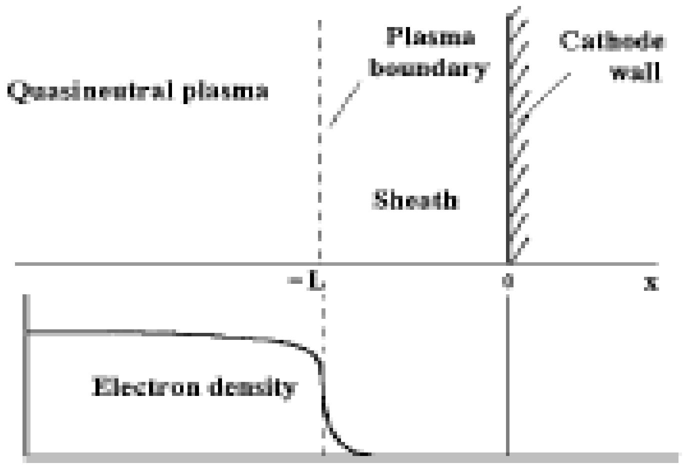
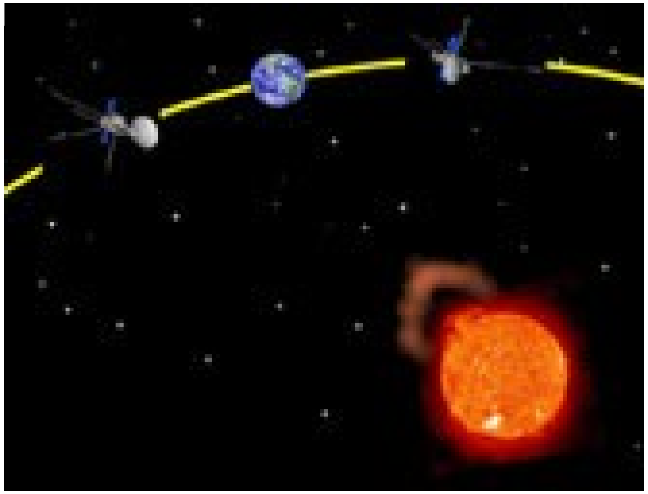
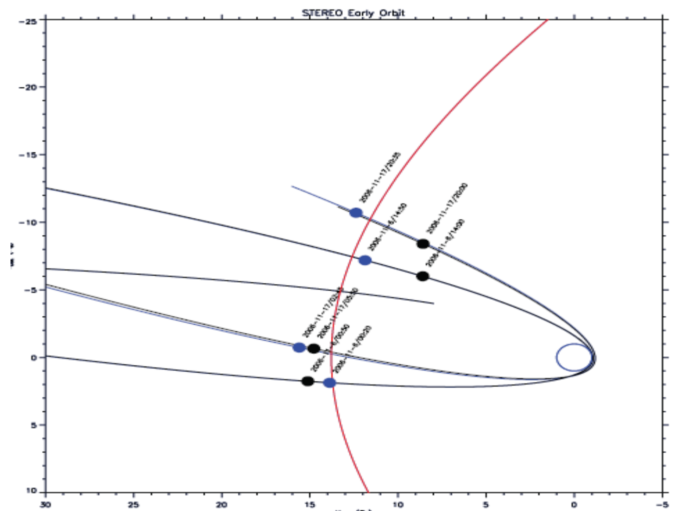
The STEREO/WAVES antenna calibration







