

An Optimized Spline Generated Horn Profile with Low Cross Polarization

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Introduction

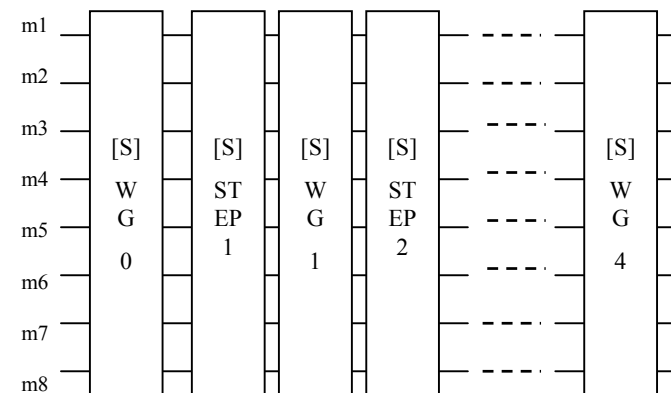
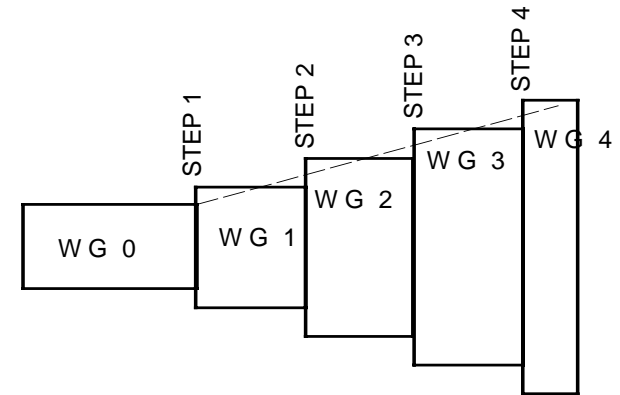
- Main motivation: Feed horn design suited for mass-production, to obtain low cost terminals
- Plastic injection molding and metallization techniques - technologies suited for low cost mass-production
- A smooth-walled feed horn is easier and costs less to manufacture by plastic injection molding and metallization than a corrugated horn
- Low cross polarization obtained by shaping the horn profile
- Design of a dual band smooth-walled feed horn with low cross polarization, terminal for DBS-RCS**, 11/14 GHz



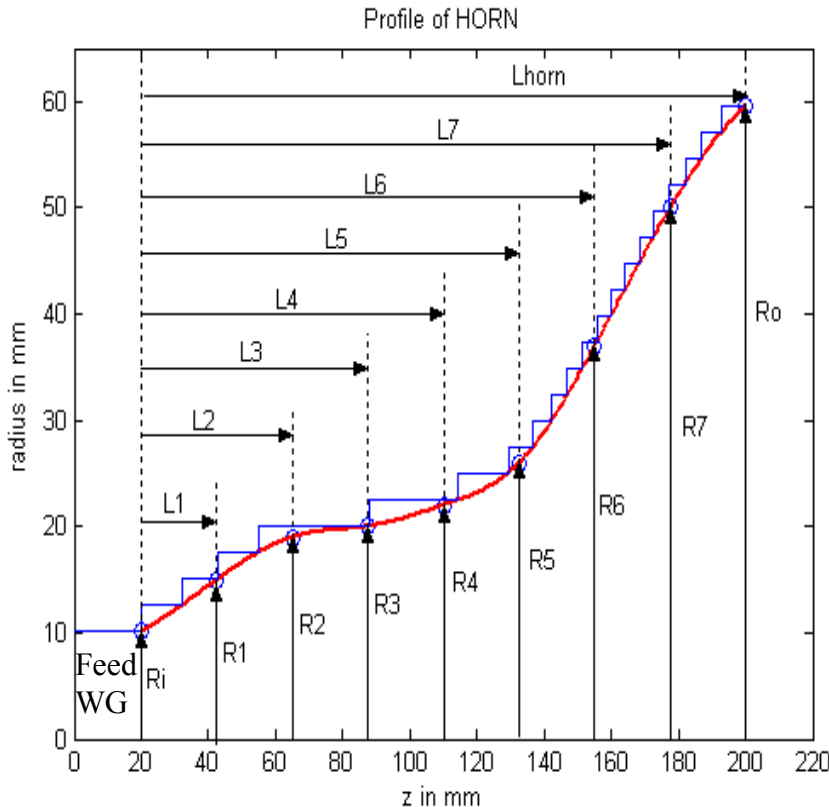
**DBS-RCS, Direct Broadcasting Satellite with Return Channel System

