Absorbers Materials for HOM Damping in CLIC PETS and Accelerating Structures

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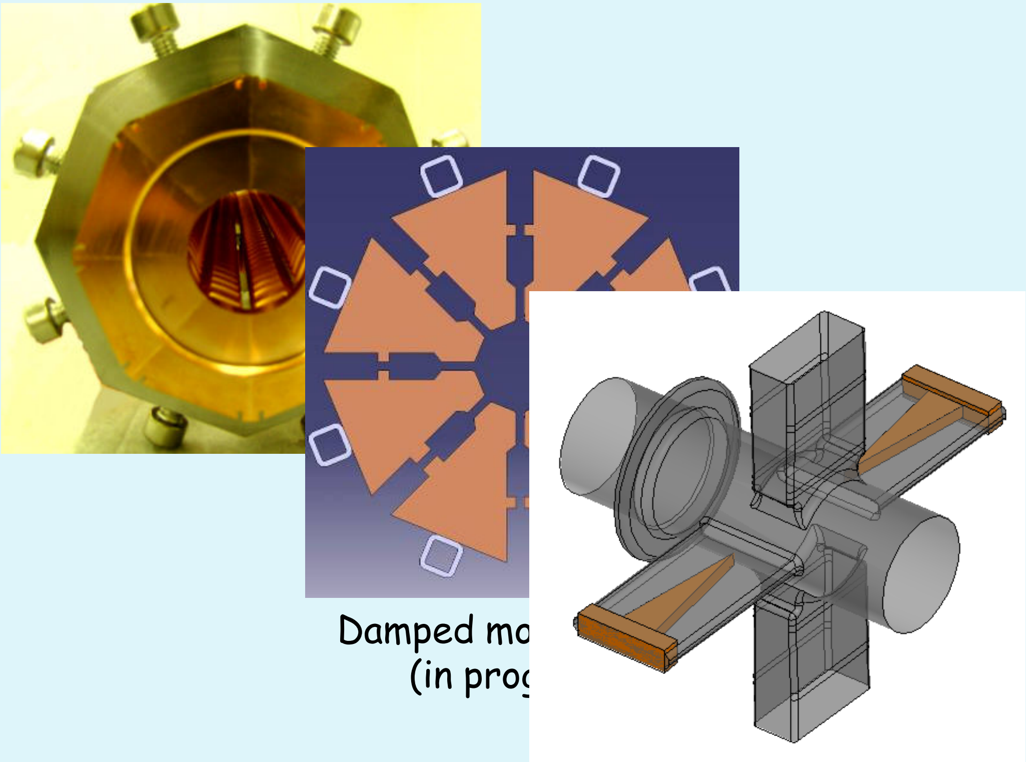
Our Short and medium term Requirements

Find a reliable supply of a reasonable vacuum compatible rf absorbing material with **known and reproducible properties**.

The material will be used by CLIC for load elements in HOM damping features of accelerating structures, PETS and BPMs. These will be tested in klystron based test stands and especially the beam-based TBTS and TBL.

This amounts to at least 30 or 40 structures – which corresponds to thousands of load elements.

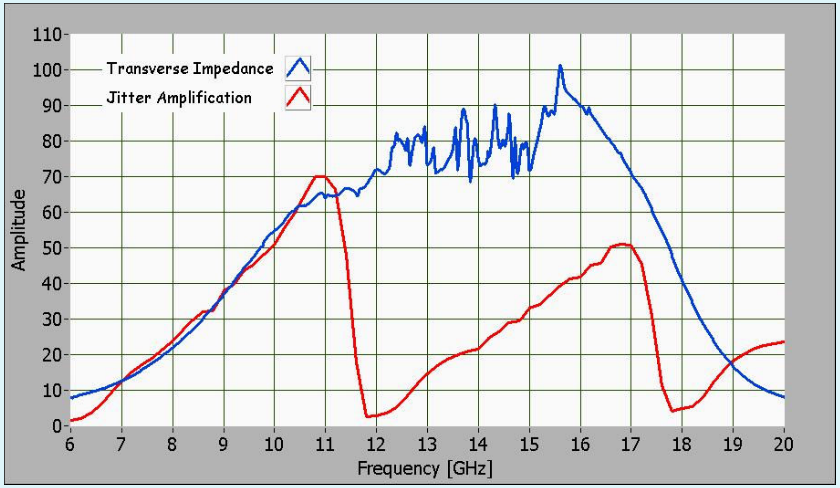
Short Term needs:
Power Extraction Structures PETS



