

FEST3D: A CAD Tool for the analysis of microwave passive components

Electron Cloud Mitigation Workshop 2008

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Introduction

→ CAE tool for the design of passive waveguide structures:

- Developed under European Space Agency projects (since 1991).
- From 2D problems until real 3D waveguide structures.

→ Benefits:

- Increase of speed and accuracy.
- Unique features such as high power effects.

Introduction

→ FEST3D analysis based on:

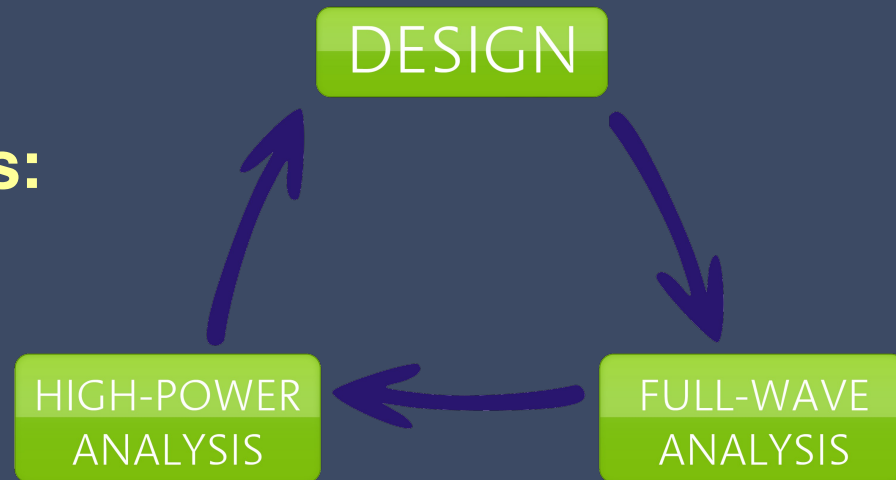
- Integral equation + Method of Moments + Network Theory.
- BI-RME Method, Cavity theory...

→ FEST3D design:

- Lowpass, Bandpass, Tapers and Diplexers.

→ FEST3D high power analysis:

- Multipactor
- Corona
- PIM



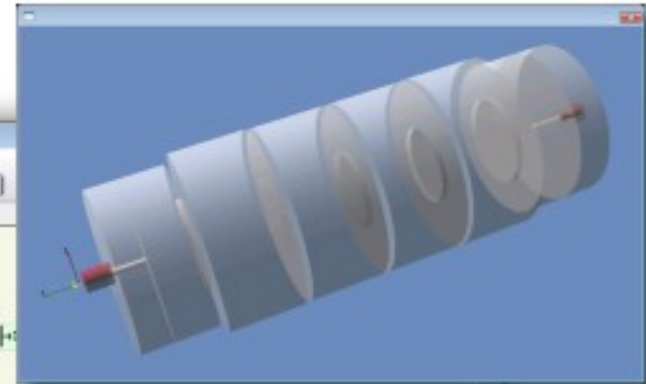
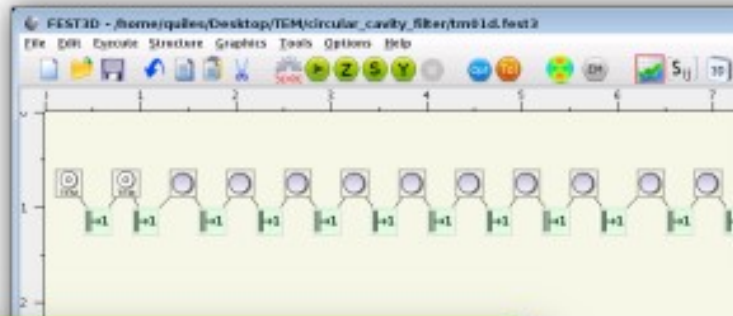
FEST3D analysis & design capabilities

FEST3D can analyse complicated structures such as:

- Band-pass filters of different topology.
- Band-stop filters of different topology.
- Evanescent filters.
- Waffle-iron filters.
- Dual mode filters based on cylindrical resonators with coupling screws.
- Dual-mode filters based on elliptical resonators.
- Couplers.
- Comb-line filters.
- Inter-digital filters.
- Multiplexers.
- Power dividers.
- Polarizers.

FEST3D analysis & design capabilities

Circular bandpass filter with coaxial excitation.

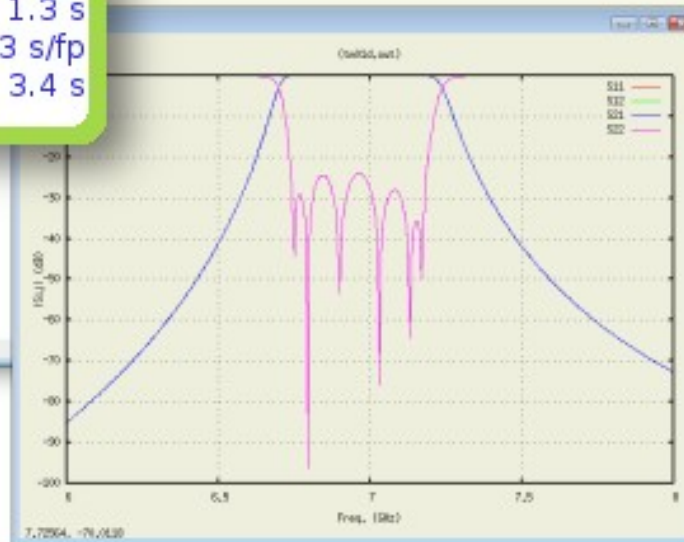


Frequency independent part: 1.3 s
Frequency dependent part: 4e-3 s/fp
Total simulation time (500 fp): 3.4 s

```
-----  
..... 60Hz 1984 GHz) Sun Aug 31 11:19:37 2008  
..... 70Hz 3588 GHz) Sun Aug 31 11:19:37 2008  
..... 80Hz 5192 GHz) Sun Aug 31 11:19:37 2008  
..... 90Hz 6796 GHz) Sun Aug 31 11:19:37 2008  
..... 100Hz 8400 GHz) Sun Aug 31 11:19:37 2008  
Fetched frequency loop Sun Aug 31 11:19:37 2008
```