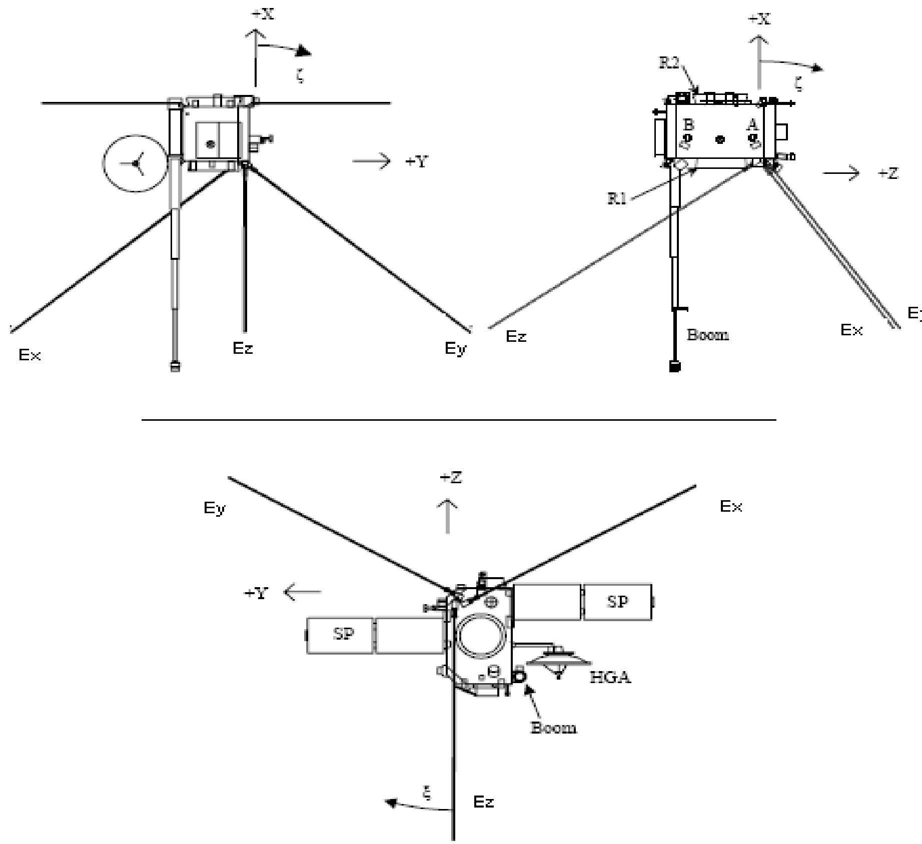
The STEREO/WAVES antenna calibration

Overview

- The goal: correct data interpretation
- Effective length vectors, impedance/ admittance matrices, field patterns
- Numerical and experimental analysis:
  - Wire/Patchgrid modeling
  - Rheometry
  - Anechoic chamber
  - Inflight calibration

The STEREO/WAVES antenna calibration

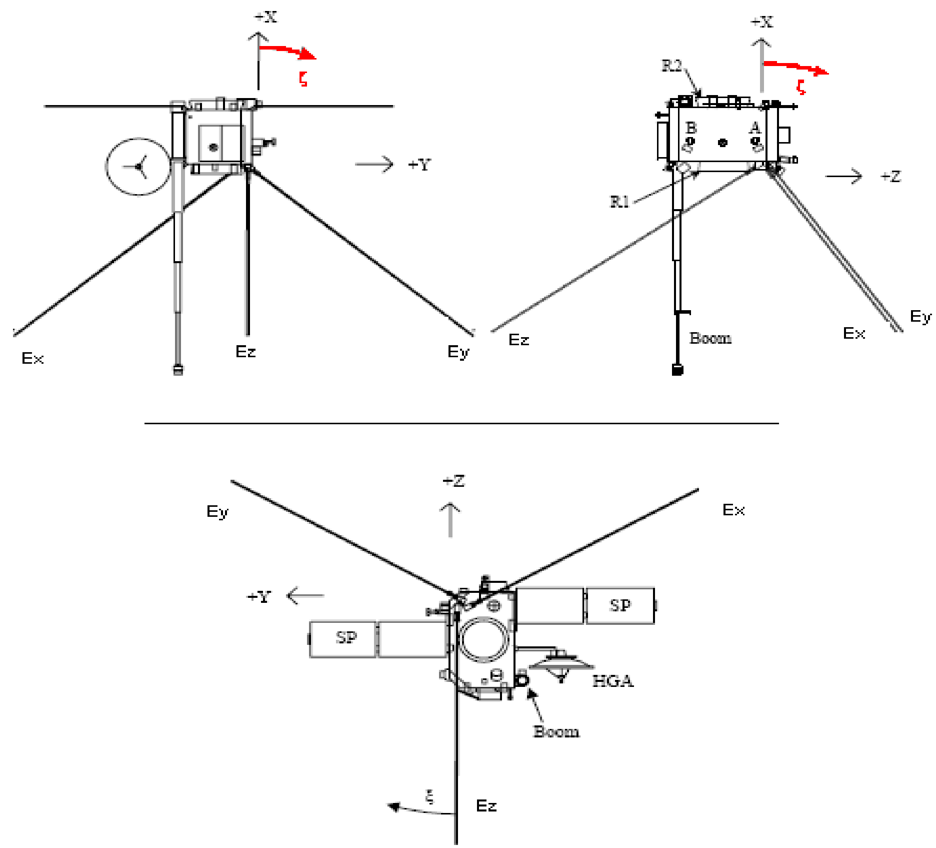
The coordinate system



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 STEREO/WAVES antenna calibration

