Low Costing Arrays Of Differentially Fed TSA Elements

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Maxwell's equations modification

$$J_{tot} = J + \frac{\partial D}{\partial t}$$

$$\mu H = \nabla \times A$$

$$\nabla \times H = J_{tot}$$

$$E = \mu v \times H - \frac{\partial A}{\partial t} - \nabla \phi$$

$$E = \frac{1}{\varepsilon} D$$

$$E = \frac{1}{\sigma} J$$

$$\nabla D = \rho$$

$$\nabla J = -\frac{\partial \rho}{\partial t}$$

€?

$$J_{tot} = J + \frac{\partial D}{\partial t} + \$$$

$$\mu H = \nabla \times A + \$$$

$$\nabla \times H = J_{tot} + \$$$

$$E = \mu v \times H - \frac{\partial A}{\partial t} - \nabla \phi + \$$$

$$E = \frac{1}{\varepsilon} D + \$$$

$$E = \frac{1}{\sigma} J + \$$$

$$\nabla D = \rho + \$$$

$$\nabla J = -\frac{\partial \rho}{\partial t} + \$$$

Outline

- What does rise the cost in an array of TSA elements?
- How can we reduce this cost?
- What are the problems reducing the cost?
- Examples of *Differentially Fed TSA Elements Array*
  – FLOWPAD^3 (ASTRON)
  – FIDA^3 (FG-IGN, Spain)

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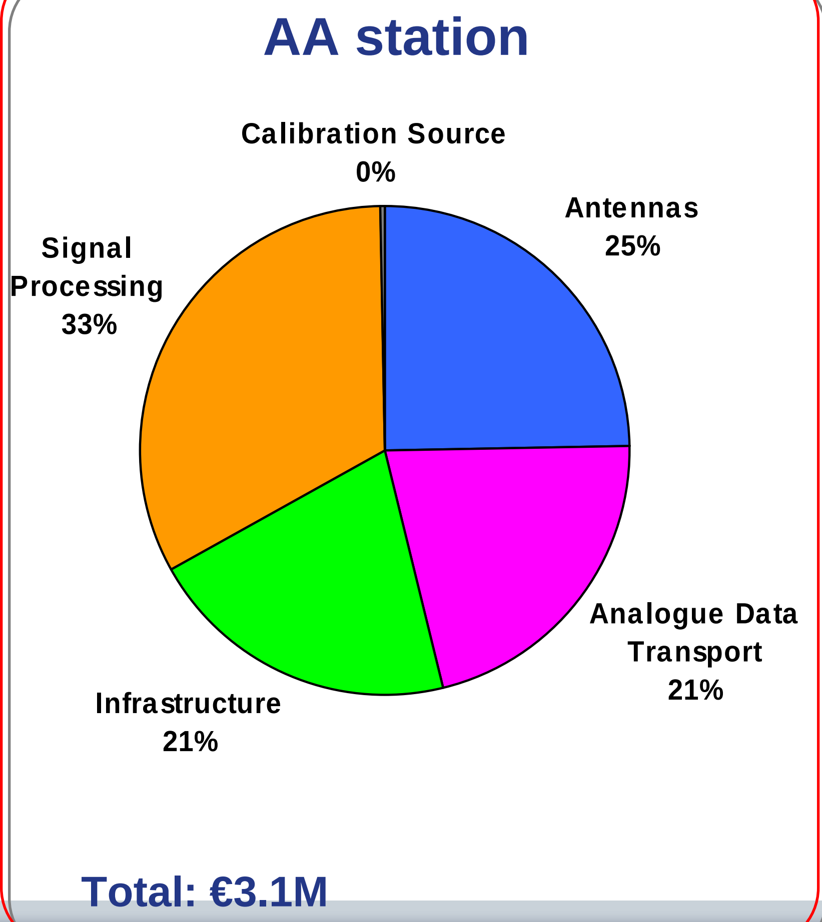
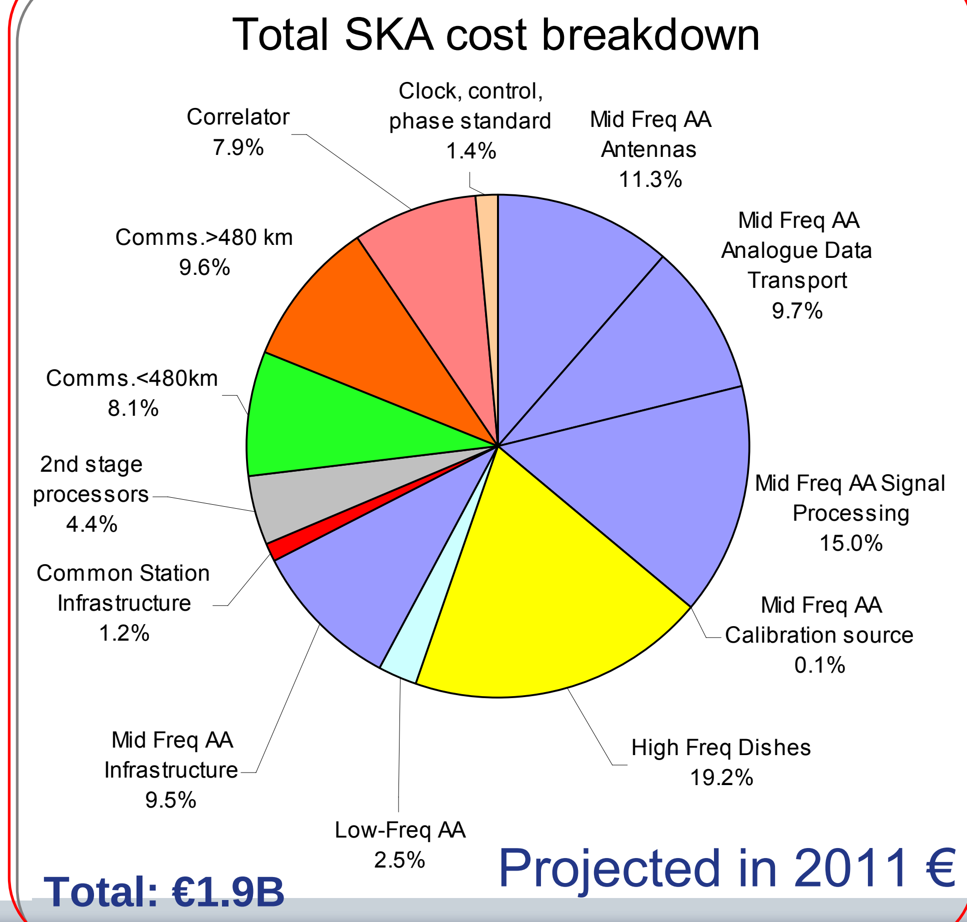
Causes of the cost

- TSA elements arrays are being considered for SKA (and therefore SKADS) to cover an important part of the mid. frequency band. SKADS -> 0.3 to 1 GHz.

Causes of the cost





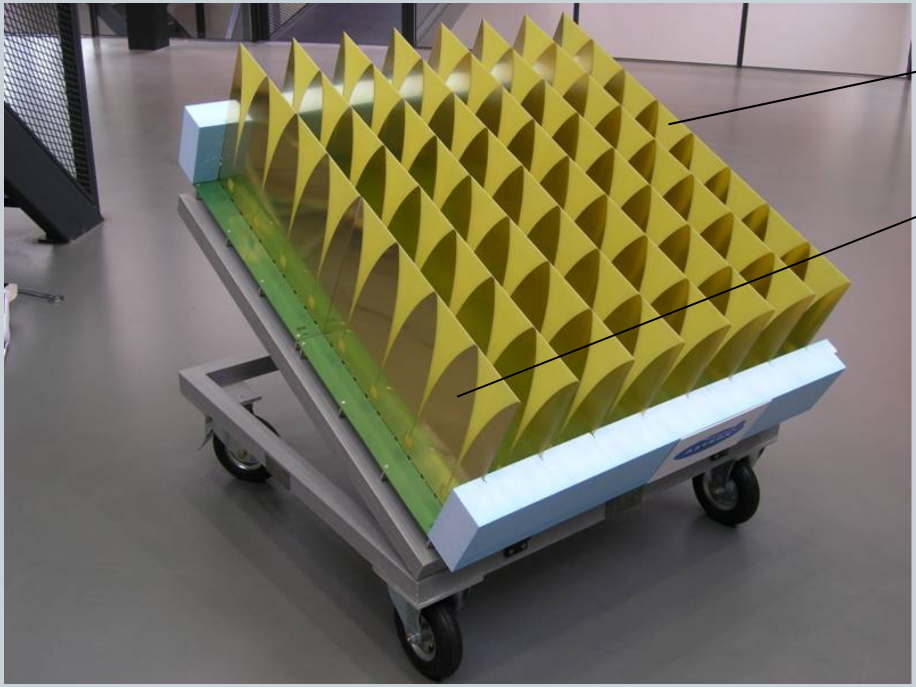
Causes of the cost

- 42% of the antenna cost is Element + Ground plane + feed board (51% accounting with assembly)
  - AA station: 25% of the cost is the antennas
  - Total SKA: 11.3% of the cost is the mid freq AA antennas
- It means: 4.7% of the total cost of SKA are those 3 elements of the mid freq. AA (5.7% with assembly)

