# Some reflector and Feed Antenna Technologies that Made a Difference

Keys to Success:
Very basic EM principles, Characterization, Protection & Commercialization

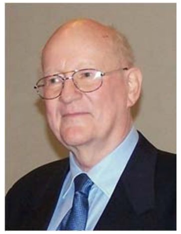
Per-Simon Kildal

CHALMERS
Chalmers University of Technology, Sweden

# My relation to Arnold

- Since 2005: Collaborated with Marianna Ivashina and Rob Maaskant
  - on efficiencies in focal plane arrays (after ESTEC workshop)
- 2006: Arnold became Adjunct Professor at Chalmers
- 2007 SKADS Workshop: Contributions
- 2010: Marianna receives Swedish VINN MER grant
- 2011: Marianna and Rob joined my research group.
- Every 2nd months since 2006: Have met Arnold
  - in connection with SKA technology

- My relation to this society
  - I have been working with Tor Hagfors (died 2007) on EISCAT and Arecibo radio telescopes



# Purpose and content

- Importance of pure science projects also for industrially useful inventions
- Science is for the free thinkers
- Industry is too focused on standards
  - Out of box thinking
  - Think different
  - In industry the free thinkers are the **Crazy Ones** (Apple campaign year 2000)
- It is the Crazy Ones that cause the big breakthroughs
  - It is among those who are crazy enough to think they can change the world you find those who do.

# Content

- Keys to success with inventions in my case
  - Basic principles (wire grid, PEC/PMC grid)
  - Characterization: Subefficiencies
- EISCAT VHF antenna (wire grid, two rods)
  - Wire grid ➔ ring for INMARSAT Ship Earth station antenna
- Gregorian feed of Arecibo radio telescope
  - Corrugated horns ➔ soft & hard surfaces ➔PEC/PMC strip grids
  - Mathematical model of line feeds ➔ successful hat feed for radio links
- SKA
  - decade bandwidth ➔ logperiodic antennas ➔ eleven feed
  - Focal-plane arrays & MIMO arrays ➔ decoupling efficiency

# Keys to success with inventions in my case

- Projects with scientific instruments and interaction with their users
- Very basic EM principles
  - Polarization-dependent PEC wire grid
  - Polarization-independent PEC/PMC wire grid
  - Rethinking of the logperiodic antenna
  - BOR antennas
- Characterization
  - We need to quantify good and bad
  - Related to physical phenomena
- Protection
  - Patent protection defines ownership
  - Makes it easier to defend most places in the world
  - The thieves are NOT the Japanese and the Chinese
  - US law favors US companies (unique in World)
- Commercialization
  - The ultimate proof of usefulness

# Subefficiencies of Paraboloids and Cassegrain Antennas

Similar formulas apply to general multi-reflector systems.

Factorization of feed efficiency: $e_{ap} = e_{sp} e_{pol} e_{ill} e_{\phi}$

Spillover, polarization, illumination and phase eff.

Spillover efficiency $e_{sp}$

Relative spillover power is given by $1 - e_{sp}$

Typically between -0.05 dB and -0.5 dB.

Major contributor to the antenna noise temperature.

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# EISCAT VHF antenna

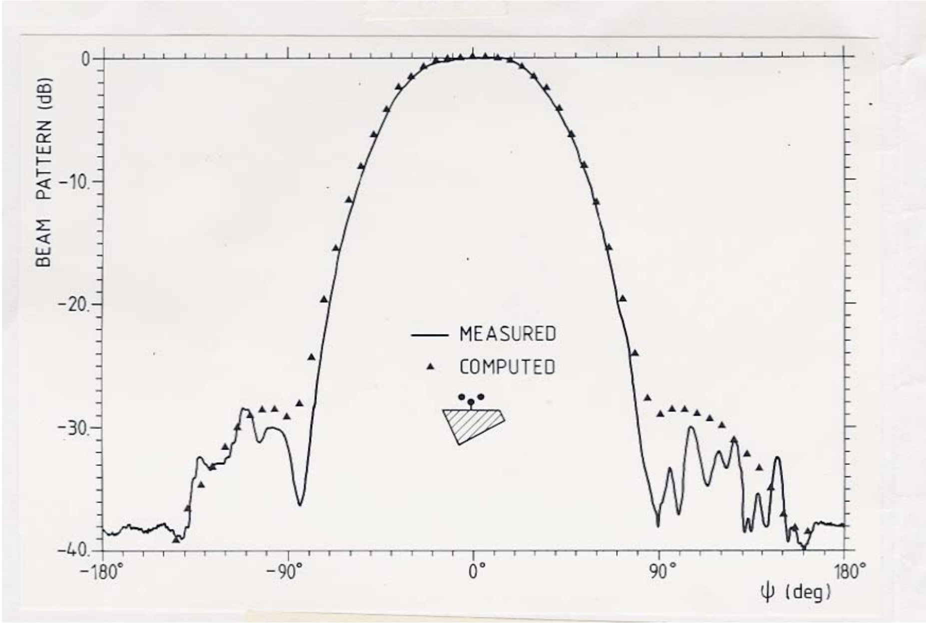
# EISCAT line feed

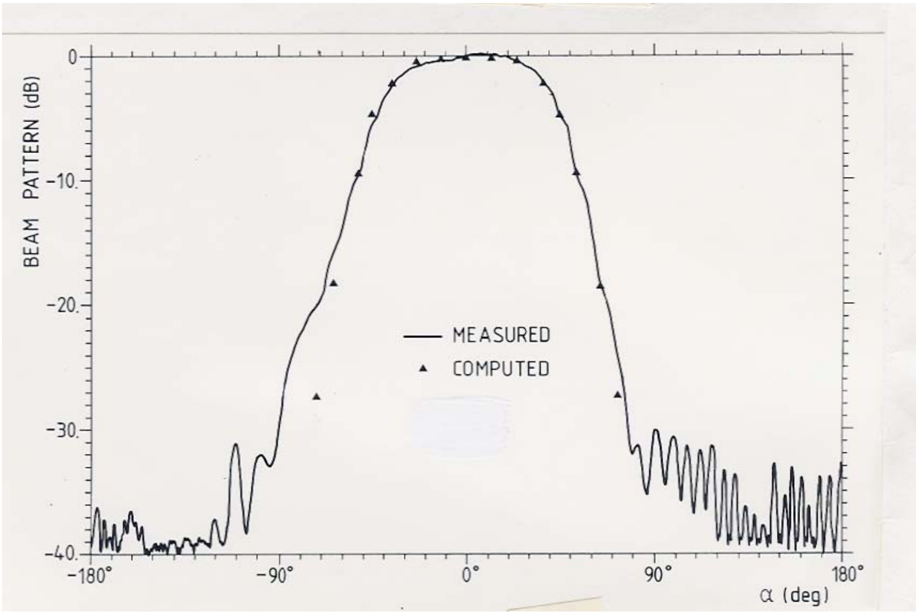
# Reflection and transmission properties of wire grids (non-gracing incidence)

| Canonical surface | E-field polarization | |
|---|---|---|
| | VERtical | HORizontal |
| Perfect Electric Conductor (PEC) | STOP (reflects) | STOP (reflects) |
| Horizontal PEC wire grid | GO (passes) | STOP (reflects) |
| Vertical PEC wire grid | STOP (reflects) | GO (passes) |