The coordinate system



Antenna	h^m [m]	ζ^m [deg]	ξ^m [deg]
E_x	6.00	125.3	-120.0
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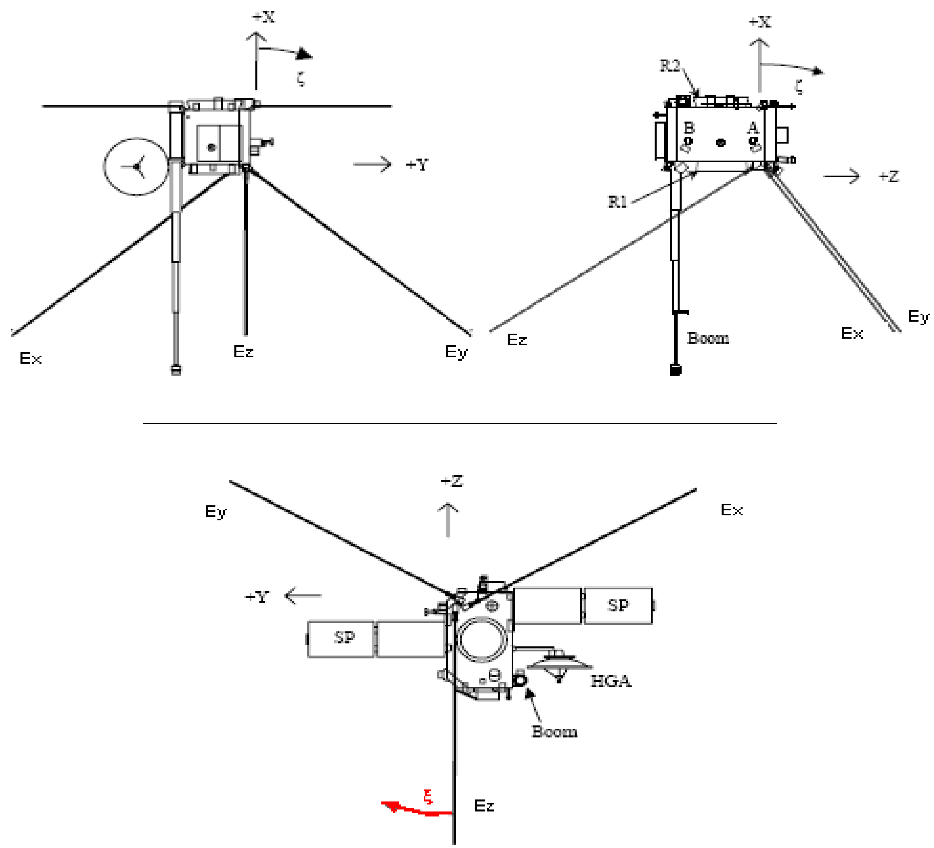
The STEREO/WAVES antenna calibration

