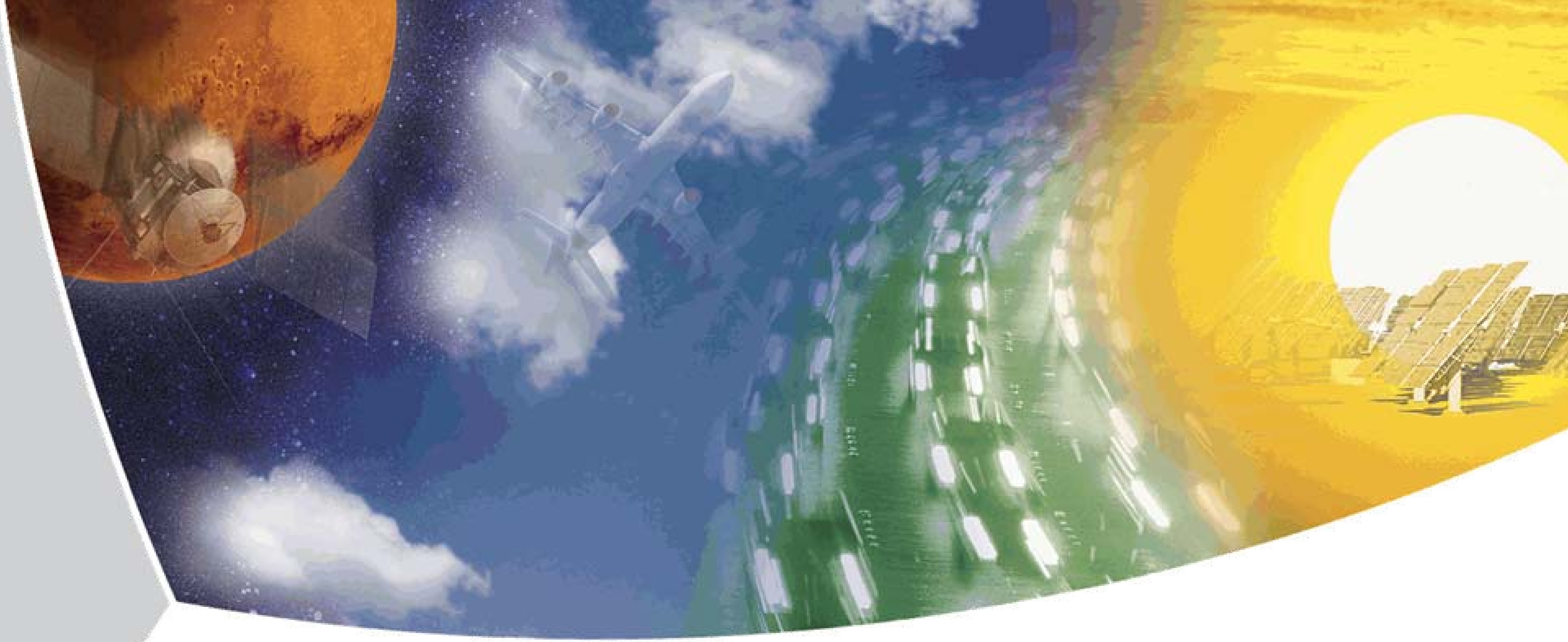

Design of an Airborne SLAR Antenna at X-Band

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Overview

- Applications of SLAR
- General Requirements for SLAR-Antenna Design
- Evolution of Slotted Waveguide Antenna
- Performance Estimation of SLAR-System
- Summary

Applications of SLAR

A **SLAR (Side-Looking-Airborne-Radar)** is member of the class of imaging radar systems. In contrary to **SAR (Synthetic-Aperture-Radar)** it is based on a **RAR (Real-Aperture-Radar)** which leads to different requirements in antenna design.

Typical range request is a distance up to 40km. The resolution in flight direction is dependent on distance and the length of the antenna aperture. Range resolution correlates with the pulse duration τ of the radar system.

