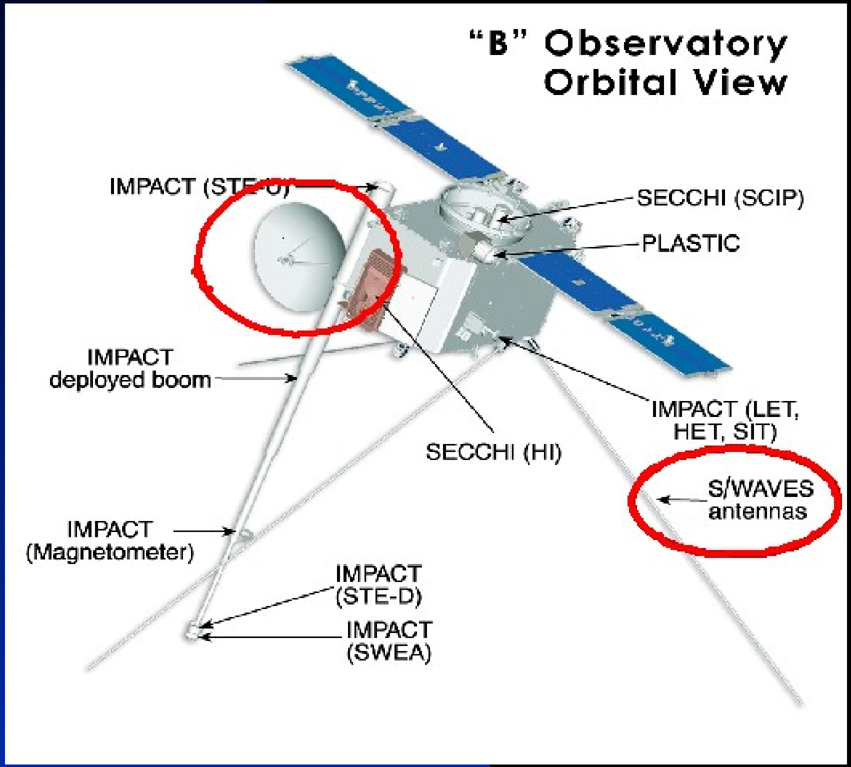
On the calibration of spacecraft antennas

Comparison and discussion of different methods

Oswald, T.H. (1), Rucker (1), W. Macher (1), A. Lecacheux (2), J.L. Bougeret (2), M.L. Kaiser (3), K. Goetz (4)

(1) IWF/OEAW thomas.oswald@oeaw.ac.at
(2) Observatoire de Paris-Meudon, France
(3) NASA/GSFC Greenbelt, MD, USA
(4) University of Minnesota, USA

Antennas on spacecraft



- Two kinds of antenas:
  - For communication
  - For scientific experiments
- Scientific antennas often used to receive natural radiation
- Sometimes direction finding is performed

Why is antenna calibration necessary ?

- To perform “Direction Finding”(DF), antenna properties must be known to a high degree of accuracy
- The receiving properties can be quantified by the effective length vector
- The effective length vector represents the antenna as it behaves electrically
- It is influenced by the geometry of the spacecraft
- Depends, in general, upon frequency and direction of incidence and is a complex vector, but at low frequency it can be treated as a constant real vector
- In this quasistatic range, DF is possible