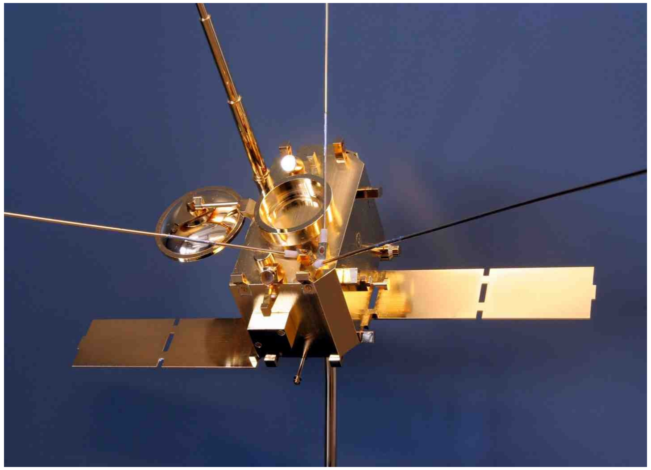
The coordinate system

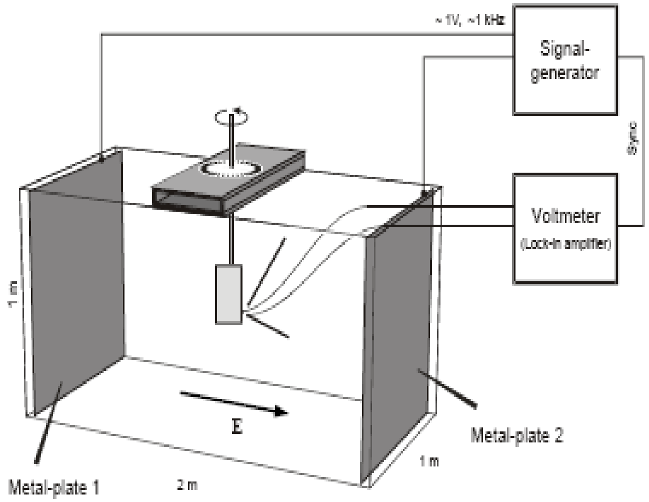


Antenna	h^m [m]	ζ^m [deg]	ξ^m [deg]
E_x	6.00	125.3	-120.0
E_y	6.00	125.3	120.0
E_z	6.00	125.3	0.0

The STEREO/WAVES antenna calibration

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

The STEREO/WAVES antenna calibration

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

The STEREO/WAVES antenna calibration

Rheometry results

open feeds

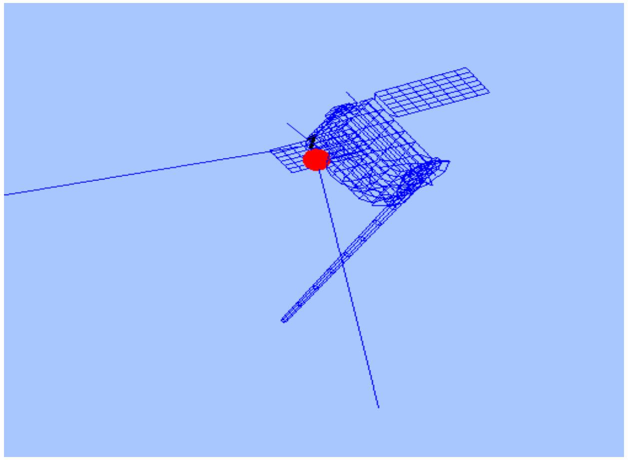
loaded feeds

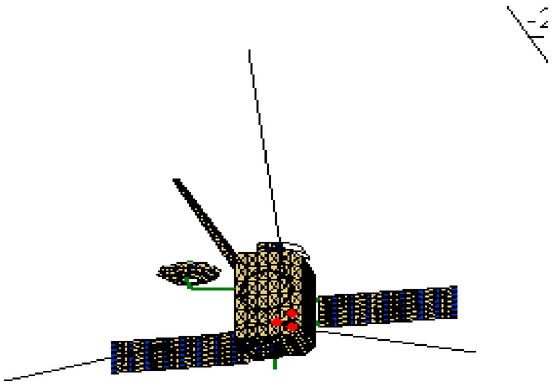
HGA orientation	Antenna	STEREO A			STEREO B		
		h^o [m]	ζ^o [deg]	ξ^o [deg]	h^o [m]	ζ^o [deg]	ξ^o [deg]
-90 deg	E_x	2.89	126.5	-140.2	2.93	126.2	-140.8
	E_y	3.83	118.9	127.8	3.86	118.8	127.7
	E_z	2.37	132.2	21.1	2.36	132.4	20.0
0 deg	**E_x**	**2.89**	**126.2**	**-140.7**	**2.92**	**126.0**	**-141.2**
	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 STEREO/WAVES antenna calibration

