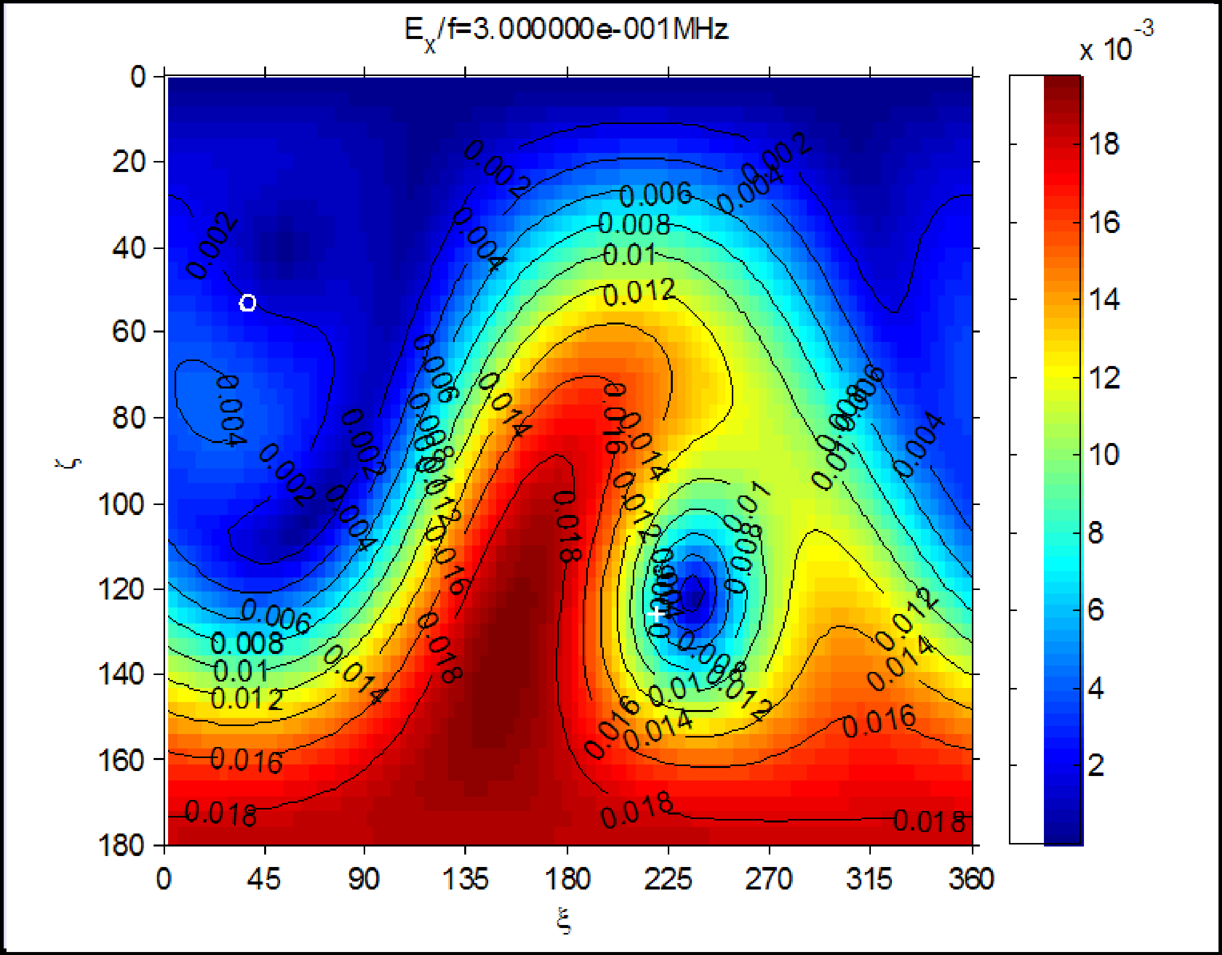
The Effect of changing the model 2

Component	Antenna	δh^{o} [m]	$\delta \zeta^{o}$ [deg]	$\delta \xi^{o}$ [deg]	Illustration
6. Redesign of feed area	E_x	0.00	0.0	0.0	
	E_y	0.01	0.1	0.0	
	E_z	0.00	0.0	0.0	
7. Redesign of HGA	E_x	0.03	0.2	0.5	
	E_y	0.03	0.1	0.4	
	E_z	0.01	0.8	0.9	
8. Redesign of boom	E_x	0.05	0.6	0.2	
	E_y	0.03	0.6	0.3	
	E_z	0.02	1.2	0.3	
9. Change of boom length by 1 m	E_x	0.10	3.1	0.9	boom length 5m → 6m
	E_y	0.07	2.8	0.3	
	E_z	0.16	3.0	1.1	