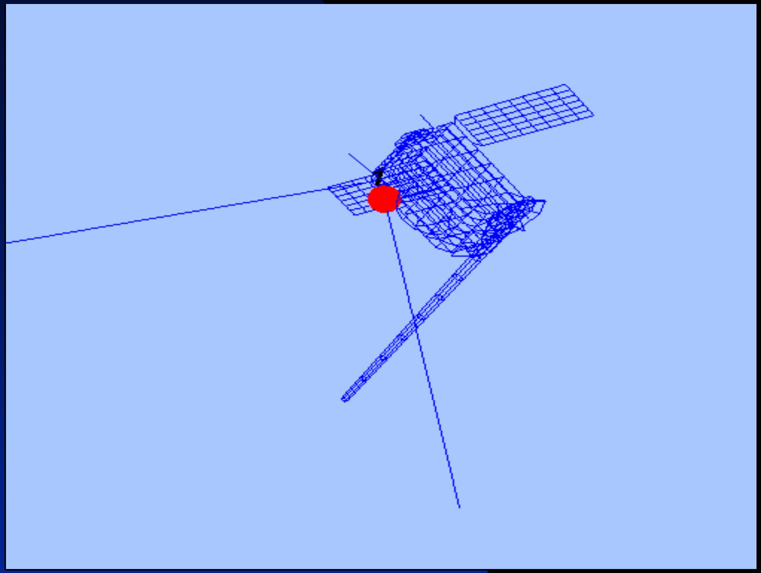
Methods to determine the effective length vector

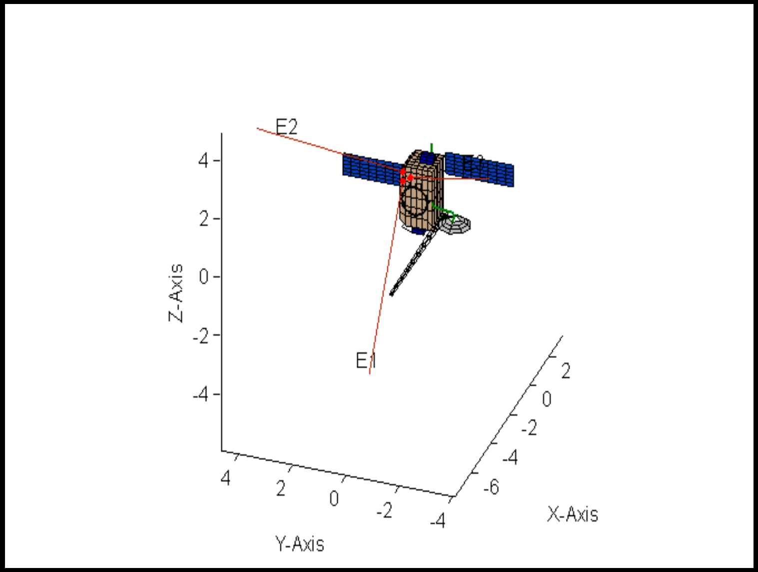
(1) Numerical electromagnetic code
(2) Rheometry
(3) The EMC chamber
(4) In-flight Calibration

The numerical method 1

- The spacecraft is modelled as a grid of wires
- Then the currents along these wires are computed
- On base of the current distribution, all other antenna properties (effective length vectors, impedances, power patterns) can be calculated

The numerical method 1





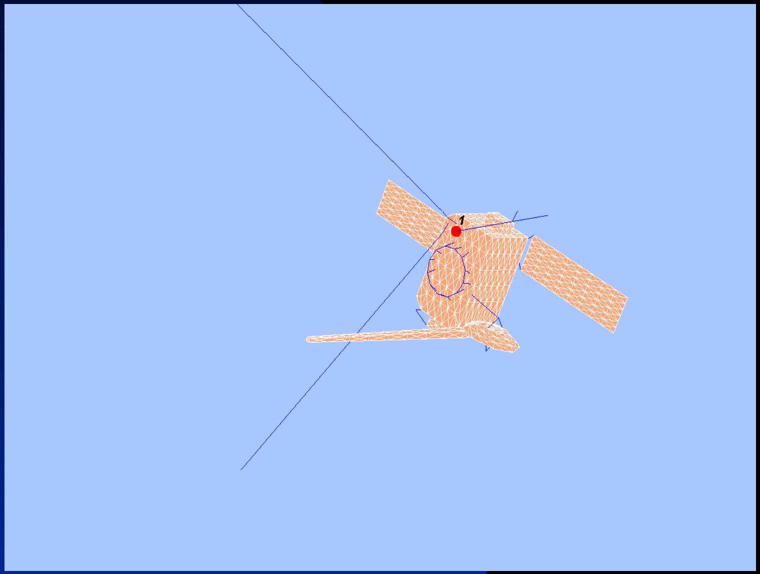
Computation of the current distribution 1