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

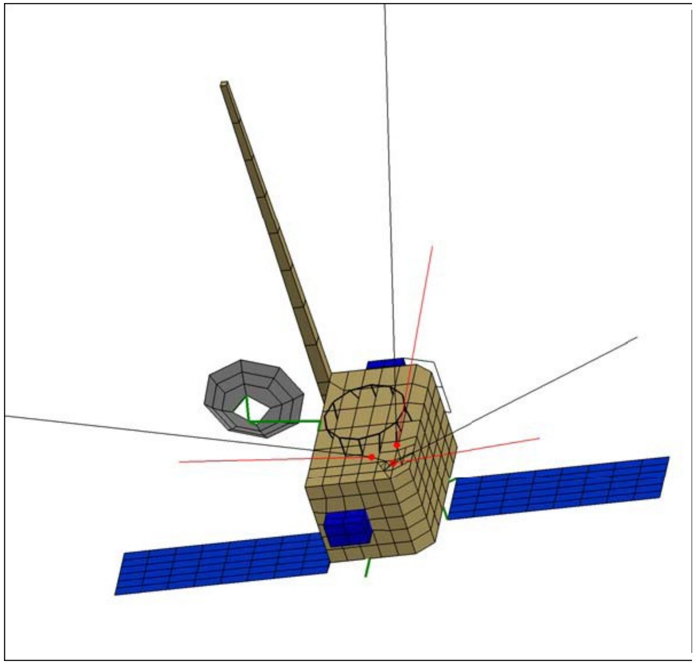




The STEREO/WAVES antenna calibration

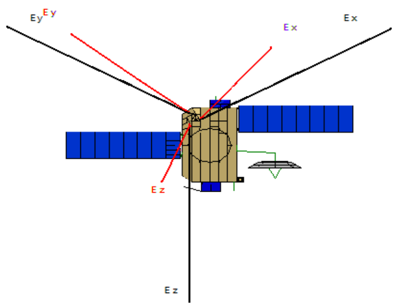
The numerical method

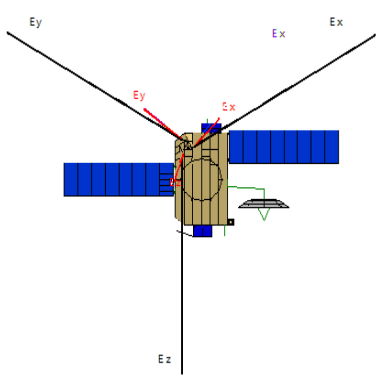
- The equation governing the current distribution is the electric field integral equation (EFIE. CONCEPT), or the reaction integral equation (RIE, ASAP)
- For patches, the magnetic field integral equation (MFIE, CONCEPT) is used
- The antenna is excited at the feed
- Due to reciprocity, the receiving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



The STEREO/WAVES antenna calibration

The numerical method

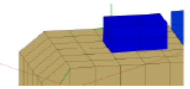
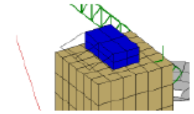
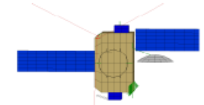
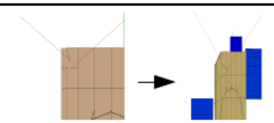
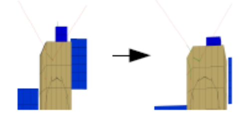
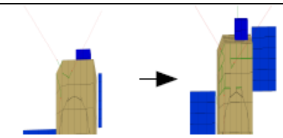
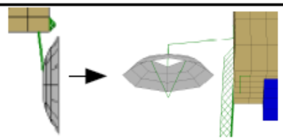
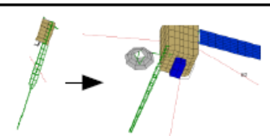




- Calculations were performed for open feeds and base capacitances of 90pF.
- A correction for the real antenna diameters has to be applied on the ASAP results. CONCEPT can deal with real antenna diameters.