Cost: € 90.2 M (€ 108.3 M with assembly)

Causes of the cost

- EMBRACE (single polarized)

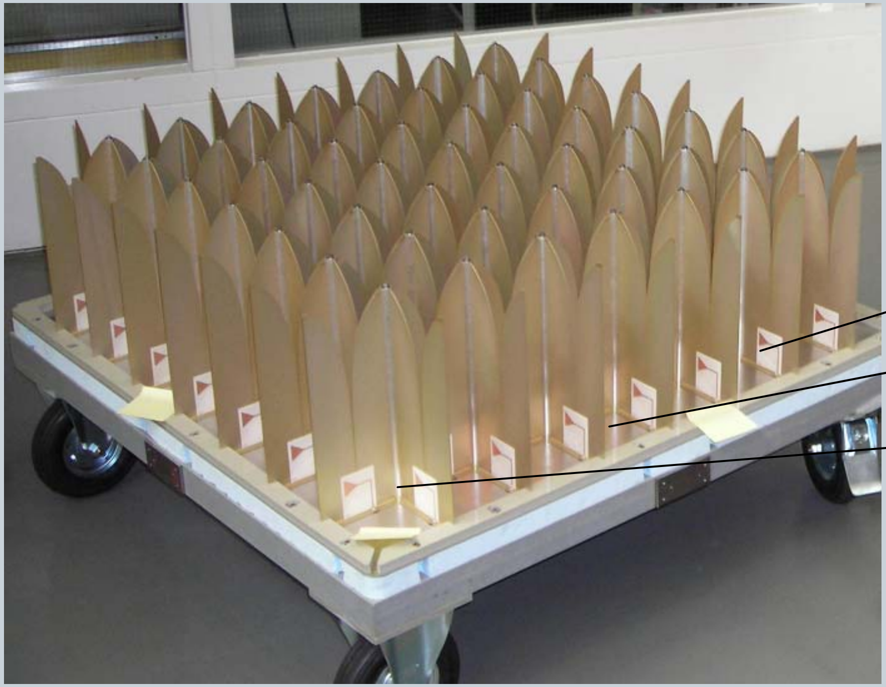


1) Substrate

2) Metal layer

Causes of the cost

- VALARRAY (dual polarized)



1) Substrate
2) Metal layer
3) Feed
4) Ground plane
5) Other elements

Causes of the cost

- Real example

% of cost per tile	Foil antenna (Rogers)	Foil antenna (FR4 board)	Al. antenna (Rogers)	Al. antenna (FR4 board)
Element (metal layer +[substrate] +[foam])	37 % (6 % is from the foam)	86.3 % (14 % is from the foam)	34.3%	76.3 %
Ground Plane	1.6 %	3.7 %	6.7%	14.5 %
Feed	61.4 %	10 %	59%	9.2 %

Causes of the cost

- Real example

	Foil antenna (Rogers)	Foil antenna (FR4 board)	Al. antenna (Rogers)	Al. antenna (FR4 board)
1st cause	Feed	Element (metal layer +[substrate] +[foam])	Feed	Element (metal layer +[substrate] +[foam])
2nd cause	Element (metal layer +[substrate] +[foam])	Feed	Element (metal layer +[substrate] +[foam])	Ground Plane
3rd cause	Ground Plane	Ground Plane	Ground Plane	Feed

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  - FLOWPAD[3] (ASTRON)
  - FIDA[3] (FG-IGN, Spain)

How to reduce this cost?

Feed	Metal layer	Antenna substrate	Foam	Ground plane	Others
1) Choose a much cheaper substrate. 2) Reduce size. 3) Alternative feeding (no board!!!)	1) Reduce size. 2) Change material. 3) Eliminate parts.	1) Choose as cheapest as possible. 2) Reduce size. 3) Don't use it	1) Choose as cheapest as possible. 2) Reduce the presence of the foam. Only supporting purposes. 3) Don't use it	1) Don't use it	1) Be cleaver.

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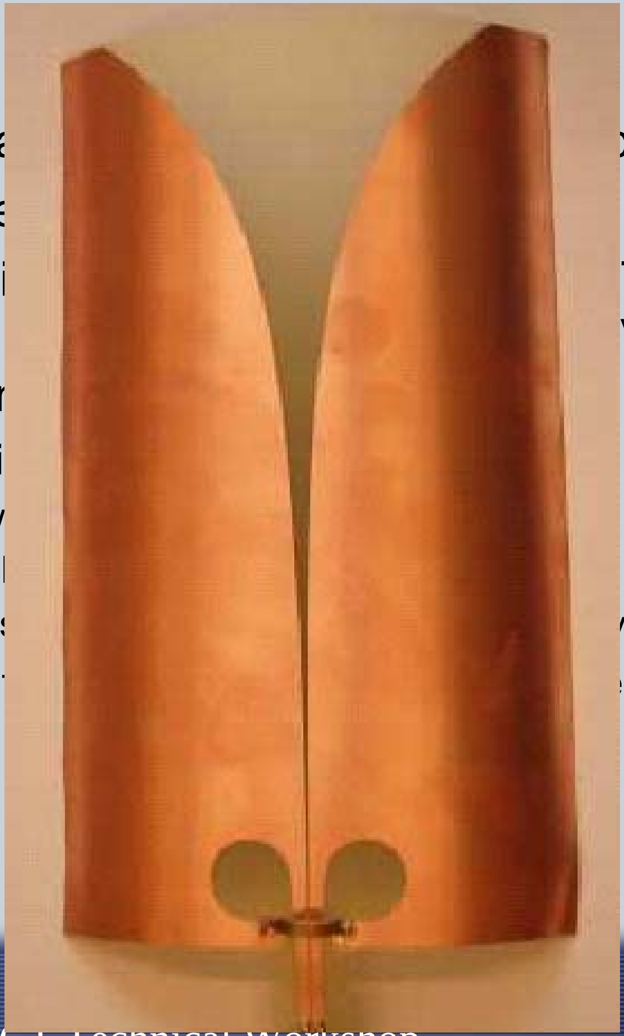
Problems reducing the cost?

- **Feed**
  - Cheaper substra  ce matching and noise.
  - Reduce size: De
  - Alternative feedi TSAs. It may bring other problems as for Very narrow band resonances four
    - Different origi
      - Gap betw
      - Parallel pl
      - Transmiss , 1993]
    - Also this solu structure (hopefully cheaper than

Problems reducing the cost?

- **Metal layer**
  - Reduce size: The relationship length to width (pitch) of every element in these very dense arrays (nominal spacing lays in the final 30 % of the band) is normally not a loose parameter. Pitch is fixed by the frequency band requirement and so it is the length.
  - Change material: From printed copper to Aluminum sheet for instance. Modifies other parts of the structure and may have an effect on the performance (i.e. absence of substrate).
  - Eliminate parts: But not much… holes in the less important parts (far from the edges normally)

Problems reducing the cost?

- **Antenna substrate**
  - Reduce size: The same than for the metal layer.
  - Don't use it: Impedance matching becomes more difficult (but still possible).
    - [Kasturi & Schaubert, 2006]
  - Cheap substrate: Effect on performance. *Er* matters, so at the noise and the stability of these properties in frequency.

Problems reducing the cost?

- **Foam**
  - Reduce presence of the foam: As far as the structure is mechanically stable it should only be positive.
  - Don’t use it: For foil antennas seems to be a straight forward solution and not very expensive.
  - Cheap foam: Effect on performance. *Er* matters, so at the noise and the stability of these properties in frequency.

Problems reducing the cost?

- **Ground plane**
  - Don’t use it: This is something to talk about… You may design your antenna so that it is not necessary. Just use antennas with endfire properties (as the most of the TSA elements), BUT, if you need it for other purposes (beamforming network, etc.) you HAVE TO design your system taking into account the effect of this plane, especially when it is placed very close to the elements. Several problems may arise, but the presence of anomalies in band increases when the plane is there:
    - Parallel plate mode effect [Schaubert, 1996]
    - Transmission line [Bayard, Schaubert & Cooley, 1993]

Problems reducing the cost?

- **Others**
  - Be cleaver:
    - Don’t use configurations which don’t bring enough improvements but too many problems (antipodal elements)
    - Carefully design every extra part needed for electromagnetic connection or mechanical support.
    - Try to avoid the use of extra elements if there is a way to do the same with the elements you already have (bridges).
    - Another idea is to make your elements as big as possible to reduce the number of LNAs per m^2 (FLOWPAD^3, FIDA^3).
    - Remember: All these things are interrelated. Choosing to modify a parameter may drive you to a certain configuration with positive and negative things. I still did not find the way of taking the best of everything… You have to design, simulate, build, measure and see.