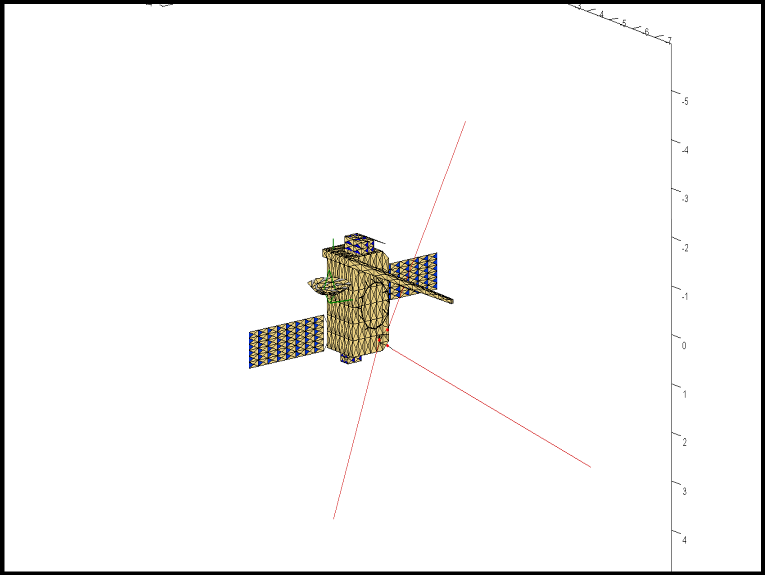
- The equation governing the current distribution is the electric field integral equation (EFIE), or the reaction integral equation
- Simplifications:
  - Thin currents along the center of the wires
  - No transverse currents

The numerical method 2

- The spacecraft is modelled of patches
- Then the surface currents on each patch are computed
- On base of the current distribution, all other antenna properties (effective length vectors, impedances, power patterns) can be calculated

The numerical method 2





Computation of the current distribution 2

- The equation governing the current distribution is the magnetic field integral equation (MFIE)
- Disadvantage: Longer computing time
- Advantage: Better results in the high frequency range

The Method of Moments

- The Method of Moments (MoM) can be used to solve integral equations
- A modified version of the antenna scatterers analysis program (ASAP) and CONCEPT II are used to calculate the currents
- Only CONCEPT II can deal with patches