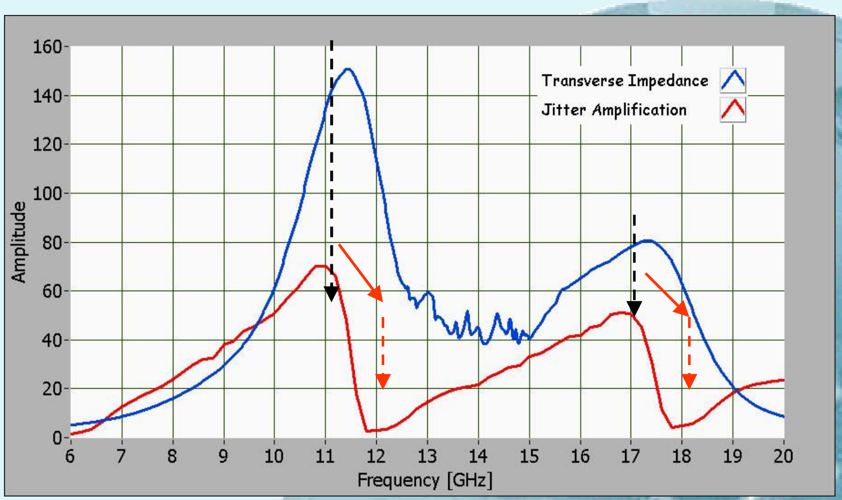
Damped mo
(in prog

Damped modification
(in progress)

Current design:



Fast example of the spectrum modification with 4 loads being switched off:

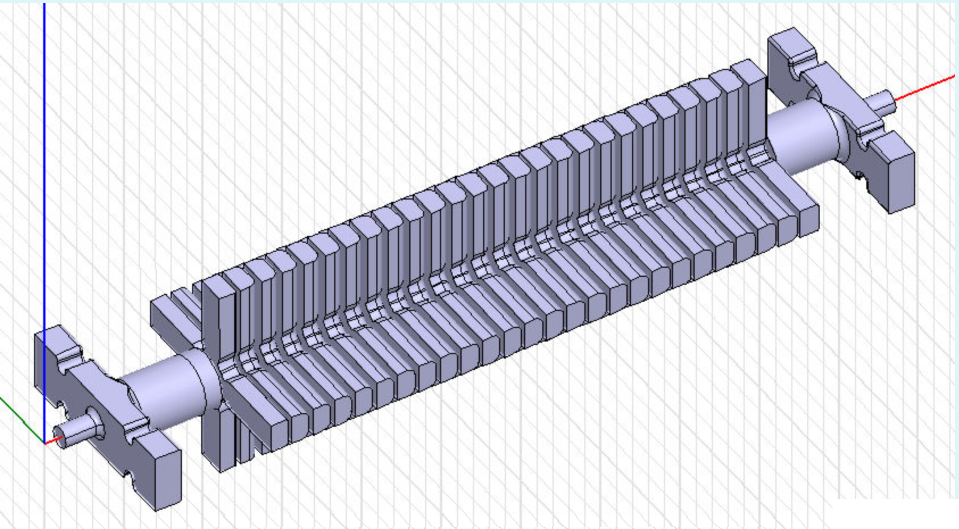


- **ε in the range of 20 to 30**
- **loss tangent of at least 0.3**
- **reproducibility of permittivity of the order of 10% is necessary**

Cortesy of I. Syratchev

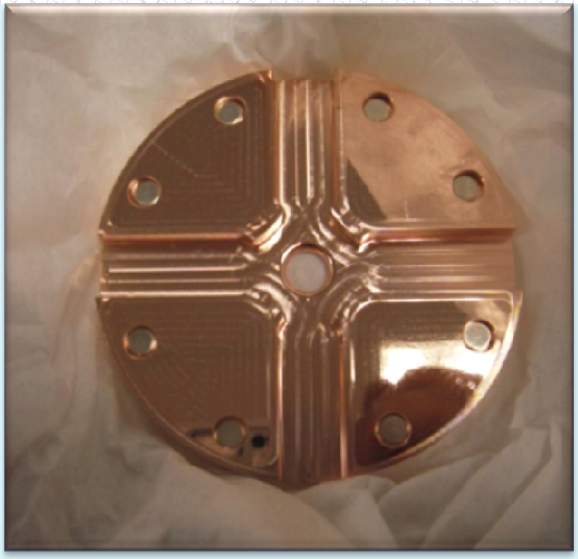
HOM FREQUENCY RANGE 10-20 GHz

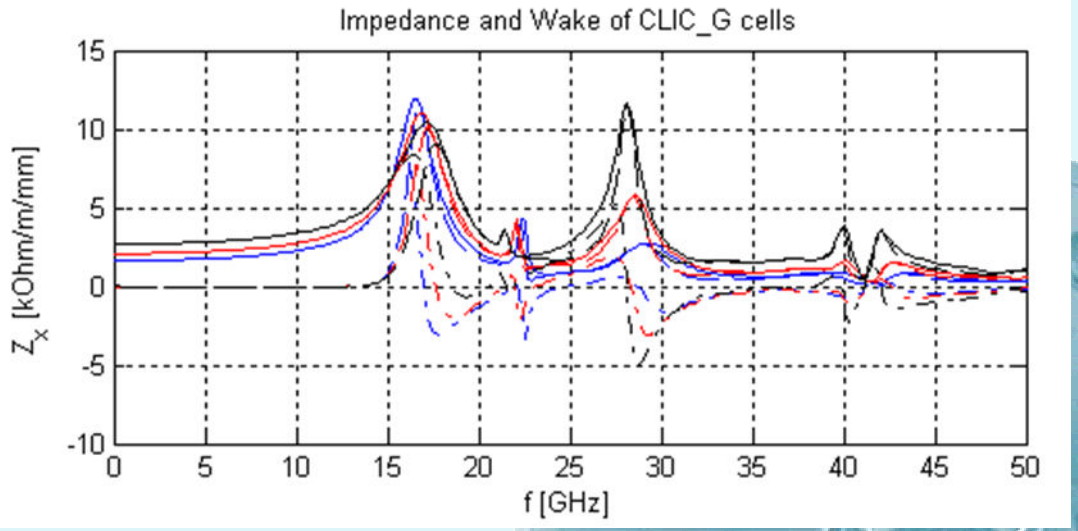
Longer Terms Need: Wave Damped Structure