# Radiation pattern of line feed in transverse plane:

## longitudinal and transverse polarisation

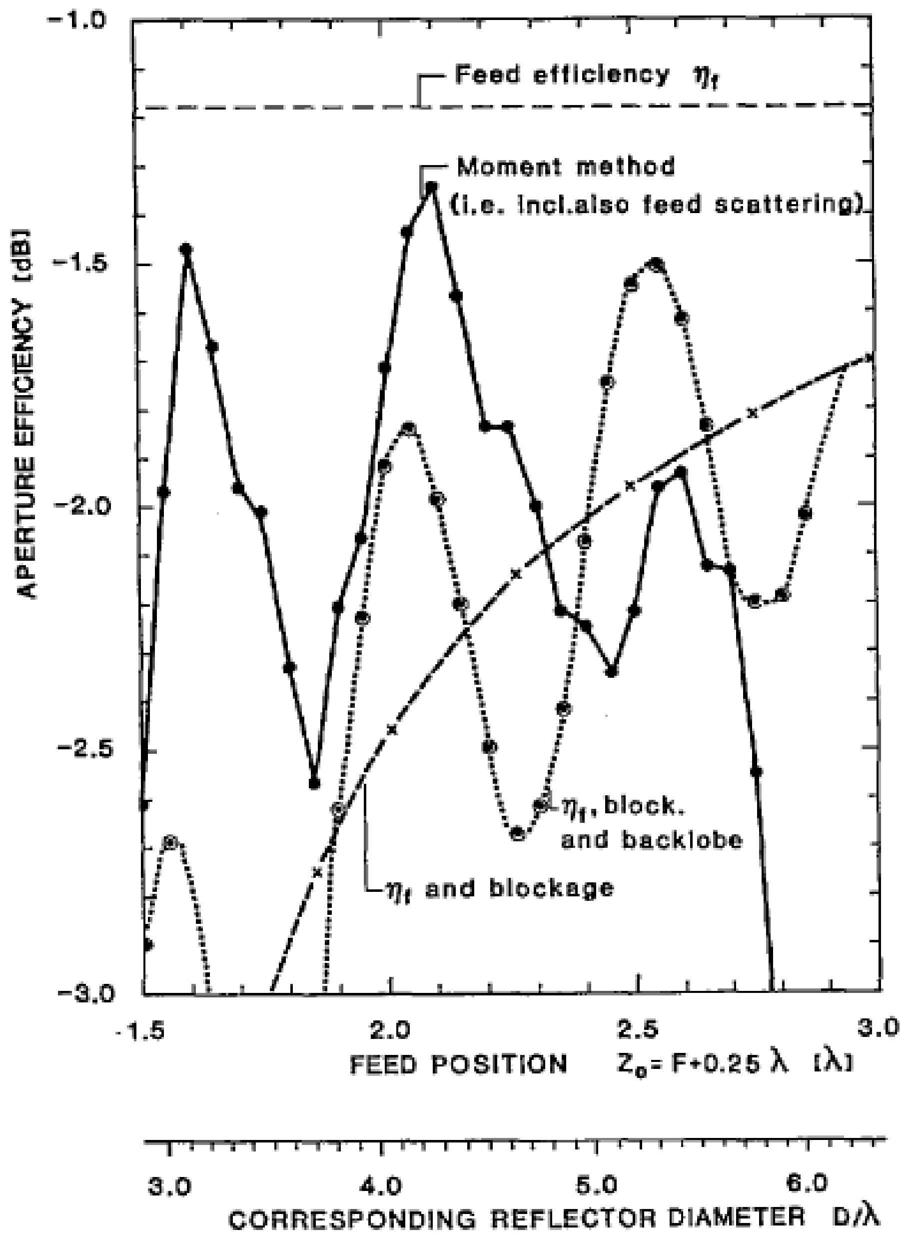


# Ca 1980: Small efficient resonant reflector antenna with dipole-disk feed

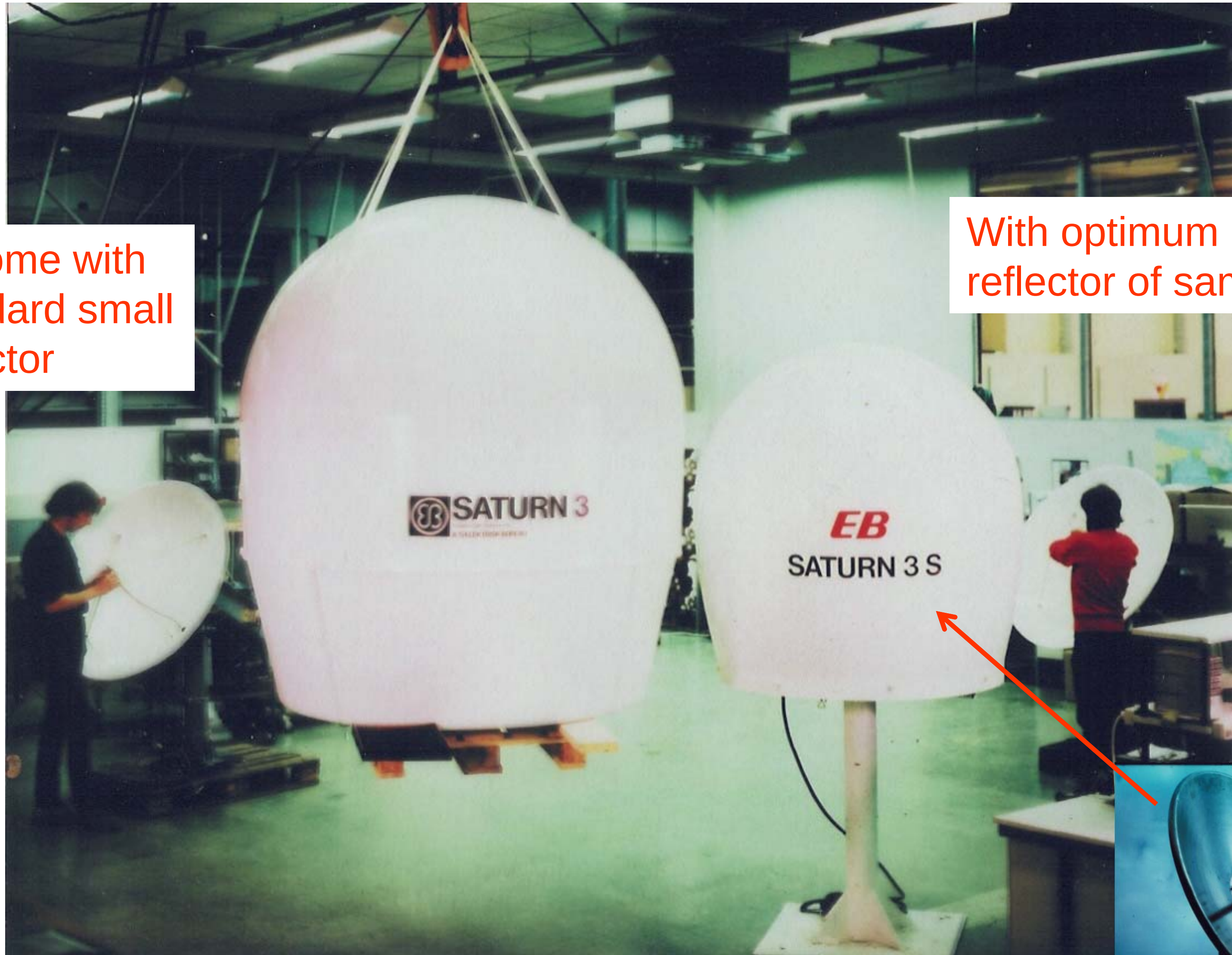

The ring makes the E- and H-plane patterns equal

In small primary-fed reflectors multiple reflections between feed and reflector can be used to increase gain

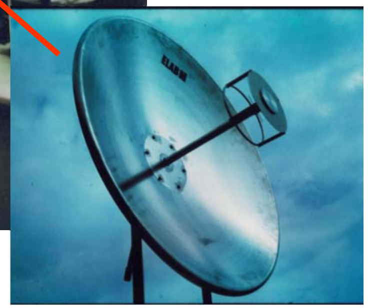


# Resonant reflectors can be very efficient and influence system design strongly

Radome with standard small reflector




With optimum resonant reflector of same gain



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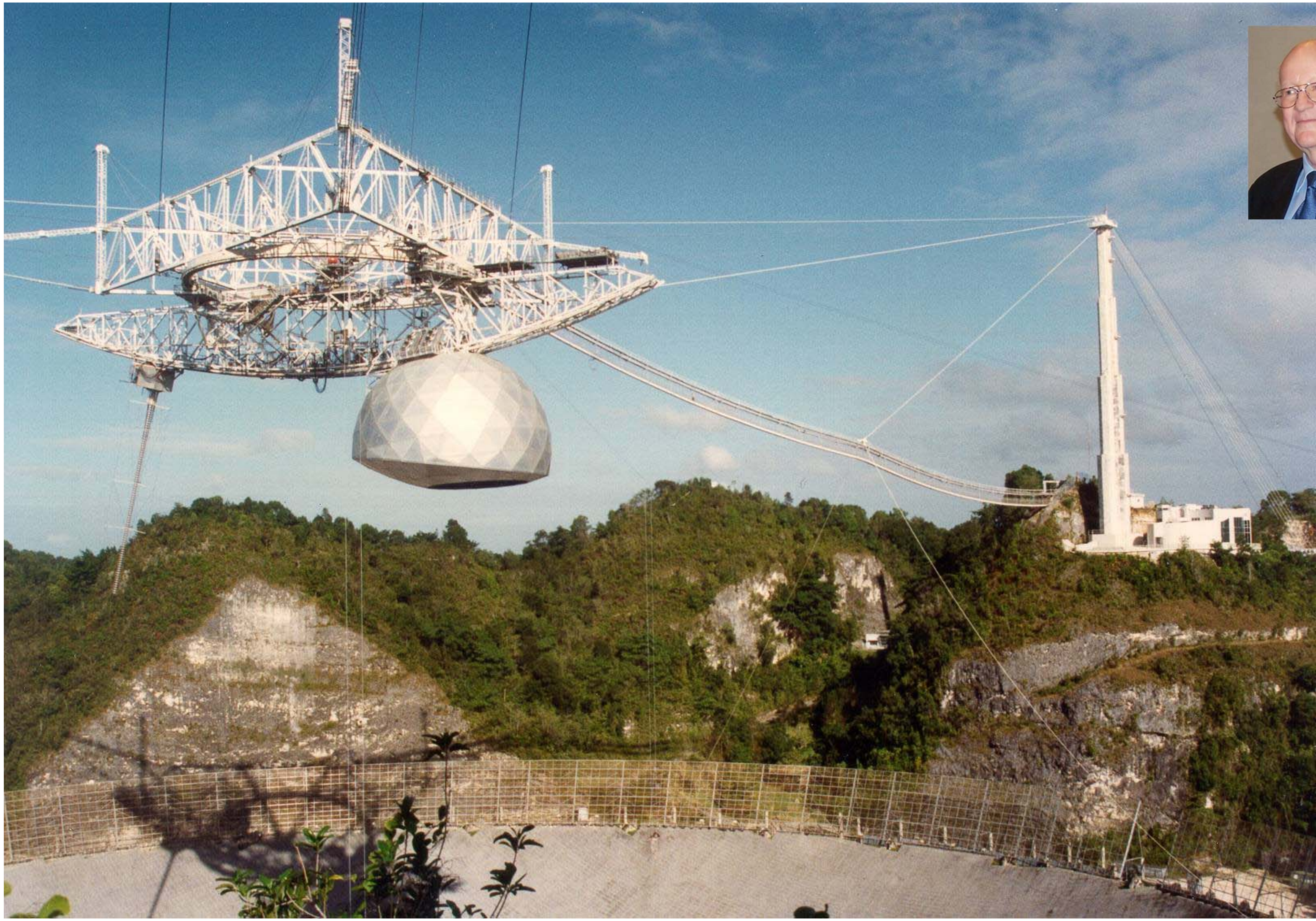
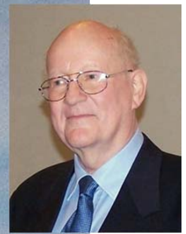
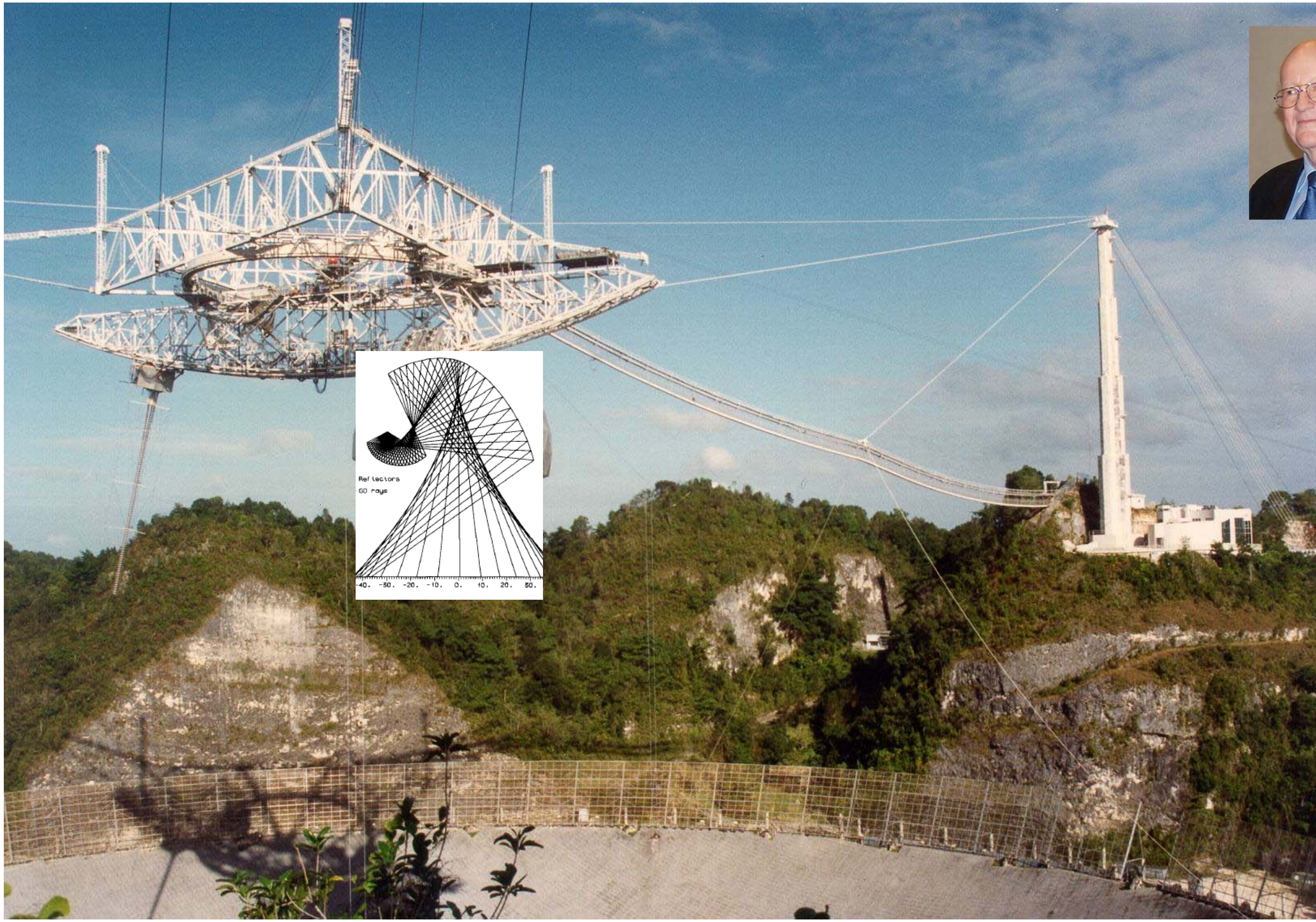
# Radiotelescope in Arecibo