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- **Examples**
  - **FLOWPAD^3 (ASTRON)**
  - FIDA^3 (FG-IGN, Spain)

FLOWPAD^3 (ASTRON)

B. Enthoven
J. Morawitz
J.G. Bij de Vaate
M. Arts
R. Maaskant
R. Witvers
R.H. van den Brink
Roberto García García
Cedric Enguehard
Eloy de Lera Acedo

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FLOWPAD^3 (ASTRON)

Al-sheet based upon 400m^2

Foil concept

	Antenna	Housing	Total	Antenna	Housing	Total
Antenna	607		607	450		450
Feed Board	640		640	-		-
Foam Block		-	-		-	-
Ground Plane	67		67	67		67
Box		10	10		69	69
Cover		139	139		-	-
Sunblock		15	15		30	30
Assembly blocks	47		47	16		16
Assembly box+cover		2	2		2	2
Carrier frame		-	-		-	-
Miscelaneos		13	13		13	13
Total	1360	179	1539	533	115	648
Price/ele.	11	1	12	4	1	5

Functional Description

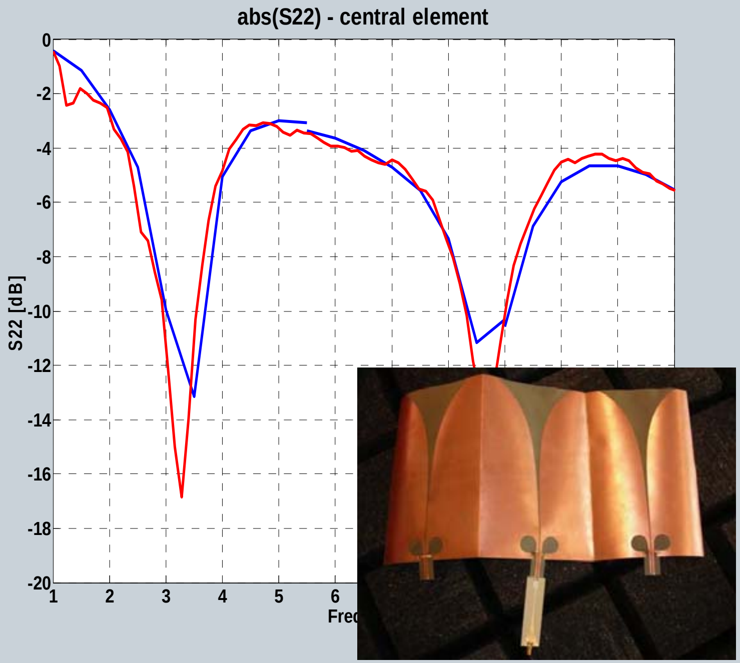
- **Elements:** Vivaldi differential (this is not done before, potentially cheaper, potentially better performance compared to single ended).
- **Polarization:** Dual polarization.
- **Frequency Band:** 300-1000 MHz.
- **Antenna pitch:** 176 mm (= 1/2λ @ 850 MHz). *Open*.
- **Tile:** Partial active; functional; LANs only.
- **Tile size:** 8x8 (Related to beam forming 4x1)
- **Beamformer:** Optional, no steering.
- **Tsys:** 35 K
- **Gain:** COTS LNA: 20 dB, Custom 1 LNA: 20-30 dB, Custom 2 LNA: reduced slope.
- **Power match versus noise match only:** dB(S11) < -5 dB. *Open*.
- **Antenna impedance:** 150 Ohm.
- **Technical antenna aspects:** Polypropylene foam box and Polyester foil with copper plating.

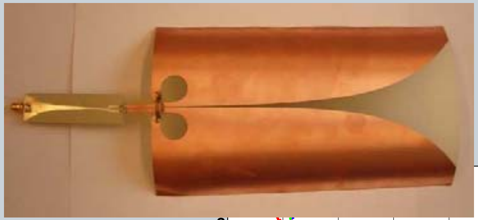
Aspects to be analyzed

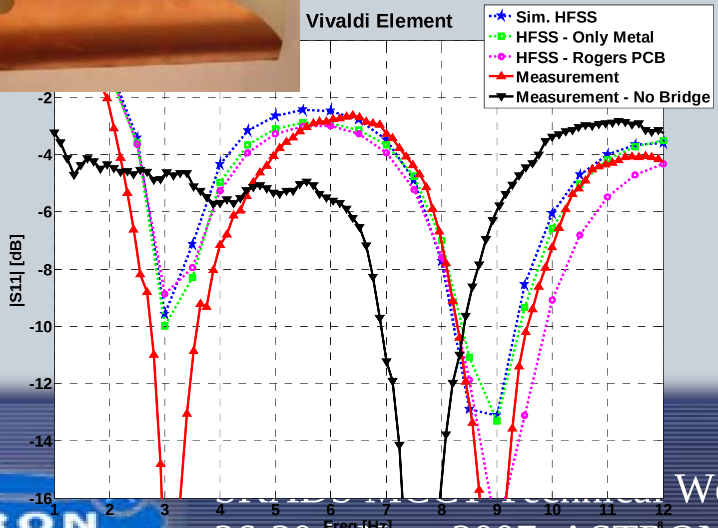
- Bridge
- Cavities
- Ground plane
- Feeding line
- Antenna dimensions

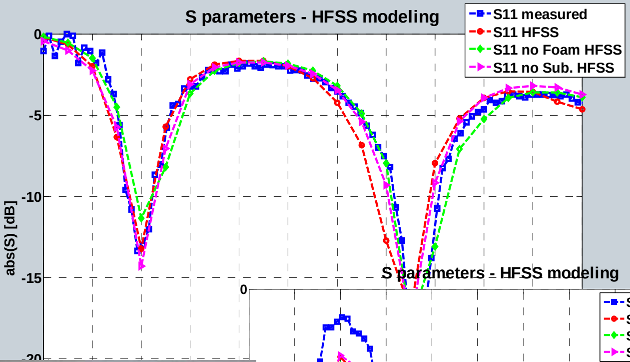
Design

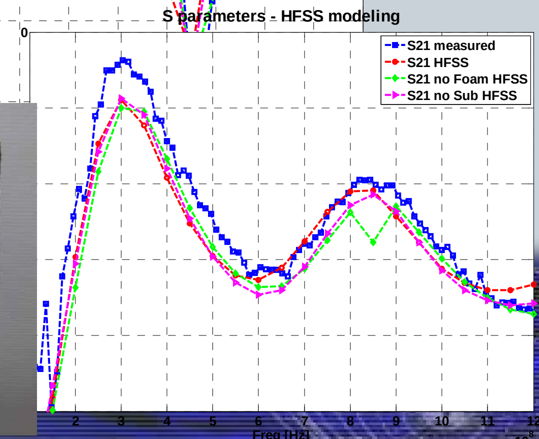
- Simulation and Measurement of first prototypes
  - Z_0 = 100 Ohm.
  - Polyester of 0.1 mm and ε_r = 3.1.
  - Polypropilene of ε_r = 1.24