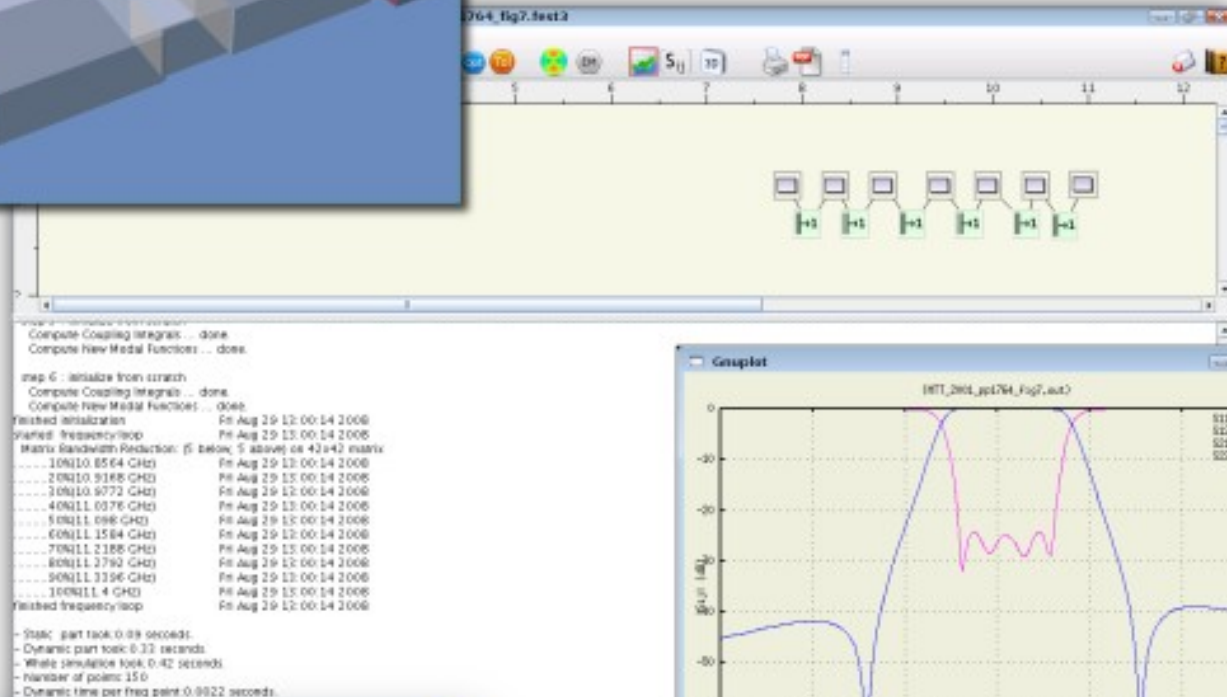
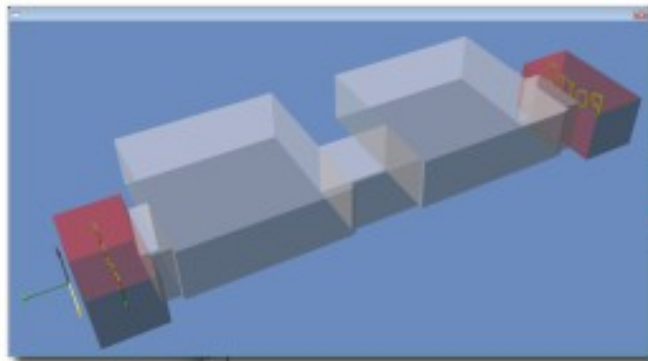
```
-----  
- Static part took 1.32 seconds.  
- Dynamic part took 2.07 seconds.  
- Whole simulation took 3.39 seconds.  
- Number of points 500  
- Dynamic time per freq point 0.98434 seconds.
```

ready.



FEST3D analysis & design capabilities

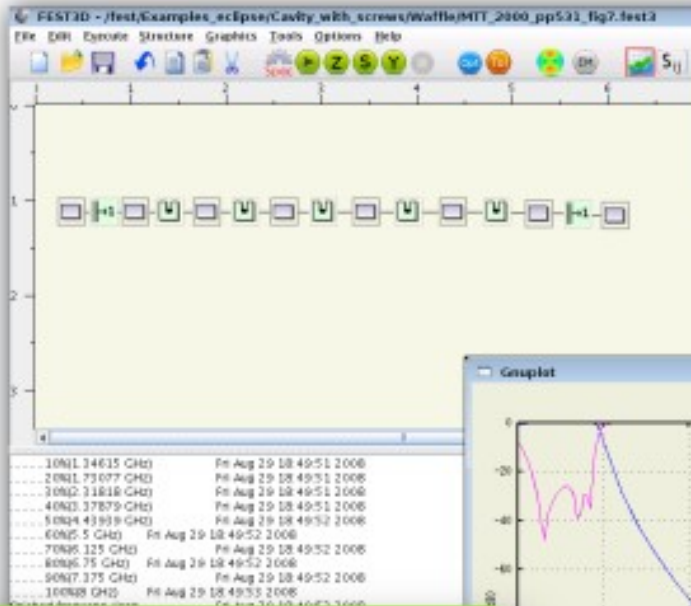
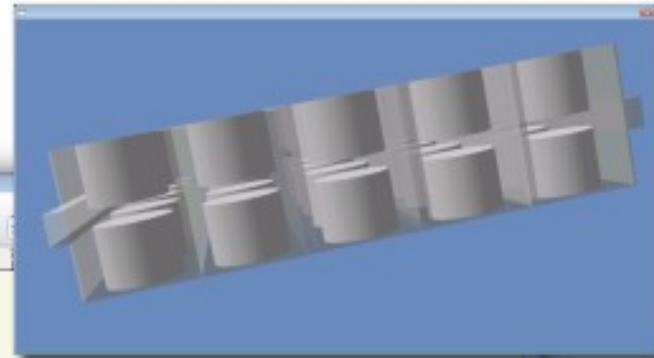
Dual-mode rectangular waveguide filter



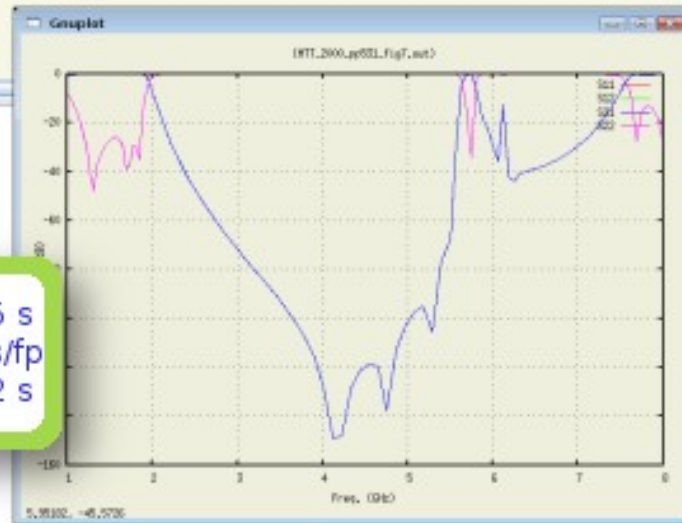
Frequency independent part: 0.1 s
Frequency dependent part: 2e-3 s/fp
Total simulation time (150 fp): 0.4 s