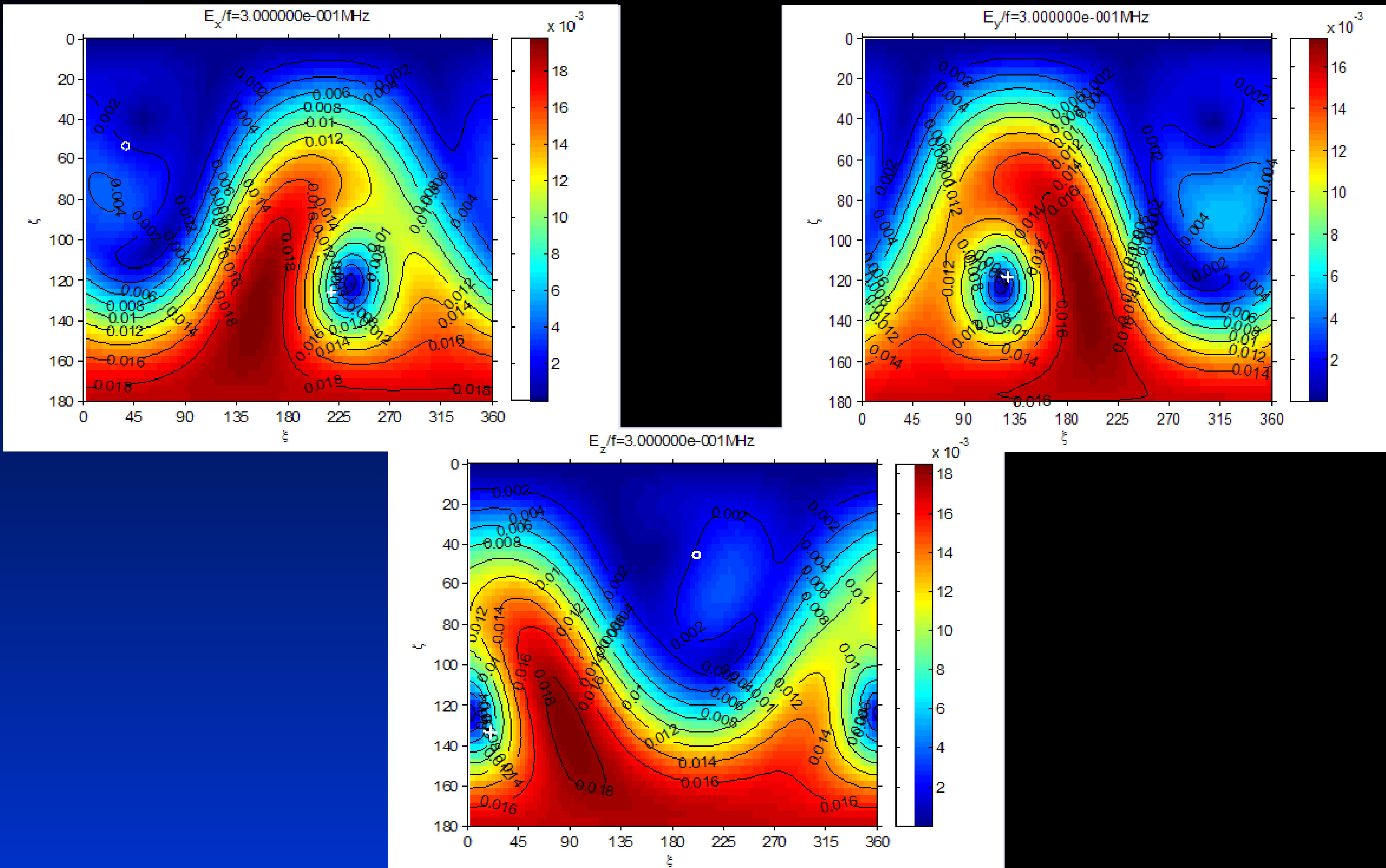
Variation due to the HGA orientation



Relative deviation of the perpendicular component of the effective length vector