In marine surveillance applications like oil slick detection the change in roughness of the sea surface is the indicator for polluted areas. In general the sea surface will be smoother and in radar image an oil slick appears as a black region in the sea back scatter image.

Applications:

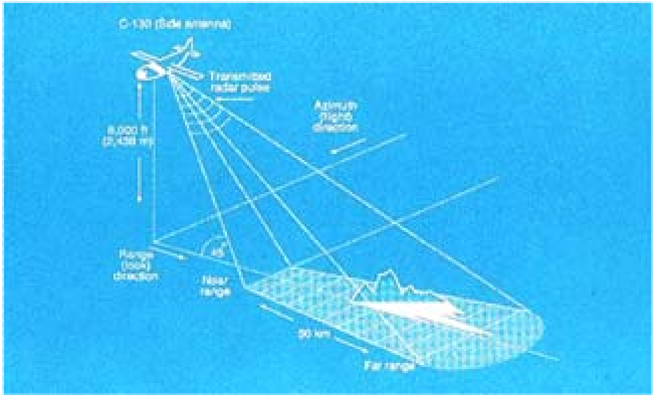
- oil slick detection on sea,
- monitoring of sea ice and icebergs,
- determination of the position of ships, drilling platforms, …

Oilrecoveryship Bottsand (Source Presse- und Informationszentrum Marine)

General Requirements for SLAR-Antenna Design

SLAR – System, typical parameters:

- center frequency: X - Band (9 -10GHz, λ_{CF}= 3 cm)
- band width: 1 MHz
- pulse power: 10 kWatt
- pulse duration: 1 µs
- antenna pattern: < 0.6° azimuth
  > 20° elevation
- gain: > 30 dBi
- polarization: linear v



Antenna Design I

The antenna pattern requirement of 0.6° degree half power beam width in azimuth leads to a minimum aperture size in the direction of motion. In general the far field pattern of the antenna is derived by the Fourier transformation of the excitation of the antennas aperture.

- pattern of a linear group with constant excitation: $E(u) = l \cdot \frac{\sin u}{u}$

- the transformation of this rect- function leads to a 3dB beam width of

$$\approx 50.8° \cdot \frac{\lambda}{l}$$

- in X - band, at 9.6 GHz, the free space wave length is 3.125 cm. For a half power beam width of 0.6° the aperture length becomes:

$$l = \frac{50.8°}{0.6°} \cdot 3.125cm$$

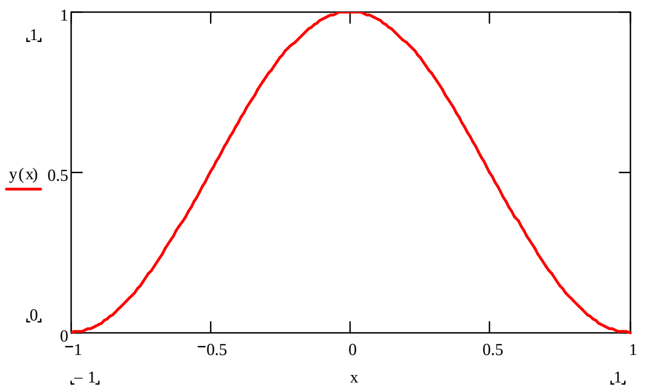
$$l = 265cm$$

Antenna Design II

In the case of a rect aperture function the side lobe suppression of -13.26 dB is not sufficient for SLAR application.

To reduce side lobe level the excitation of the aperture should match a $\cos^2$- function.

From this it follows that the beam will broaden and the efficiency of the aperture decreases. We calculate the antenna length with the following formula:



COS2 - function

$$l = \frac{83.2^\circ}{0.6^\circ} \cdot 3.125cm$$

$$l = 433cm$$

first side lobe level: -32 dB

efficiency (gain factor) 0.667

➔ An optimum antenna design is somewhere between this extreme aperture excitation functions.

Antenna Design III

The beam width requirement is strong because the system performance in resolution depends on it. For the next steps the antenna aperture length is set to 4 meters with a slightly understated $\cos^2$ aperture function to achieve the desired beam width.