FEST3D analysis & design capabilities

Waffle-iron filter with circular posts

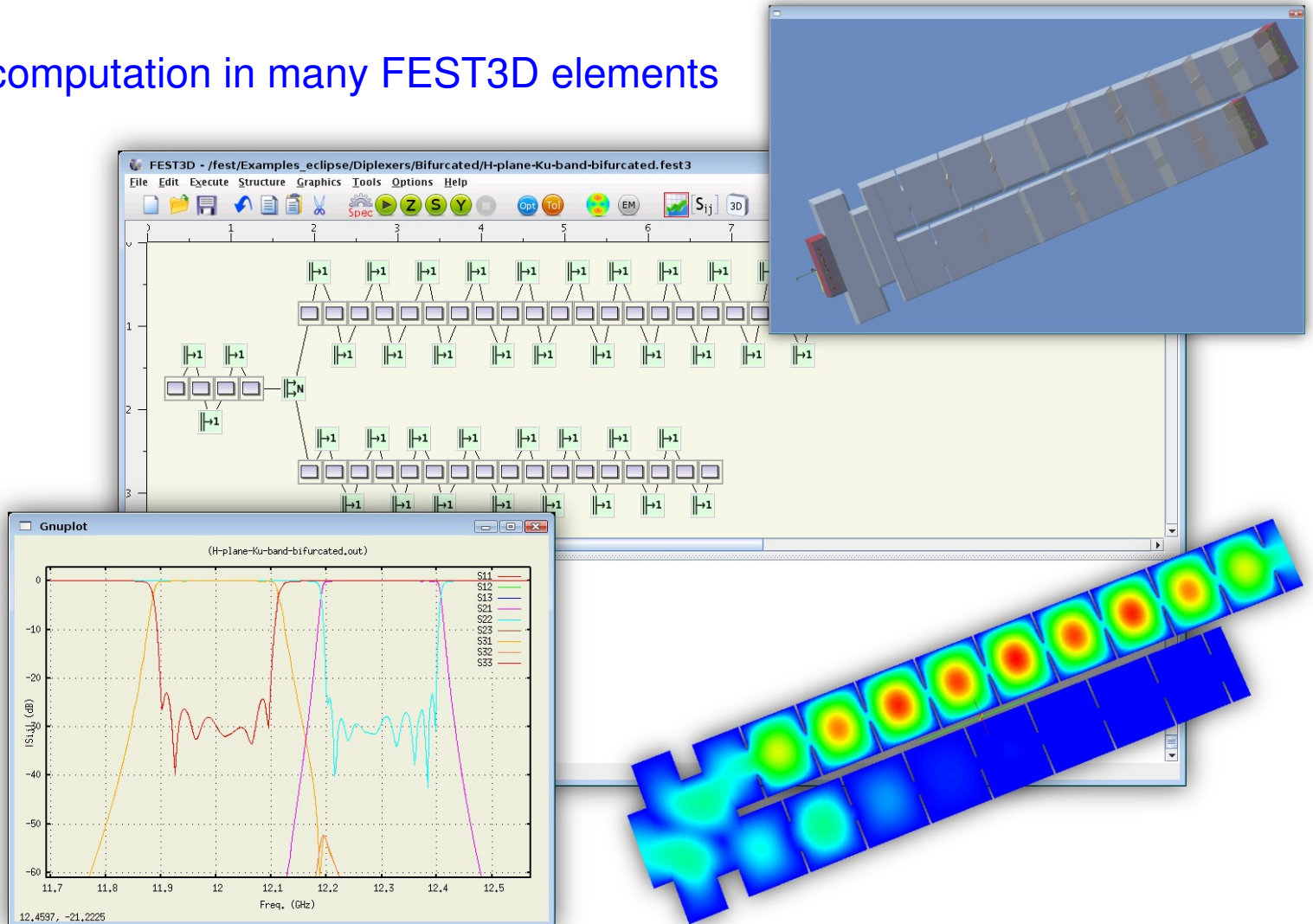


Frequency independent part: 5.5 s
Frequency dependent part: 0.02 s/fp
Total simulation time (100 fp): 7.2 s