Electromagnetic analysis by the mode matching method

- Antenna geometry limited to axisymmetric horns with coupling limited to TE_{1n} and TM_{1n} modes, with incident TE_{11} mode
- Horn modeled as circular waveguide sections connected by waveguide steps
- Each waveguide step analyzed by mode matching to find coupling between modes, which are converted to generalized scattering matrices (S-parameters)
- S-parameters of all waveguide steps and waveguide sections are cascaded to find the S-parameters of the horn model
- Mode conversion (S21) at the horn aperture used to scale radiation patterns from each mode. Scaled patterns summarized to get total patterns
- Accuracy increases with number of modes involved



Spline generated horn profile



- Horn profile defined by 7 inner and 2 end nodes
- Each node defined by a radius and a distance from the feed WG
- Distance from feed WG to node given as a ratio of Lhorn, total length of horn
- The smooth curve is the cubic-spline generated horn profile
- Stepped profile is fitted to the spline curve
- With predefined steps, only WG lengths varied to fit spline profile

The particle swarm optimization (PSO) method

- Global optimization method based on social behavior of swarms, first publication in 1995
- A set of particles making up the swarm, searches the N-dimensional solution space and keeps track of personal best position and global best position within the swarm. N is number of variables in optimization
- For each particle the direction towards the next position to explore is a combination of current velocity and a weighted combination of velocities towards personal and global best positions
- Goodness of position evaluated by a fitness function

References:

- J.Kennedy and R. Eberhart, "Particle Swarm Optimization", Proc. IEEE Conf. Neural Networks, VOL. 4, 27.Nov-1.Dec 1995, pp 1942-1948
- J. Robinson and Y. Rahmat-Samii, "Particle Swarm Optimization in Electromagnetics", IEEE Trans. AP, VOL. 52, NO. 2, Feb. 2004, pp. 397-407

Description of PSO algorithm

1. Define solution space: N-dimensional solution space with N parameters to optimize
2. Define fitness function: single output number with functional dependence to each of the characteristics to be optimized
3. Initialize random swarm location and velocities: first *pbest* for each particle
4. Search solution space:
 - Evaluate particle's fitness function, compare to *pbest* and *gbest* and update
 - Update particle's velocity: particle accelerate towards the *pbest* and *gbest* positions according to equation:

$$v_n = \omega \cdot v_n + c_1 \cdot rand() \cdot (p_{best,n} - x_n) + c_2 \cdot rand() \cdot (g_{best,n} - x_n)$$

- Move the particle: apply velocity for a time step Δt , usually set to 1
- $$x_n = x_n + \Delta t \cdot v_n$$
5. Repeat from step 4 if termination criteria not met

