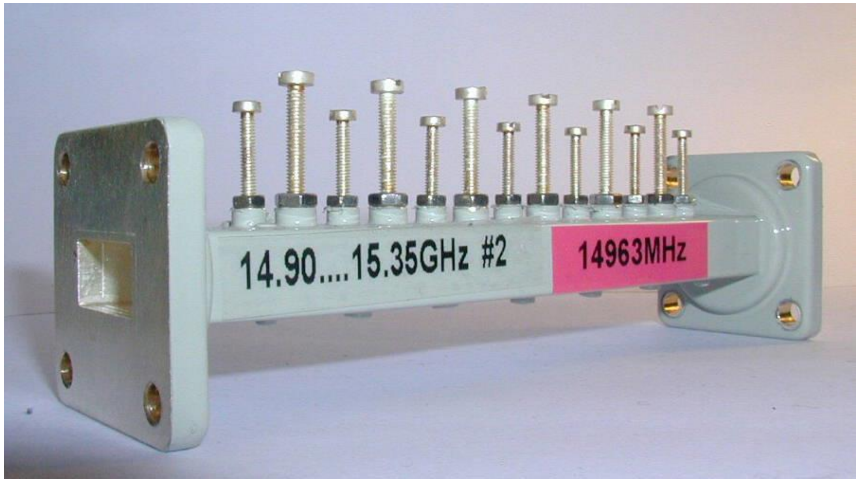
# Step-by-step procedure for design of waveguide filters with HFSS



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# Outline

- Filters at Nera
- Introduction / Motivation
- Step-by-step design procedure
- Detailed design example
- Other examples
- Conclusion

# Filters at Nera

- Channel filters:
  - ➢ Narrow-band (< 1 %) ⇨ tuning
  - ➢ 2 GHz - 15 GHz
- Sub-band filters:
  - ➢ “Broad-band” (2-5%) ⇨ no tuning
  - ➢ 15 GHz - 40 GHz

- Waveguide (inductive iris, circular posts)
- Dielectric resonator

- Other waveguide components
  - ➢ OMT, bends, hybrids, transitions, ...

# Motivation

- There exist many EM computer programs for design of waveguide filters, but these are limited to specific filter topologies or coupling structures

    ⇨ need for a general tool like HFSS

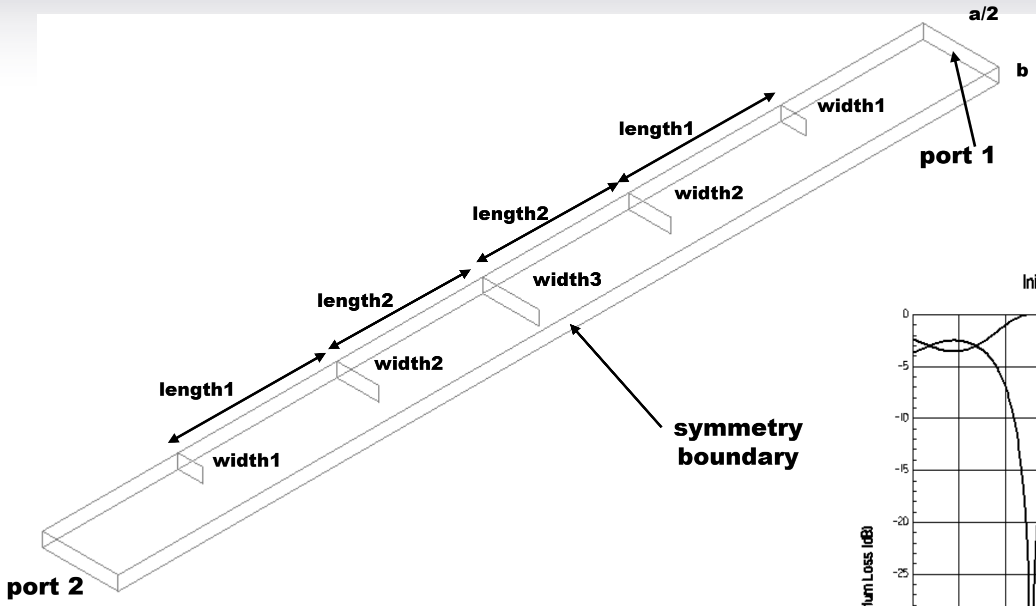
- HFSS can be used for global optimization of filters, but optimization is slow for large structures with a large number of optimization variables

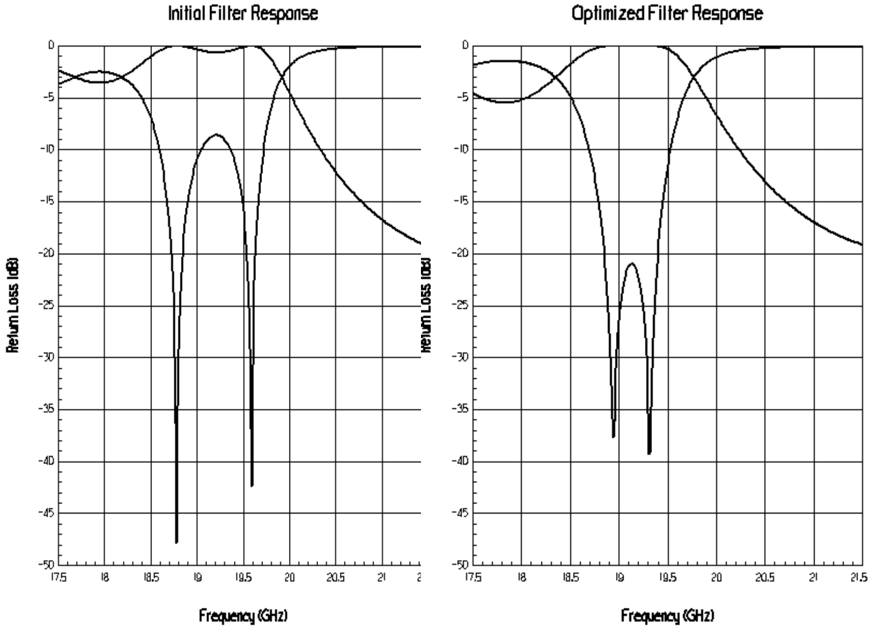
    ⇨ need for a better design procedure

- Solution:

    Apply well known circuit theory synthesis methods in combination with HFSS

# Global optimization

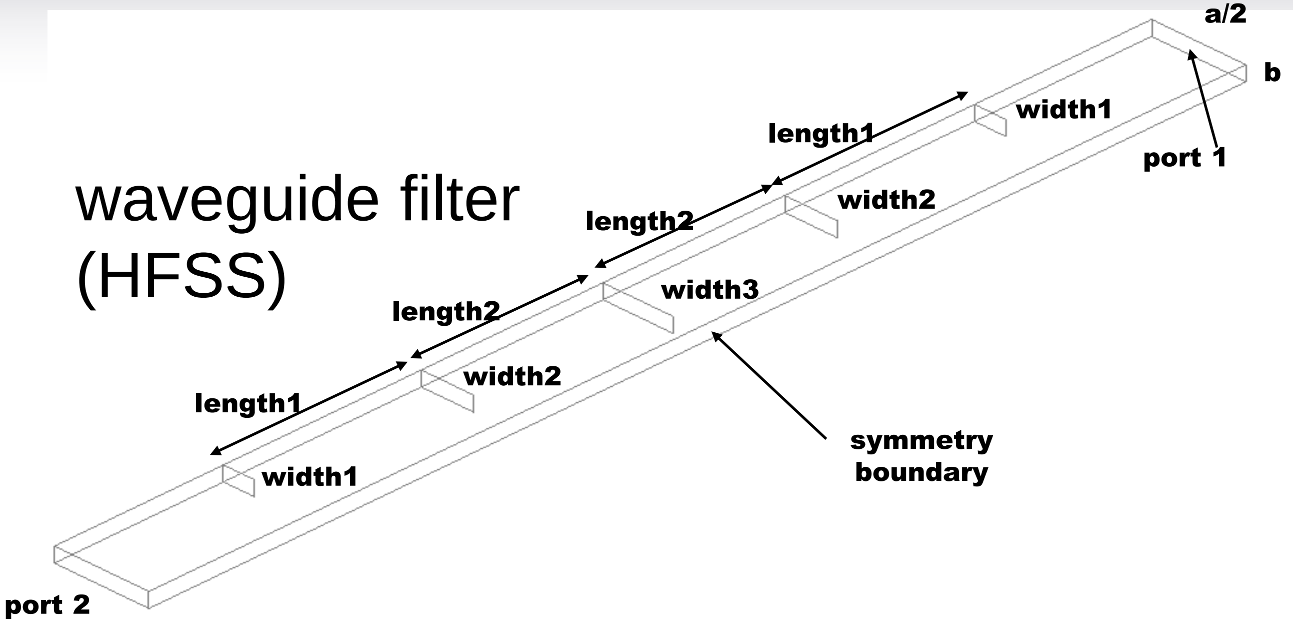




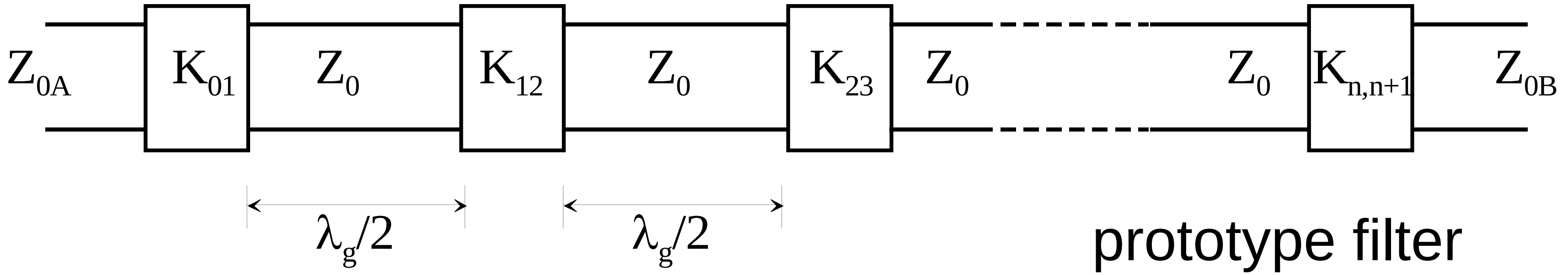
- many variables to optimize,
- long simulation time,
- non-optimum solution

Brian Gray, Ansoft, ”*External Optimization Using Ansoft HFSS*”, AB053-9905, May 1999.
Michael Brenneman, Ansoft, ”*AnsoftHFSS V7: OptimetricsTM Case Studies of Optimization and Parametrics*”, 1999 HFSS User Workshop

# Equivalent circuit



waveguide filter (HFSS)

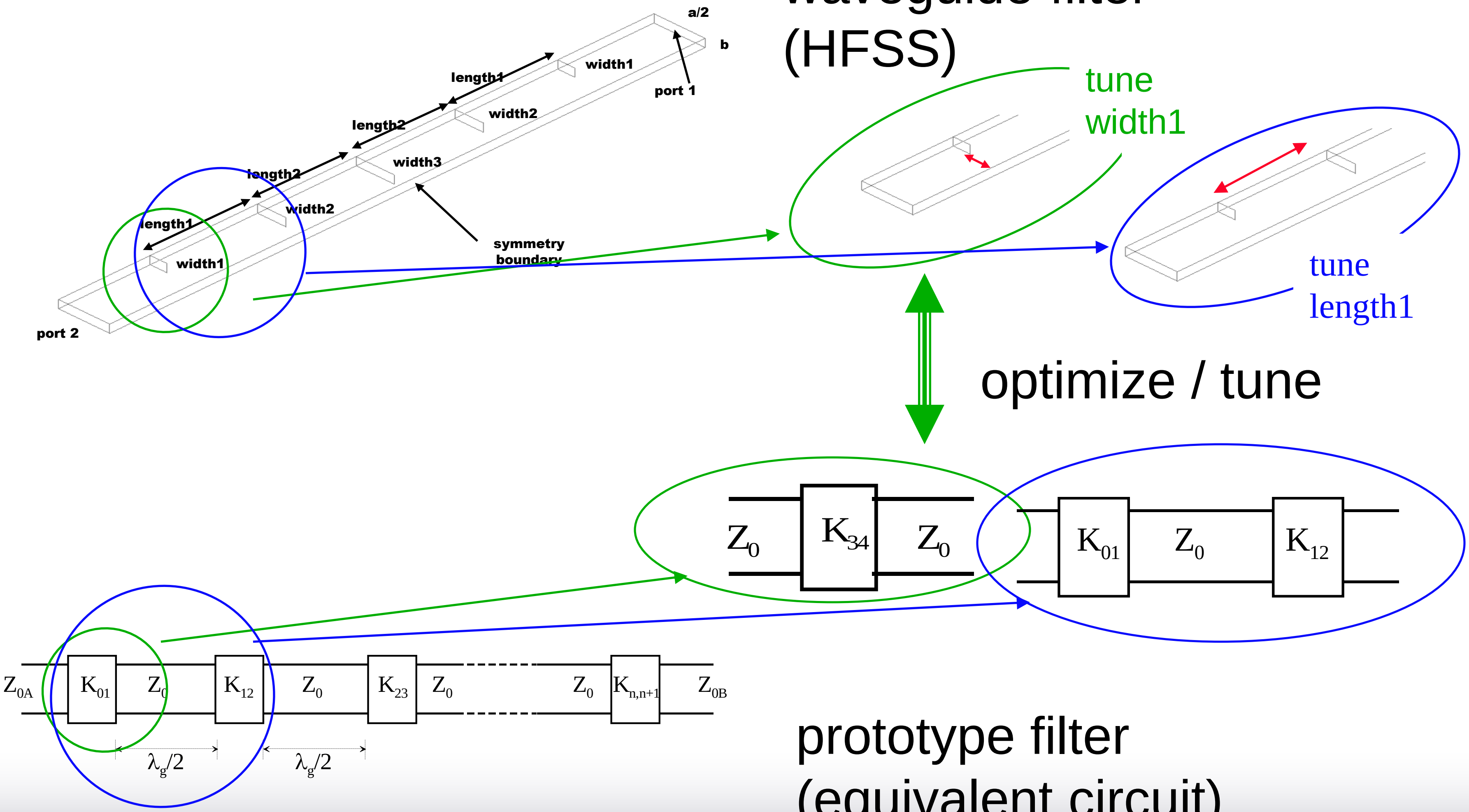


prototype filter (equivalent circuit)