Waveguide Damped Structure
(WDS) 2 cells

- **ε_r as low as possible (20 still ok)**
- **loss tangent of at least 0.3**
- **reproducibility of permittivity of the order of 10% is necessary**





HOM FREQUENCY RANGE 10-45 GHz

Courtesy of A. Grudiev

Historical Overview

- Work on load elements for CLIC multibunch structures started in 1996. Samples of carbon loaded AlN supplied by R. Campisi
- No supplier was available so switch to SiC 100®
- In 1999 successful test of structure, designed by M. Dehler, in ASSET which had 600 SiC load elements. Material also used CTF2 30GHz PETS
- SiC used successfully by E.Jensen in 3GHz SICA structures of the CTF3 main linac. The stability of the linac is some proof that the loads worked.
- By this time Ceramiques&Composites had been bought by ESK and the product line was overhauled. The SiC Erk chose was a version of EKasic, a material intended for mechanical applications. But it worked.
- A few years ago, Erk ordered Ekasic for a 3 GHz dry load development. The measured load performance differed from expected based on previously measured permittivity. Permittivity measurements by R.Fandos of *new* batches gave a (weirdly) high ε’ of 130 while old batches were just fine.

Common Interest of many groups to characterize electromagnetic properties of SiC and Ceramics in general

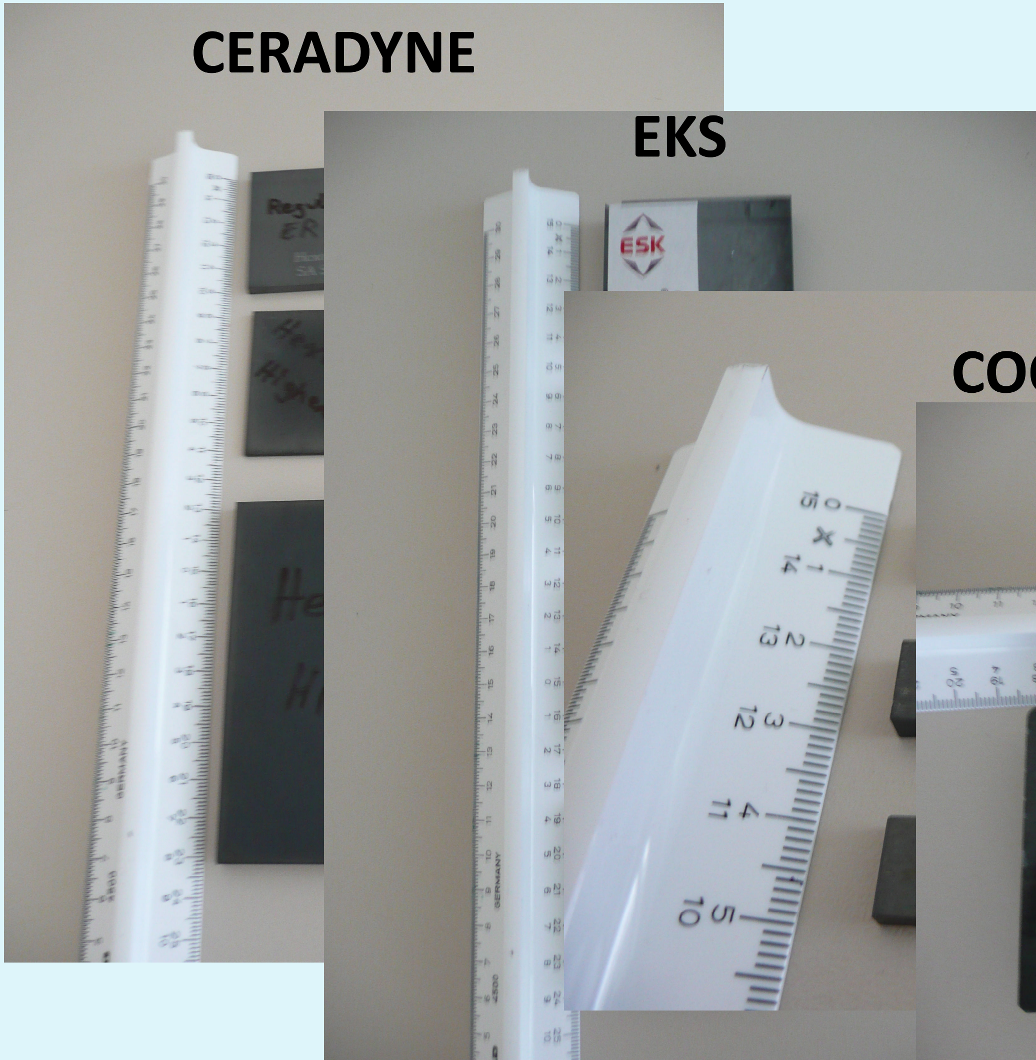
- CIEMAT interest in defining PETS load material
- CERN Collimation Phase II interest in characterizing SiC for possible application
- EPFL-Laboratory of Electro-Magnetism interest in performing measurements at high frequencies
- EPFL -PLASMA group interest in finding material for Gyrotrons