Relative deviation of the perpendicular component of the effective length vector



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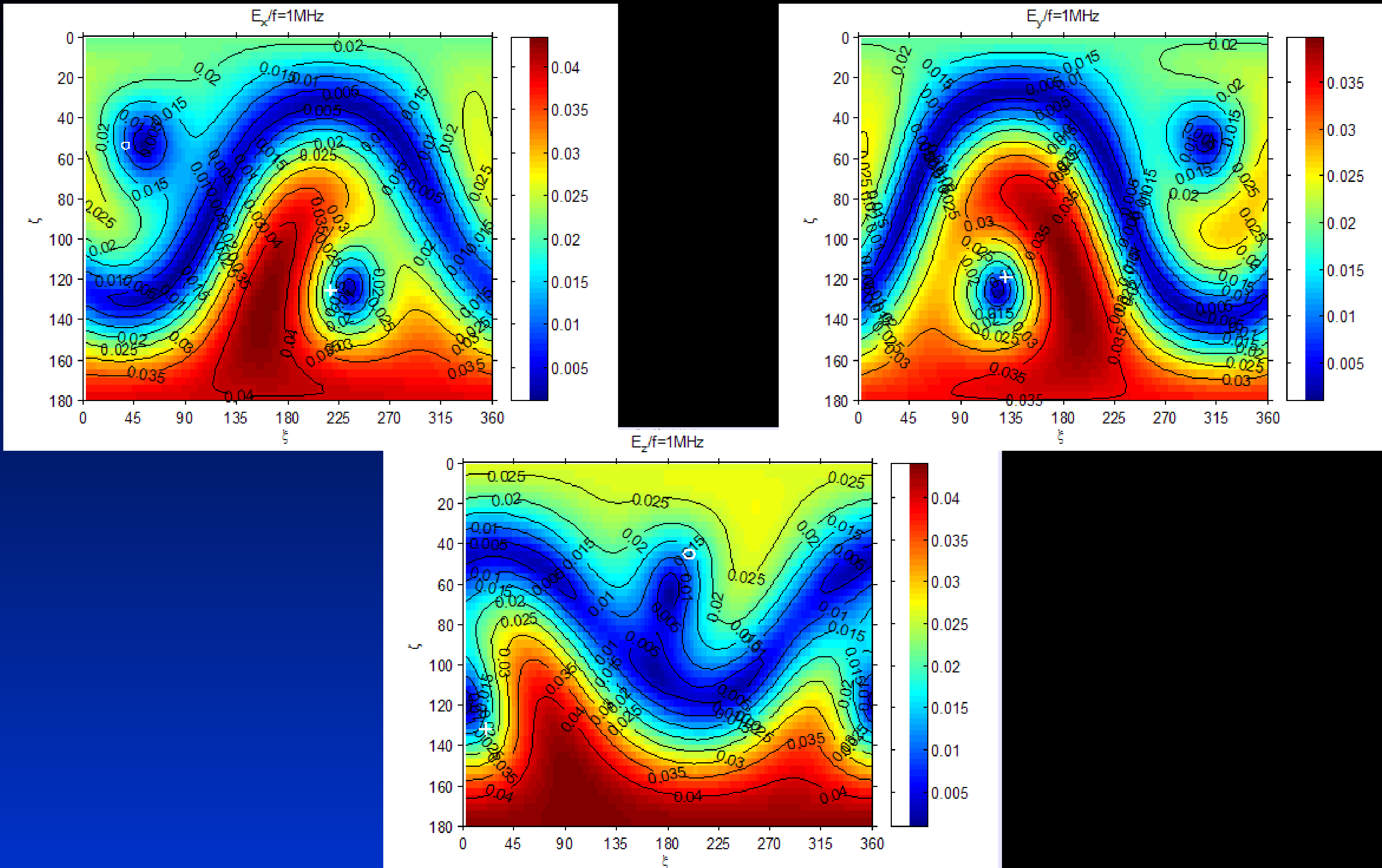
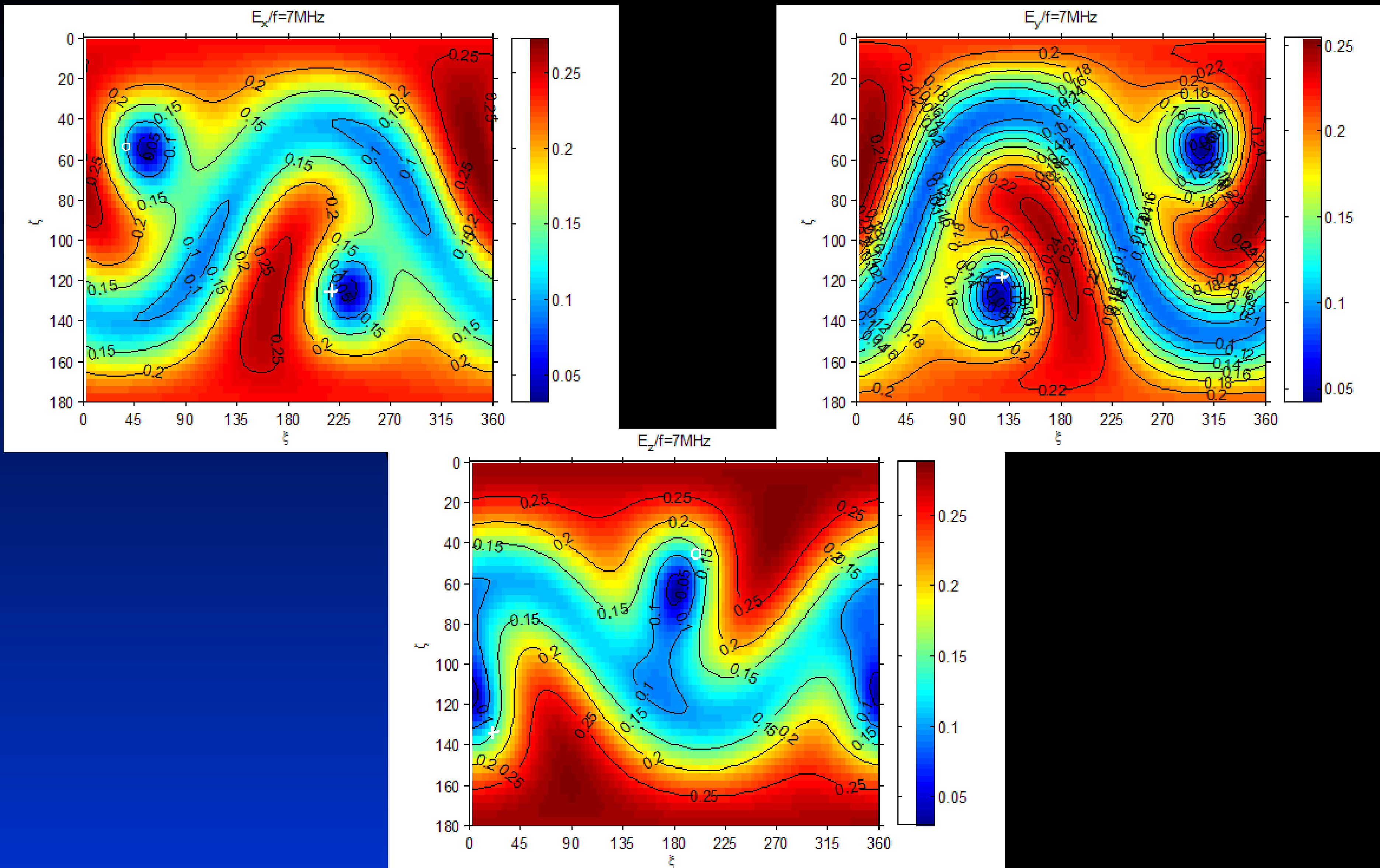
Relative deviation of the perpendicular component of the effective length vector