S B Cohn “Direct-coupled-resonator filters” Proc. IRE pp187-96, Feb 1957

# Step-by-step procedure

## - optimization of one dimension in each step



waveguide filter (HFSS)

tune width1

tune length1

optimize / tune

prototype filter (equivalent circuit)

# Step-by-step procedure

Advantages:

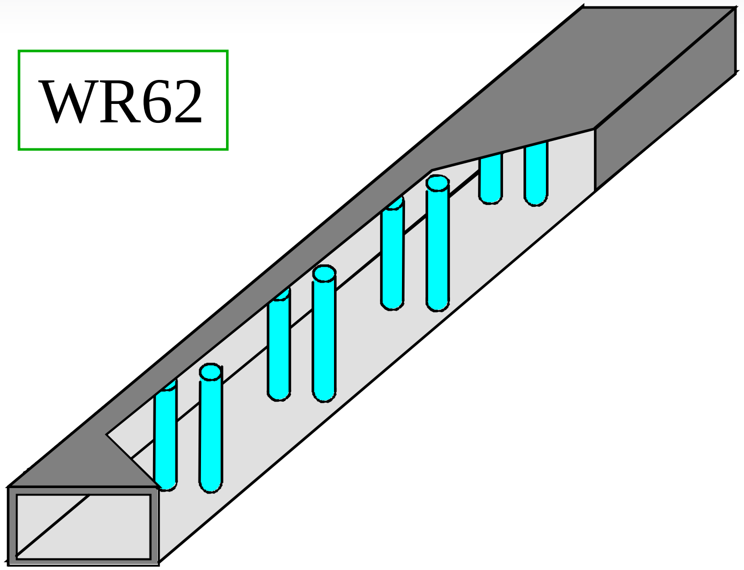
- Simulation of small structures in each step => fast simulation
- Only one dimension is optimized in each step => fast convergence

Procedure:

- 1) Obtain prototype filter from filter specifications
- 2) For all couplings: Optimize coupling with HFSS to give the right K-inverter value at the center frequency
- 3) For all resonators: Calculate resonator length, fine tune parameter with HFSS

# Design Example

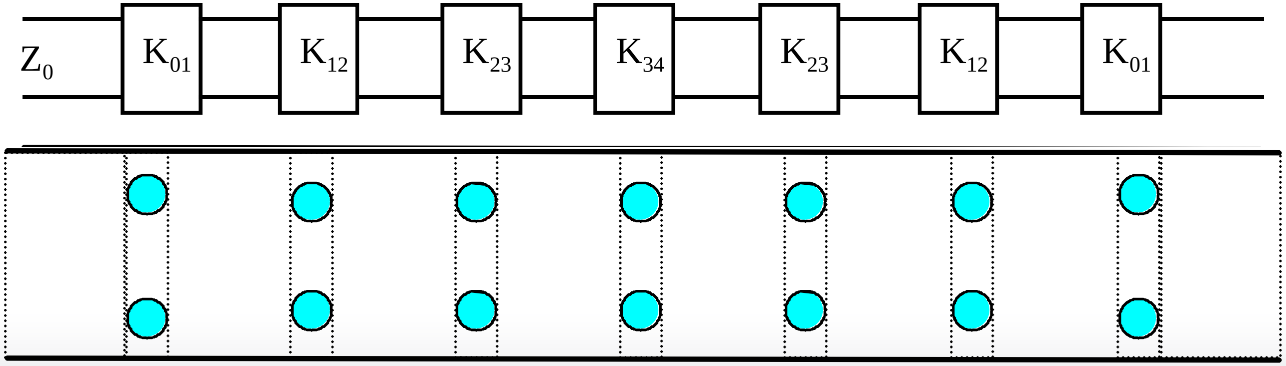
## Filter with inductive posts



### Design Requirements

- $f_0$ = 15.35 GHz  BW= 32 MHz
- $S_{11} < -20$ dB
- $S_{21} < -40$ dB @ $f_0 \pm 40$ MHz

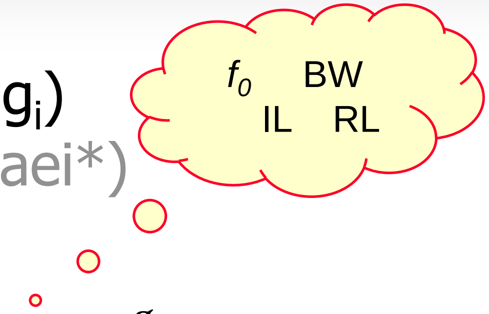
The filter shall be tunable from 14.9 to 15.35 GHz

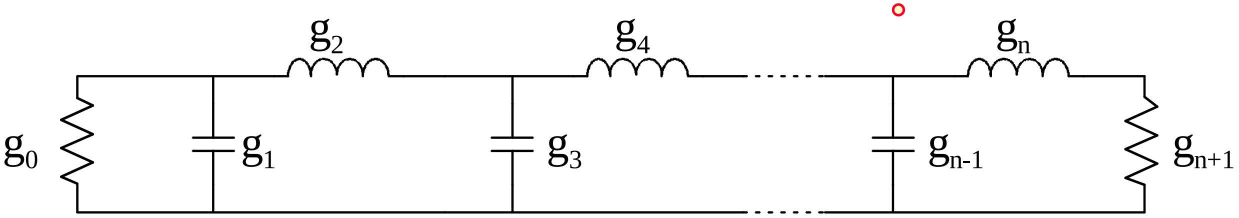


# Step-by-step procedure

# step 1: Prototype filter

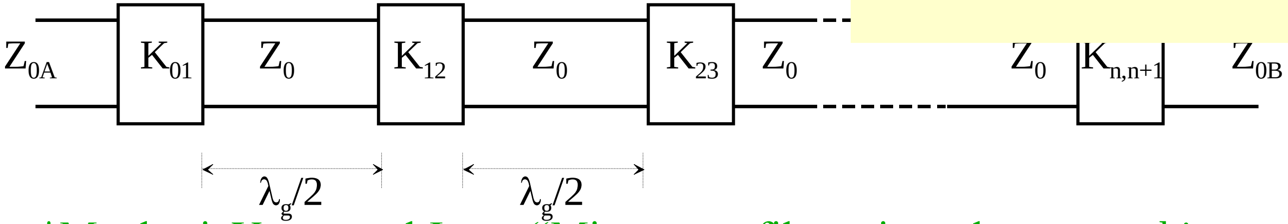
1a) Obtain low-pass prototype parameters ($g_i$) from filter specifications (see e.g. Matthaei*)