Material Survey CIEMAT

Company	Material	Description	Theoretical Resistivity
Dynamic Ceramic (UK)	SiC	Direct Sintered	10^2 Ωcm
	Si_3N_4		10^{10} Ωcm
COORSTEK (USA)	SC-DS	Direct Sintered SiC	10^5 Ωcm
	SC-RB	Reaction Bonded SiC	10^3 Ωcm
	SiC HR Grade	Chemical Vapor Depositions	10^6 Ωcm
ESK (DE)	Ekasic F		10^6-10^8 Ωcm
	Ekasic F-Plus		10^6-10^8 Ωcm
	Ekasic P		10^6-10^8 Ωcm
	Ekasic S		>10^{11} Ωcm
SAINT GOBAIN	Hexoloy SA SiC 1	Regular Elec. Resistivity	10^4-10^6 Ωcm
	Hexoloy SA SiC 2	Higher Elec. Resistivity	10^7-10^9 Ωcm
	Hexoloy SA SiC 3	Highest Elec. Resistivity	10^{10}-10^{11} Ωcm

Cortesy of L.

Material Survey CIEMAT

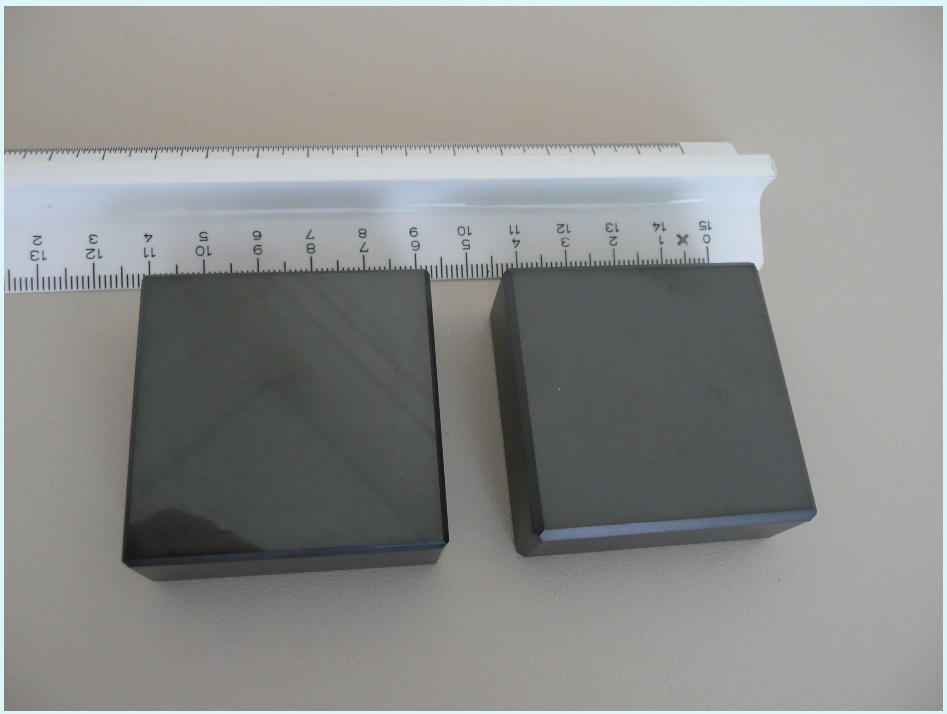


All material samples will be machined and measured

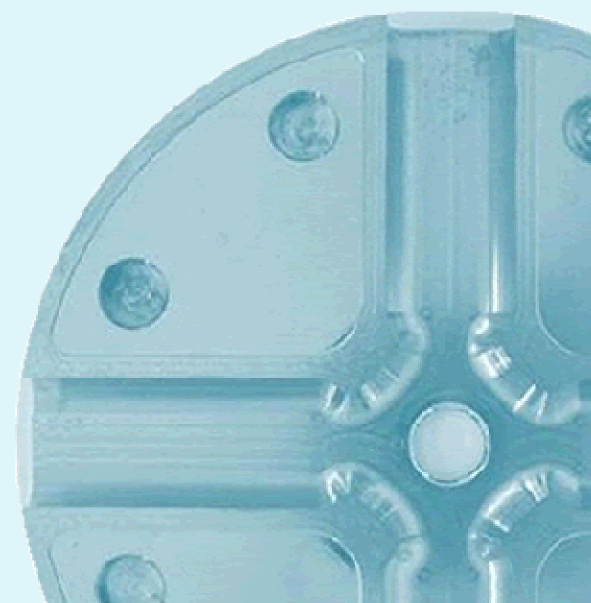
Cortesy of L. Sanchez CIEMAT

KEK Cerasic-B SiC Tiles

Company	Material	Description	Theoretical Resistivity
Covalent Materials Corporation (JP)	Cerasic B	SiC	10^4-10^6 Ωcm