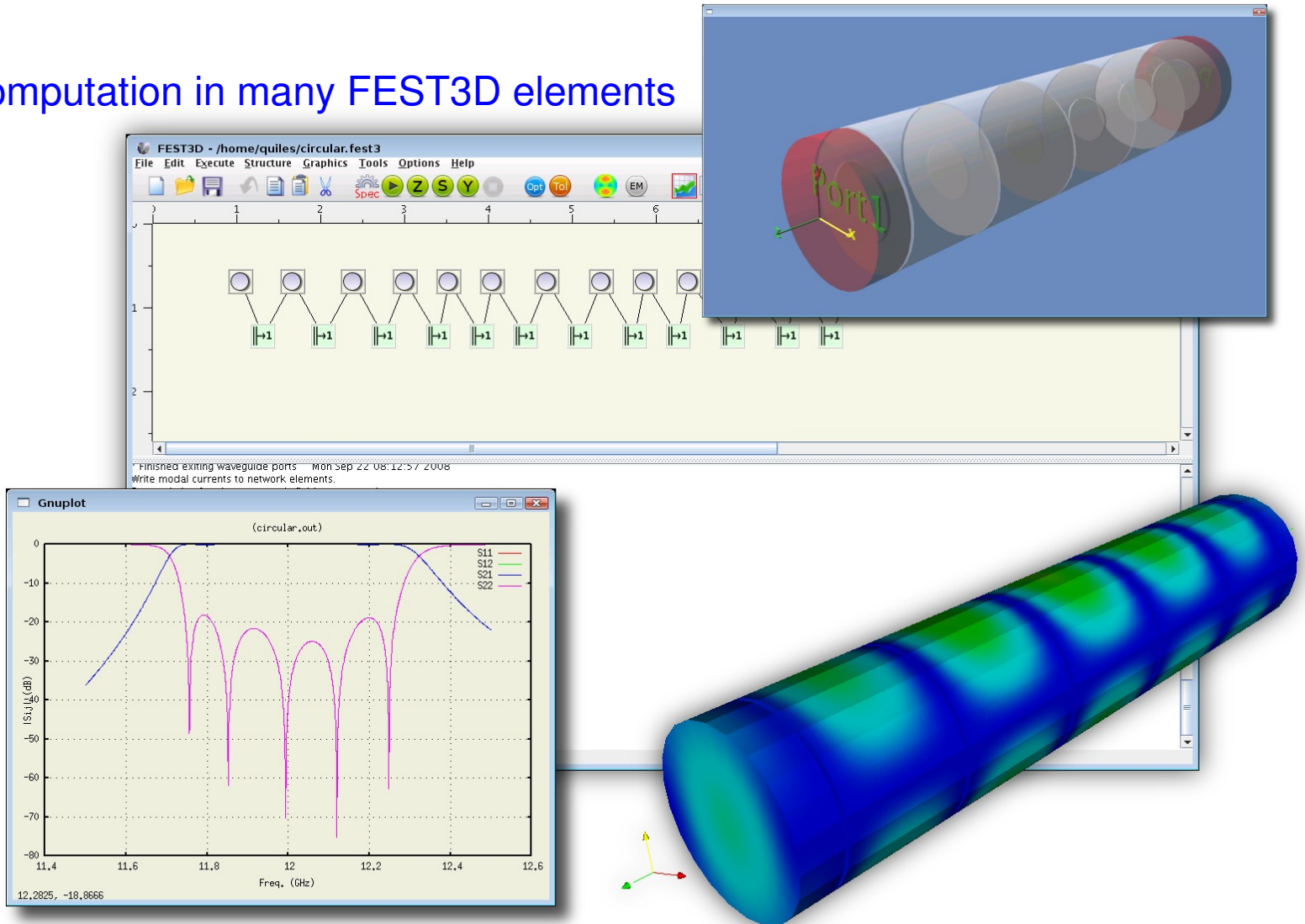
FEST3D analysis & design capabilities

EM Fields computation in many FEST3D elements



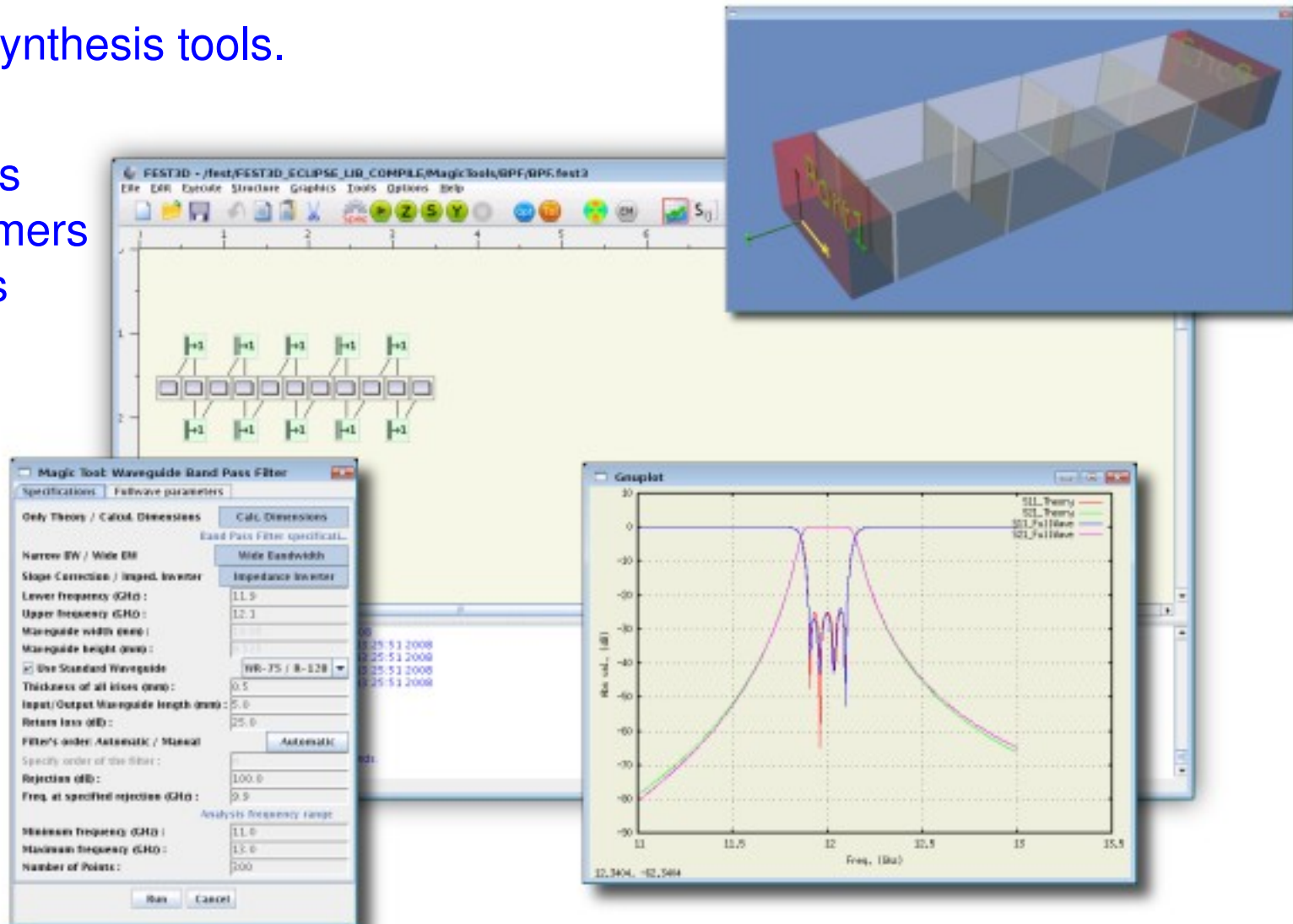
FEST3D analysis & design capabilities

EM Fields computation in many FEST3D elements



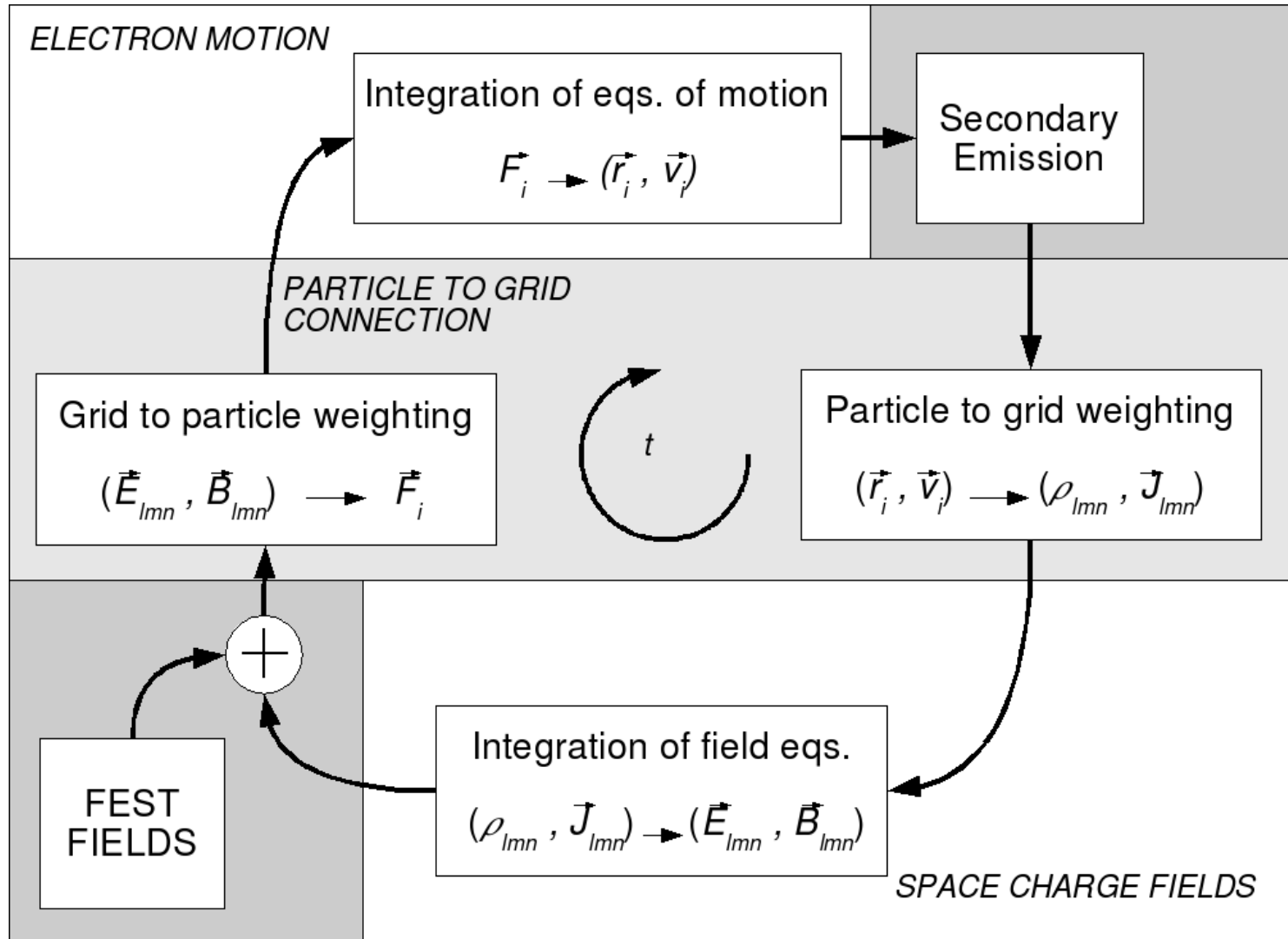
FEST3D analysis & design capabilities

- Advanced Synthesis tools.
 - Lowpass
 - Bandpass
 - Transformers
 - Diplexers



FEST3D High power capabilities: Multipactor

Multipactor module in FEST3D