# Platform with old 300 MHz line feed (left) and enclosure with dual-reflector feed inside (right)



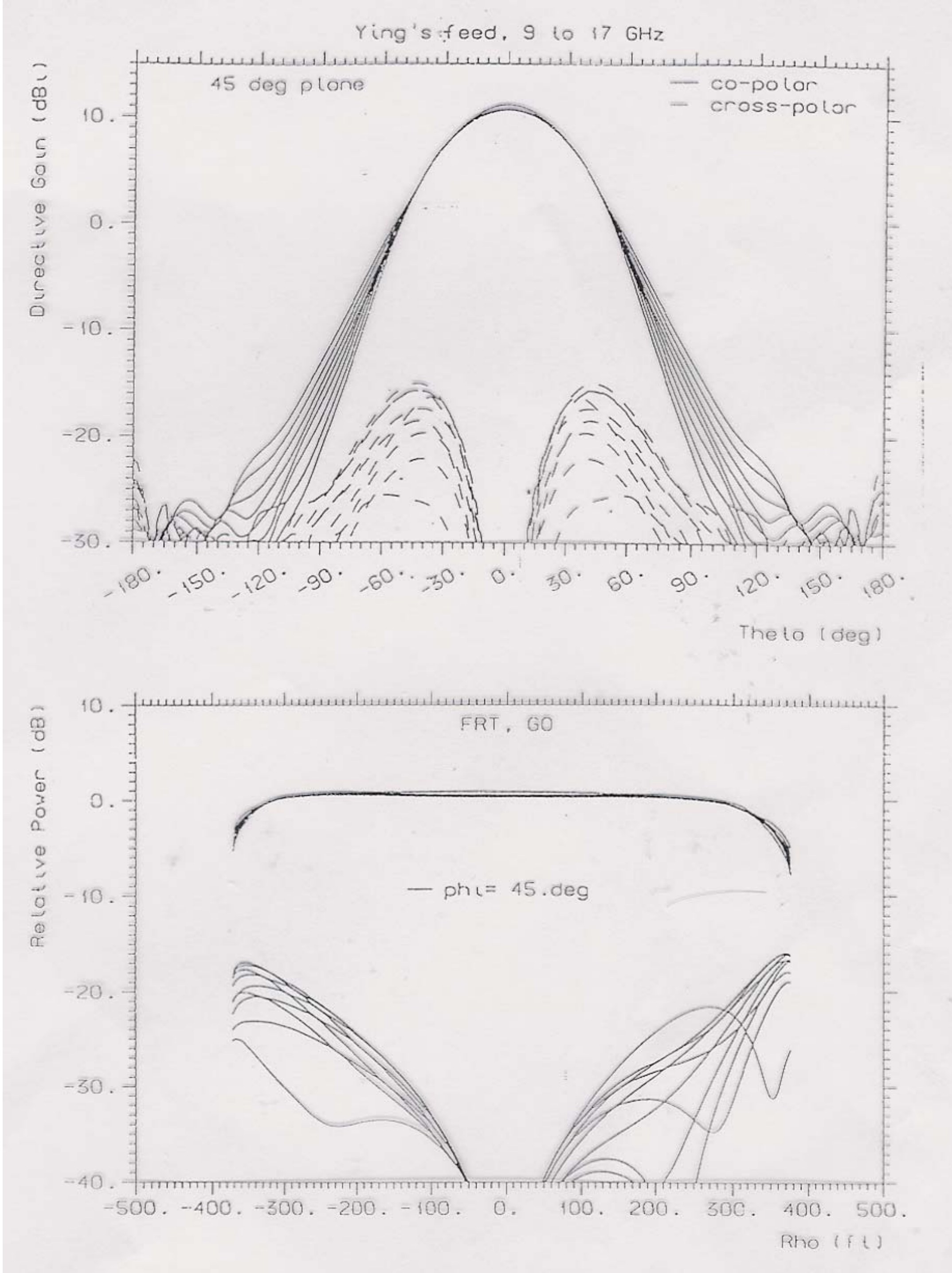


# Platform with old 300 MHz line feed (left) and enclosure with dual-reflector feed inside (right)



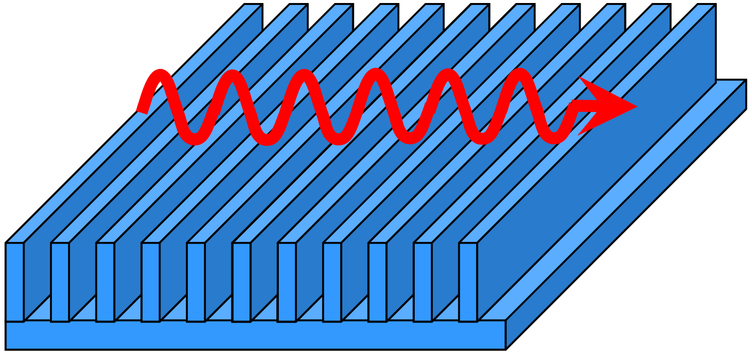

Constant beamwidth over 0.9-1.7 GHz

Aperture-field when used in arecibo three-reflector system



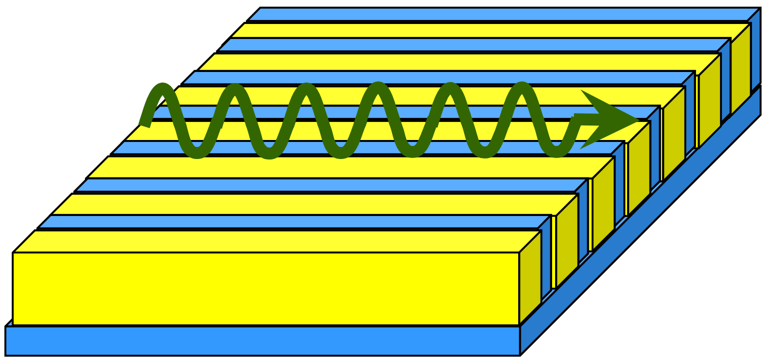
# Realization of soft and hard surfaces with corrugations

**Soft STOP surface (left)**



**Transverse**
**air-filled corrugations**

**Hard GO surface (right)**

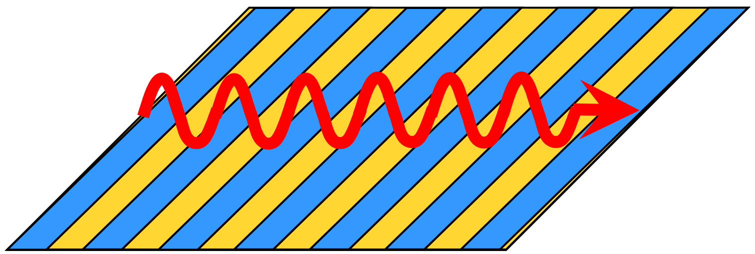


**Longitudinal**
**dielectric-filled corrugations**

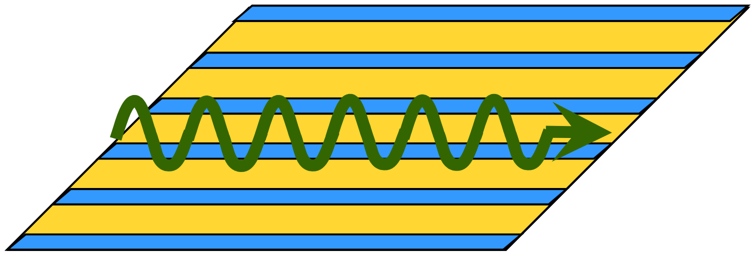
# PEC/PMC strip model of ideal soft and hard surfaces