Next parameter is antenna gain. The gain is a function of directivity weighted by the losses of the antenna. Losses are coupled to radiator type, network topology,…

The minimum aperture size results from the specified gain (>30dBi) and the excitation function:

$$A \simeq \frac{gain \cdot \lambda^2}{8.3}$$

$$A \simeq 1176 cm^2$$

With a length of 400 cm the height of the antenna should be at least 3 cm.

Cross check with a rect-function for the aperture excitation in height direction results in a beam width in elevation of:

$$\theta_B \approx 53°$$

Antenna Design IV

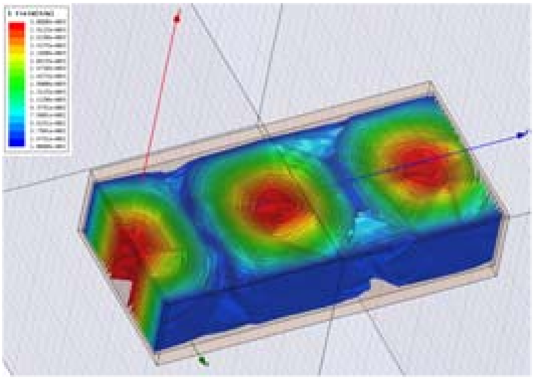
The beam width in elevation was specified to ≈ 20° degree. Therefore height of the antenna increase to 8 cm. A positive effect will be a noble offset between directivity and required gain of ≈ 4 dB.

With the constraints of an airplane the antenna has to be small in depth. Mounting points could be at the edges of the fuselage (e.g. Dornier Do 228). Only a group antenna with discrete radiators is feasible. To excite the single elements a network is necessary. Due to losses, caused by the length of the antenna array, microstrip lines or coaxial lines are not suitable.

A rectangular wave guide can deal with the high pulse power as well has it has only marginal losses.

➝ All these requirements motivates a slotted wave guide antenna design.

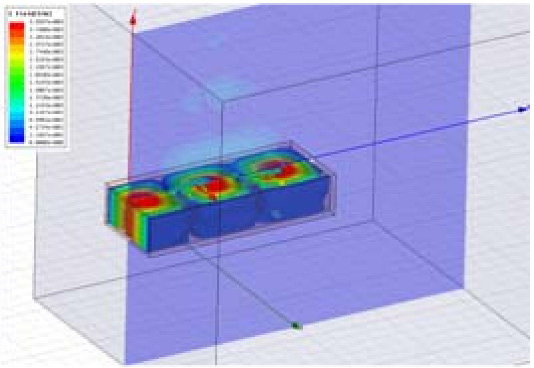
Antenna Design V



The animation demonstrates the magnitude of the electric field vector at dominant mode H_{10} in a section of a standard X – band wave guide, WR-90 at 9.6 GHz.

If we insert a slot at the broad side it is not possible to couple out an adequate level of power into free space, due to the change in the direction of the electric field vector as the wave passes through.

A short at the end of the wave guide forces a standing wave and the position of the field distribution is constant. So a number of slots could be arranged in the wave guide and a group antenna is designed. Slot distances are coupled to the specific wave length λ_g in the wave guide.



Unfortunately the positions of the slots are very sensitive to even small displacements in length direction.
A displacement could be generated out of mechanical and / or electrical reasons.

A change in ambient temperature gives a displacement due to elongation and is dependent on the total length of the structure. A similar distortion results from differences in transmit frequency. Vibrations from aircraft engines is another source for pattern distortions.

Antenna Design VI

The length of the slotted waveguide is limited by reasons of elongation. Thus the SLAR antenna is divided into short antenna segments. A subarray with 8 shunt slots, fed by a coupling slot at the center of the element was designed as a core cell for the array antenna.