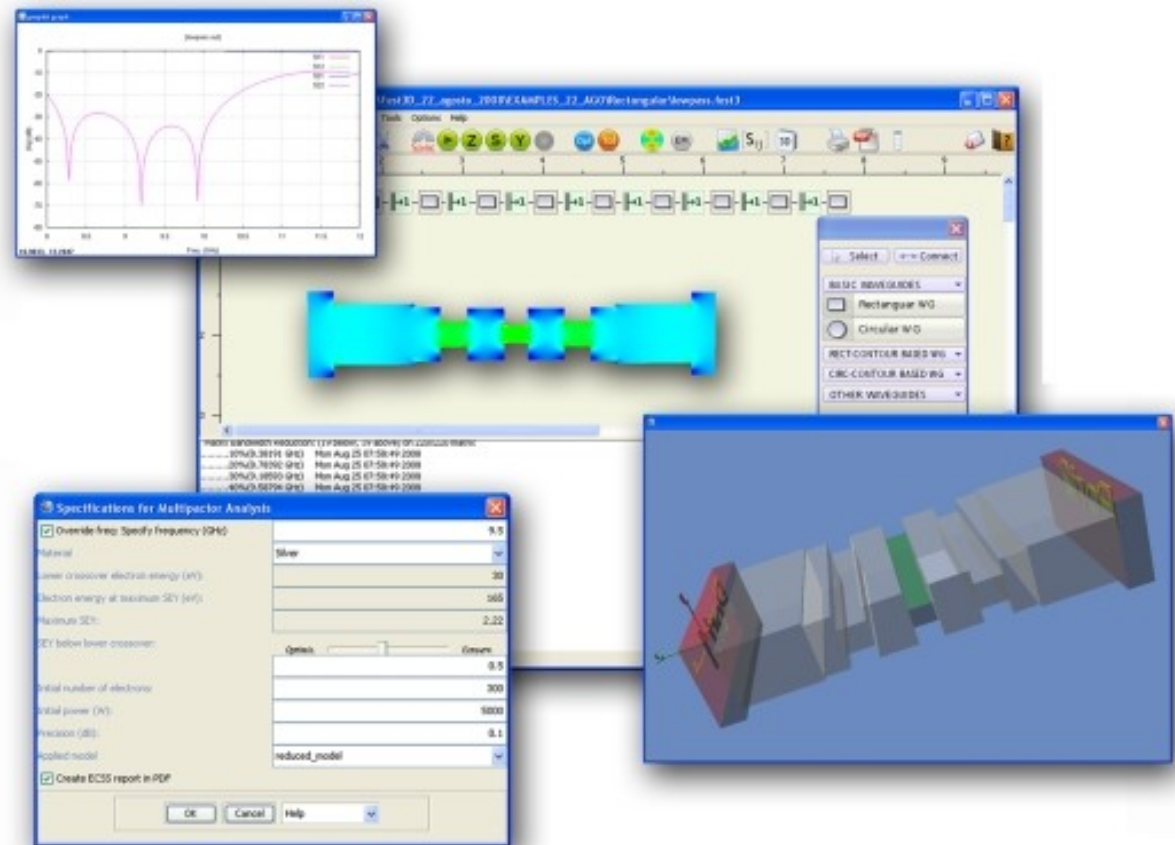
FEST3D High power capabilities: Multipactor

→ Multipactor module:

- Initial external EM fields from FEST3D (very fast computation).
- Equations of motion integration: Leap-Frog.
- Yee's cube for EM fields.
- Modified Vaughan's formula for SEY.
- Maxwellian distribution for electron velocity and cosine law.

FEST3D High power capabilities: Multipactor

Multipactor Analysis



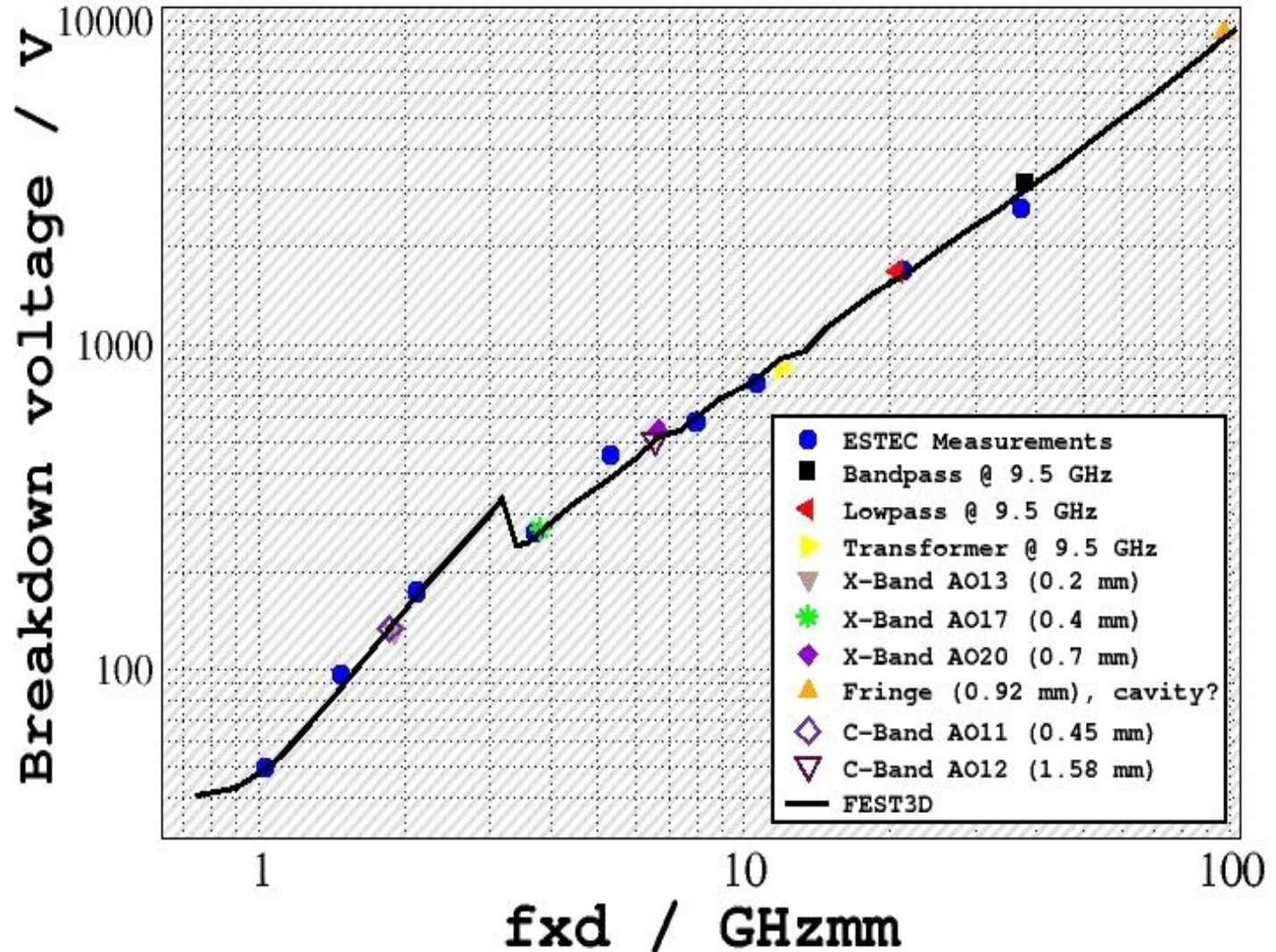
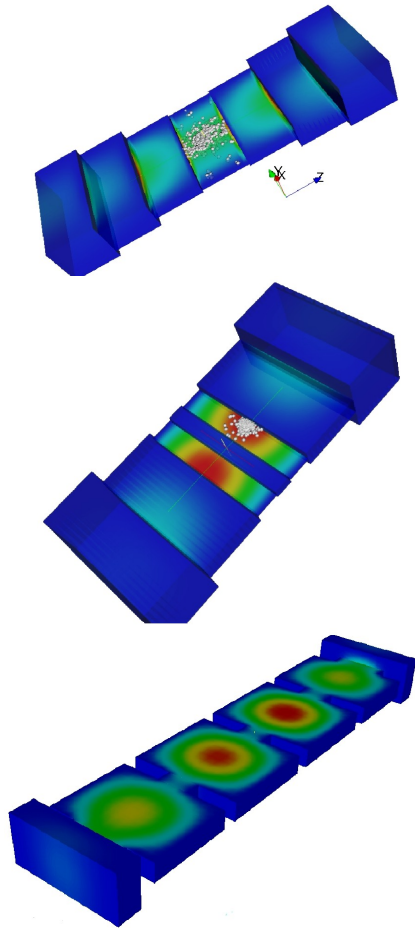
FEST3D / W
8450