**Example:**
$f_0$ = 15.35 GHz BW= 32 MHz
$S_{11} < -20$ dB
$S_{21} < -40$ dB @ $f_0 \pm 40$ MHz

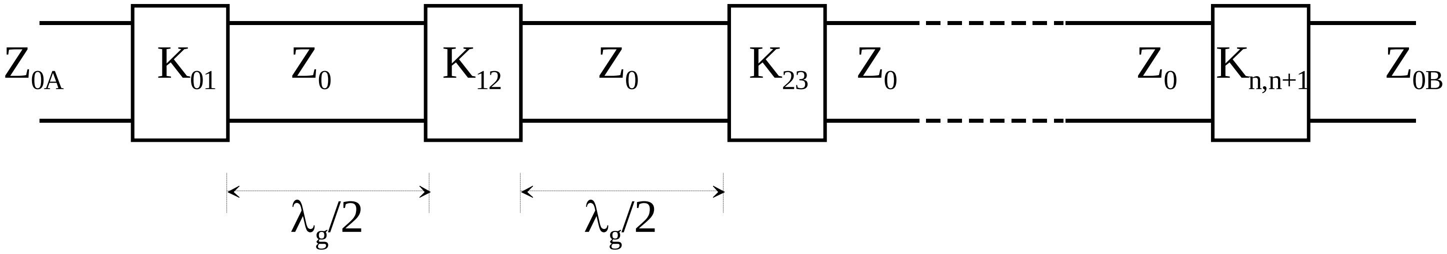
**6th order Chebychev filter**
*prototype elements*
$g_0 = 1.0000$
$g_1 = 0.8836$
$g_2 = 1.3966$
$g_3 = 1.7894$
$g_4 = 1.5528$
$g_5 = 1.6095$
$g_6 = 0.7667$
$g_7 = 1.1524$



*Matthaei, Young and Jones "Microwave filters, impedance-matching networks, and coupling structures", Artech House, Norwood, MA, 1992

# Step-by-step procedure
## step 1: Prototype filter

1b) Calculate K-inverters (band-pass prototype parameters)



$$K'_{01} = \frac{K_{01}}{Z_{0A}} = \sqrt{\frac{\pi}{2}\frac{w_{\lambda A}}{g_0 g_1}}$$

$$K'_{i,i+1} = \frac{K_{i,i+1}}{\sqrt{Z_{0i} Z_{0,i+1}}} = \frac{\pi w_{\lambda i}}{2}\sqrt{\frac{1}{g_i g_{i+1}}}$$

$$K'_{n,n+1} = \frac{K_{n,n+1}}{Z_{0B}} = \sqrt{\frac{\pi}{2}\frac{w_{\lambda B}}{g_n g_{n+1}}}$$

$$w_{\lambda i} = \left(\frac{\lambda_{gi0}}{\lambda_0}\right)^2 \frac{\Delta f}{f_0}$$

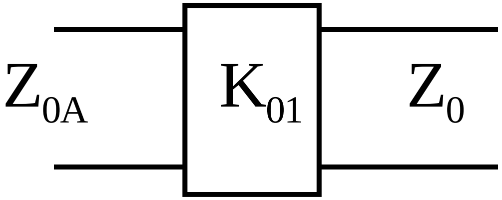
Example:

$K'_{01}=0.0775$
$K'_{12}=0.0048$
$K'_{23}=0.0034$
$K'_{34}=0.0032$

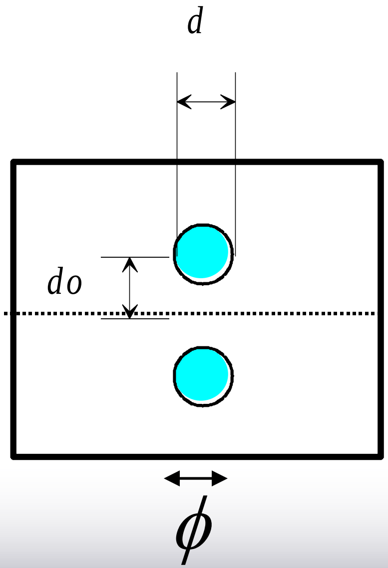
# Step-by-step procedure

## step 2: Optimize couplings

- For all couplings: Optimize coupling to give the right K-inverter value at the center frequency



$$S_{21} = \frac{2}{jK' + j/K'}$$



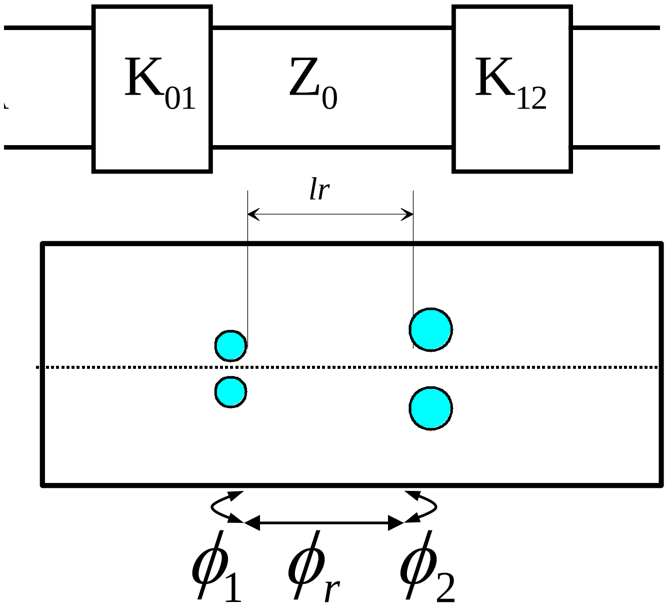
| Coupling | $S_{21}$ (dB) |
|---|---|
| 1 | -16.14 |
| 2 | -40.40 |
| 3 | -43.47 |
| 4 | -43.93 |
| 5 | -43.47 |
| 6 | -40.40 |
| 7 | -16.14 |

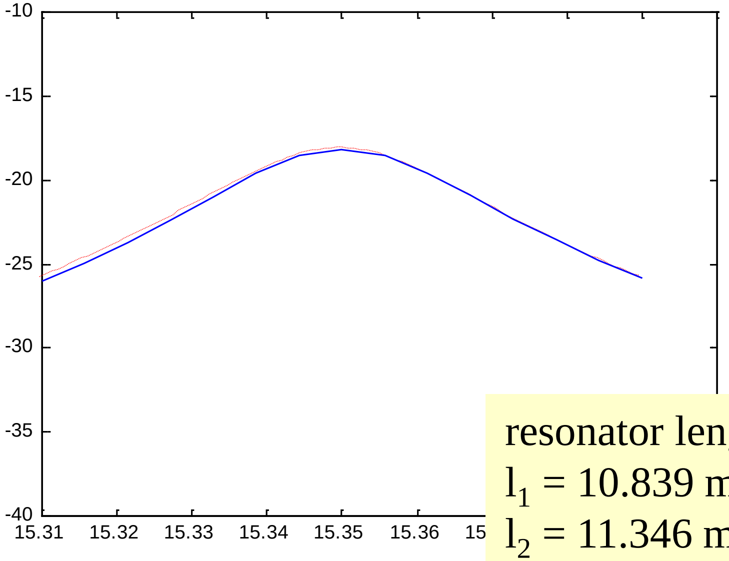
| diameter | offset |
|---|---|
| $d_1$ = 2.50 mm | $do_1$ = 3.845mm |
| $d_2$ = 3.50 mm | $do_2$ = 3.135 mm |
| $d_3$ = 3.50 mm | $do_3$ = 2.960 mm |
| $d_4$ = 3.50 mm | $do_4$ = 2.972 mm |
| $d_5$ = 3.50 mm | $do_5$ = 2.960 mm |
| $d_6$ = 3.50 mm | $do_6$ = 3.135 mm |
| $d_7$ = 2.50 mm | $do_7$ = 3.845 mm |