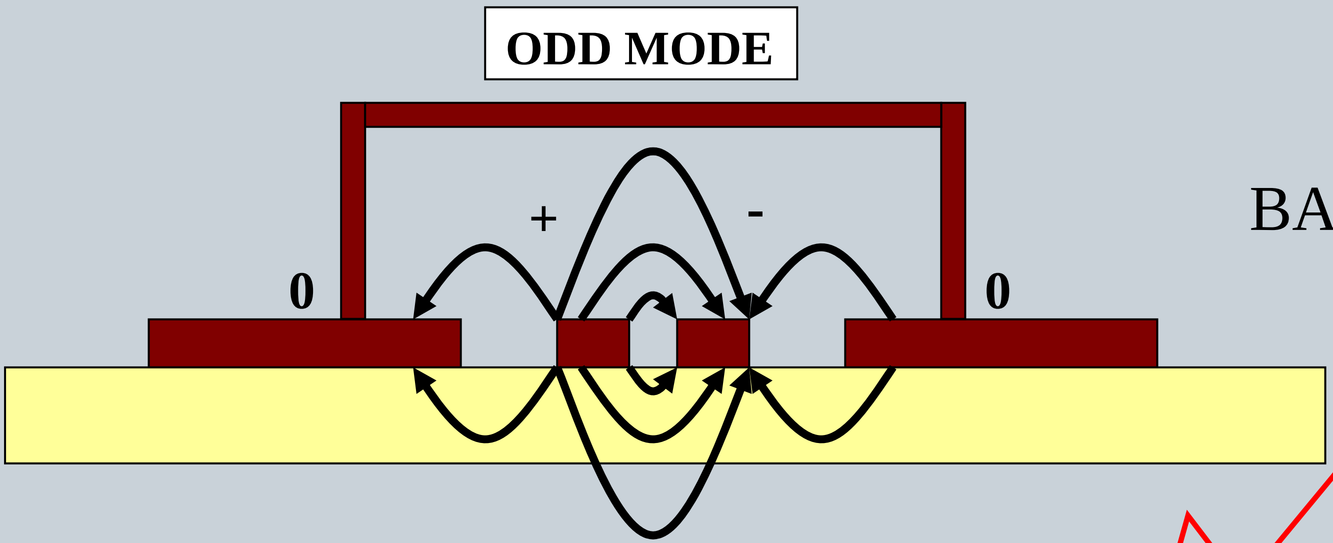




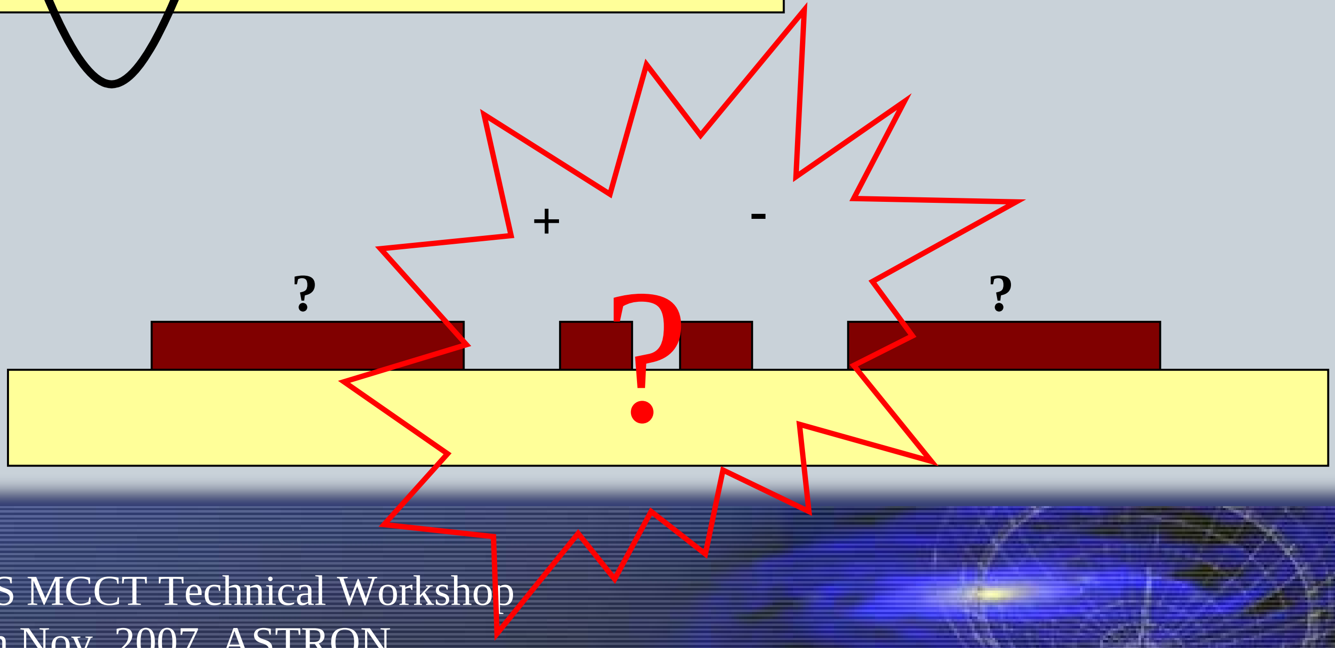




Design II



BALANCED

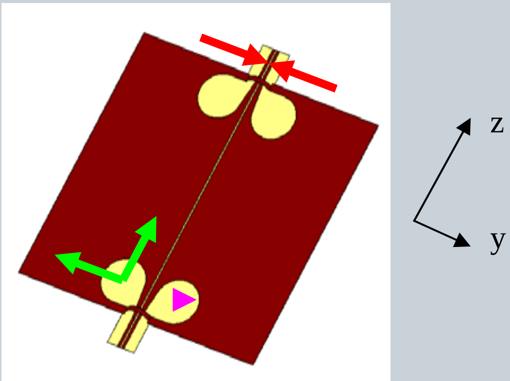


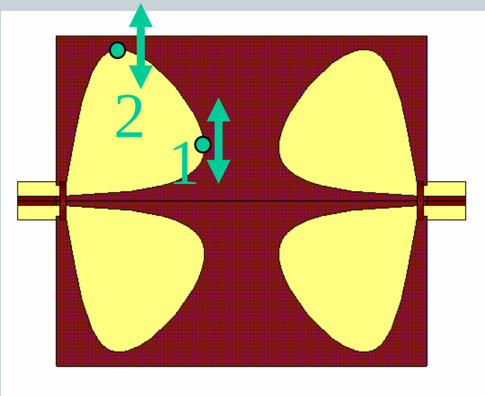
Simulation and Measurement of first prototypes

- ***Conclusions***

- A good agreement between simulations and measurement has been shown. In principle HFSS may be used for the simulations of this kind of differential Vivaldi elements.
- The presence of the bridge seems to affect the results of single elements very much.
- The difference between making the bridge with a strip wire or as a printed strip in the DLNA PCB is low.
- The effect of the Polyester foil and the foam box is low in terms of impedance matching (I am not talking about noise contribution).

Feed optimization





The Best CPS to Slot transition comparing to literature: average 1.5 dB of radiation losses in B2B configuration

Infinite Array

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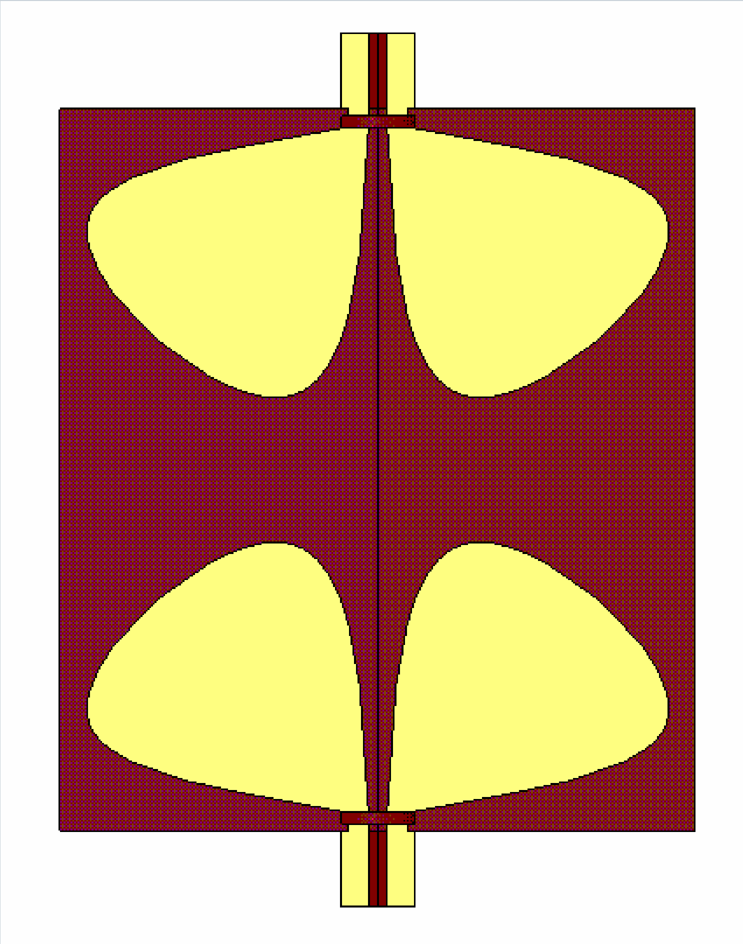
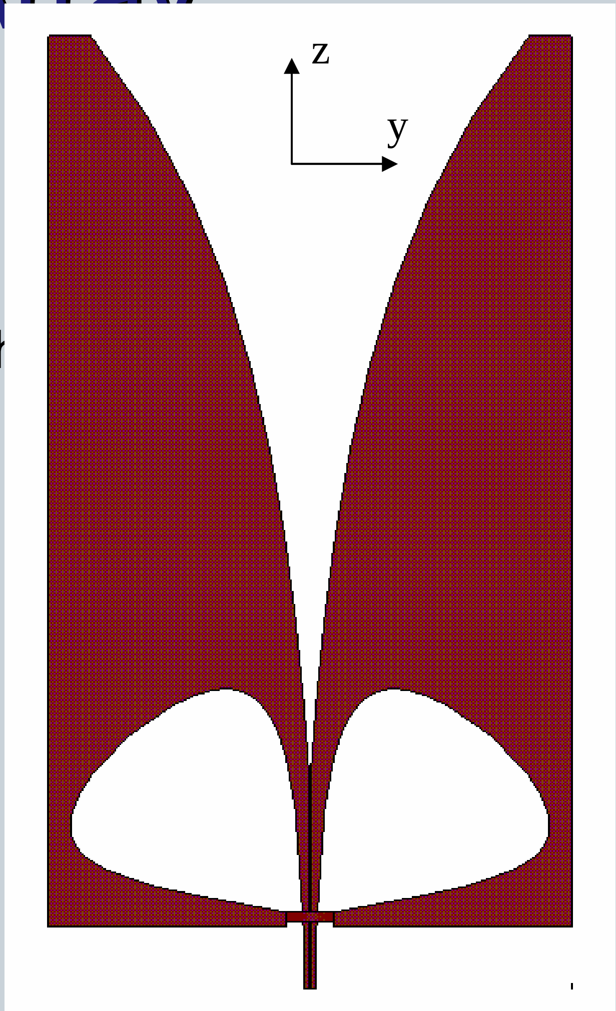