- Ideal soft surface
  = polarization-independent
  **STOP** surface

- Ideal hard surface
  = polarization-independent
  **GO** surface



**Current fences**



**Current lanes**

$$strip\ \ period \rightarrow 0$$

| Canonical surface (non-gracing incidence) | E-field polarization | |
|---|---|---|
| | VERtical | HORizontal |
| Perfect Electric Conductor (PEC) | STOP (reflects) | STOP (reflects) |
| Horizontal PEC wire grid | GO (passes) | STOP (reflects) |
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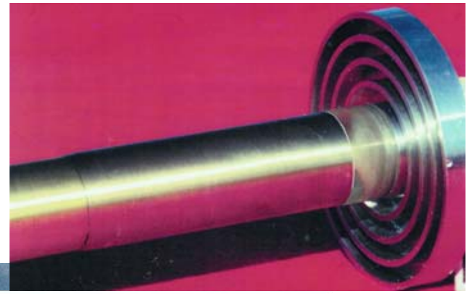
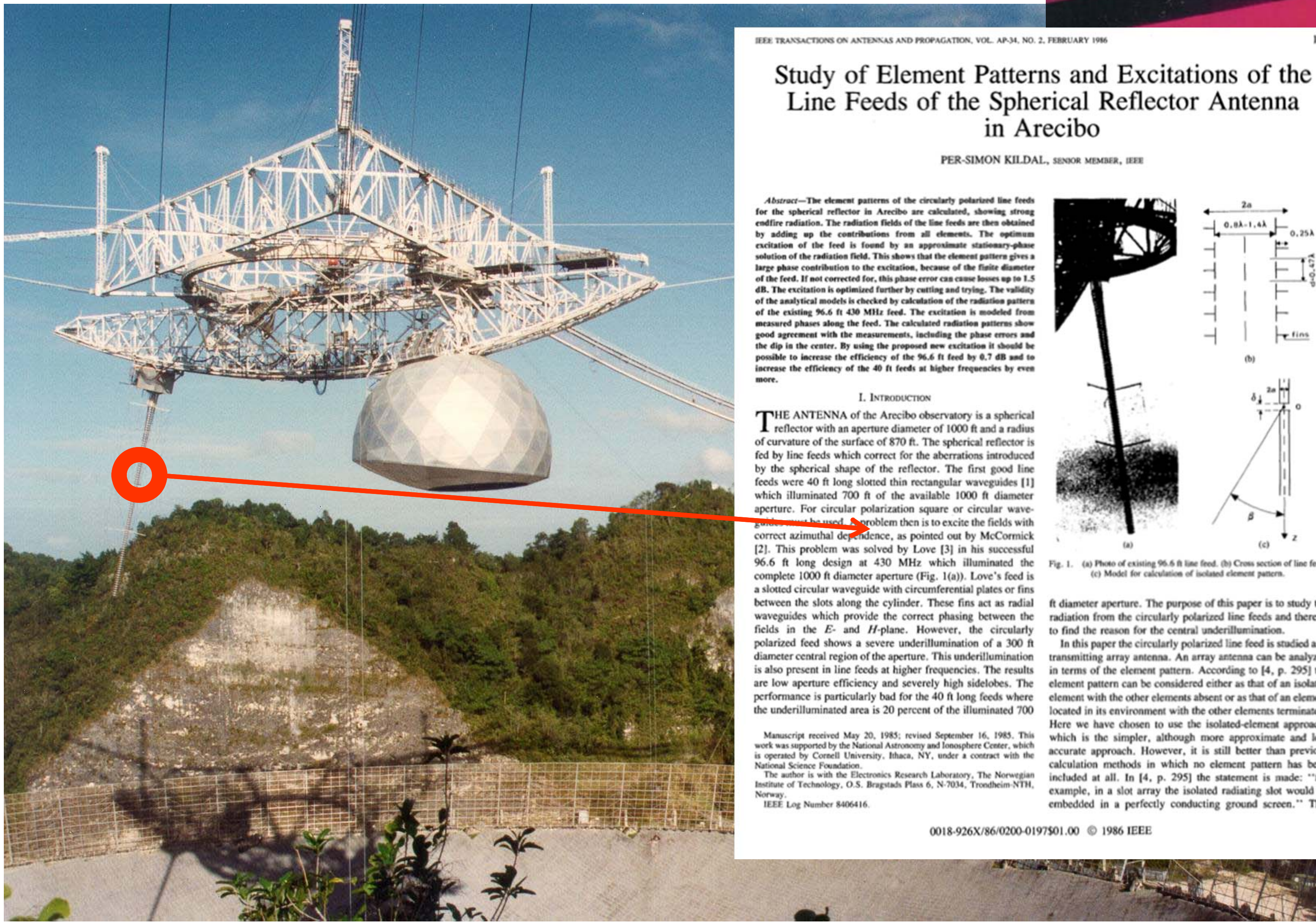
| Canonical Surface Gracing incidence | | E-field Polarization | |
|---|---|---|---|
| | | VER or TM | HOR or TE |
| PEC | | GO | STOP |
| PMC | | STOP | GO |
| PEC/PMC Strip grid | SOFT | STOP | STOP |
| | HARD | GO | GO |

2005: Table for comparing surfaces
with respect to propagation along surfaces
ERC funded GAP WAVEGUIDES are results of this table

| Canonical Surface | | E-field Polarization | |
|---|---|---|---|
| | | VER or TM | HOR or TE |
| PEC | | GO | STOP |
| PMC | | STOP | GO |
| PEC/PMC Strip grid | SOFT | STOP | STOP |
| | HARD | GO | GO |
| PMC-type EBG | grazing | STOP | STOP |
| | close to normal | PMC | |

# Hat feed is a result of Kildal's theoretical modeling av the Arecibo line feeds





IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. AP-34, NO. 2, FEBRUARY 1986


## Study of Element Patterns and Excitations of the Line Feeds of the Spherical Reflector Antenna in Arecibo

PER-SIMON KILDAL, SENIOR MEMBER, IEEE

*Abstract*—The element patterns of the circularly polarized line feeds for the spherical reflector in Arecibo are calculated, showing strong endfire radiation. The radiation fields of the line feeds are then obtained by adding up the contributions from all elements. The optimum excitation of the feed is found by an approximate stationary-phase solution of the radiation field. This shows that the element pattern gives a large phase contribution to the excitation, because of the finite diameter of the feed. If not corrected for, this phase error can cause losses up to 1.5 dB. The excitation is optimized further by cutting and trying. The validity of the analytical models is checked by calculation of the radiation pattern of the existing 96.6 ft 430 MHz feed. The excitation is modeled from measured phases along the feed. The calculated radiation patterns show good agreement with the measurements, including the phase errors and the dip in the center. By using the proposed new excitation it should be possible to increase the efficiency of the 96.6 ft feed by 0.7 dB and to increase the efficiency of the 40 ft feeds at higher frequencies by even more.

### I. Introduction

THE ANTENNA of the Arecibo observatory is a spherical reflector with an aperture diameter of 1000 ft and a radius of curvature of the surface of 870 ft. The spherical reflector is fed by line feeds which correct for the aberrations introduced by the spherical shape of the reflector. The first good line feeds were 40 ft long slotted thin rectangular waveguides [1] which illuminated 700 ft of the available 1000 ft diameter aperture. For circular polarization square or circular waveguides must be used. A problem then is to excite the fields with correct azimuthal dependence, as pointed out by McCormick [2]. This problem was solved by Love [3] in his successful 96.6 ft long design at 430 MHz which illuminated the complete 1000 ft diameter aperture (Fig. 1(a)). Love's feed is a slotted circular waveguide with circumferential plates or fins between the slots along the cylinder. These fins act as radial waveguides which provide the correct phasing between the fields in the $E$- and $H$-plane. However, the circularly polarized feed shows a severe underillumination of a 300 ft diameter central region of the aperture. This underillumination is also present in line feeds at higher frequencies. The results are low aperture efficiency and severely high sidelobes. The performance is particularly bad for the 40 ft long feeds where the underilluminated area is 20 percent of the illuminated 700 ft diameter aperture. The purpose of this paper is to study the radiation from the circularly polarized line feeds and thereby to find the reason for the central underillumination.



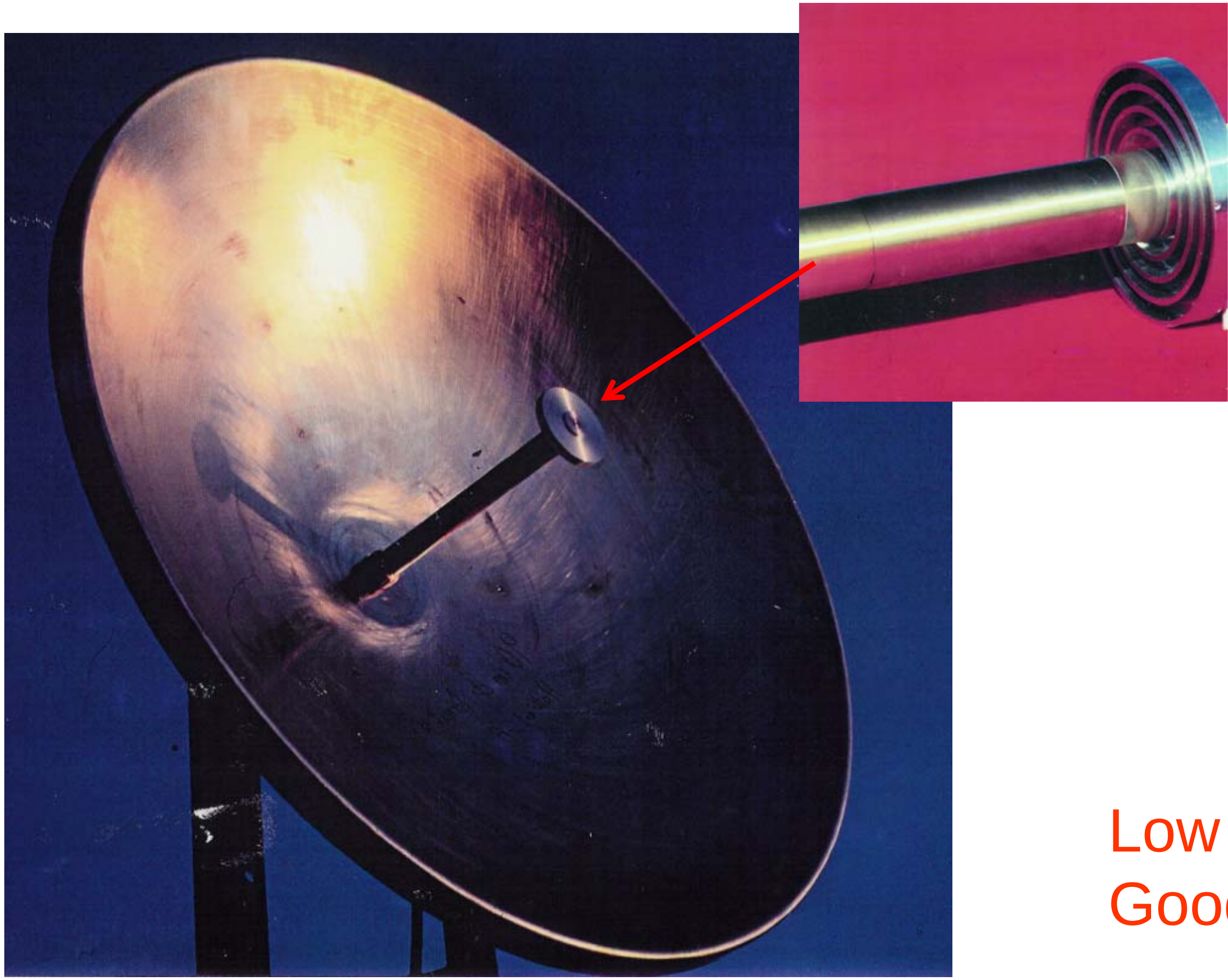
Fig. 1. (a) Photo of existing 96.6 ft line feed. (b) Cross section of line feed. (c) Model for calculation of isolated element pattern.