# Step-by-step procedure

## step 3: Optimize resonator lengths

- For all resonators: calculate resonator length, fine tune until the structure resonates at the center frequency





resonator length
$l_1$ = 10.839 mm
$l_2$ = 11.346 mm
$l_3$ = 11.395 mm
$l_4$ = 11.395 mm
$l_5$ = 11.346 mm
$l_6$ = 10.839 mm

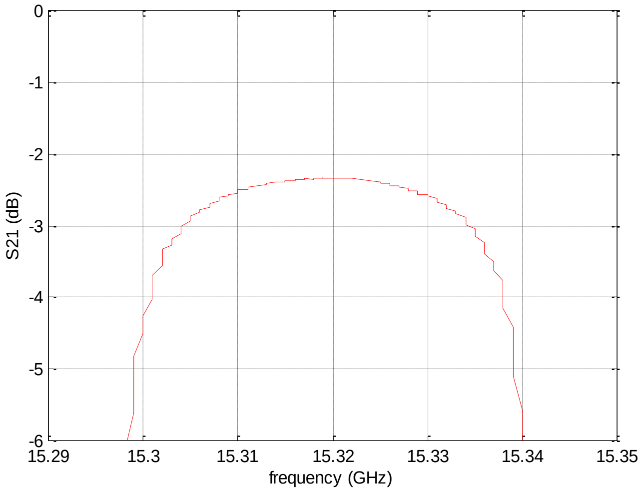
$$\phi_r = \pi - \tfrac{1}{2}\left(\phi_1 + \phi_2\right)$$