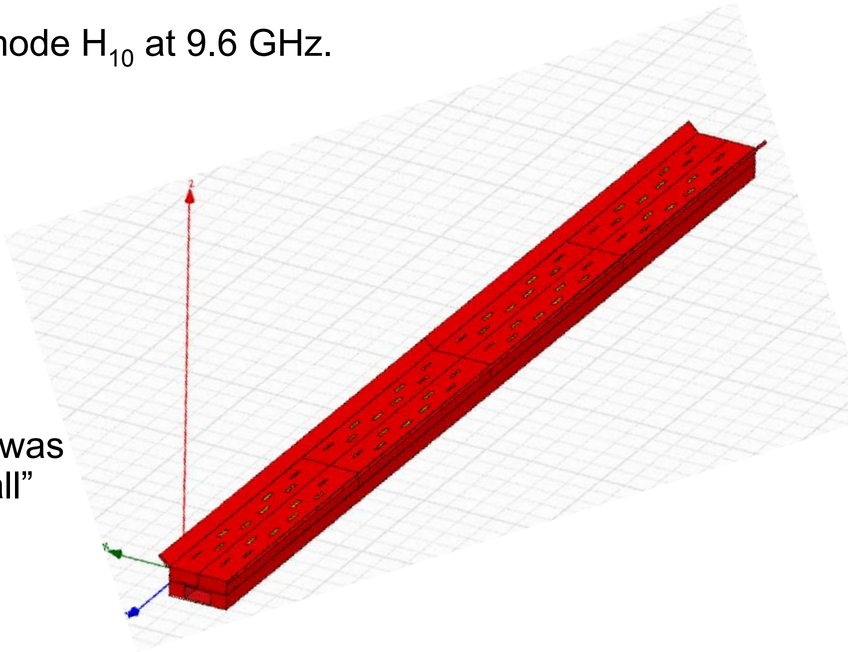
Basis for the antenna is a standard WR-90 wave guide. WR-90 standard is used from 8.2 to 12.4 GHz. :

width:	22.86 mm
height:	10.16 mm
wall thickness:	1 mm

These dimensions allows operations in dominant mode H_{10} at 9.6 GHz.

The antenna of interest is designed at:

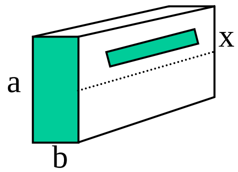
center frequency	9.6 GHz
band width up to	200 MHz
operating band width	1 MHz



A short segment consisting of 4 x 2 core elements was designed to study its properties. Intention is a “small” lightweight antenna which could be offered for SLAR applications.

Antenna Design VII

The shunt slot interrupts the transverse currents on the broad wall of the wave guide. Naturally the slots have to have a displacement from the center line to be able to couple out some energy into free space. The leakage power of the shunt slot is proportional to the shunt conductance. Hence the distribution over the array is given by its varying conductance. The conductance is dependent on the offset '*x*' to the center line:

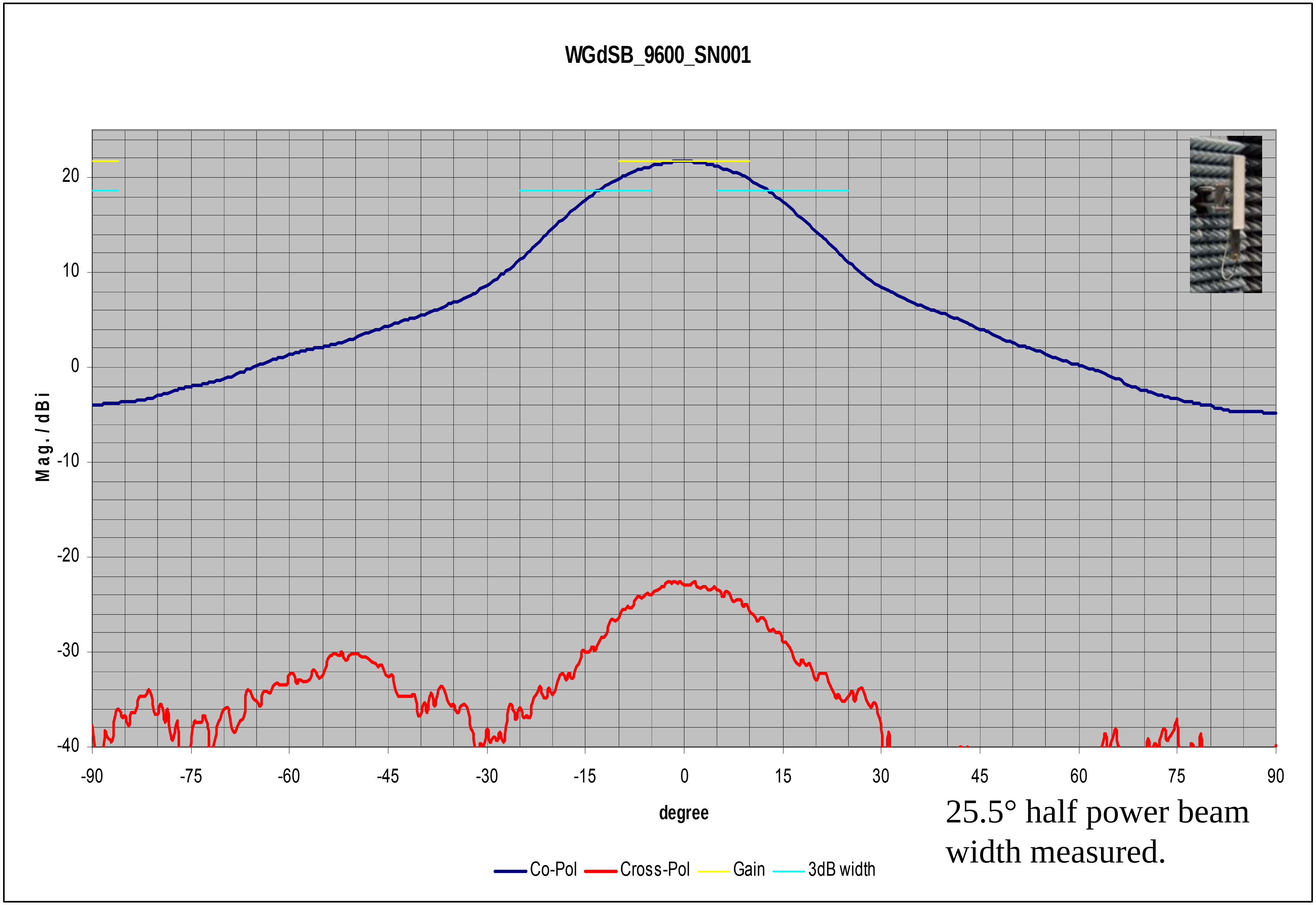


$$G = G_0 \cdot \sin^2 \frac{\pi \cdot x}{a}$$

The length of the slot is near to resonance length at design frequency to arise a purely real load to the wave guide.

One degree of freedom to reduce the side lobe level is the offset position of the slot as a radiating element in the array. Another item is the coupling ratio between the core elements and the feeding wave guide. The outcome of this could be an adequate side lobe suppression for the SLAR antenna, near to a $\cos^2$ aperture excitation.

Antenna Design VIII



25.5° half power beam width measured.

Performance Estimation I

To estimate the performance of the SLAR system the radar equation is used and reconverted to signal to noise ratio:

$$\left(\frac{S}{N}\right) = \frac{P_T \cdot G^2 \cdot \lambda^2 \cdot \sigma_c}{(4\pi)^3 \cdot R^3 k_B T B} \qquad k_B = 1.38 \cdot 10^{-23}$$