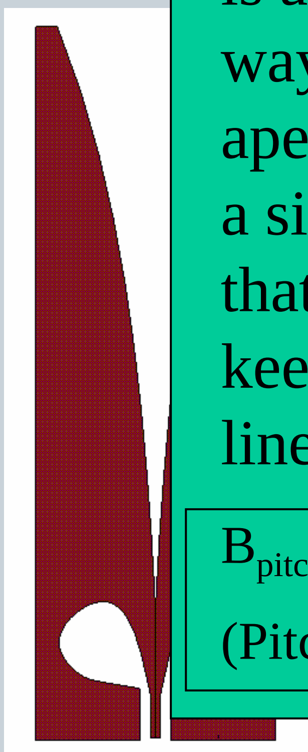
Infinite Array III

- ***Effect of the pitch***
  - The requirement is a pitch of 176 mm.
  - We know from previous studies that increasing the ratio Length of the antenna to pitch increases the bandwidth, but Increasing antenna length also leads to VSWR humps. It also means more expensive antennas.
  - Antenna length = 37.2 cm. (MECO process: current maximum is 38 cm).

Infinite Array IV

- ***Effect of t***

125 mm



The tapering (parameter B) is also changed in such a way that the antenna aperture is also increased in a similar manner and so that the tapering profile keeps a similar degree of linearity.

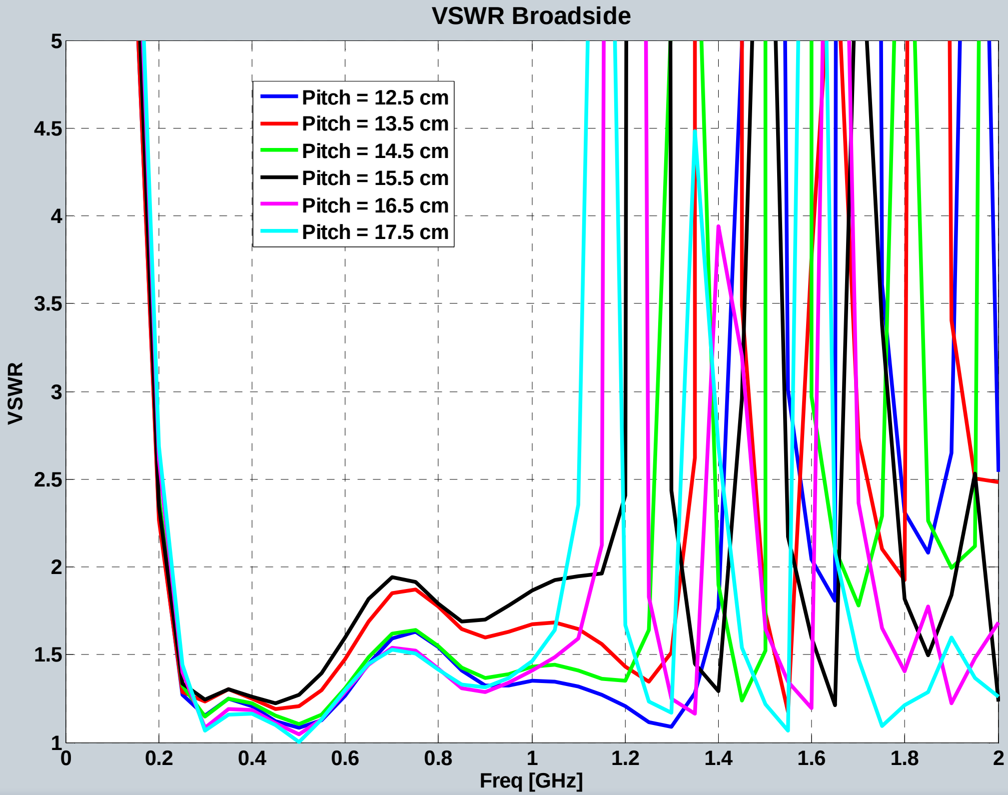
B_{pitch_X} =

$(Pitch\_X - 125)*2e\text{-}5+B_{pitch\_125}$

176 mm

Infinite Array V

- ***Effect of the pitch III***



10 mm increase in pitch means 90-100 MHz less bandwidth.

- ***Final I***

Name	Value	Unit	Evaluated Value	Description
$Sub_thick	0.1	mm	0.1mm	Thickness of substrate
$A	5		5	z=A*exp(B*y)*C. Vivaldi Curve...
$B	($V_pitch-125...		0.00802mm	z=A*exp(B*y)*C. Vivaldi Curve...
$V_pitch	176	mm	176mm	Width of Vivaldi element
$V_length	300	mm	300mm	Length of Vivaldi element
$D	50	mm	50mm	y = t*V_length + D. Vivaldi Cu...
$C	0.32		0.32	z=A*exp(B*y)*C. Vivaldi Curve...
$Txl_slot	0.7	mm	0.7mm	Slot width in CPS
$p4Z	0.7	cm	0.7cm	...
$p5Y	1	cm	1cm	...
$p5Z	0.5	cm	0.5cm	...
$BridgeH	5	mm	5mm	
$BridgeW	3	mm	3mm	

- Requirements fulfilled.
- Band 0.21 to 1.08 GHz in Broadside.
- VSWR around 1.5 (-14 dB).
- Using a Bridge connection.
- Pitch = 176 mm.
- Length = 37.2 cm.

Optimization of scanning

- An optimization of the scanning performance in order to achieve -45 to 45 Deg scan capabilities in E and H plane was done.
- Sweeps of: Slot Width, Strip width and the cavity size and shape were realized.

Optimization of scanning

- ***Conclusions***
  - Bigger slot widths seem to perform better for scanning angles and 150 Ohm reference impedance. But also bigger humps show up.
  - Bigger cavities produce smaller humps in the VSWR but also lower maximum operating frequency.
  - Even with a proper combination of parameters it may happen that a pitch = 176 mm is to big for -45 to 45 Deg. Scan.
  - Using an antenna pitch = 165 mm a new optimization was realized.