IWF

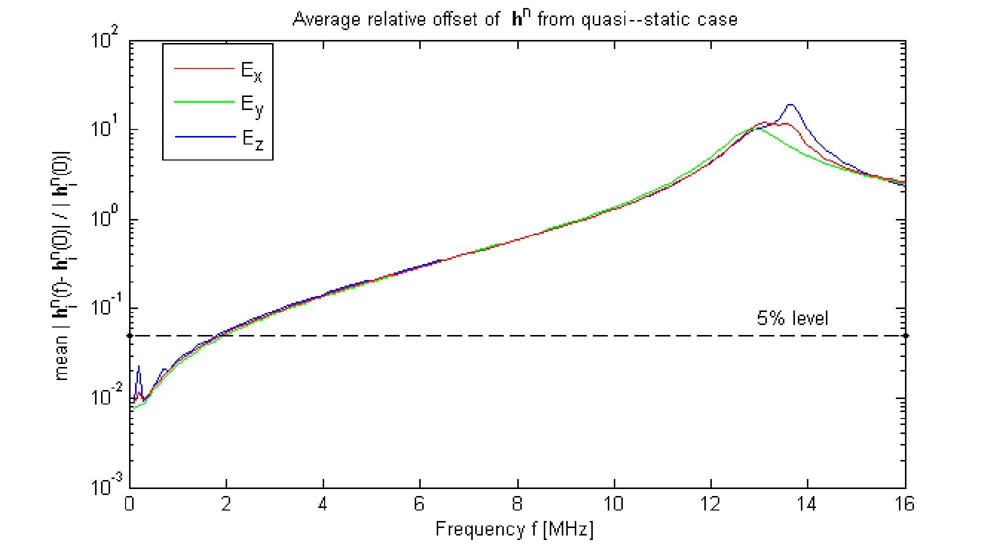


Relative deviation of the perpendicular component of the effective length vector