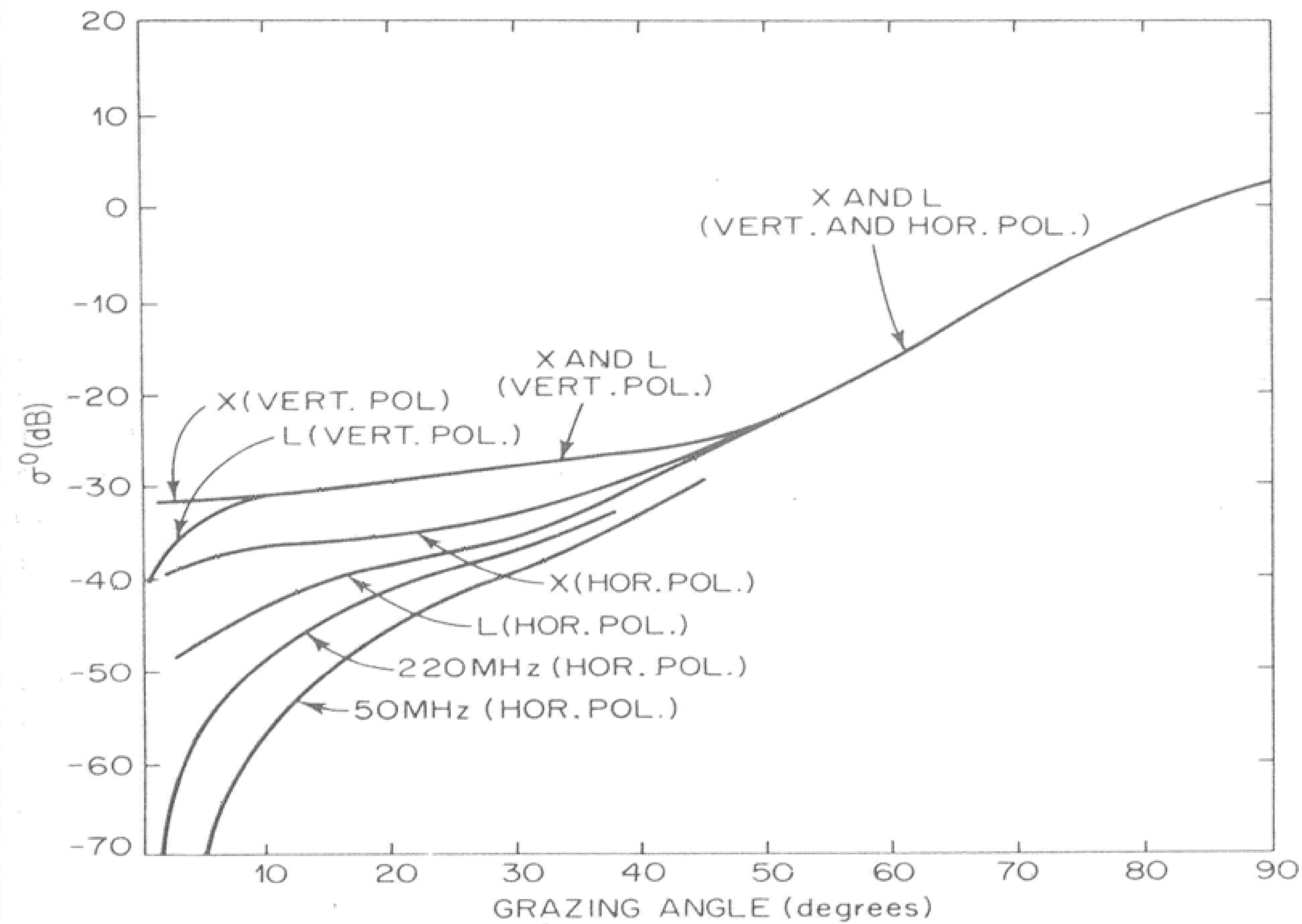
For a signal-to-noise ratio of 10dB the maximum range *R* is dependent on *σ* :

$$R = \sqrt[4]{\frac{P_T \cdot G^2 \cdot \lambda^2 \cdot \sigma_c}{(4\pi)^3 \cdot k_B \cdot TB \cdot \left(S/N\right)}}$$