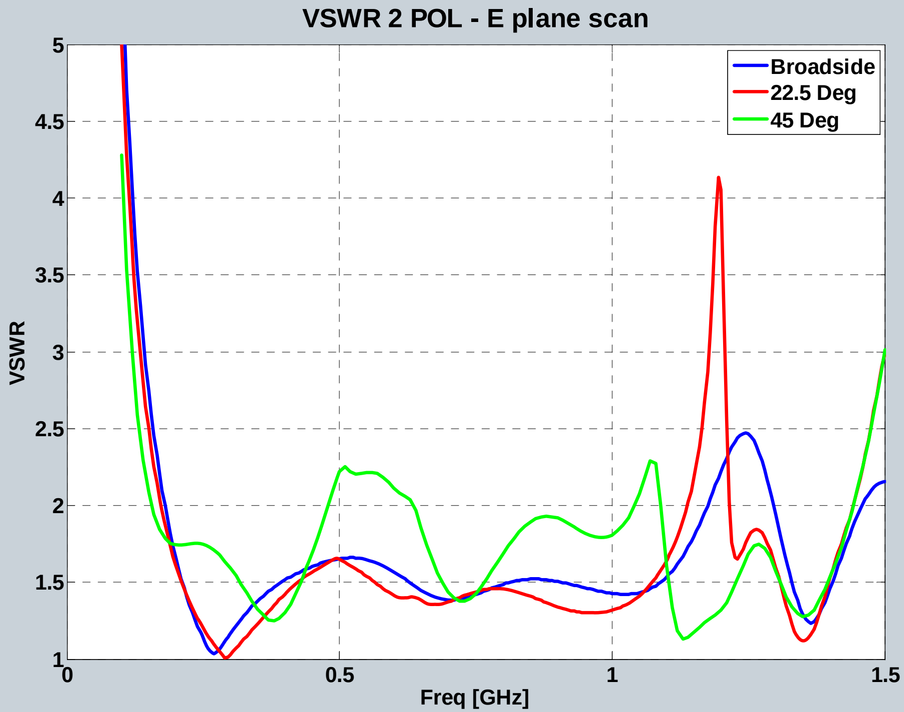
Optimization of scanning for

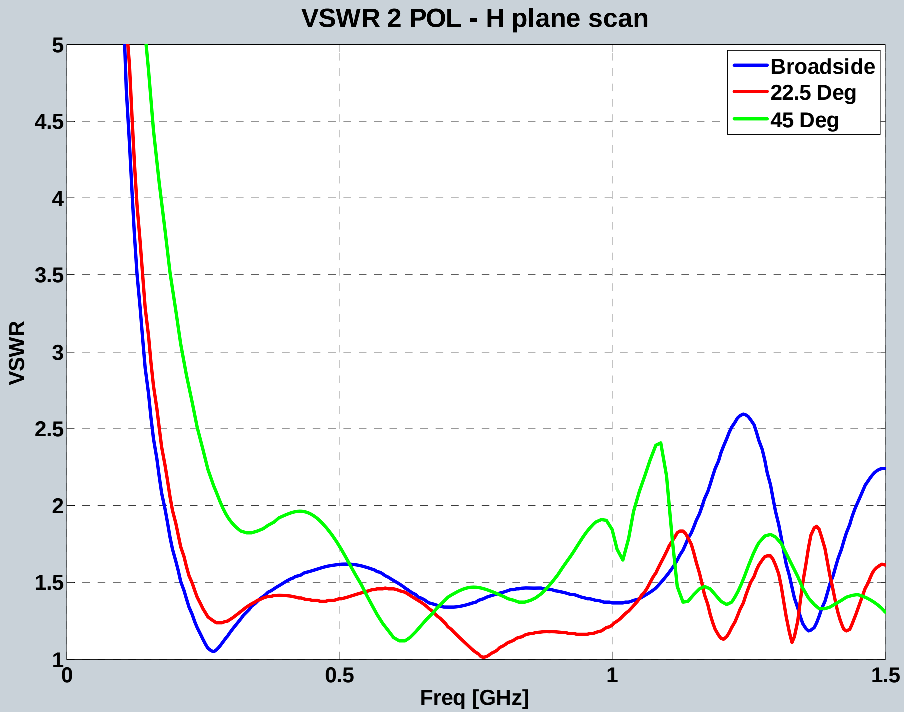
- ***Final R***
  - A fine … m.

$A	5		5	z=A*exp(B*y)*C. Vivaldi Curve...
$B	0.008		0.008	z=A*exp(B*y)*C. Vivaldi Curve...
$V_length	300	mm	300mm	Length of Vivaldi element
$D	50	mm	50mm	y = t*V_length + D. Vivaldi Cu...
$C	0.32		0.32	z=A*exp(B*y)*C. Vivaldi Curve...
$TxL_slot	1.5	mm	1.5mm	Slot width in CPS
$CurvePoints	10		10	Number of curve points
$V_pitch	165	mm	165mm	Width of Vivaldi element
$box_shift	30	mm	30mm	
$extraGND	$TxL_length+...		9mm	
$TxL_length	8	mm	8mm	Length of Tx line CPS
$Zdim_AirBox	220	mm	220mm	Extra Z space of air at the en...
$Rad_Add	100	mm	100mm	
$port	1.5	mm	1.5mm	
$Cavity_Y	20	mm	20mm	Center Position of Cavity, Y c...
$Cavity_Z	20	mm	20mm	Center Position of Cavity, Z c...
$Cavity_Radius	15	mm	15mm	Radius of the cavity
$TxL_width	2	mm	2mm	Strip width in CPS
$CavitySlot_width	4	mm	4mm	Width of cavity slot
$p1Y	3	cm	3cm	Point p1Y of Transition
$p1Z	7	cm	7cm	...
$p2Y	7	cm	7cm	...
$p2Z	3	cm	3cm	...
$p3Y	3.5	cm	3.5cm	...
$p3Z	1	cm	1cm	...
$p4Y	2	cm	2cm	...
$p4Z	0.7	cm	0.7cm	...
$p5Y	1	cm	1cm	...
$p5Z	0.5	cm	0.5cm	...
$BridgePos	5	mm	5mm	
$BridgeW	3	mm	3mm	
$BridgeH	5	mm	5mm	

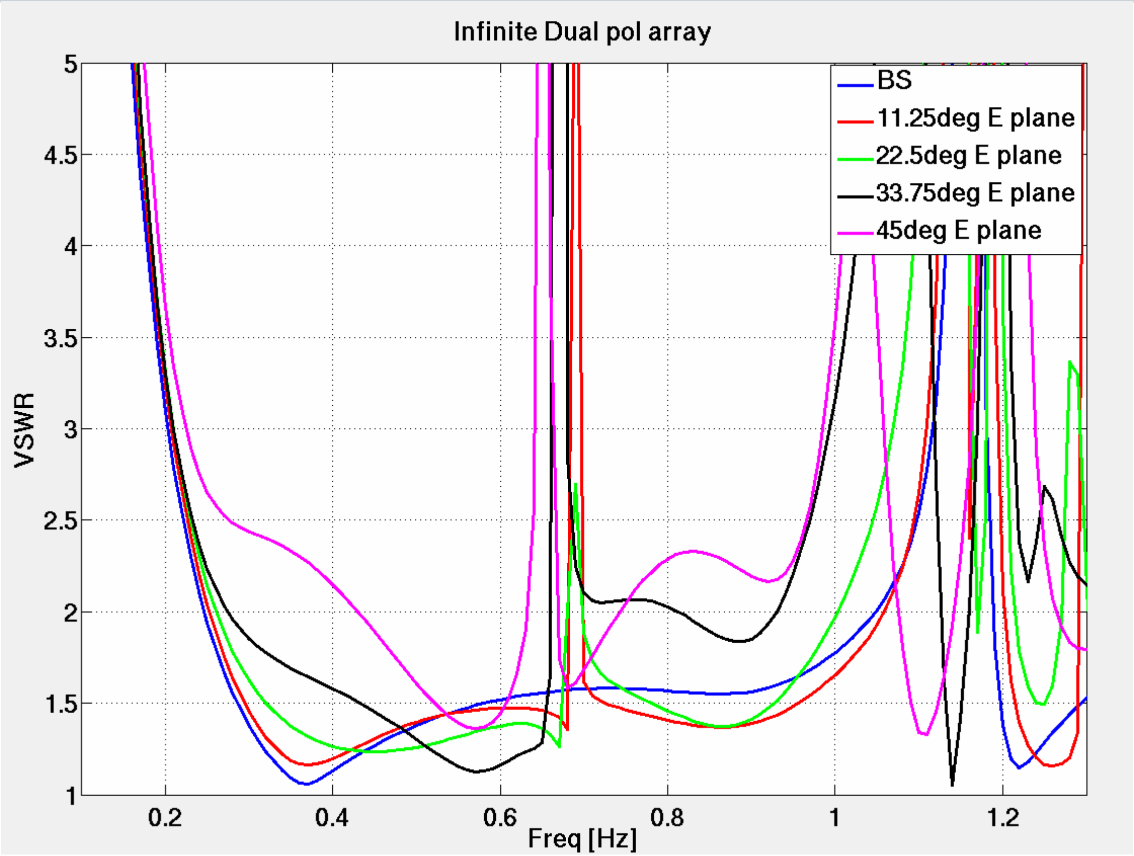
Optimization of scanning for pitch = 165mm II