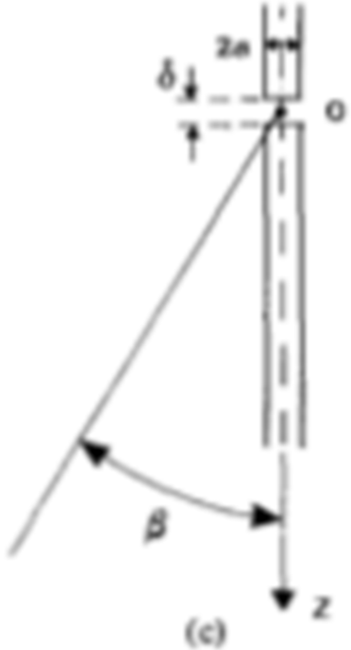
In this paper the circularly polarized line feed is studied as a transmitting array antenna. An array antenna can be analyzed in terms of the element pattern. According to [4, p. 295] the element pattern can be considered either as that of an isolated element with the other elements absent or as that of an element located in its environment with the other elements terminated. Here we have chosen to use the isolated-element approach, which is the simpler, although more approximate and less accurate approach. However, it is still better than previous calculation methods in which no element pattern has been included at all. In [4, p. 295] the statement is made: "for example, in a slot array the isolated radiating slot would be embedded in a perfectly conducting ground screen." This

Manuscript received May 20, 1985; revised September 16, 1985. This work was supported by the National Astronomy and Ionosphere Center, which is operated by Cornell University, Ithaca, NY, under a contract with the National Science Foundation.
The author is with the Electronics Research Laboratory, The Norwegian Institute of Technology, O.S. Bragstads Plass 6, N-7034, Trondheim-NTH, Norway.
IEEE Log Number 8406416.

0018-926X/86/0200-0197$01.00 

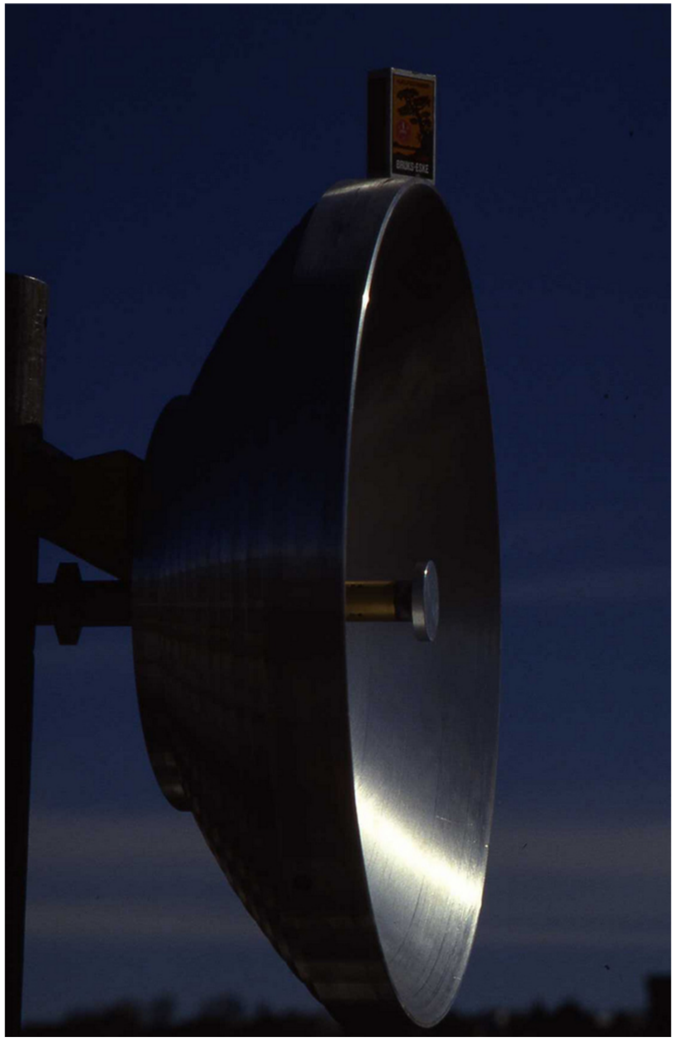
# Hat feed in ring-focus paraboloid (new phase efficiency)