Measurement / W
8360

FEST3D High power capabilities: Multipactor

Silver:

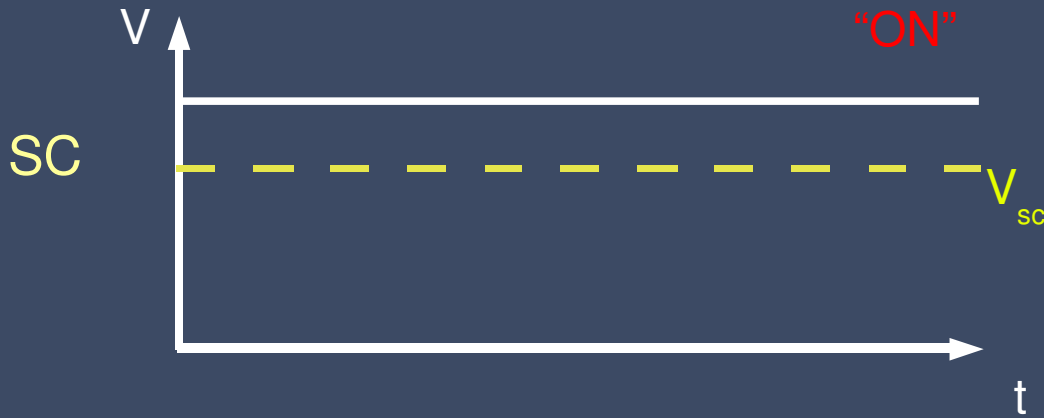
Around 20 tests



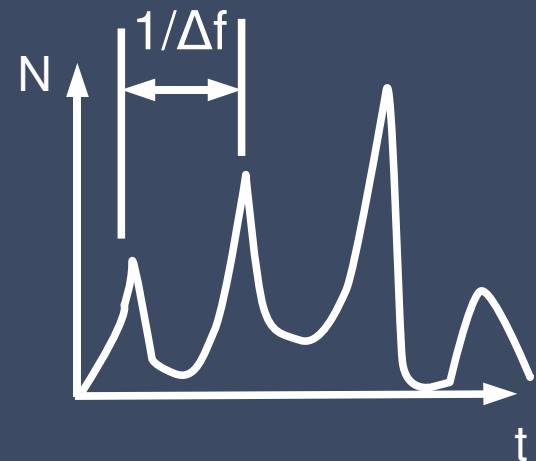
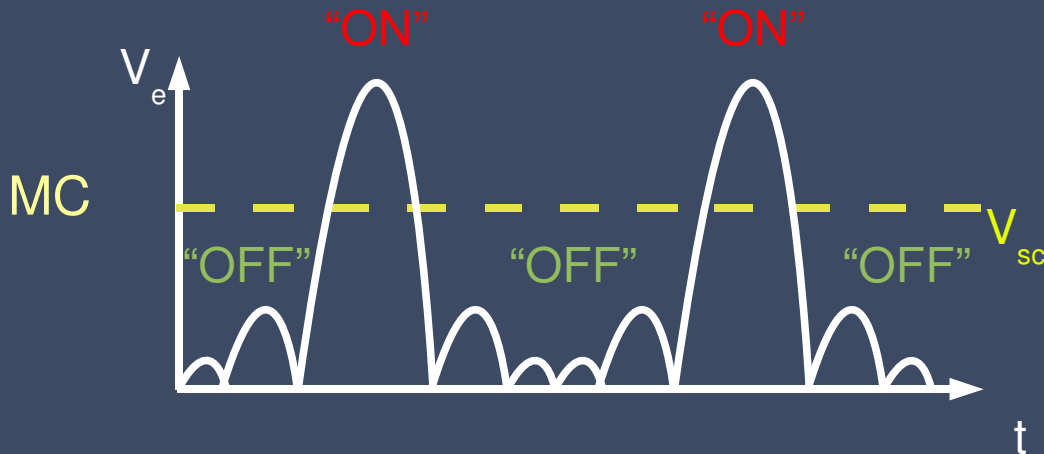
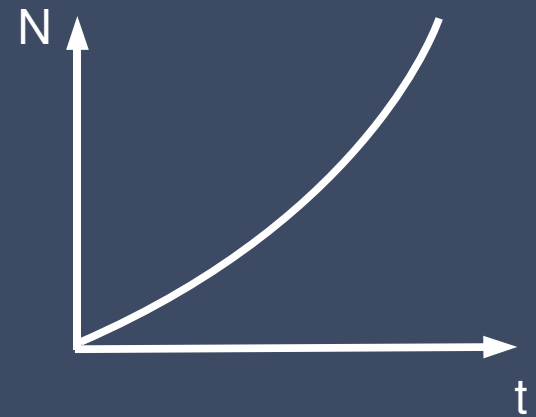
FEST3D High power capabilities: MC Multipactor