Absorbers material used for KEK

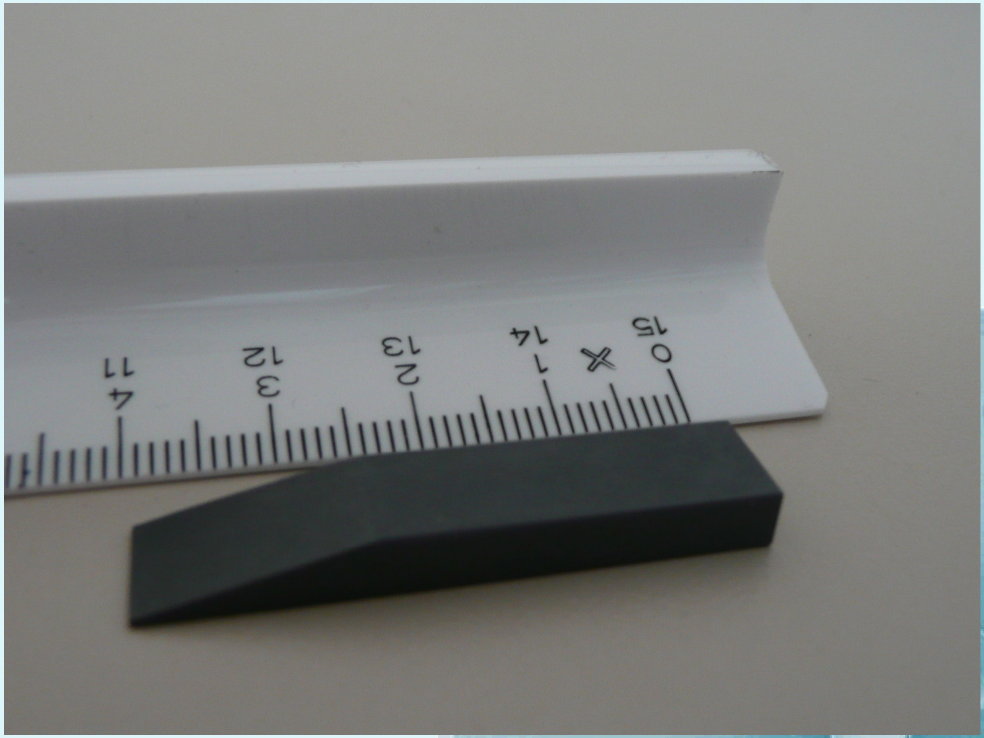


Cortesy of Y. Takeuchi and T. Higo

Argonne SiC-AlN sample

Company	Material	Description	Theoretical Resistivity
Ceradyne Inc (USA)	Ceralloy 13740Y	Hot pressed AlN + 40% SiC	>10^8 Ωcm

Material currently tested in a 26GHz load at Argonne Nat. Lab.



Cortesy of Chunguang Jing

Material Characterization

For each Material Sample we want to measure and keep track of:

- Resistivity (in collaboration with Coll. Phase II)
- Complex permittivity (1-50GHz freq. range)

SiC and Ceramics Survey common effort for CLIC RF and for LHC Collimation Phase II

The choice between metallic - ceramic jaw depends on the method of stabilization will be used (LANDAU Damping – Transverse Feedback).

Requirements for Ceramic jaw:

- Electrical resistivity (1-10 Ωm)
- Ceramic tiles bonded on conductive support
- Tile thickness (5-10 mm)
- Gap between tiles (up to 2-3mm)
- Resistivity :1-100 Ωm
- **Diel. Const: as low as possible (up to 5)**
- **Loss factor: < 1E-2**
- Brazability to metal support.
- High density
- High geometrical stability
- High thermal shock resistance

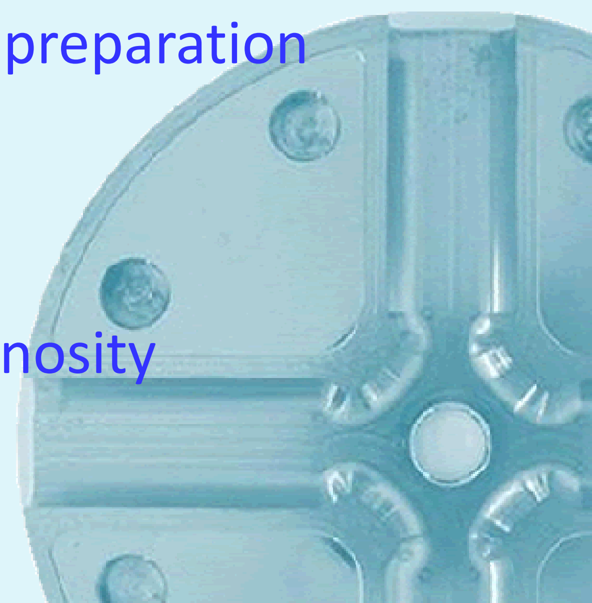
SiC is a promising candidate

Cortesy of A. Dallocchio and A.Bertarelli *from* LHC Collimation Phase II – Design Meeting