$$R = 18.4 km \cdot \sqrt[4]{\sigma_c}$$

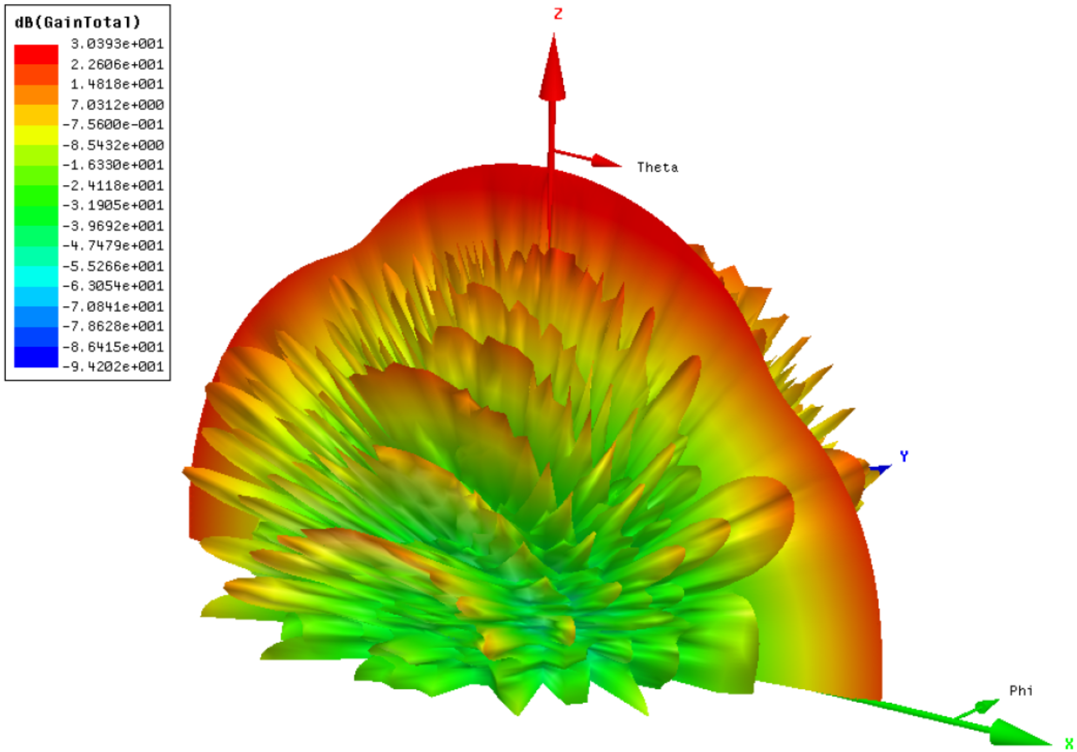
To detect a target in 40 km distance a σ_c of *23* is required. From literature the radar cross section σ_0 of water under flat incidence angle is known by experiments.