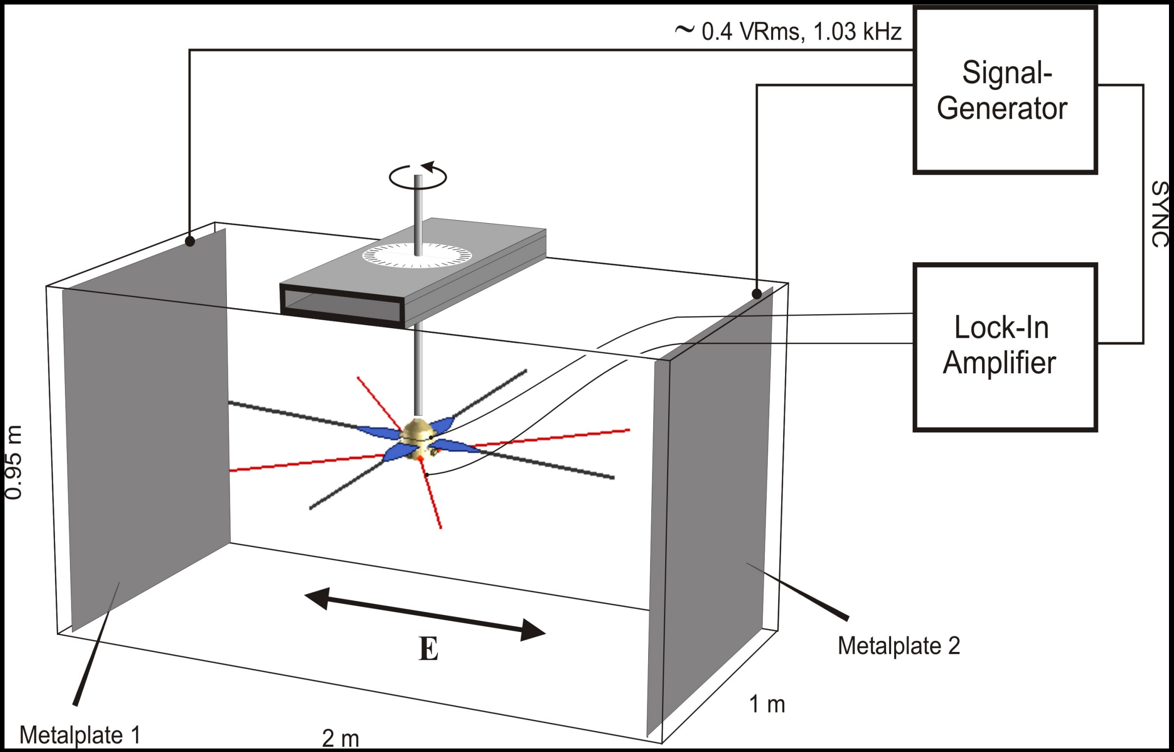
Further calculations

- The effective length vectors, impedances and power patterns are calculated by Matlab routines created in the space research institute
- Calculations were performed for open feeds and base capacitances of 90pF

Rheometry

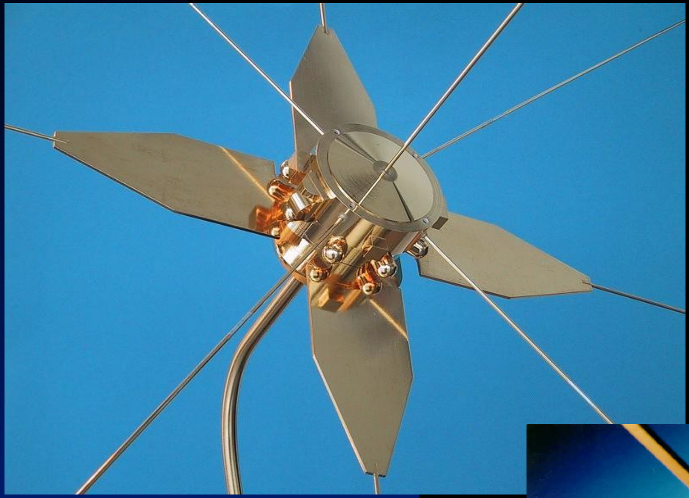
- A gold-plated model of the spacecraft is submerged into a water tank
- A low-frequency electric field is applied
- The response (induced voltage) of the antennas is measured as a function of spacecraft orientation
- The effective length vectors and the antenna impedances can be computed from the data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