Electrical Resistivity Measurements

Measurements constraints and solutions:

- Contact resistances between ohmmeter pins and SiC
  - » Four points method
- Carbon layer on SiC due to high temperature (>1100°C)
  - » Evaporation of Si = graphitization (e.g. during sintering)
  - » Mechanical and thermal surface preparation
- Photosensitivity (1 - 5 % of the result)
  - » Measurements must be done at
  - » Regulated temperature and luminosity



Cortesy of R. Blanchon and G. Arnau Izquierdo

Measurements Procedure and Set-up

1. Surface preparation has to be proceeded

Mechanical grinding on each surface of the ceramic to remove the carbon layer

Heat treatment at 1000°C to remove residual impurities

2. Four points method

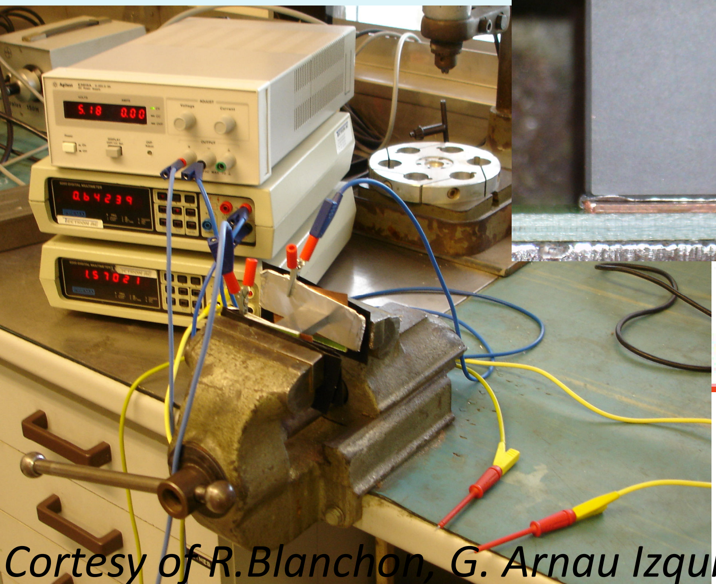
Injection of current – Measurement of voltage

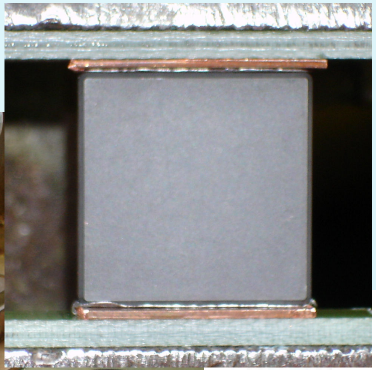
$$R = \frac{U}{I}$$

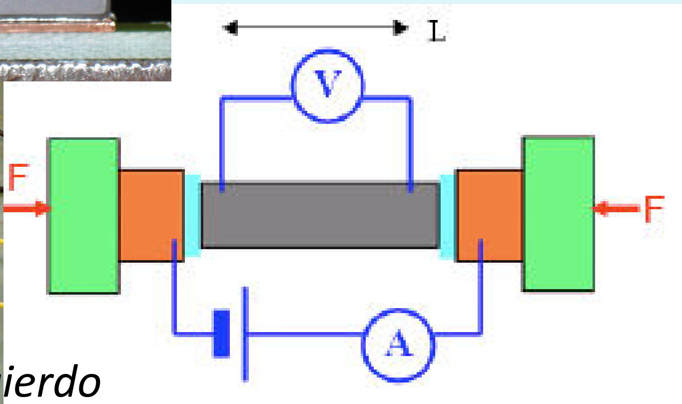
Calculation of electrical resistivity

$$\rho = R \times \frac{S}{L}$$

- Voltmeter
- Silicon Carbide
- In or Al sheet
- Copper
- Insulating material
- Current source
- Ammeter







Cortesy of R.Blanchon, G. Arnau Izquierdo

Measurements of CERASIC-B SiC Tiles

- Results on 2 tiles of CERASIC – B no surface preparation:

$$\rho_1 = (24071 \pm 3662)\ \Omega.\mathrm{cm}$$

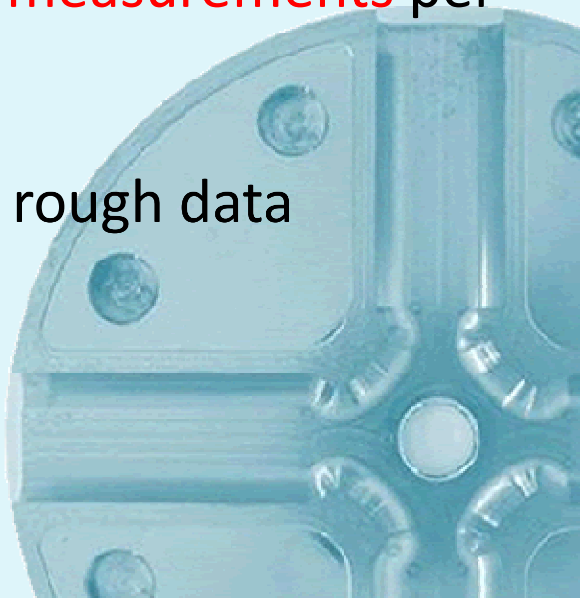
$$\rho_2 = (18772 \pm 3595)\ \Omega.\mathrm{cm}$$