Single carrier vs. multicarrier

Envelope vs. time



Electron population vs. time

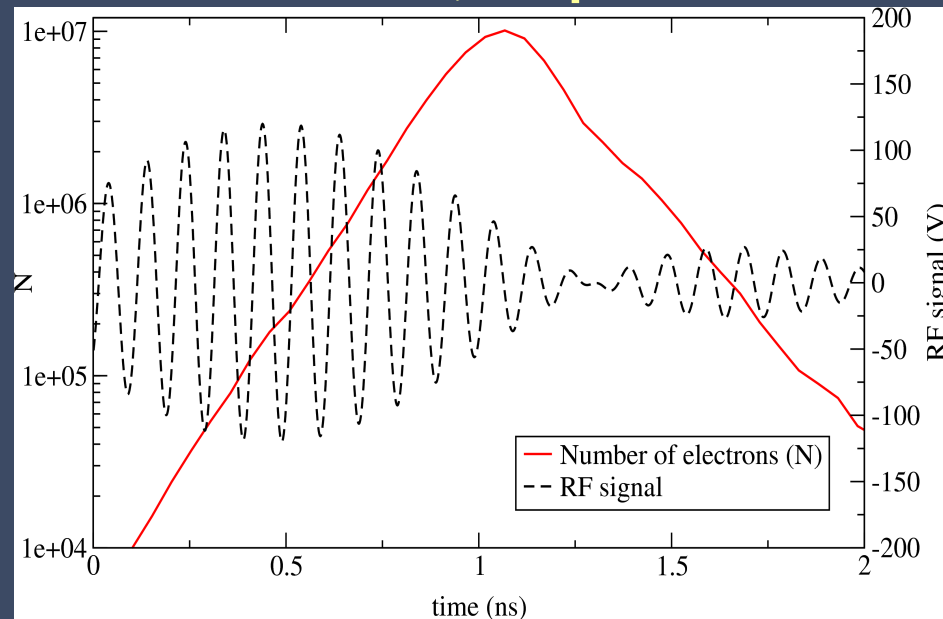


FEST3D High power capabilities: MC Multipactor

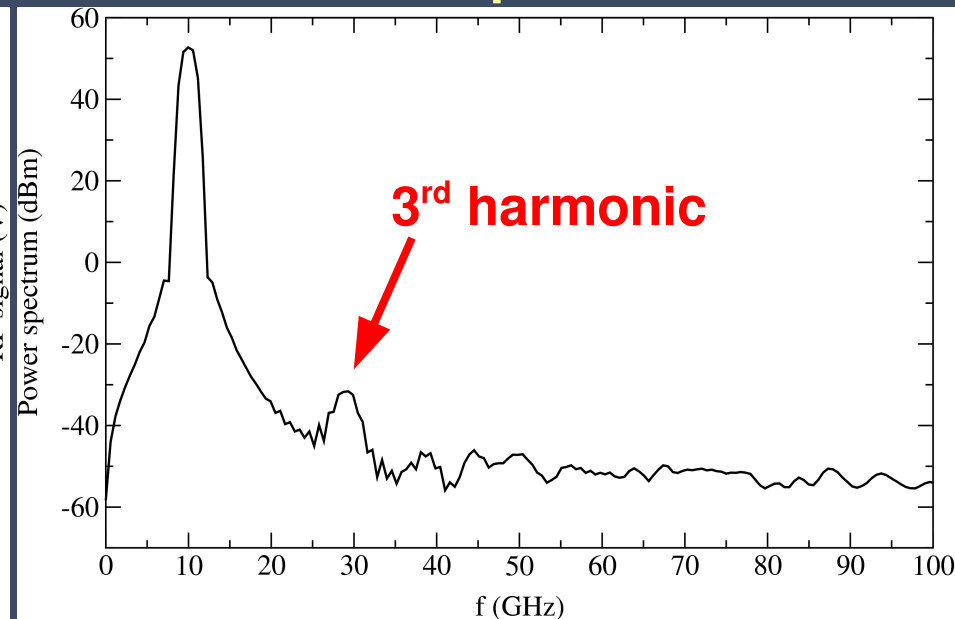
Single event multipactor in multicarrier regime

Rectangular waveguide, silver, $a=22.86\text{mm}$, $d=0.1\text{mm}$, $f=10\text{GHz}$, $n=1$
10 carriers, $\Delta f=120\text{MHz}$, in-phase

Electrons vs time, Amplitude vs time



Power Spectrum



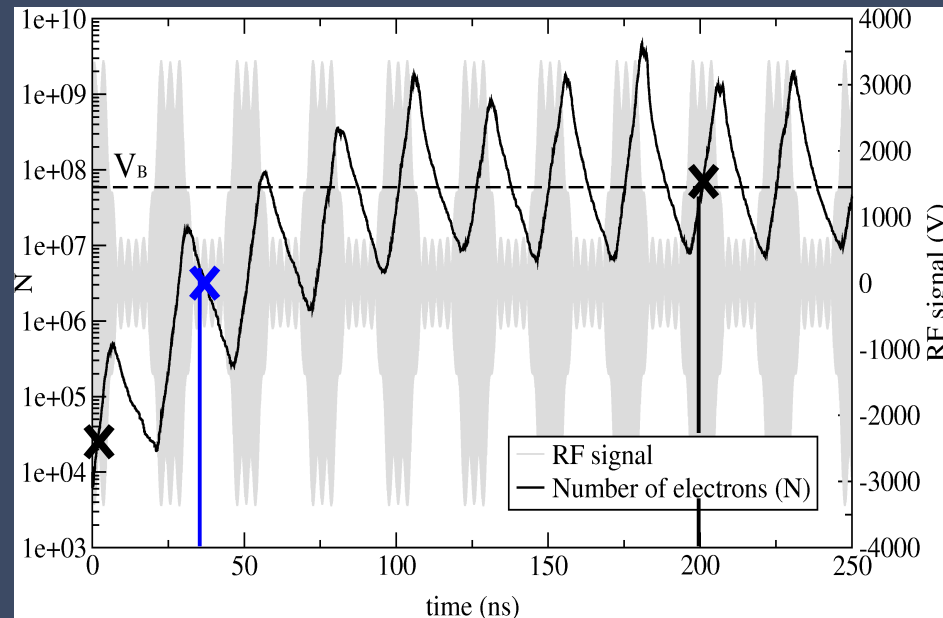
FEST3D High power capabilities: MC Multipactor

Long-term multipactor in multicarrier regime

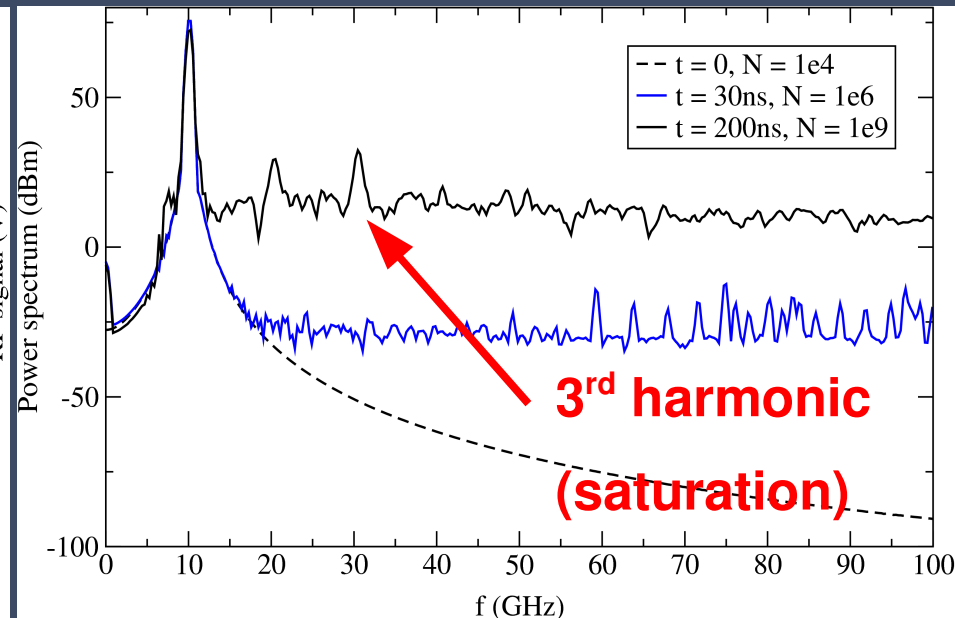
Rectangular waveguide, silver, $a=22.86\text{mm}$, $d=2\text{mm}$, $f=10\text{GHz}$, $n=15$

10 carriers, $\Delta f=40\text{MHz}$, triangular phasing

Electrons vs time, Amplitude vs time



Power Spectrum



FEST3D High power capabilities: Gas Breakdown

- **Description:**

- Phenomenon in the presence of a gas.
- Electron plasma is formed due to ionisation.