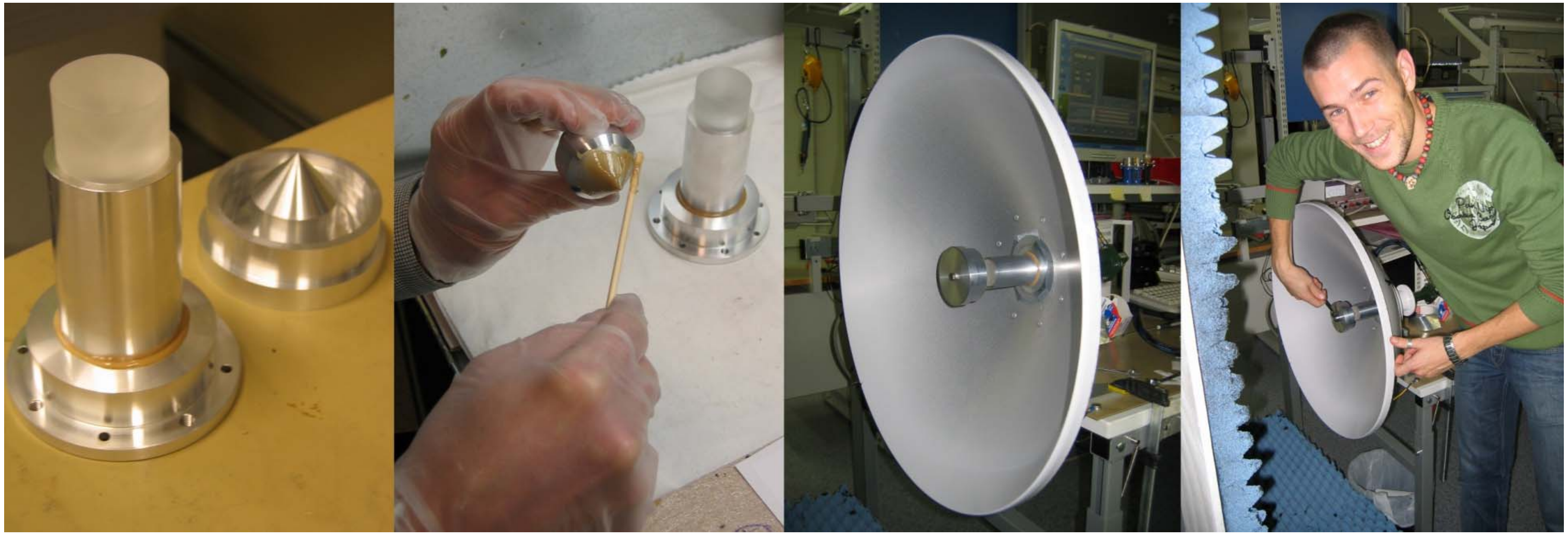

Low sidelobes
Good efficiency

# 1987-88: 15 GHz military link project for EB NERA (low volume)

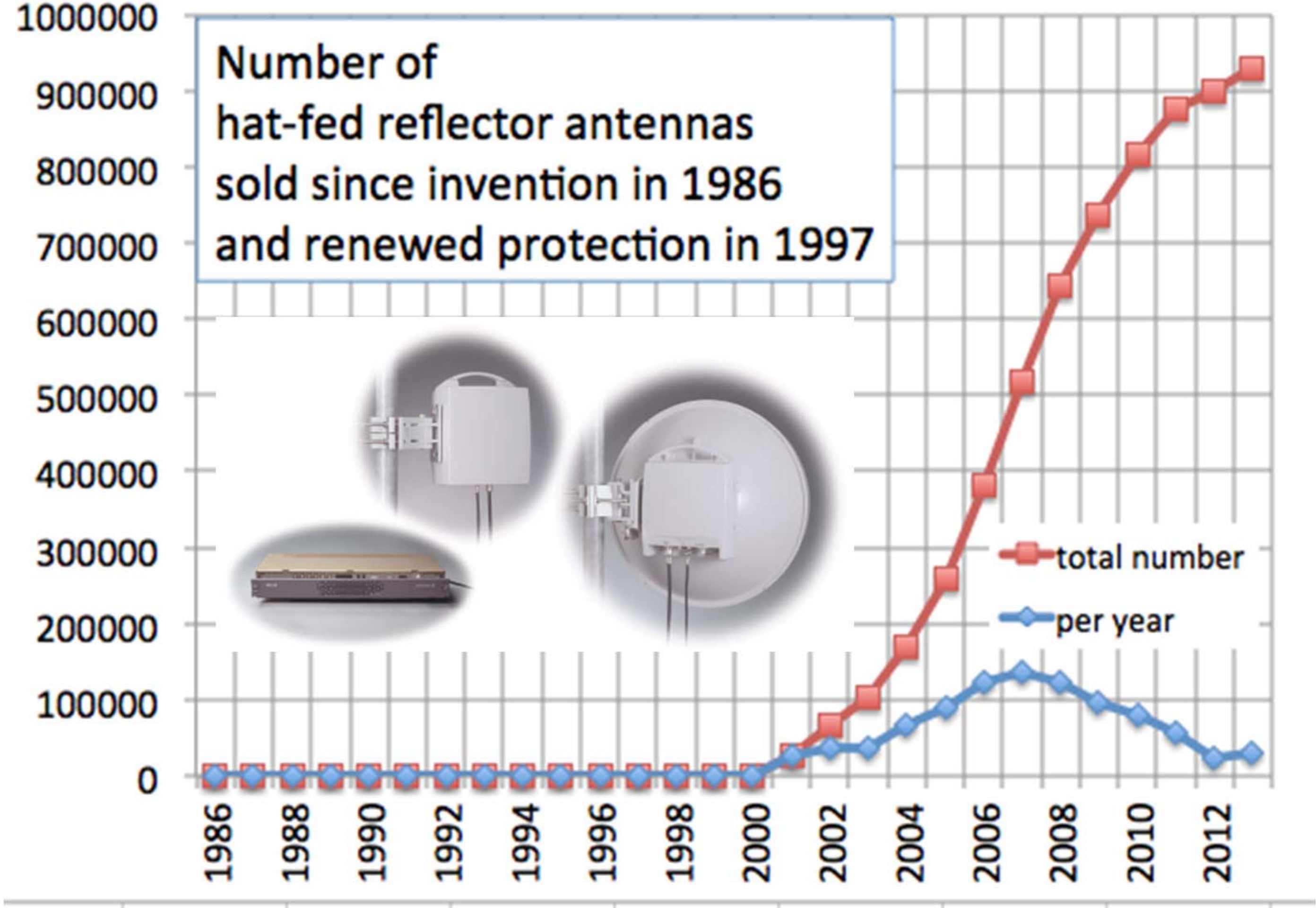


# Hat fed reflectors are in production

The below photos are from an improvement done in 2006.



More than 930 000 hat antennas has been produced
Started Comhat AB in 1997.
Now these products are in Arkivator AB.

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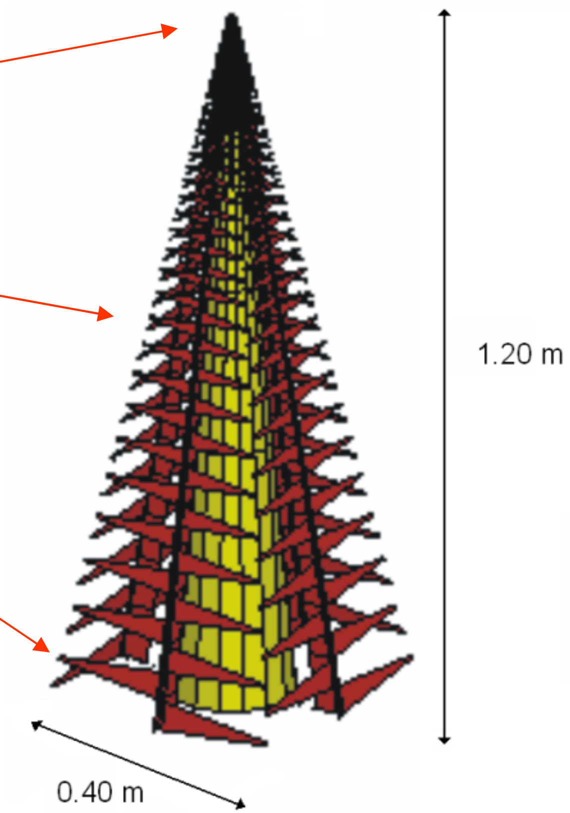
# Allan telescope Array
# a forerunner for SKA, 2003

Feed developed at UC Berkley

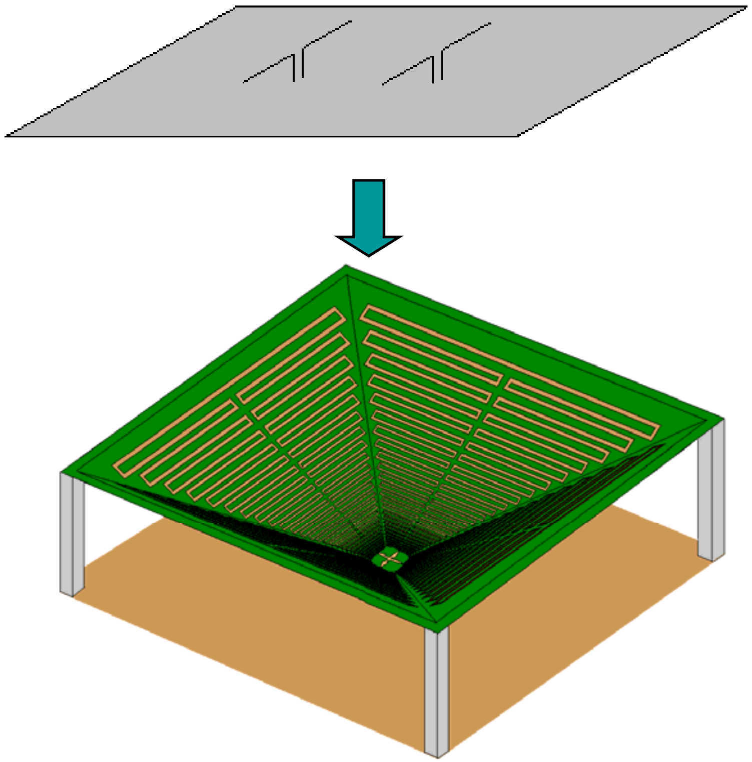
Allen Telescope Array (ATA)

ATA- Artist's impression, bird's eye view



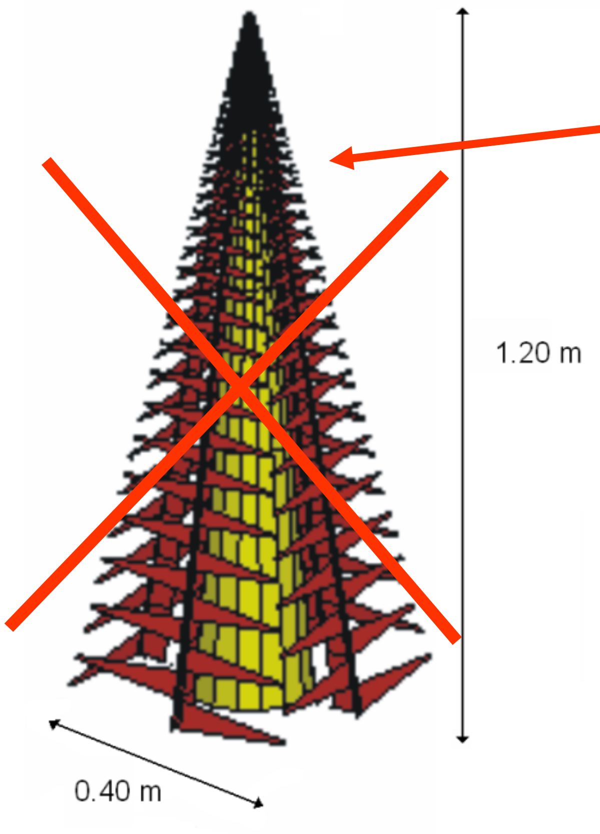
# Idea behind Eleven feed new invention

- Two parallel dipoles over ground (Eleven configuration)
  - from book by Christiansen and Högbom Radio Telescopes
  - equal E- and H-plane patterns
  - Beamwidth constant with frequency
  - phase center is locked to the ground plane
  - low far-out sidelobes and backlobes.
- Decade bandwidth by
  - Logperiodic
  - Folded dipoles



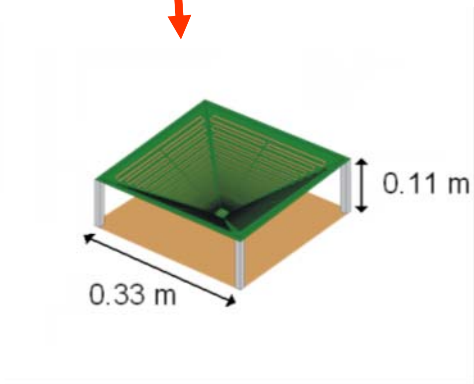
# Log-periodic feeds for reflector antennas, 2003

Example: Lowest frequency 500 MHz




Old technology

New technology




Background:

UWB antennas = logperiodic

The Eleven antenna:

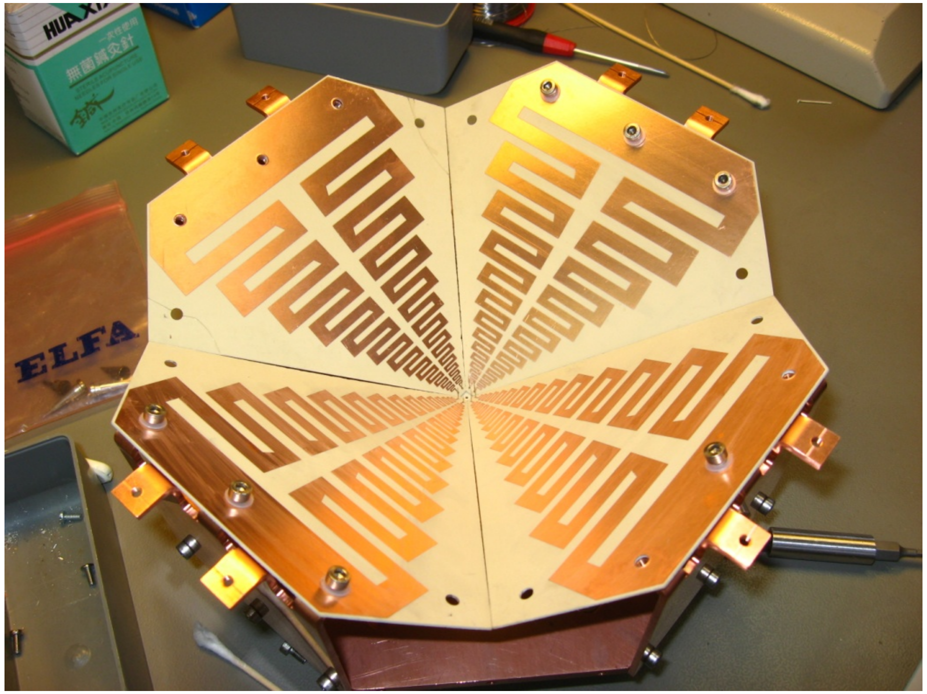
11 times smaller

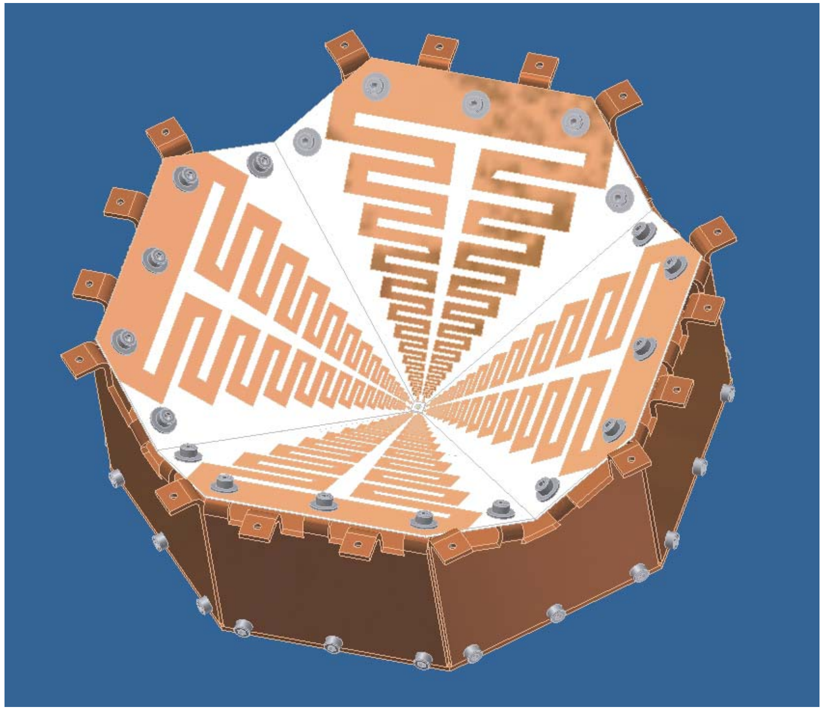
…….-and better

Breakthrough in wideband technology

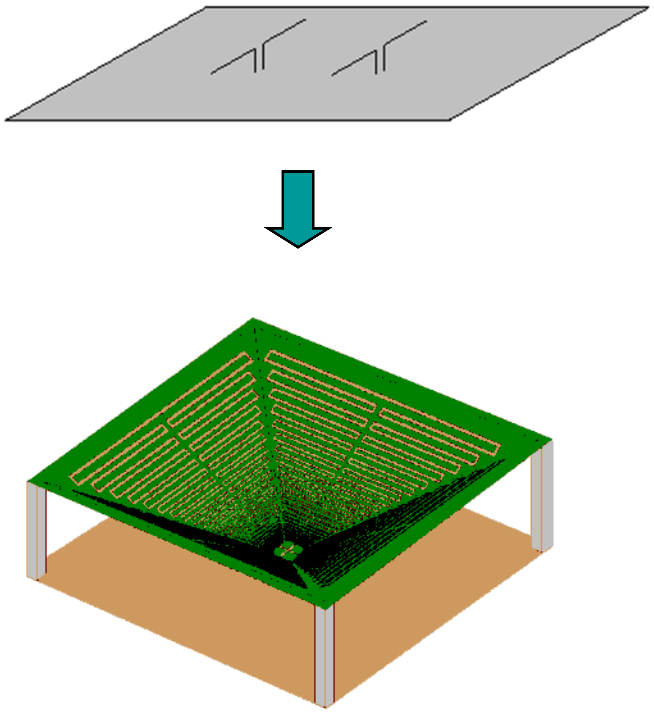
# Design of GMRT Eleven feed by Yogesh Karandikar on Master project Autumn 2006

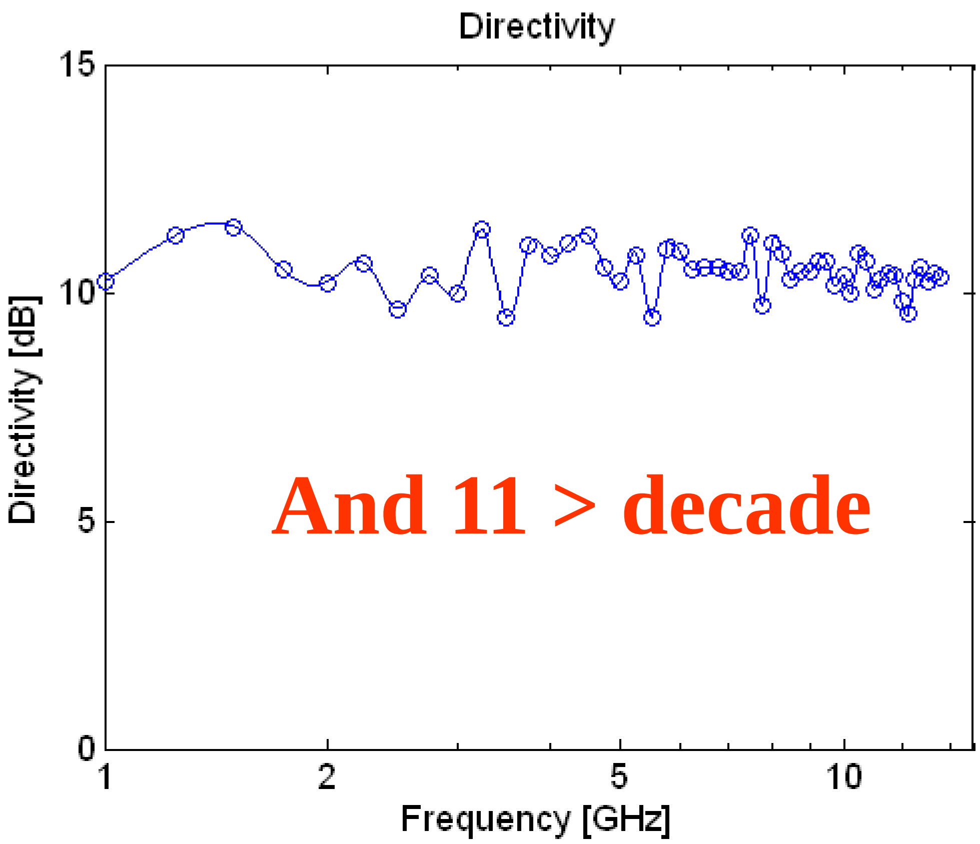
# Assembled hardware and drawing of 1-14 GHz Eleven feed



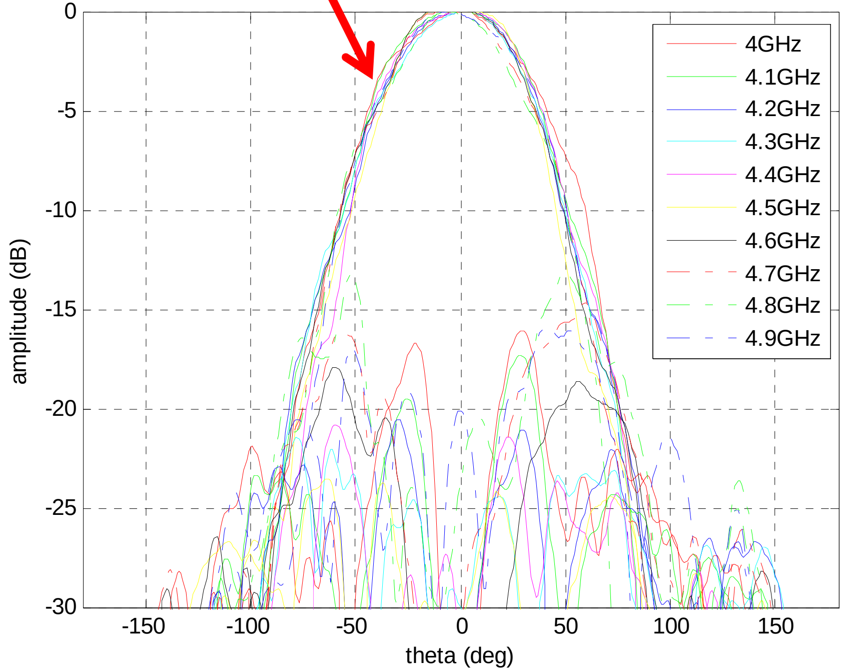
# Directivity 11 dBi
## over more than a decade bandwidth