- Datasheet from supplier:

$$\rho_{th} = 10^4 - 10^5\ \Omega.\mathrm{cm}$$

- These experimental results are an average of 10 measurements per tile of SiC.

- High dispersion of results → increase number of rough data
  - Several samples for each supplier
  - Measurements on each face of the sample
  - Statistical exploitation of data



Cortesy of R.Blanchon, G. Arnau Izquierdo

Complex Permittivity Measurements

To measure Loss Tangent and Relative Permittivity of Absorber materials in frequency range 1-50 GHz different techniques are under investigation:

- **S-parameters measurements for wave guides with material**
- **Surface and contour plots**
- **Agilent Dielectric High Performance Probe 85070E 1-50GHz**
- **EPFL-LEMA laboratory of electromagnetism**

S-par Measurements of Material in WG

Wave guides

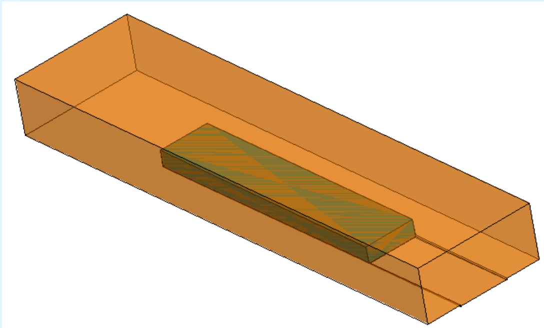
S parameters measurement:

- **HFSS + Measurements** (Ref. CLIC-NOTE-766)
- Exploring New analysis method

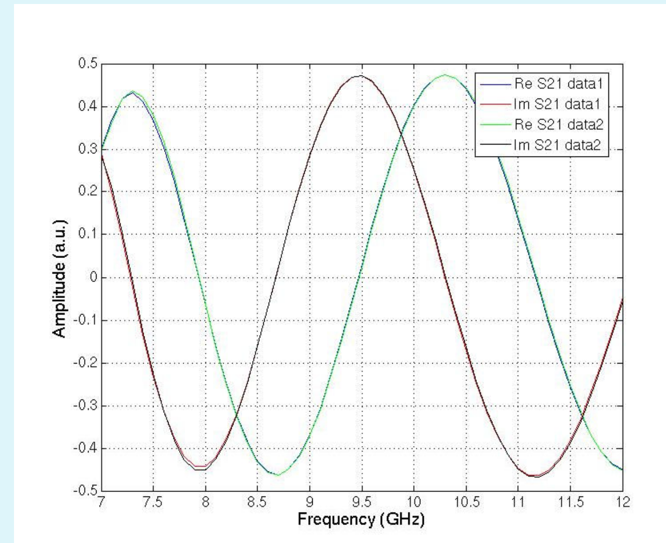
Samples Preparation:

- **Machining of samples**
  - **Different sizes (to define geometry effects)**
  - **Many samples to have statistics and non-homogeneity effects**
- **Measurements also after heat treatment (1000 Celsius)**

S-par Measurements



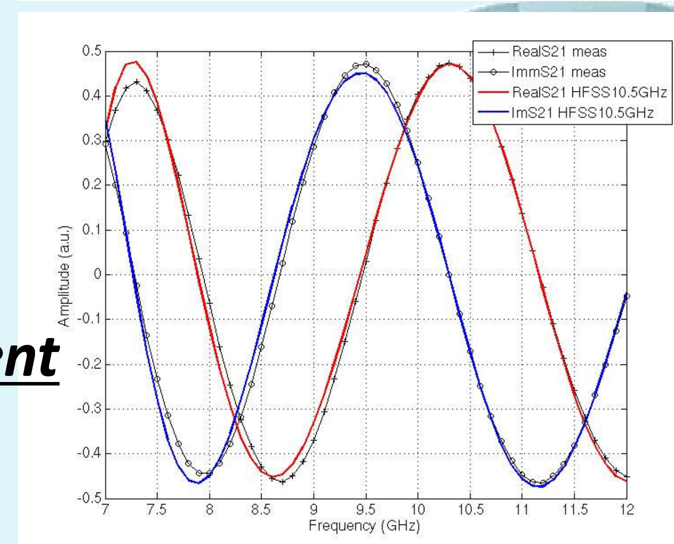
1) Sample in wave guide we **measure S-parameters** with Network Analyzer



2) We **model with HFSS** the measurements with the sample ε_r and **tgδ** as **free parameters** and we find best values to **match measurements** at different frequencies