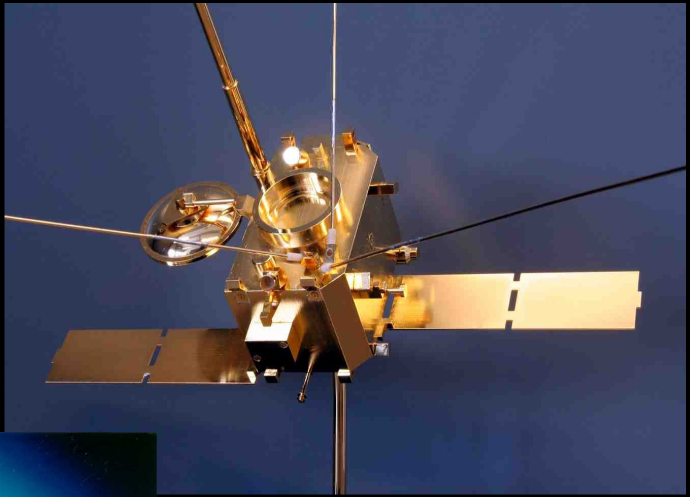
Rheometry

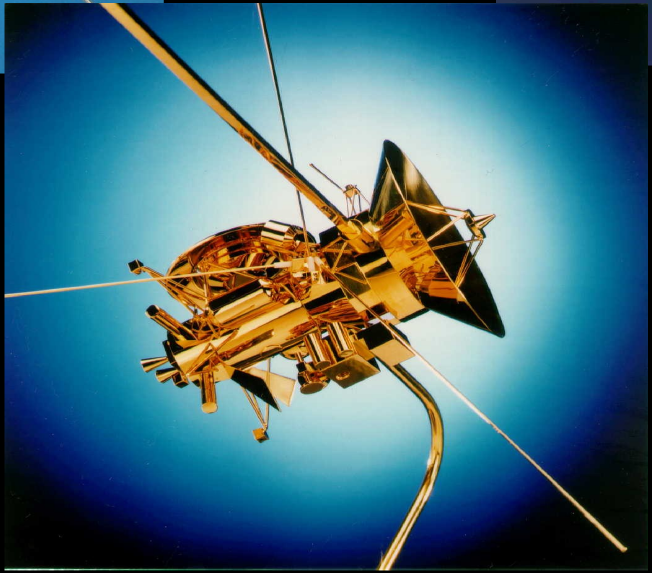


~ 0.4 VRms, 1.03 kHz
Signal-Generator
SYNC
Lock-In Amplifier
0.95 m
E
Metalplate 1
2 m
1 m
Metalplate 2

Some models







The EMC chamber

- In the EMC (electromagnetic cleanliness) chamber a scale model is illuminated by coherent electromagnetic radiation.
- The respons of the antennas is measured.
- Different frequencies can be dealt with.

The EMC chamber

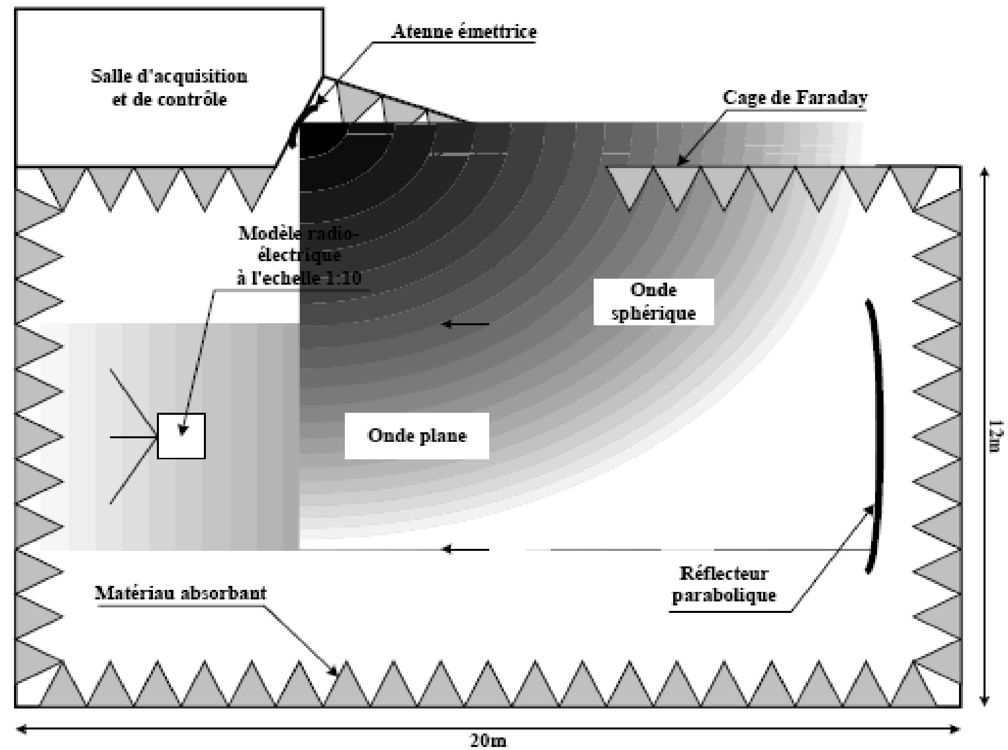
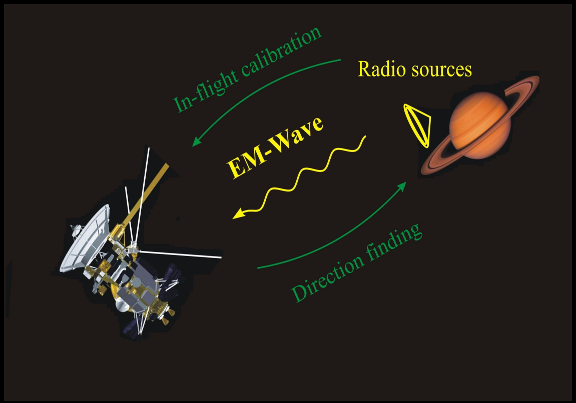