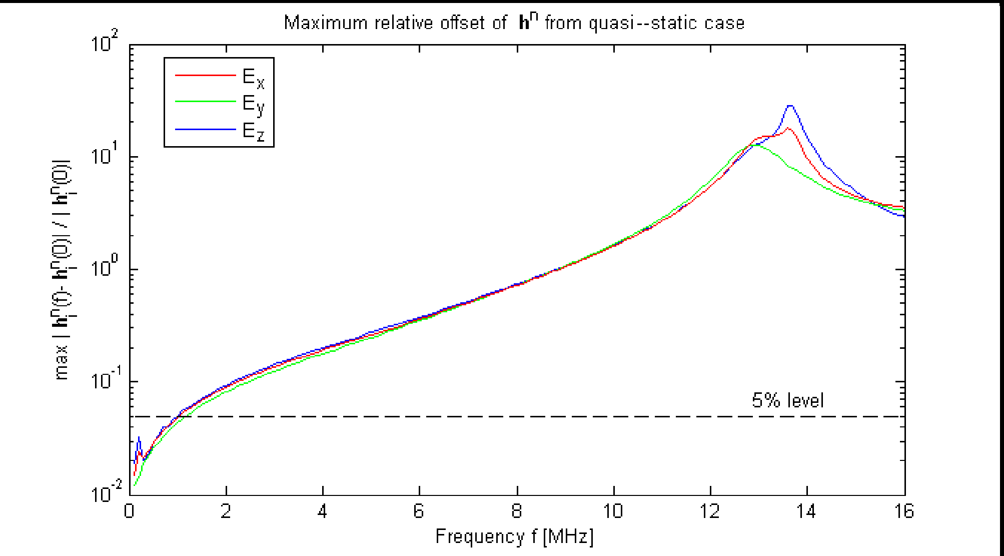


Relative offset from the quasi-static case

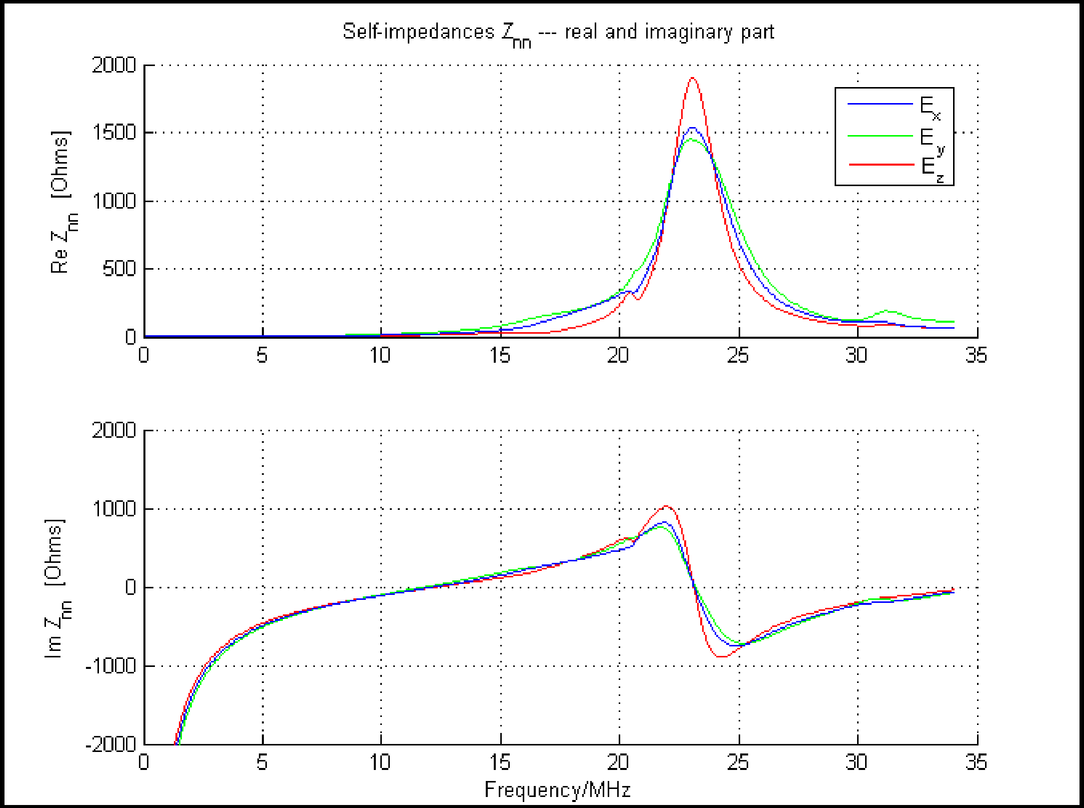