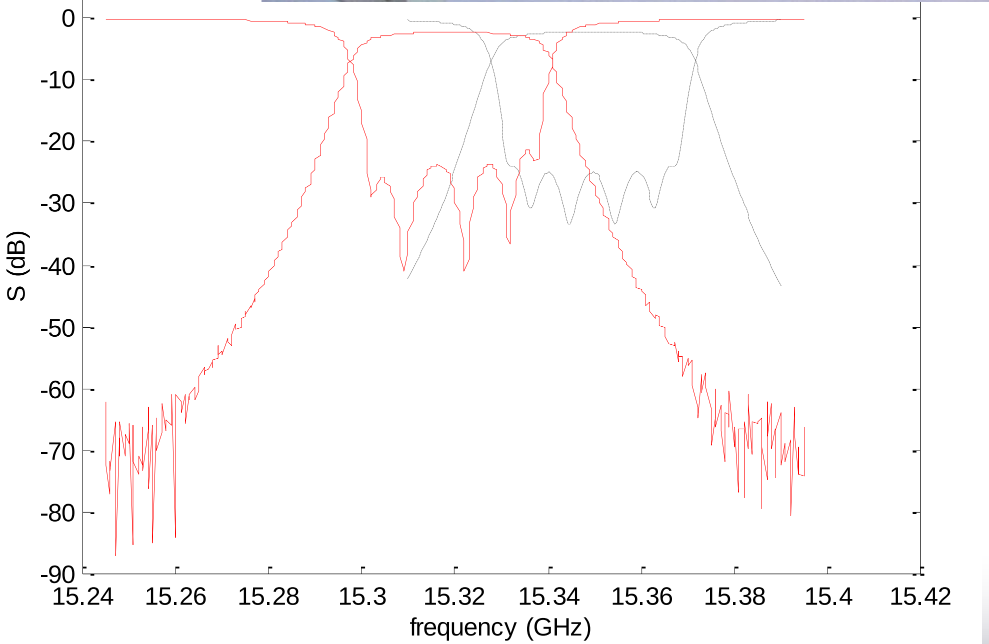
$$l = \frac{\phi_r \lambda_g}{2\pi}$$

# Measurements

## Filter with inductive posts

- Designed at 15.35 GHz
- Tunable from 14.9 to 15.35 GHz
- Measured at 15.32 GHz

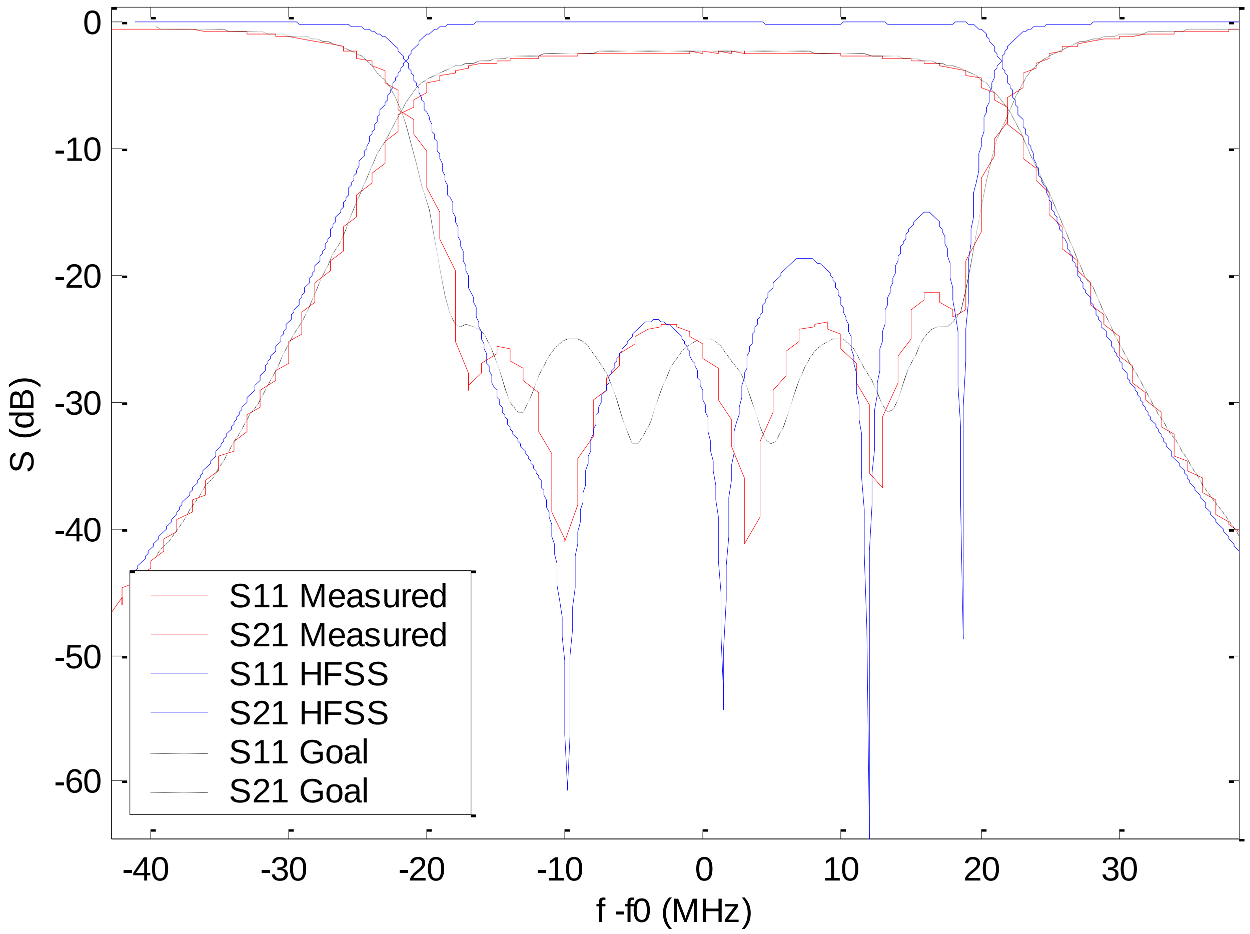




# Measurements

# Filter with inductive posts

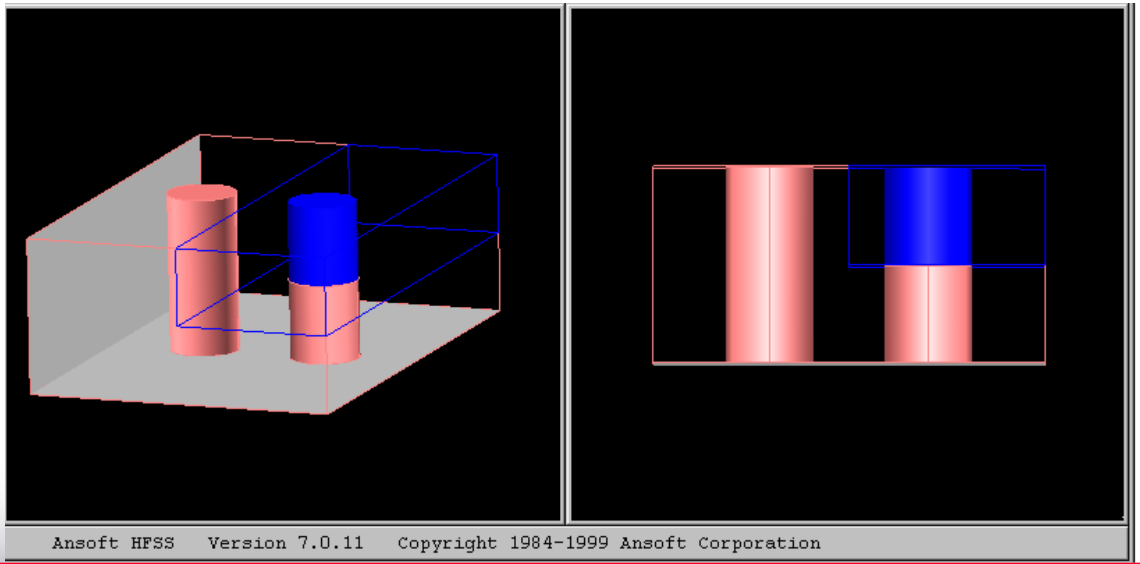
- data centered on $f_0$



# Simulation Setup

## Filter with inductive posts

- The procedure is automated with Octave (/Matlab)
- Assume infinite conductivity
- 3 frequency points enough to determine the resonator length
- Use symmetry (E- and H-plane)



# Simulation Data

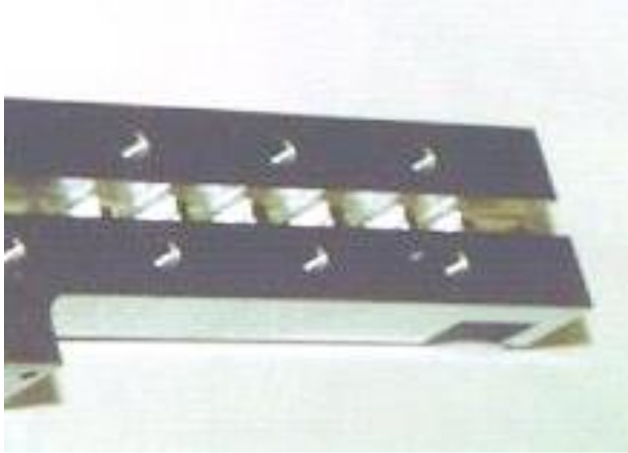
## Filter with inductive posts

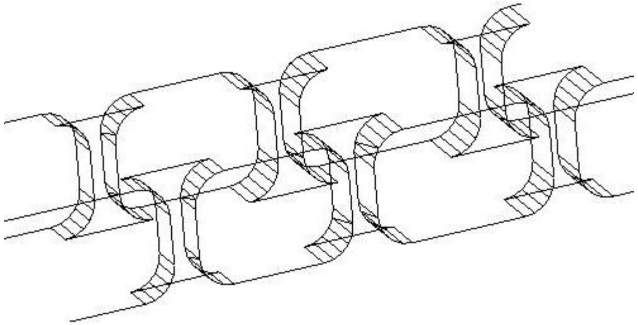
- Couplings:
  - 10 adaptive passes
  - 2274 tetrahedra
  - appr. 1 min solution time per simulation
- Resonators
  - 10 adaptive passes
  - 3871 tetrahedra
  - appr. 2 min solution time per simulation