- **Risk:**

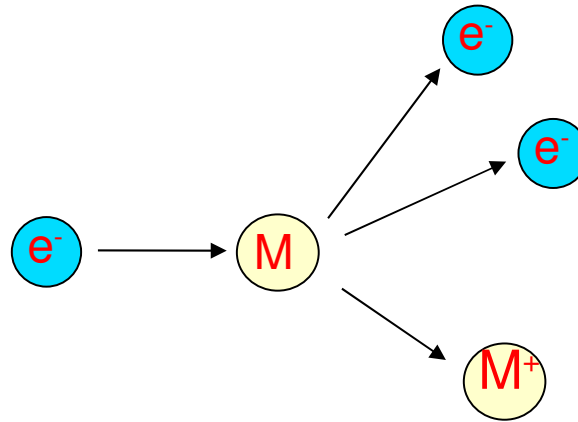
- TT&C subsystem is switched during launching.
- Outgassing during satellite lifetime.
- Re-entry vehicles, interplanetary missions,...
- Hardware destruction: *Satellite becomes useless.*

Parameter of interest: Breakdown power threshold

FEST3D High power capabilities: Gas breakdown

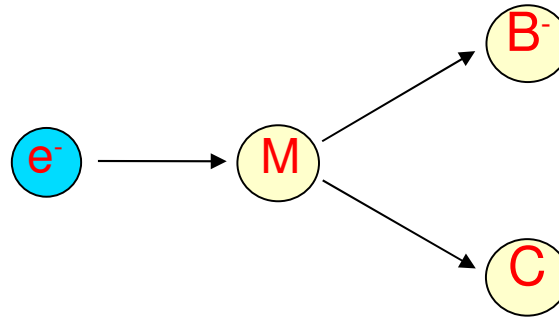
Physics:

Ionization



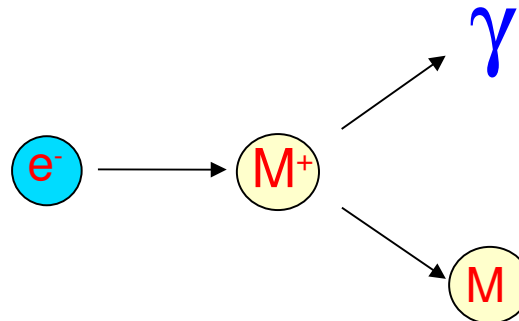
Free electron source

Attachment



Free electron drain

Recombination



Free electron drain

FEST3D High power capabilities: Gas Breakdown

- Corona Discharge can be investigated from the continuity equation of the
- free electron density*:

$$\frac{\partial n}{\partial t} = D \nabla^2 n + (\nu_i - \nu_a) n$$

n Free electron density

D Diffusion coefficient.

ν_i Ionization rate.

ν_a Attachment rate.

D, ν_i, ν_a depend on the electric field, pressure, frequency, gas...

* MacDonald, *Microwave Breakdown in Gases*, 1967

FEST3D High power capabilities: Gas Breakdown

- Corona Discharge can be investigated from the continuity equation of the
- free electron density*:

$$\frac{\partial n}{\partial t} = D \nabla^2 n + (v_i - v_a) n$$

- Breakdown if: $\frac{\partial n}{\partial t} > 0$

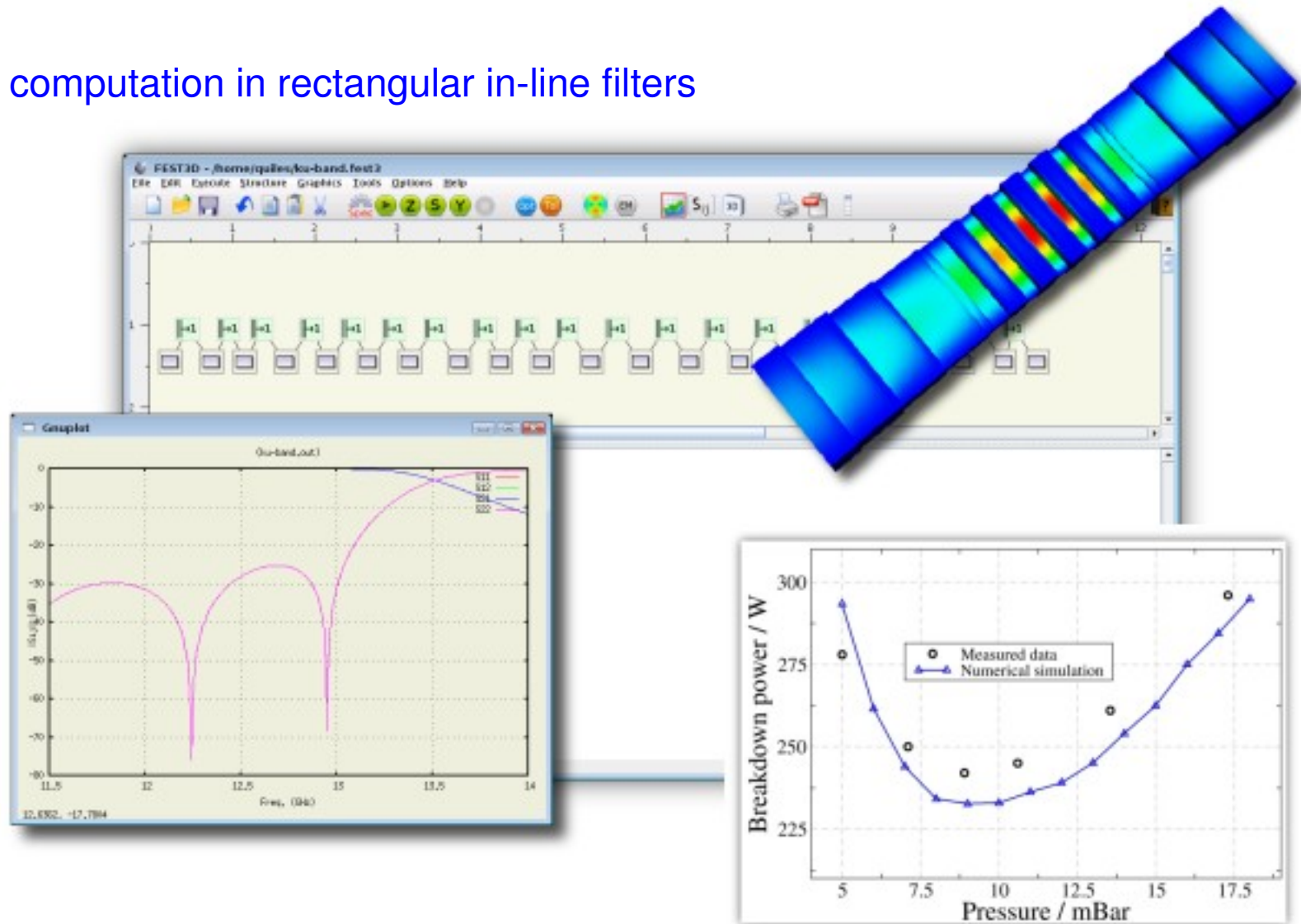
- Breakdown condition: $\frac{\partial n}{\partial t} = 0$

- For complex microwave devices the solution has to be found numerically.
- Finite Differences + iterative solution.

* MacDonald, *Microwave Breakdown in Gases*, 1967

FEST3D High power capabilities: Gas breakdown

Corona computation in rectangular in-line filters



Conclusions

- FEST3D CAD Tool has been presented
- High power applications have been described
 - Multipactor in single carrier
 - Multipactor Multicarrier
 - Gas breakdown