- ***Final Result II***

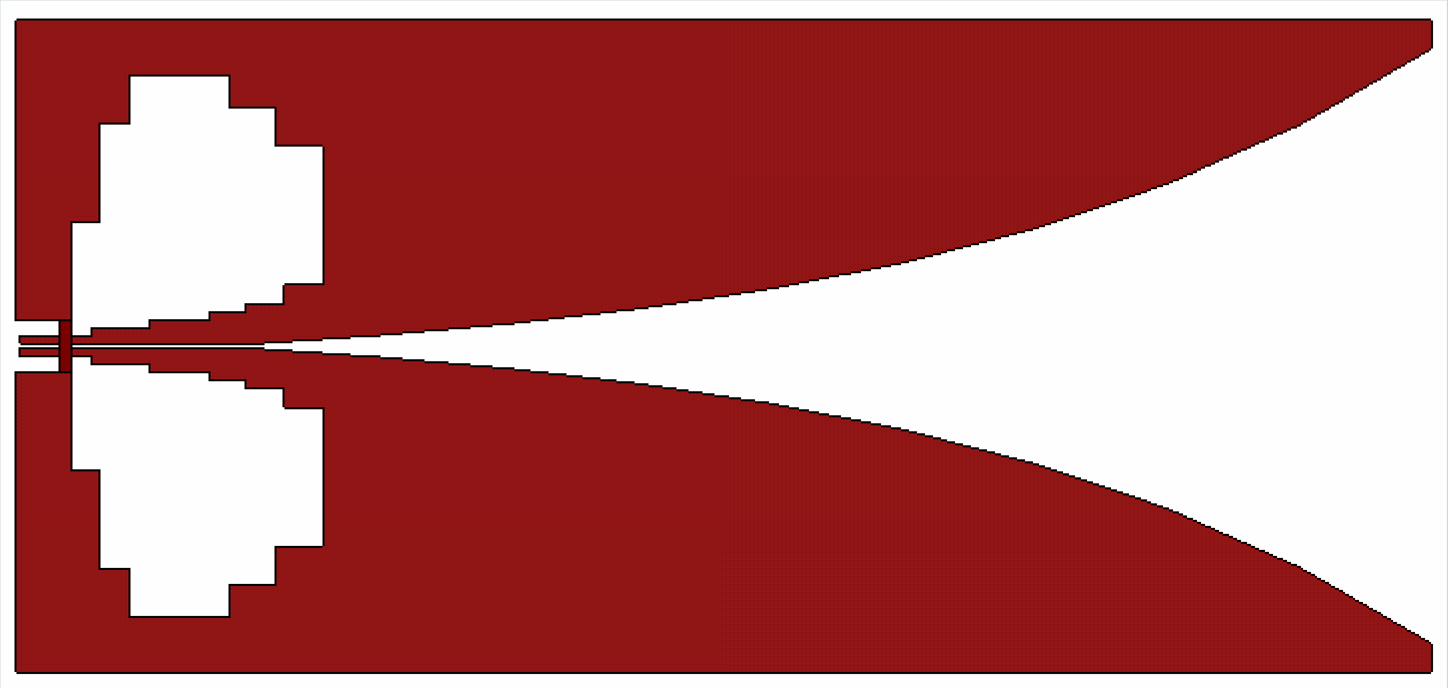




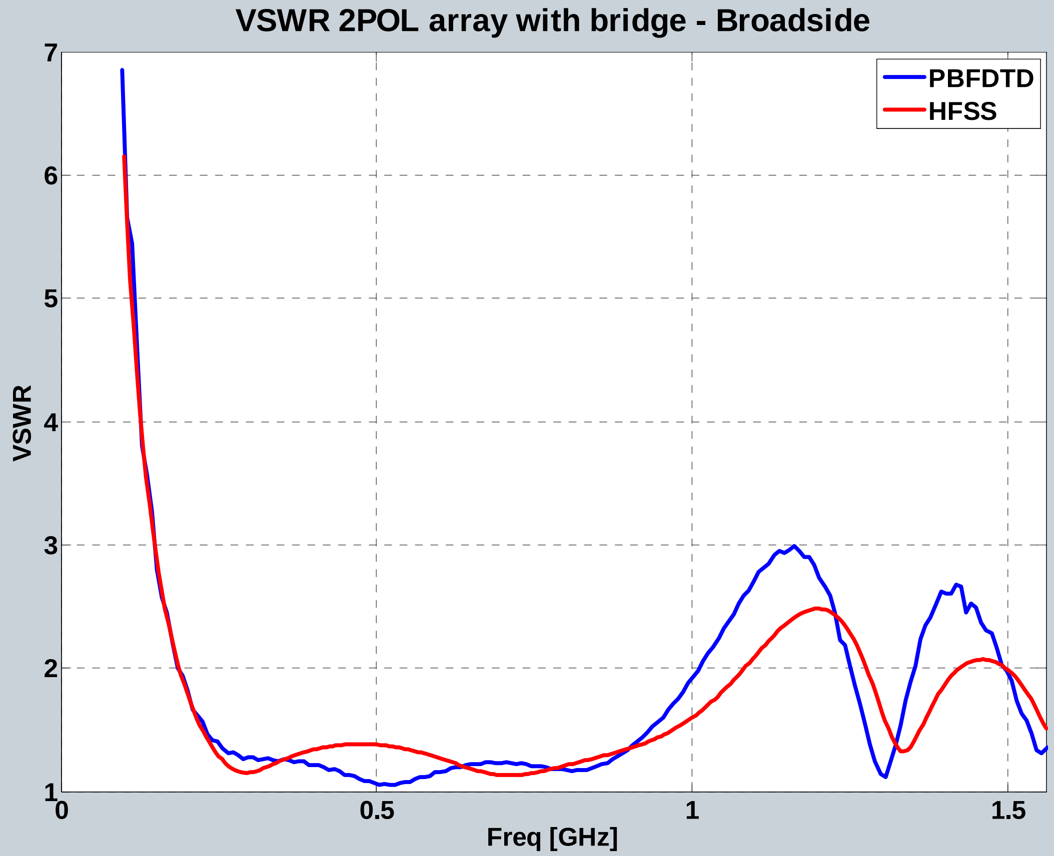
Scan blindness



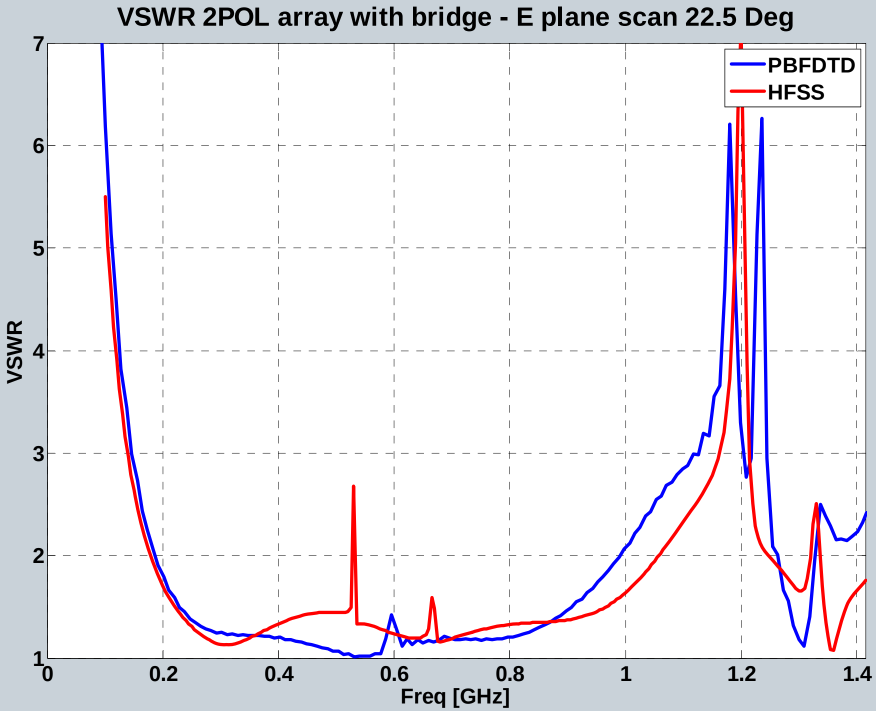
Comparisons HFSS - PBFDTD

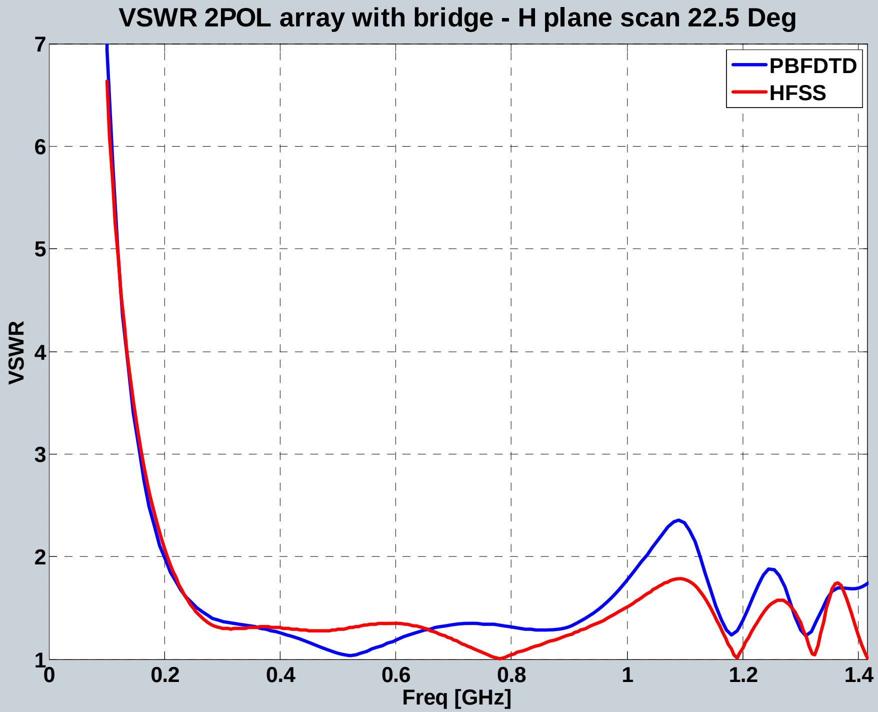


Comparisons HFSS - PBFDTD II



Comparisons HFSS - PBFDTD III





Conclusions

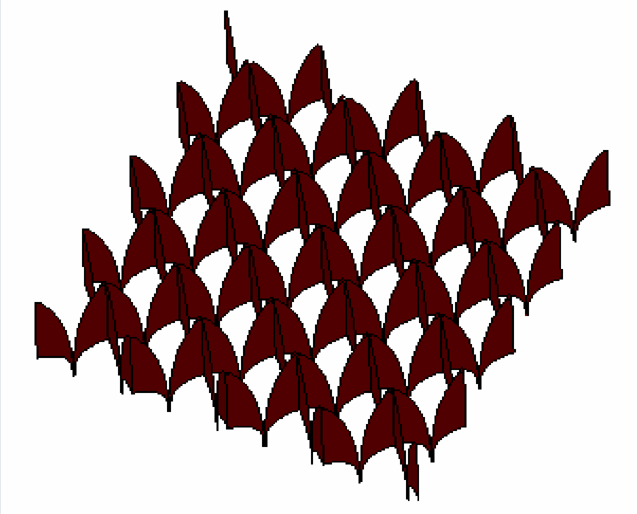
- The effect of the different parameters of the structure were studied for the case of a B2B and an infinite by infinite dual polarized array: Cavities, Transmission line, Bridge, etc.
- The requirements were achieved for an infinite array:
  - A Broadside array working at least from 0.3 GHz to 1 GHz.
  - Made of differentially fed Vivaldi antennas of pitch 176 mm (64 LNAs per m^2) and a very thin substrate.
  - A scanning array up to +/-45º for 165 mm elements (73.5 LNAs per m^2).
- When scanning some High Q resonances may appear. They have different origins and redesign (search of the optimum trade off between different dimensions of the elements) is the key to eliminate them. These designs are normally experience based…

Outline

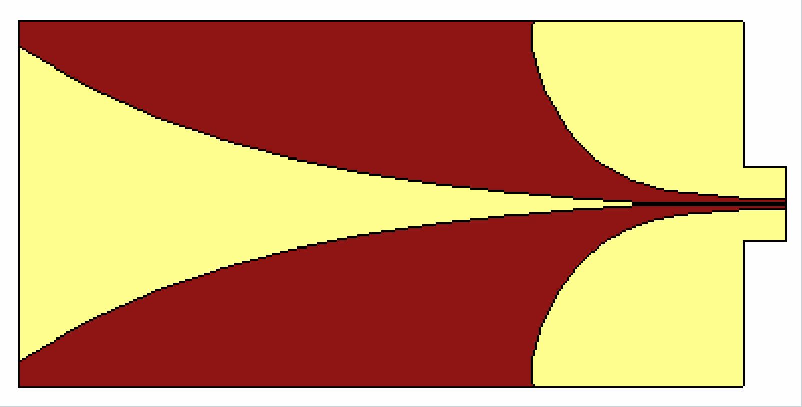
- What does rise the cost in an array of TSA elements?
- How can we reduce this cost?
- What are the problems reducing the cost?
- **Examples**
  - FLOWPAD^3 (ASTRON)
  - **FIDA^3 (FG-IGN, Spain)**

FIDA³ (FG-IGN, Spain)

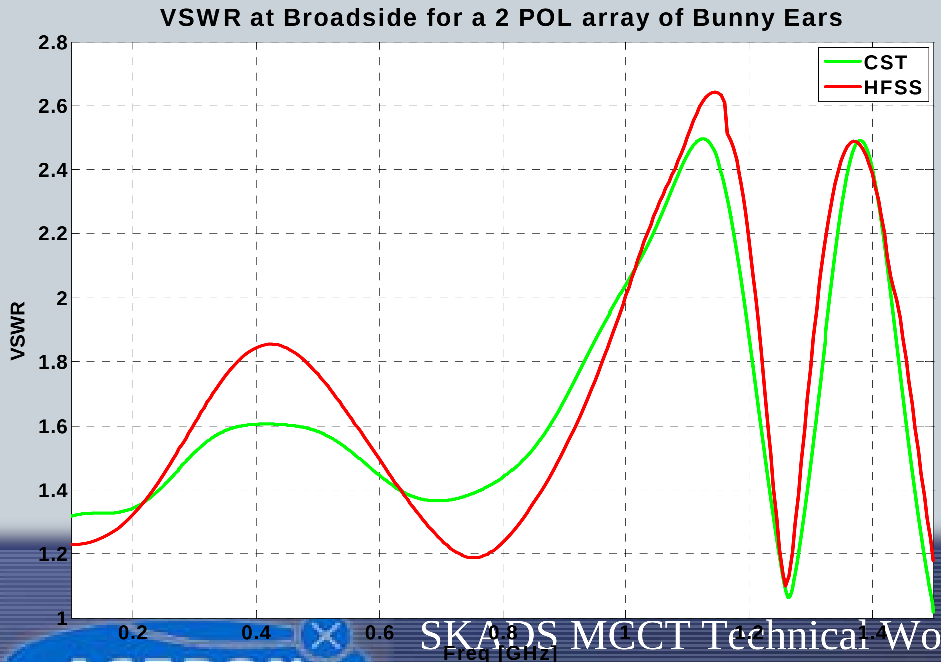
- Array FIDA³: *F*G-*I*GN *D*ifferential *A*ctive *A*ntenna *A*rray
  - FIDA³ is an active tile of differentially fed antennas to demonstrate the capabilities of differential technology, easiness of fabrication and low cost.