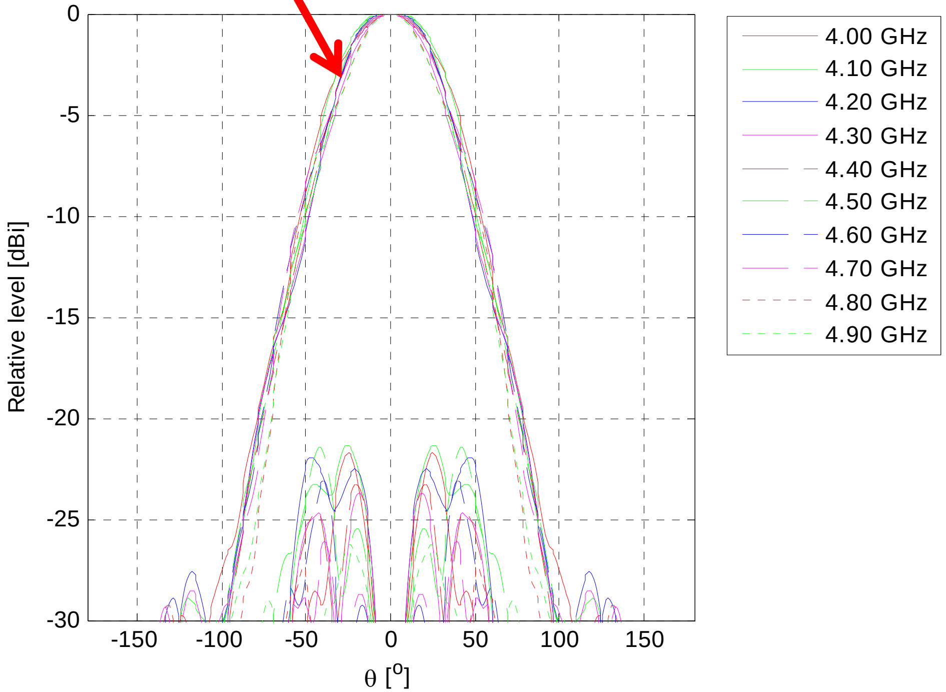




# Co- and crosspolar patterns in 45 deg plane

total and with removed higher order $\phi$ variations

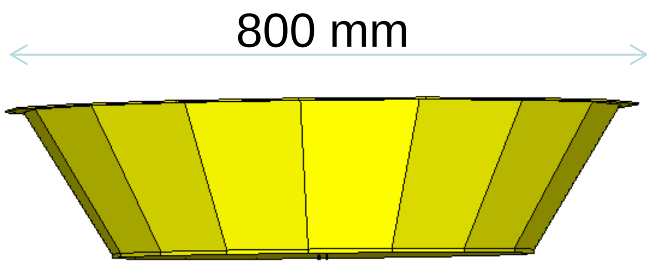



A new subefficiency characterizes purity of feed pattern BOR1 efficiency)

# Leightweight 400 – 2000 MHz Eleven antenna version

Weight 8.5 kg

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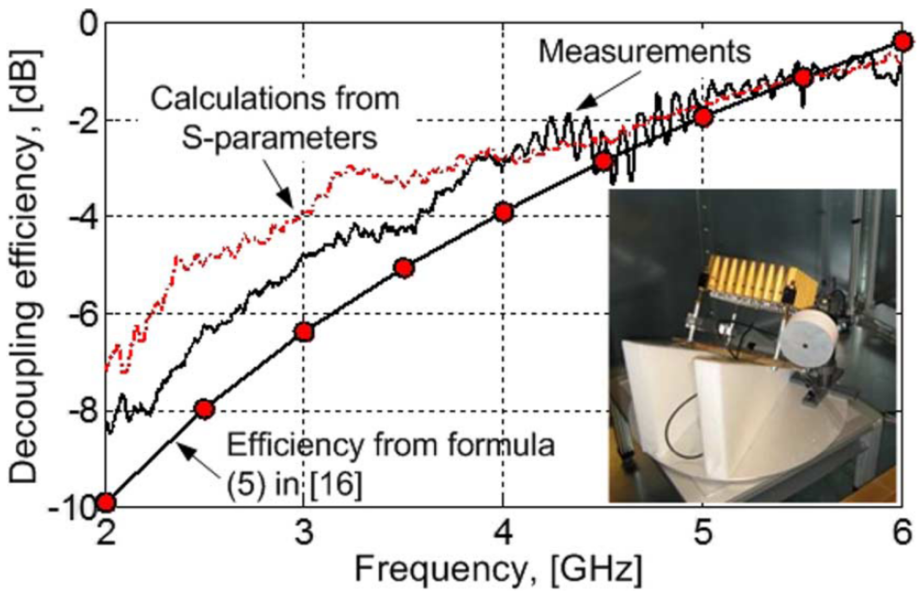
# Research efforts towards characterization of Mutual Coupling Effects in dense Focal Plane Arrays

2002 First studies by M. Ivashina & A. van Ardenne (2002).

2007 Invited lecture by Kildal on the characterization of reflector antennas feeds at the SKADS Marie Curie workshop, Dwingeloo

2007 Introduction of the unified decoupling efficiency for array feeds by the CHALMERS-ASTRON team (M. Kehn, M. Ivashina, P.-S. Kildal, and R. Maaskant)

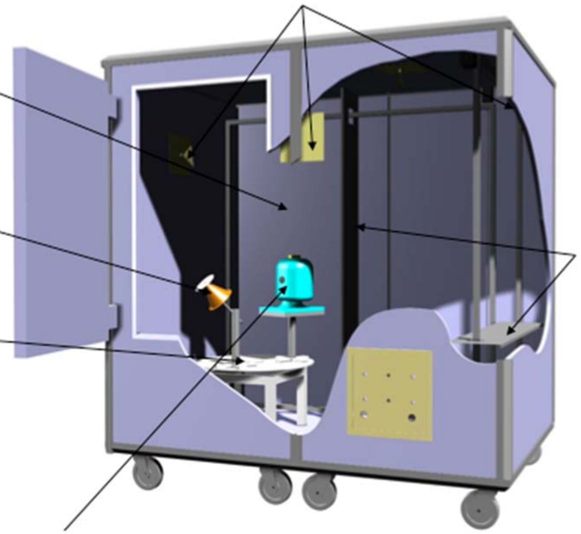



**Measurements of the FPA decoupling efficiency in the BlueTest reverberation chamber in Gothenburg**

Since that time:

- Several common journal and conference papers,
- FP7 MCA-VINNMER Fellowship (co-)funded by ASTRON and Chalmers,
- 2 PhD projects on FPAs (co-)funded by the Swedish and SA national research councils

# Characterization in rich isotropic multipath in reverberation chamber

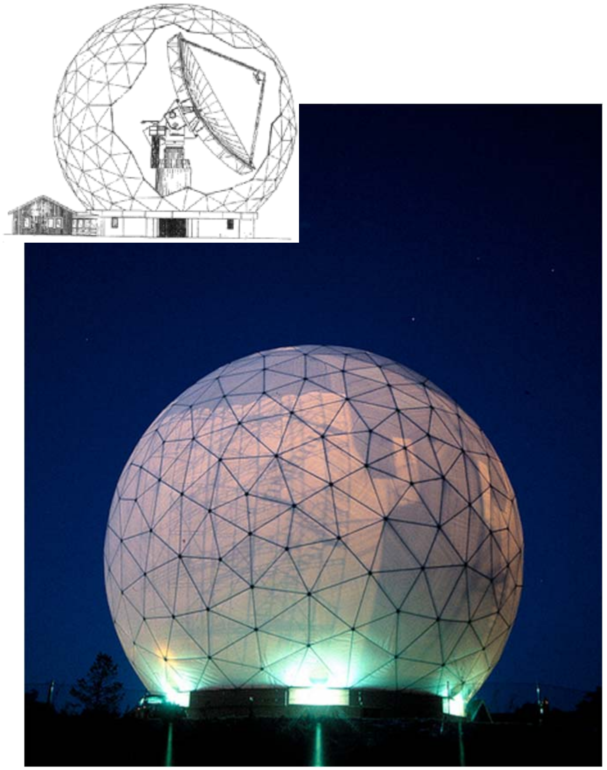



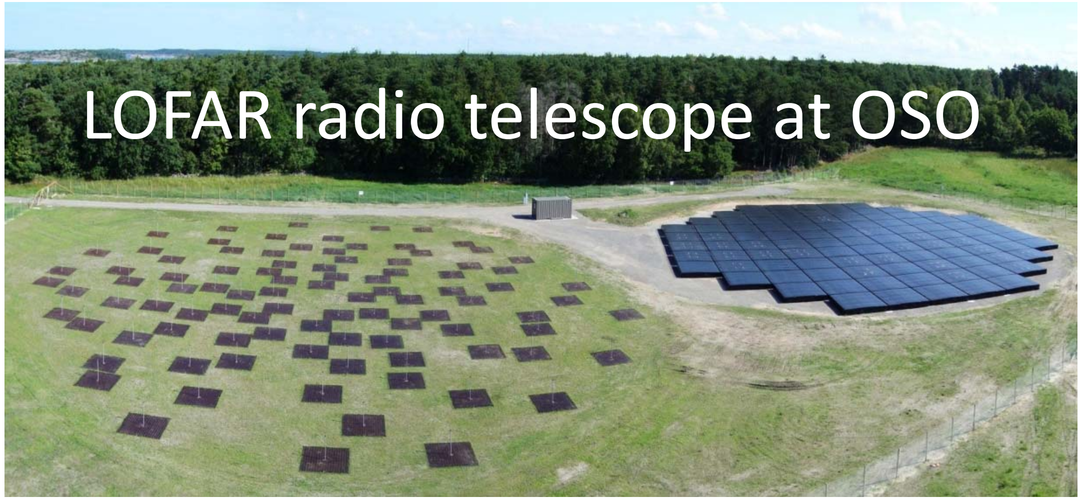

Since 2010 Spin-off company Bluetest has success in market.

# LOFAR - the biggest telescope built in Sweden in the last 35 years

CHALMERS receives the national infrastructure funding for installing two LOFAR stations (Adj. Prof. Arnold van Ardenne – co-applicant of this LOFAR proposal)

Traditional technology
25-m radio telescope at OSO







Inauguration of LOFAR at OSO (26th, September 2011)

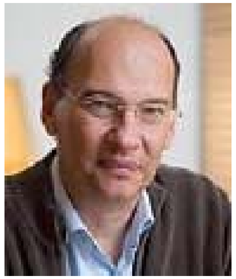
CHALMERS

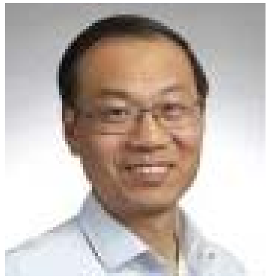
Chalmers University of Technology, Sweden

'*We are going to develop new technology for both antennas and receivers for the SKA*', says John Conway, deputy director for Onsala Space Observatory.



**Science/Engineering management**


**- Electromagnetic design of wideband feeds for reflector antennas**

**- Modeling of antenna-receiver systems and calibration of radio telescopes**




# Keys to success with inventions in my case

- Projects with scientific instruments and interaction with their users
- Very basic EM principles
  - Polarization-dependent PEC wire grid
  - Polarization-independent PEC/PMC wire grid
  - Rethinking of the logperiodic antenna
  - BOR antennas
- Characterization
  - We need to quantify good and bad
  - Related to physical phenomena
- Protection
  - Patent protection defines ownership
  - Makes it easier to defend most places in the world
  - The thieves are NOT the Japanese and the Chinese
  - US law favors US companies (unique in World)
- Commercialization
  - The ultimate proof of usefulness