average



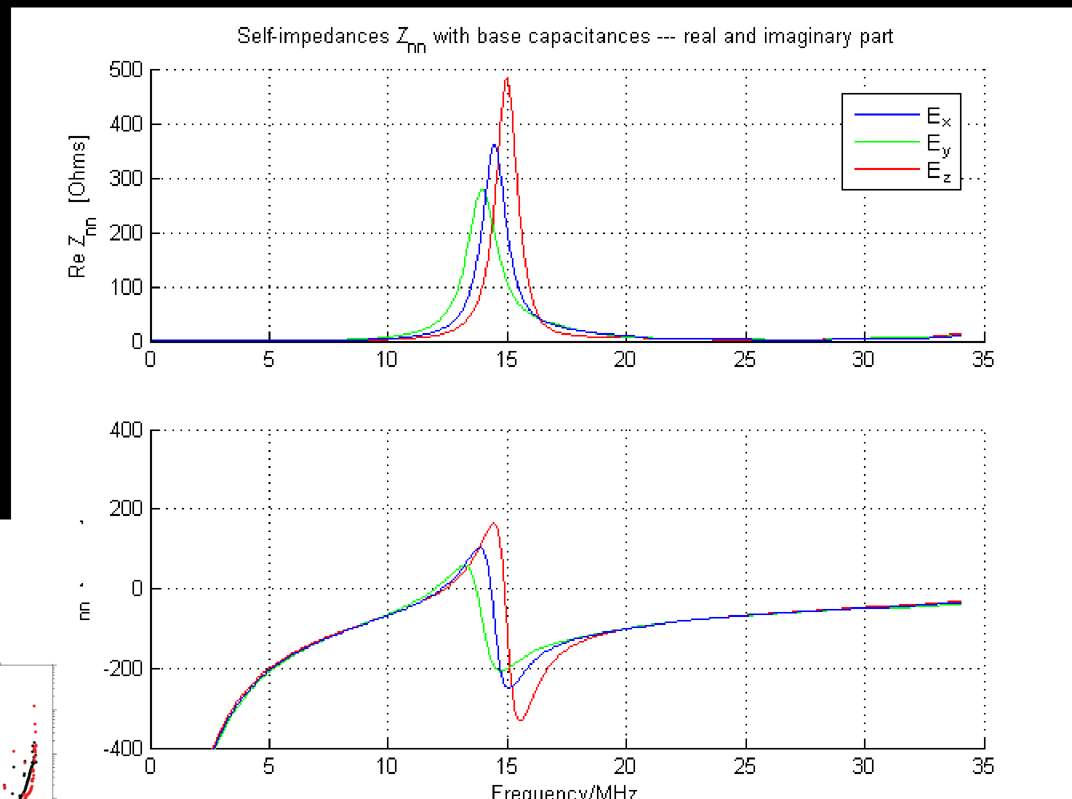
maximum

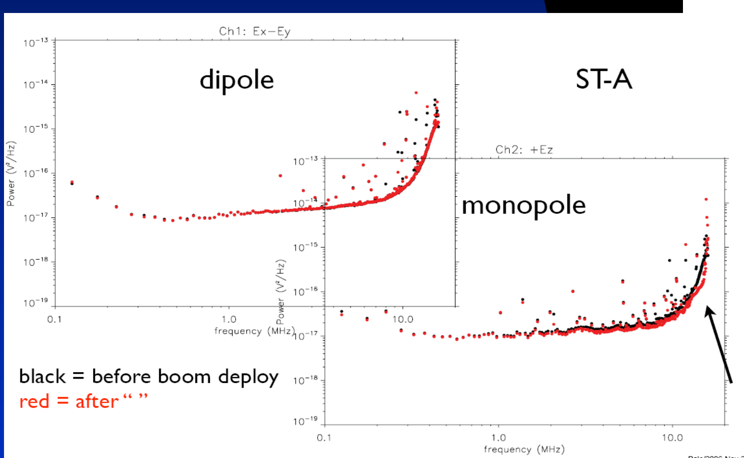


The self-impedances(open)