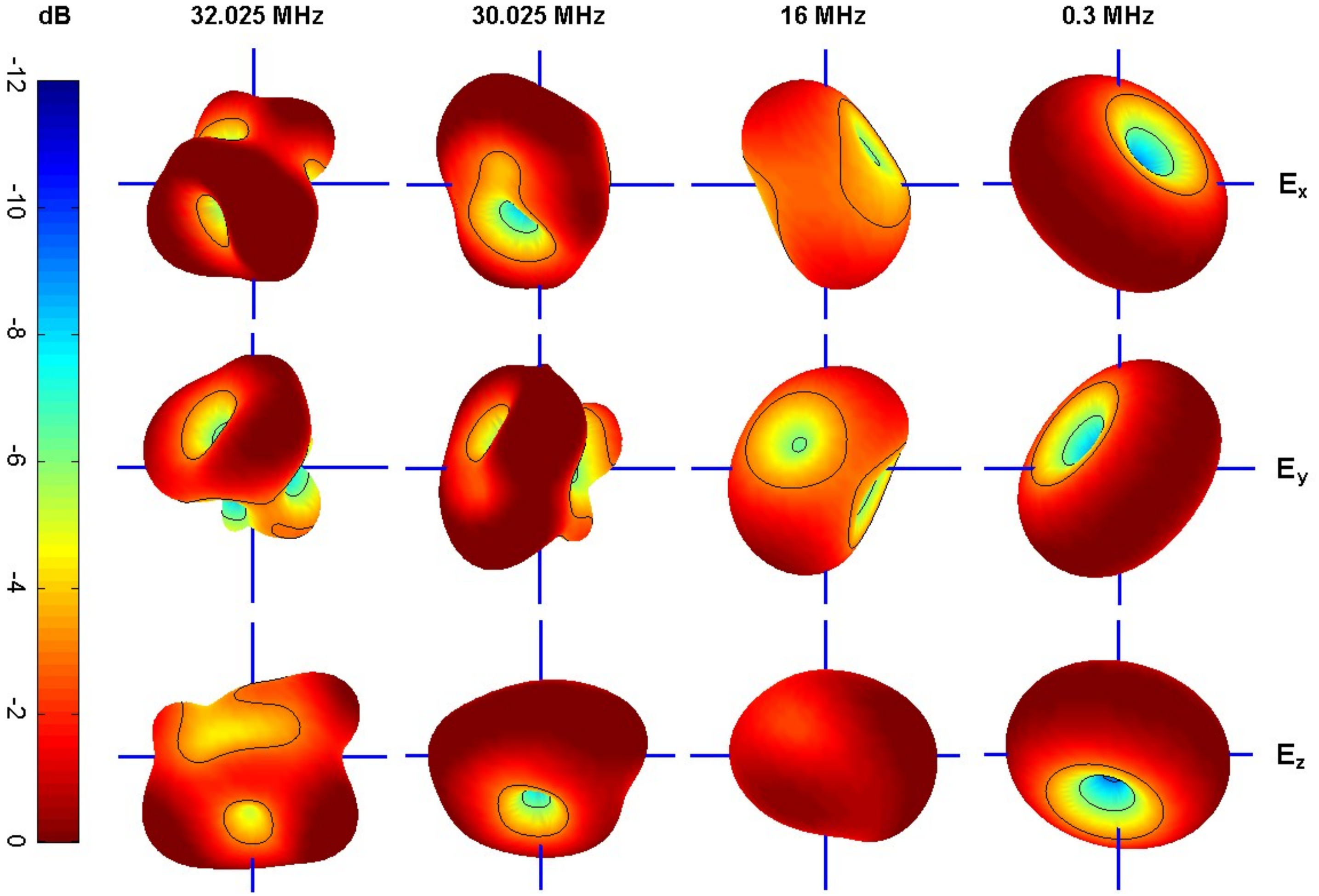
The STEREO/WAVES antenna calibration

The effect of changing the model

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	
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	
	E_y	0.07	2.8	0.3	
	E_z	0.16	3.0	1.1	boom length 5m → 6m

The STEREO/WAVES antenna calibration

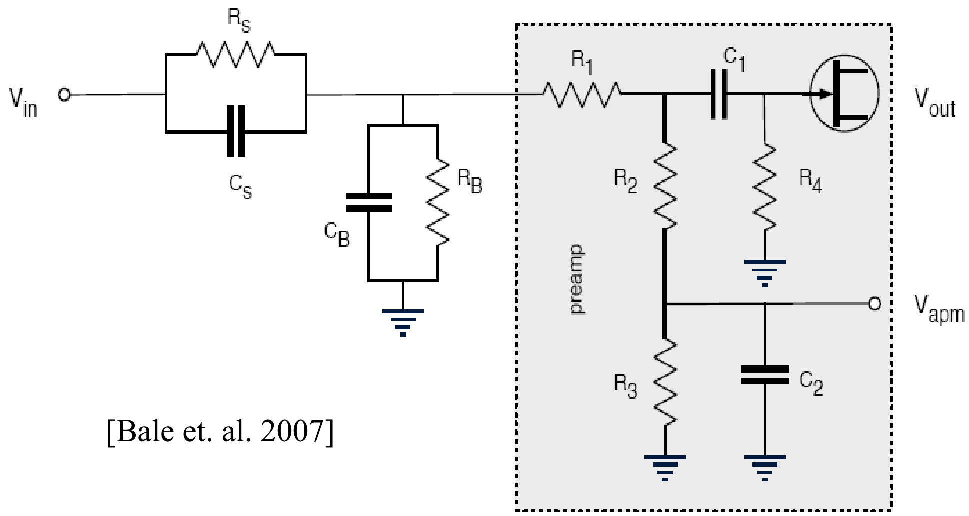
Relative gain Pattern



The STEREO/WAVES antenna calibration

Including the plasma sheath

- Spacecraft antennas are usually coupled to the surrounding space plasma.
- The electromagnetic coupling can be modeled by a system of a resistance and a capacitance.
- In rarefied plasma the coupling can not take place without photoelectrons.
- The sheath thickness must not be larger than the antennas.