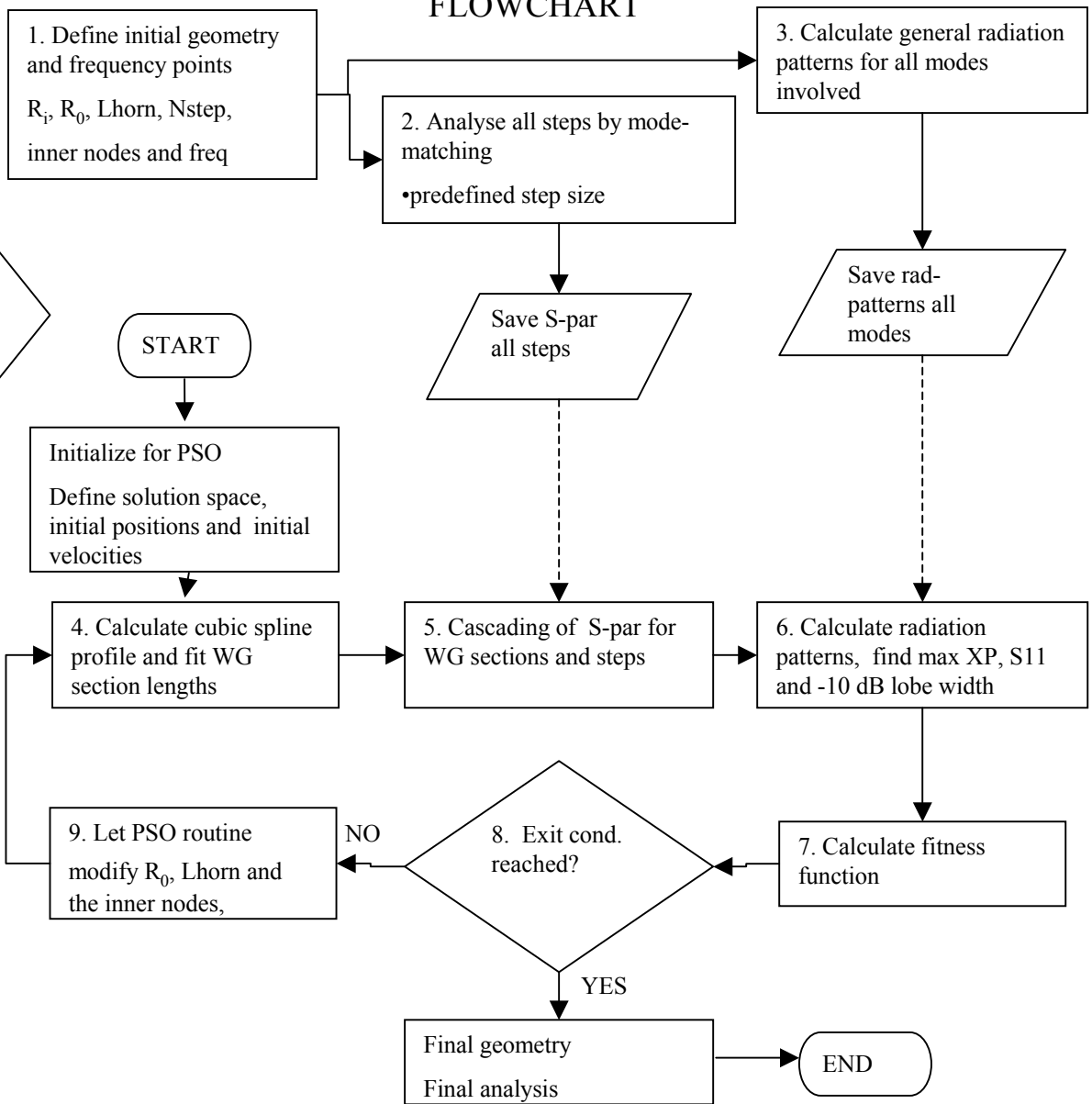
Suggested parameter values for particle velocity function
(after Robinson and Rahmat-Samii, IEEE 2004)

$\omega=0.9 -0.4$ (linearly decreased)	$c_1=1.49$	$c_2=1.49$	Population size ≤ 30
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Initial calculations

Optimization feed horn
With PSO

FLOWCHART



Example: Optimization of a dual band feed horn for a DVB-RCS terminal

Specifications	RX-band	TX-band
Frequency [GHz]	10.7 – 12.75	13.75 – 14.5
Cross polarization [dB]	< -20	< -35
Return loss [dB]	> 25	> 25
Lobe width at -10 dB illumination [deg]		16-18 (reflector rim at 17 deg)