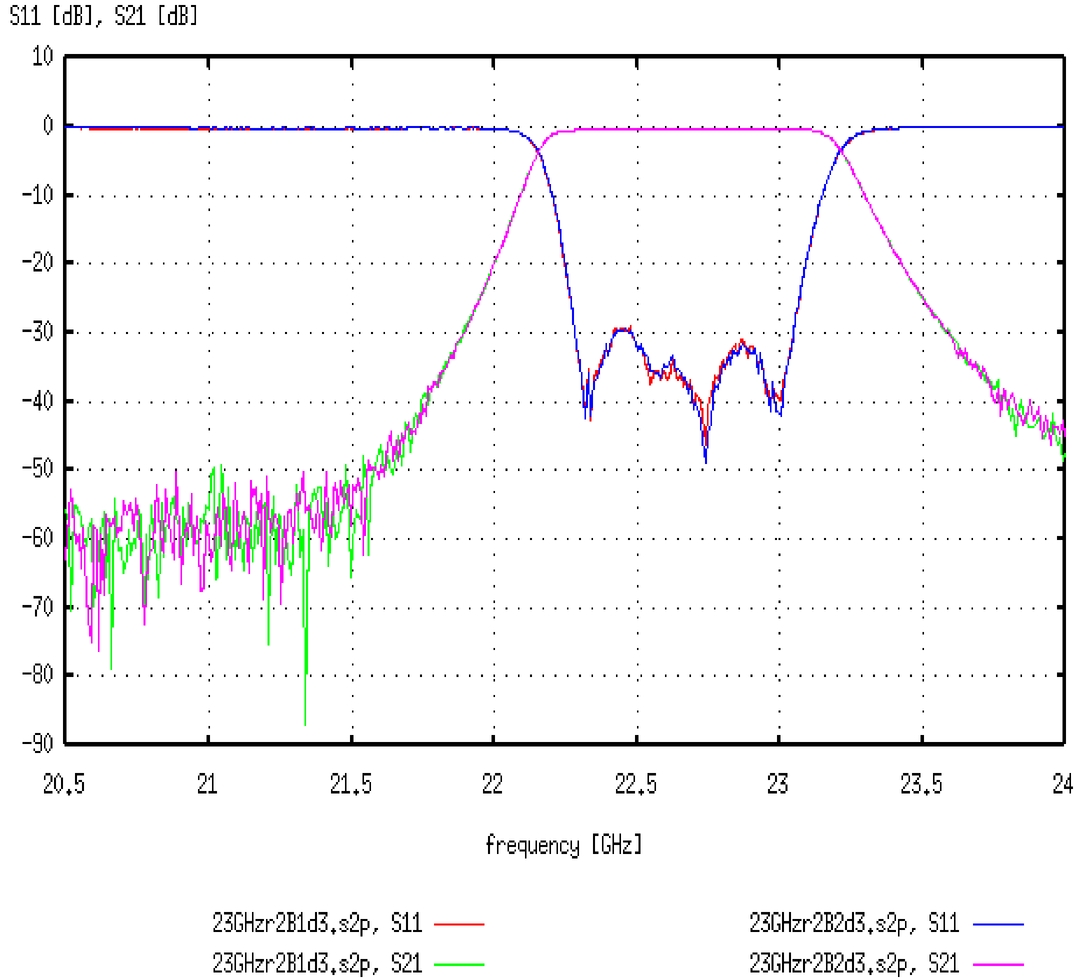
Dual Pentium III 866 MHz, 768 MB RAM

# Example

# Inductive iris filter with “rounded” corners

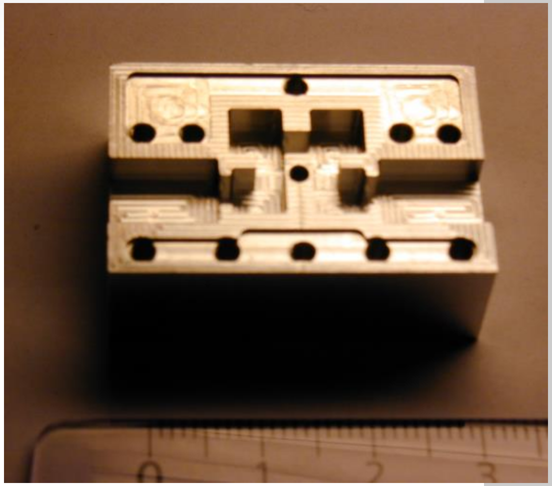


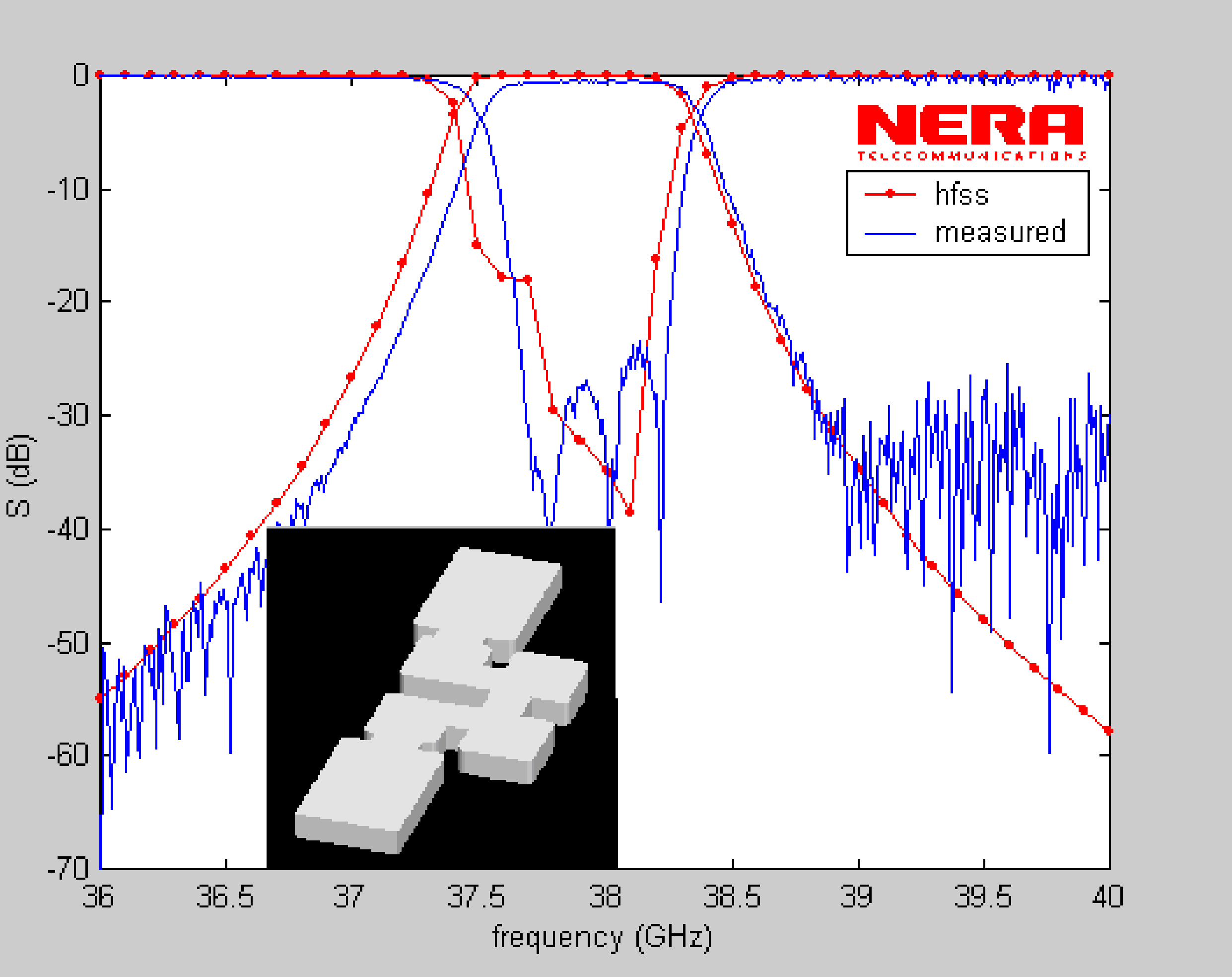




# Example

## Folded inductive iris filter



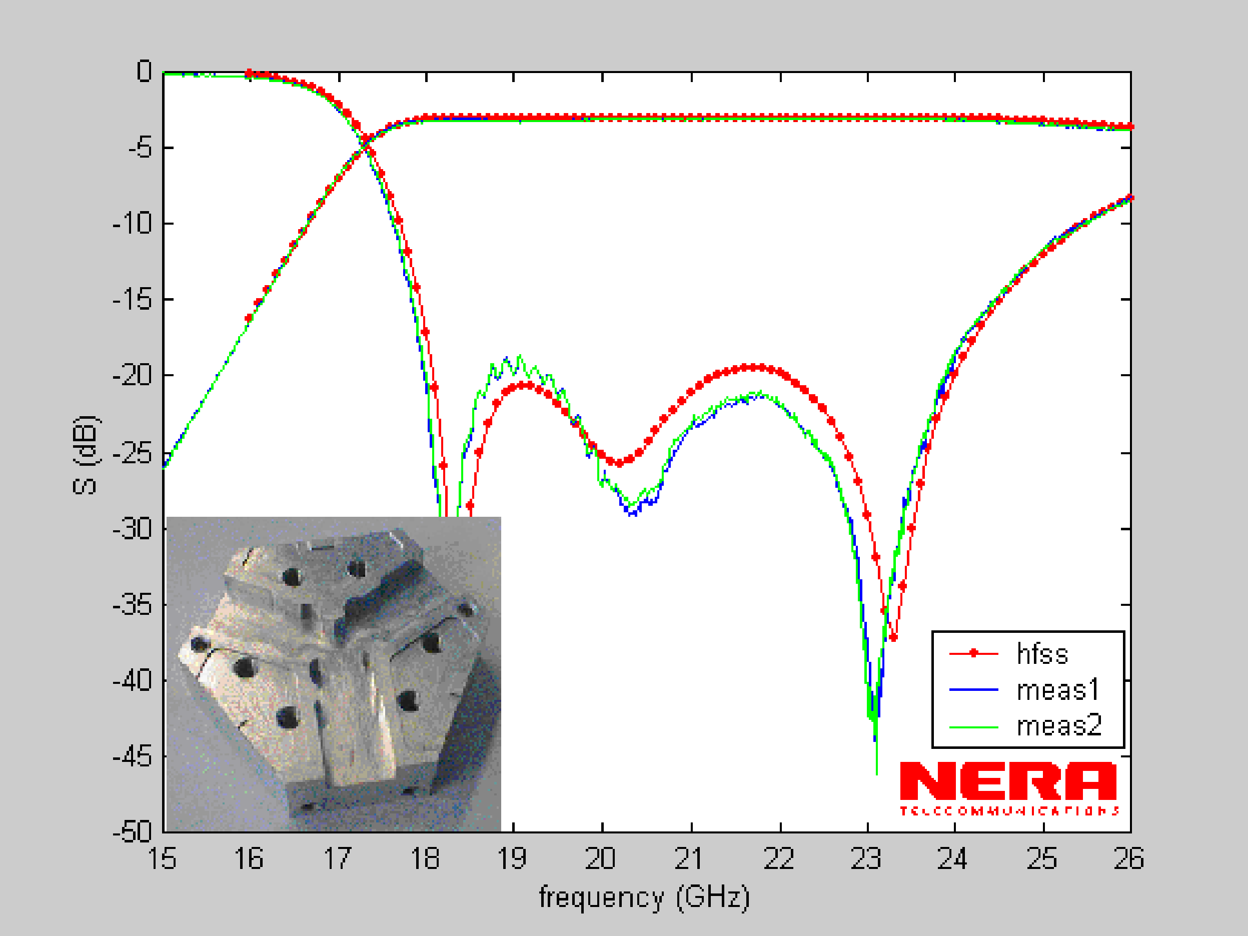


Design procedure:

M. Guglielmi, *Simple CAD procedure for microwave filters and multiplexers*, IEEE Trans. Microwave Theory Tech., vol 42, pp 1347-1352, July 1994

# Example

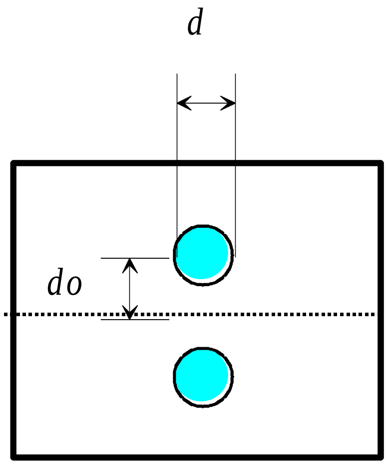
## Power divider

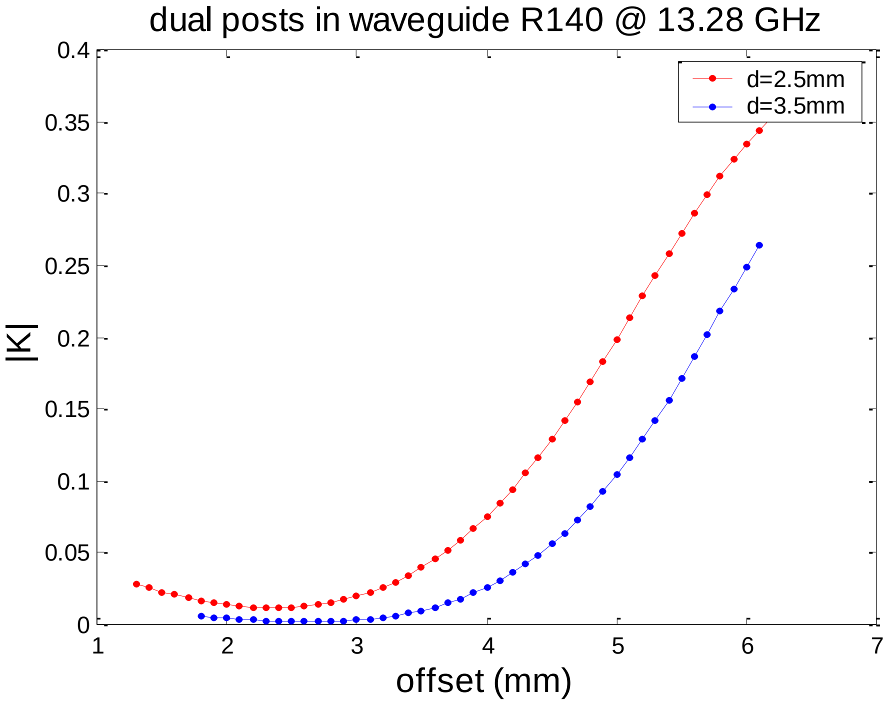


M Guglielmi, B Ginemo, T Kjøde “A new equiripple power splitter for radio link applications” , Proc. 28th European Microwave Conf ,vol 2, pp 30, 1998

# Refinements of the design-procedure

- Consider other prototype filters for broadband filters
  - see e.g. S Yin, T. Vasilyeva, P Pramanick “Use of three-dimensional field simulators in the synthesis of waveguide round rod bandpass filters”, Int J RF and Microwave CAE, vol 8, no 6, pp 484-497, 1998
- Build coupling databases





# Conclusion

- Easy-to-use design procedure
- Fast convergence of the optimizations because only one parameter is optimized in each step
- Fast solution times because all simulated structures are small

- This design procedure allows us to use HFSS for controlled design of filters - not only for design verification and fine tuning