Figure 3.2 : Principe de la BCMA

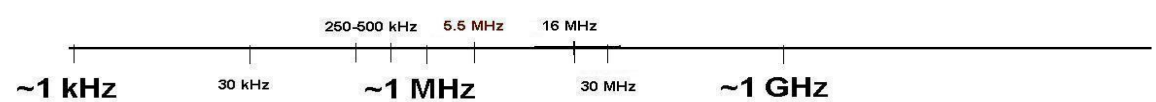
Inflight calibration

- A known radio source, natural or manmade, is used to calibrate the antennas after launch
- The spacecraft should make an appropriate roll manoeuvre to measure the dependence of the respons as a function of orientation



Overview

	Quasistatic	Medium and High Frequency	Very High Frequency
Experimental (includes Calibration)	Rheometry (Electrolytic tank measurements with scale model	Scale model and appropriate receiver: Measurements in open-air or inside a room, the walls of which are covered with absorbers	
Theoretical	Electrostatic and Magnetostatic potential analogy	Numerical Codes based on EFIE and MFIE Hybrid	Short wavelength scattering, Geometrical optics Methods
Scale for CASSINI antennas	SKR		
Scale for STEREO antennas	SOLAR BURSTS		
Scale for INTERBALL antennas	AKR		
Scale for MARSIS antennas			



The results in case of the stereo spacecraft

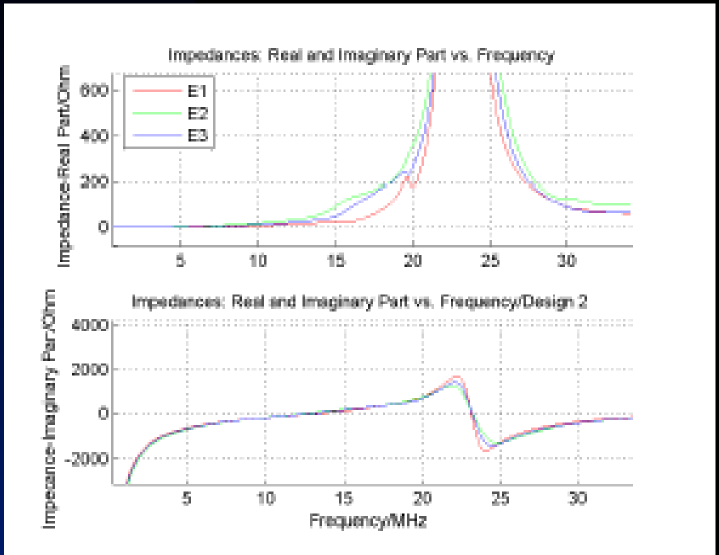
Table 23: STEREO A, Design 2 without capacitances