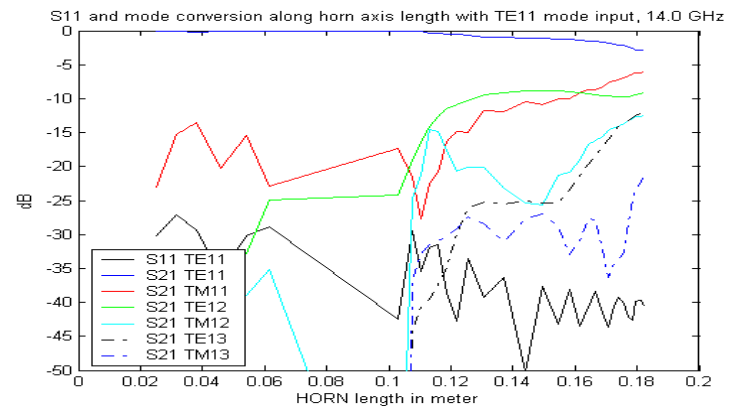
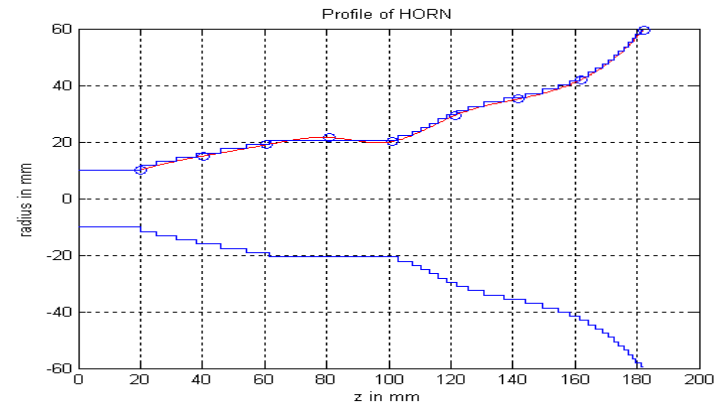
Fitness function for PSO:

$$f = - \sum_{i=1}^{N_{freq}} \{XP \max(i) + \omega_{S11} S11(i)\} + \sum_{i=1}^{N_{freq} \text{ TX}} \omega_{\theta} |\theta_{-10dB}(i) - \theta_{Goal}|^2$$

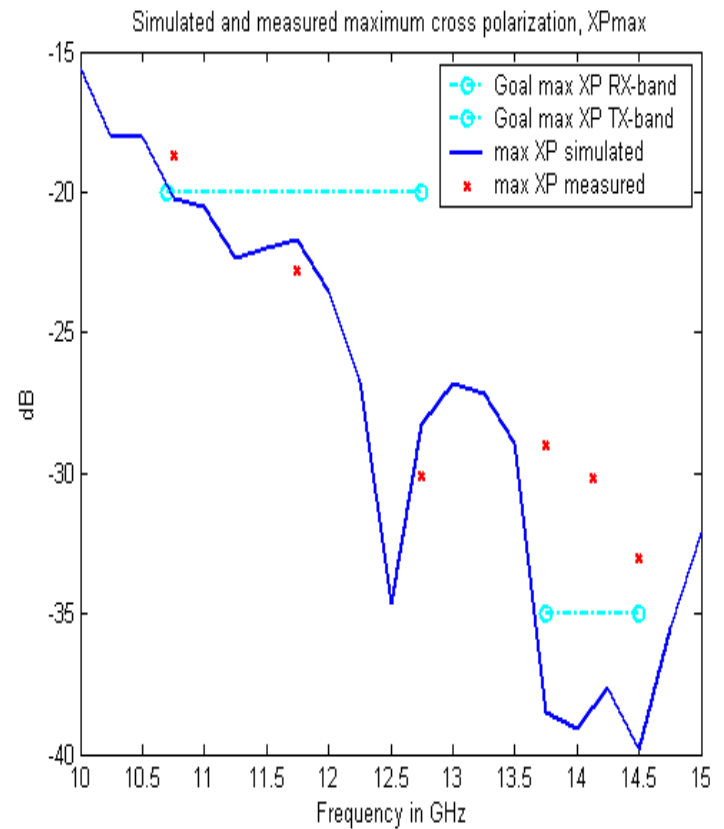
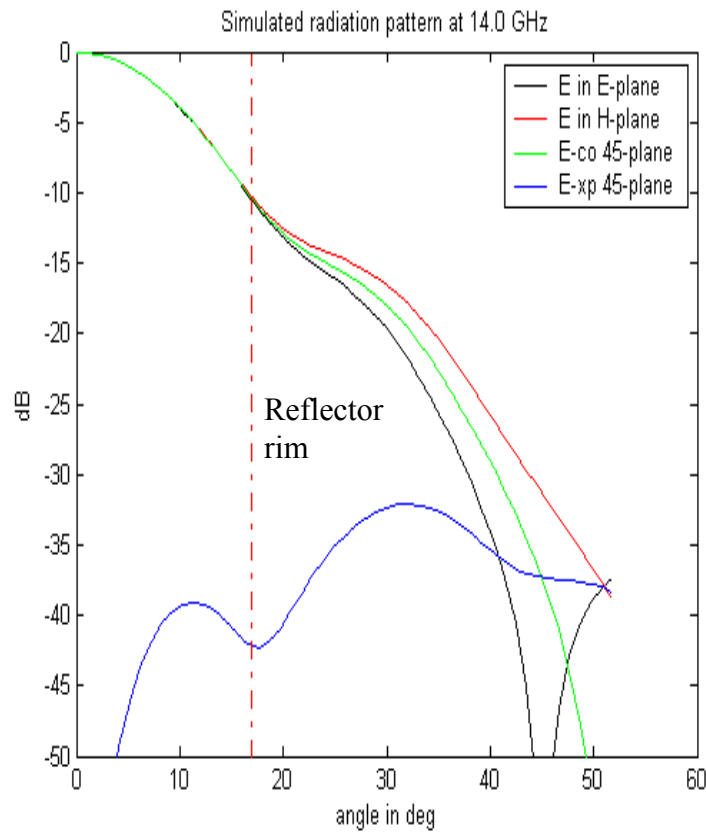
Optimized horn profile