[Bale et. al. 2007]

The STEREO/WAVES antenna calibration

Application

- STEREO operates in solar wind conditions at 1AU.
- The photo-electron production rate is higher than the thermal electron impact rate.
  --> positive charge.
- i_{ph}...$10^{-4}Am^{-2}$ [Fahrleson 1967]
- A_{rel}...0.5
- l=6m
- d=1in (0.0254m) on average
- Mean energy of photo-electrons=1.5eV [Grard 1973]
- Mean energy of thermal electrons=10eV

$$I_{ph} = A_{rel} i_{ph} l d \sim 7.6 \cdot 10^{-6} A$$

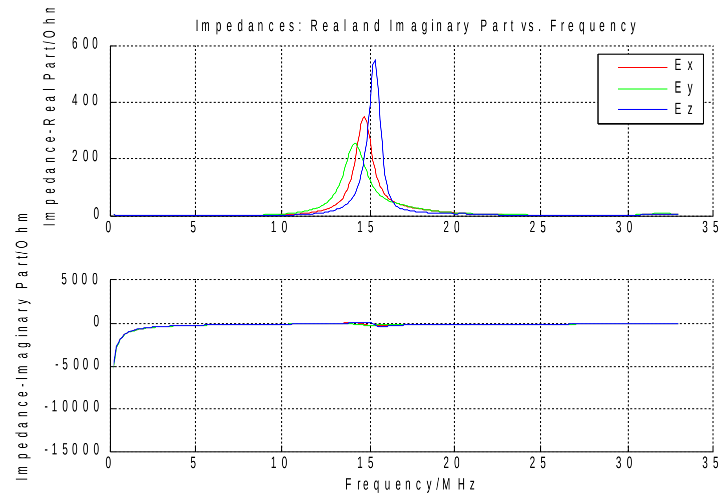
$$I_e = -e n_e d \pi \sqrt{\frac{\kappa T_e}{2\pi m_e}} \sim -2 \cdot 10^{-7} A$$

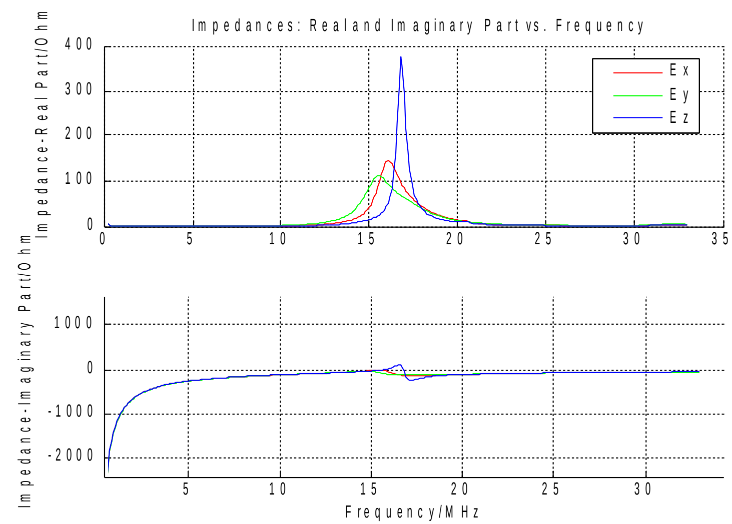
- -->V=5.5V
- $\overline{n}_e=10^6 m^{-3}$
- -->$n_{ph}(0)=2\times10^8 m^{-3}$
- -->2.5% of the photo-electrons reach the plasma.
- -->λ_{sh} =0.6m or 0.4m, depending on the method.

The STEREO/WAVES antenna calibration

Application

- Using the appropriate equations, one finds:
  - $R_s = 0.2 M\Omega$
  - $C_s = 87 pF$
- Via these parameters the sheath can be included into the numerical antenna calibration (wire-grid).
- Computation of the impedances show that the inclusion of the sheath has an effect.