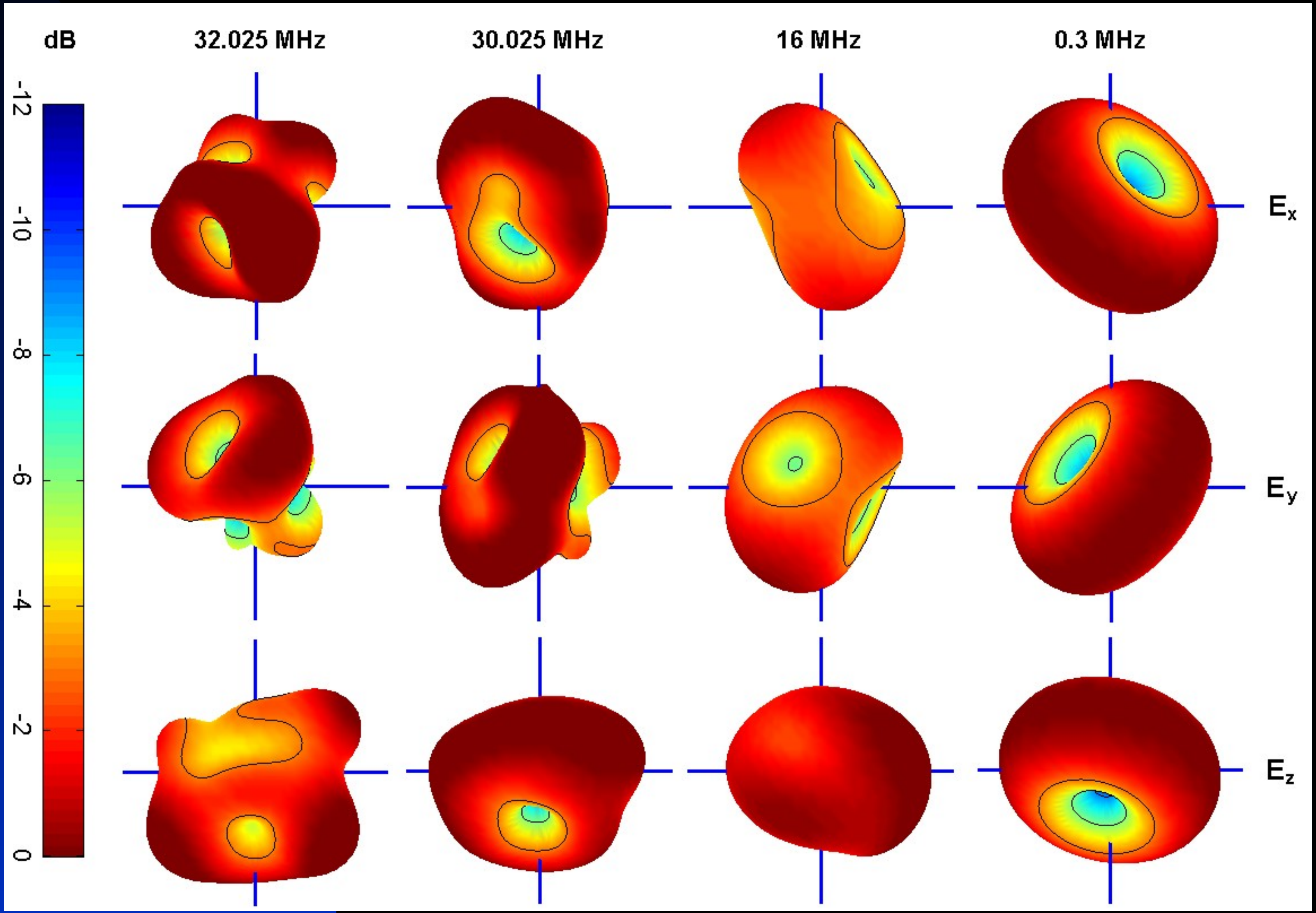


The self-impedances(loaded)





Relative Gain Patterns



Summary

The following parameters have been determined and investigated:

- Open port transfer matrices
- Antenna capacitances
- Transfer matrices of the loaded antennas
- The change of the results due to variation of the spacecraft structure
- The effect of the orientation of the HGA
- An estimation of the upper frequency limit below which the quasi-static result can be used
- A new technique of correcting for inexact modeling of the antenna radii.
- An estimation of the surface impedance of the rheometry model
- The reception patterns at the FFR frequencies