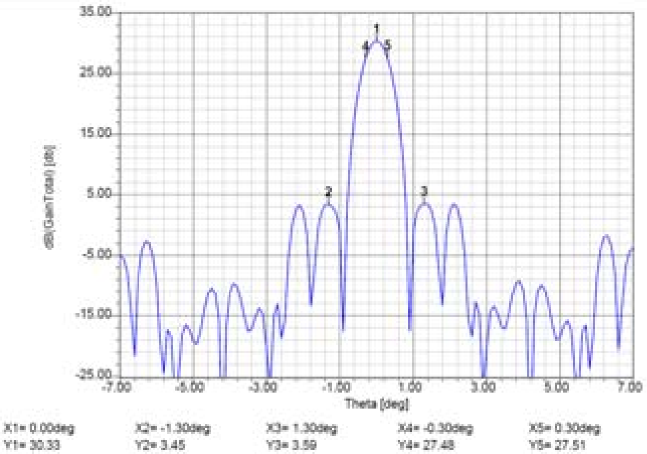
Performance Estimation II

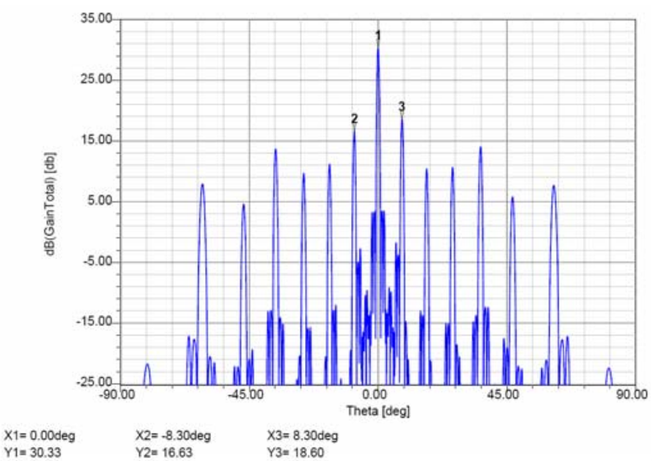


Results

Simulation outcomes of a 19 by 2 core elements array. The software HFSS from Ansoft Corporation was used to generate these results.
The antenna length is 4.05 m.

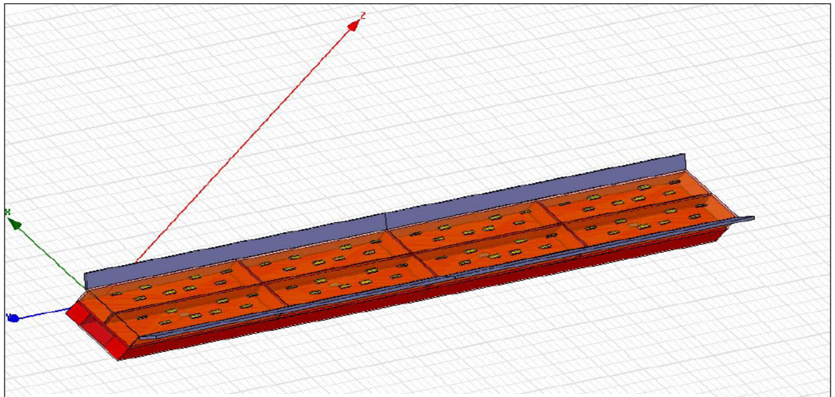




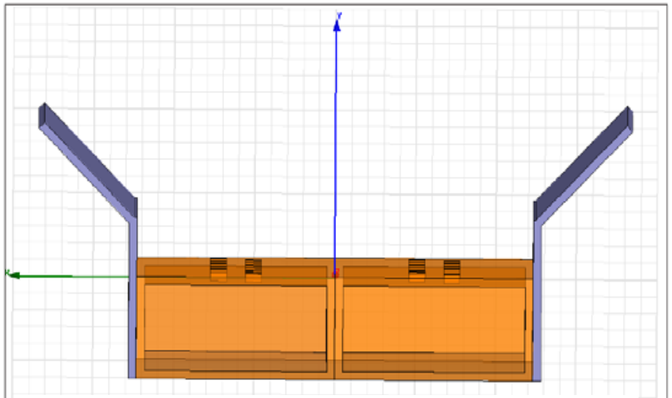


3 dB beam width	**0.6°**
first side lobe level	**-26.5 dB**
gain	**30 dBi**

Summary I



Antenna section with 4 by 2 core elements, feed by corporate wave guide.



Cross-section of the radiating elements with flare configuration.

Image of 1 by 2 core elements with Teflon cover.

Summary II

A reasonable design for a SLAR antenna was presented. It was shown, that a simple structure, prepared of short antennas, feed by a corporate wave guide can obtain the requirements. In the end system performance was demonstrated.

- short radiating elements,
- corporate feeding wave guide,
- flares to shape elevation beam,
- easy to cover the aperture,

This study presents a general layout for a SLAR antenna system. For a dedicated system the design can change, for example core elements with 12 slots instead of 8. This could give an advantage in far field pattern. The grating lobe position will start farther.

Another point could be an unsymmetrical excitation of the core elements, like a saw tooth pattern which will suppress the grating lobes, proper dimensioning assumed.

Thank you for your attention!

Any Questions?