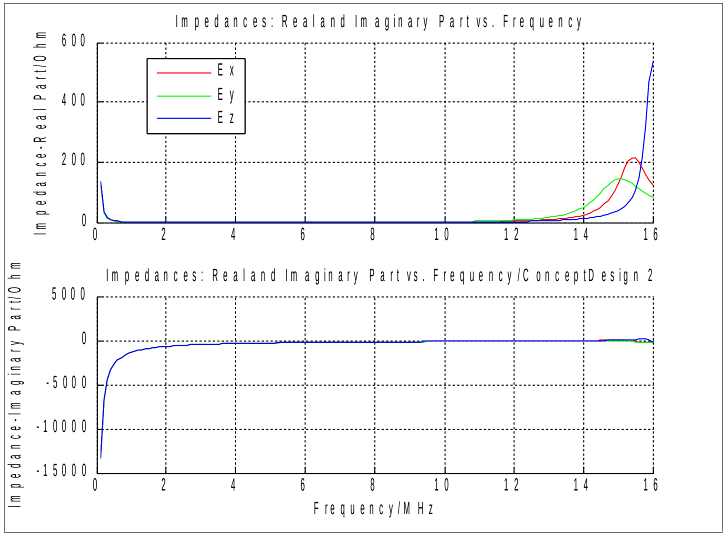


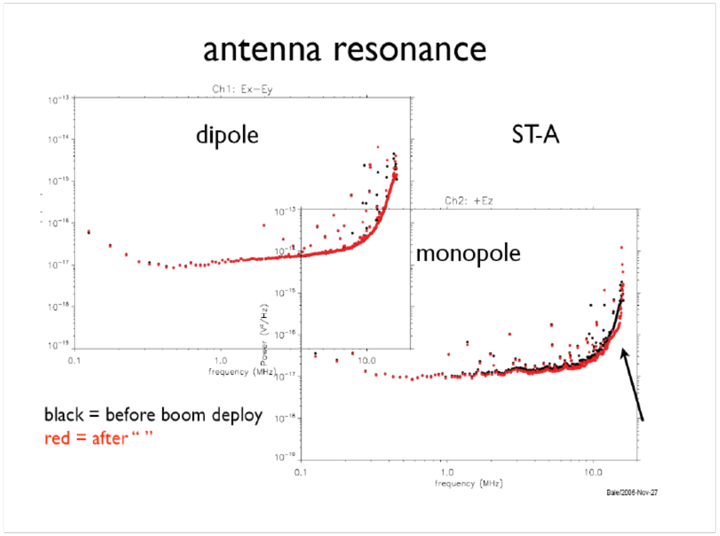


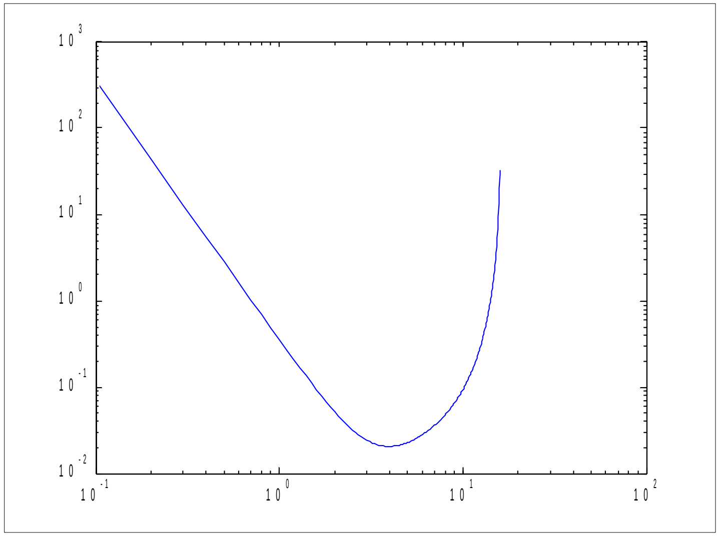
The STEREO/WAVES antenna calibration

Application

- Comparing the location of the second resonance of antenna E_z with measured data shows that the inclusion of the sheath capacitance has a corrective effect.
- Further and more accurate data is needed to verify the model.







The STEREO/WAVES antenna calibration

The End

Thank You for Your attention !