  - Working band: 0.3-1 GHz.

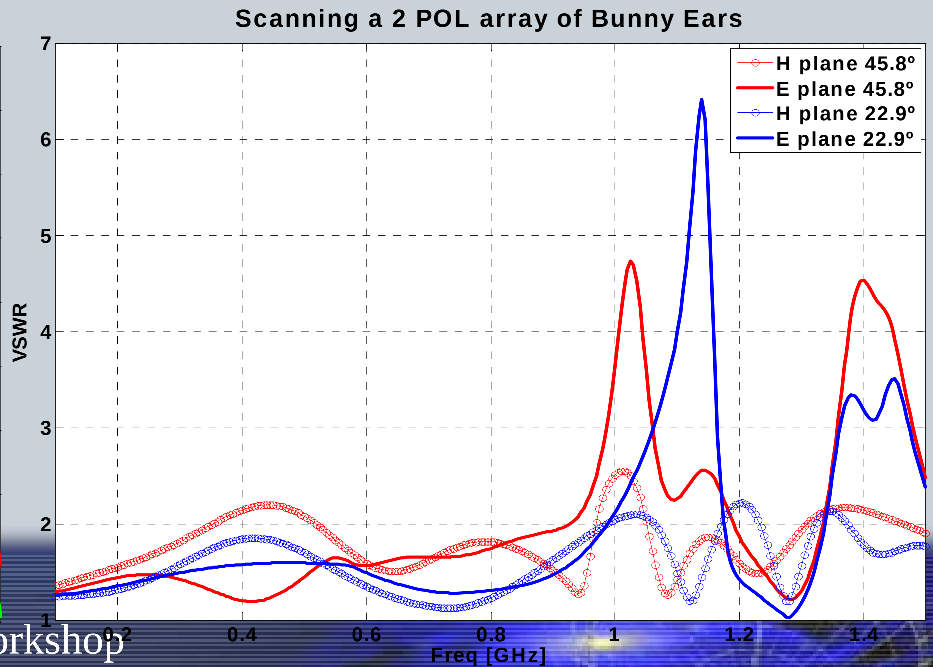


FIDA³ (FG-IGN, Spain)



- FIDA³:
  - Differentially fed antennas – Bunny Ears
  - No extra substrate, no ground plane.
  - Aluminum elements are being considered





REFERENCES

- [Schaubert, 1994]:
  - A gap-induced element resonance in single-polarized arrays of notch antennas, Schaubert, D.H., Antennas and Propagation Society International Symposium, 1994. AP-S. Digest Volume 2, Issue , 20-24 Jun 1994 Page(s):1264 - 1267 vol.2
- [Schaubert, 1996]
  - A class of E-plane scan blindnesses in single-polarized arrays oftapered-slot antennas with a ground plane, Schaubert, D.H., Antennas and Propagation, IEEE Transactions on, Volume 44, Issue 7, Jul 1996 Page(s):954 – 959
- [Bayard, Schaubert & Cooley, 1993]
  - E-plane scan performance of infinite arrays of dipolesprinted on protruding dielectric substrates: coplanar feed line andE-plane metallic wall effects, Bayard, J.-P.R.; Schaubert, D.H.; Cooley, M.E., Antennas and Propagation, IEEE Transactions on, Volume 41, Issue 6, Jun 1993 Page(s):837 - 841
- [Kasturi & Schaubert, 2006]
  - Effect of dielectric permittivity on infinite arrays of single-polarized Vivaldi antennas, Kasturi, S. Schaubert, D.H., Antennas and Propagation, IEEE Transactions on, Volume: 54, Issue: 2, Part 1, Feb. 2006, Page(s): 351- 358

Conclusions

- We have seen:
  - What is creating the cost in “dense” arrays of TSA elements.
  - Some ideas to reduce it.
  - 2 examples of low cost arrays based on the idea of differentially fed TSA elements. (only one layer of metal)

End

THANKS FOR YOUR ATTENTION

QUESTIONS?