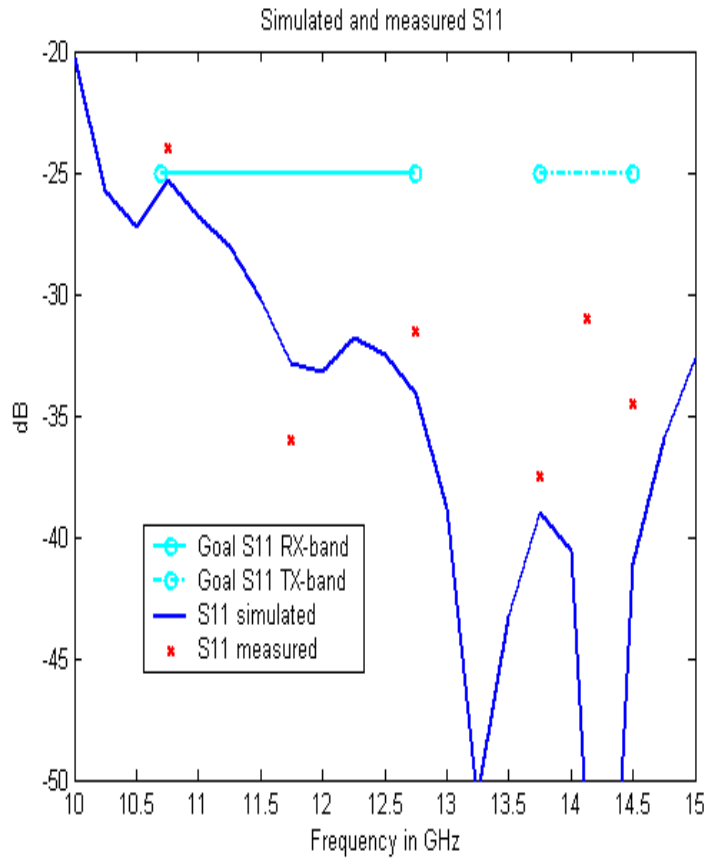
- 9 parameters optimized, R_o , L_{horn} and radius of 7 inner nodes
- 33 steps á 1.5 mm
- 20.24 mm feed waveguide diameter
- 119.24 mm horn aperture diameter
- 162.1 mm horn length, feed WG excluded



Results



Results



- S11 measured with TRL calibration on circular waveguide interface

Summary

- Optimization of horn profile by:
 - Mode matching analysis of pre-defined steps
 - A stepped horn profile is fitted to a smooth cubic-spline generated profile, only WG-section lengths are varied to fit spline profile. Spline profile based on 7 inner and 2 end nodes
 - Physical swarm optimization (PSO) of only 9 parameters: 7 inner nodes, horn length and horn aperture radius (end node)
- Low cross polarisation obtained by shaping the horn profile
- Initial measurements performed, difficult to measure low cross-polarization levels. More measurements will be performed
- Horn antennas with smooth or stepped wall profile suited for low cost mass-production based on plastic injection molding and metallization techniques