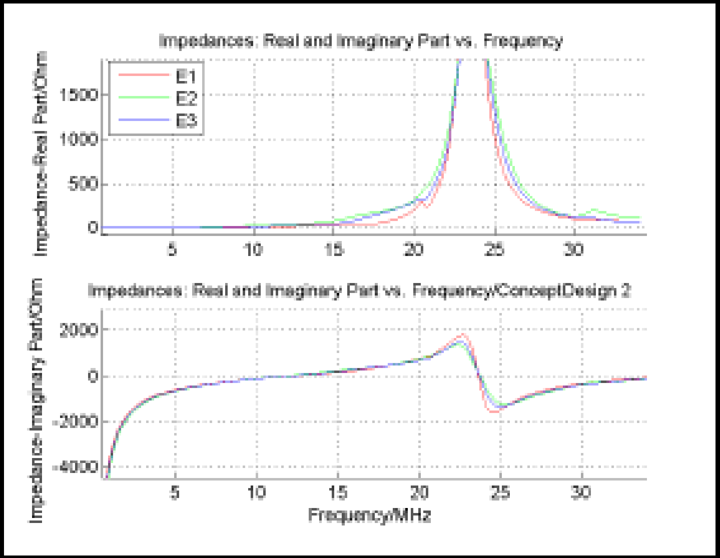
		ASAP	CONCEPT II	Rheometry	Physical antennas
E1	length/m	2.30	2.37	2.36	6.00
	$\zeta/^{\circ}$	133.7	133.8	132.2	125.3
	$\xi/^{\circ}$	21.4	21.2	21.6	0.0
E2	length/m	3.82	3.89	3.84	6.00
	$\zeta/^{\circ}$	119.1	119.0	118.7	125.3
	$\xi/^{\circ}$	129.3	129.2	127.9	120.0
E3	length/m	3.03	3.09	2.89	6.00
	$\zeta/^{\circ}$	126.0	125.9	126.2	125.3
	$\xi/^{\circ}$	-141.6	-141.4	-140.7	-120.0

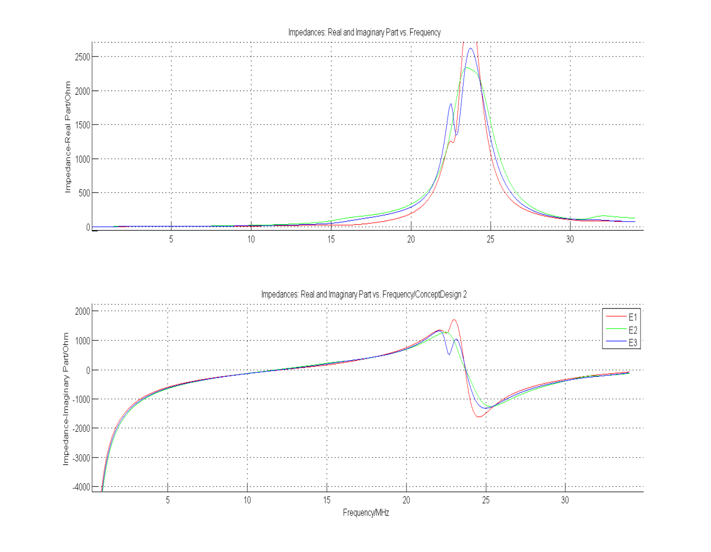
Table 25: STEREO A, Design 2 with Capacitances

		ASAP	CONCEPT II	Rheometry	Physical antennas
E1	length/m	0.79	0.80	0.98	6.00
	$\zeta/^{\circ}$	126.2	125.5	126.8	125.3
	$\xi/^{\circ}$	16.2	15.6	17.0	0.0
E2	length/m	1.20	1.20	1.46	6.00
	$\zeta/^{\circ}$	115.4	114.9	115.7	125.3
	$\xi/^{\circ}$	127.8	127.6	126.9	120.0
E3	length/m	0.99	0.99	1.16	6.00
	$\zeta/^{\circ}$	121.2	120.6	122.3	125.3
	$\xi/^{\circ}$	-136.2	-135.6	-135.9	-120.0

The impedances







Thank You for Your attention !