3) We define ε_r and tgδ solutions

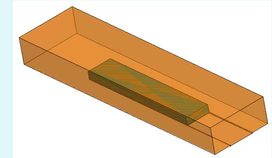
For this case ε_r = 11 and tgδ = 0.09

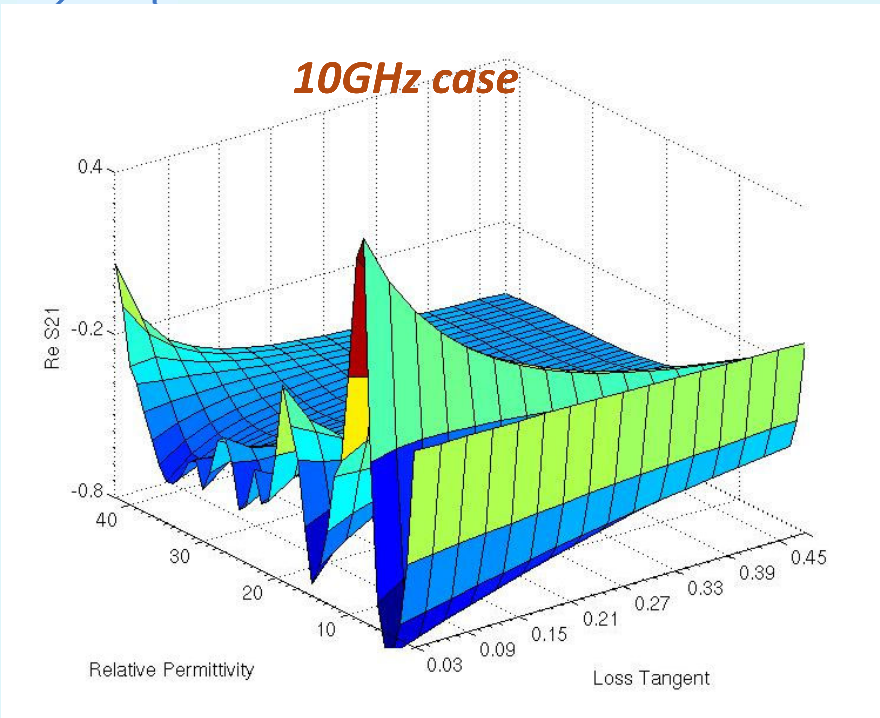


Issues: LONG HFSS RUNS at each measurement and MULTIPLE SOLUTIONS from Optimizer

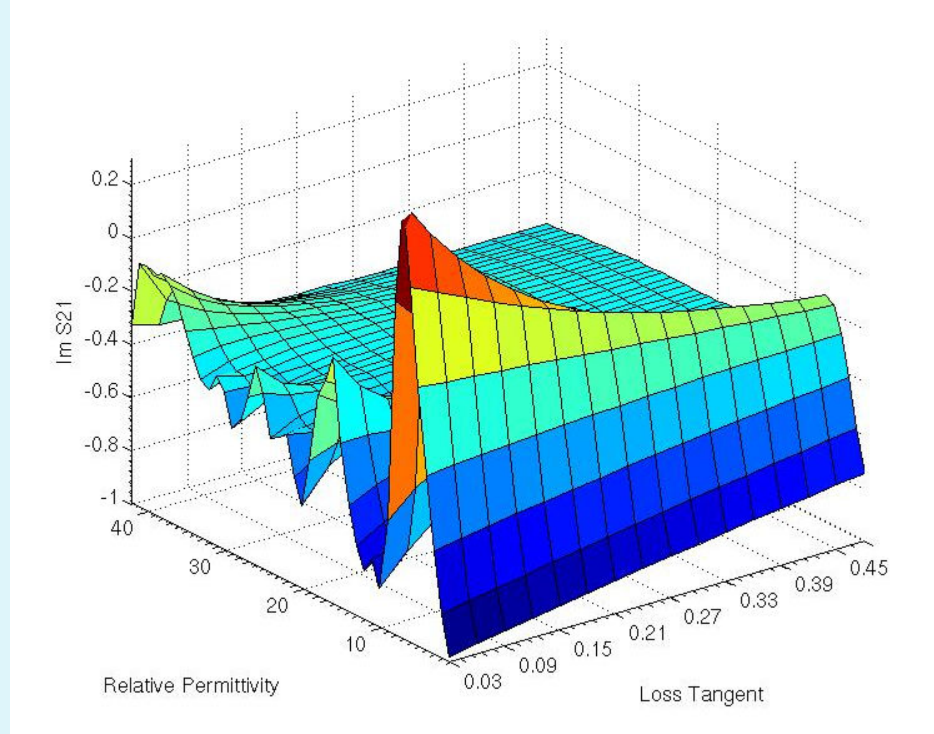
Collaboration for the analysis with CIEMAT D.Carrillo

SURFACE METHOD





For defined geometry a scan over all possible values of Loss Tangent and Relative Permittivity we have:
Re and Im S21 and Mag S11



Measured transmission and reflection coefficients define intercepting plane

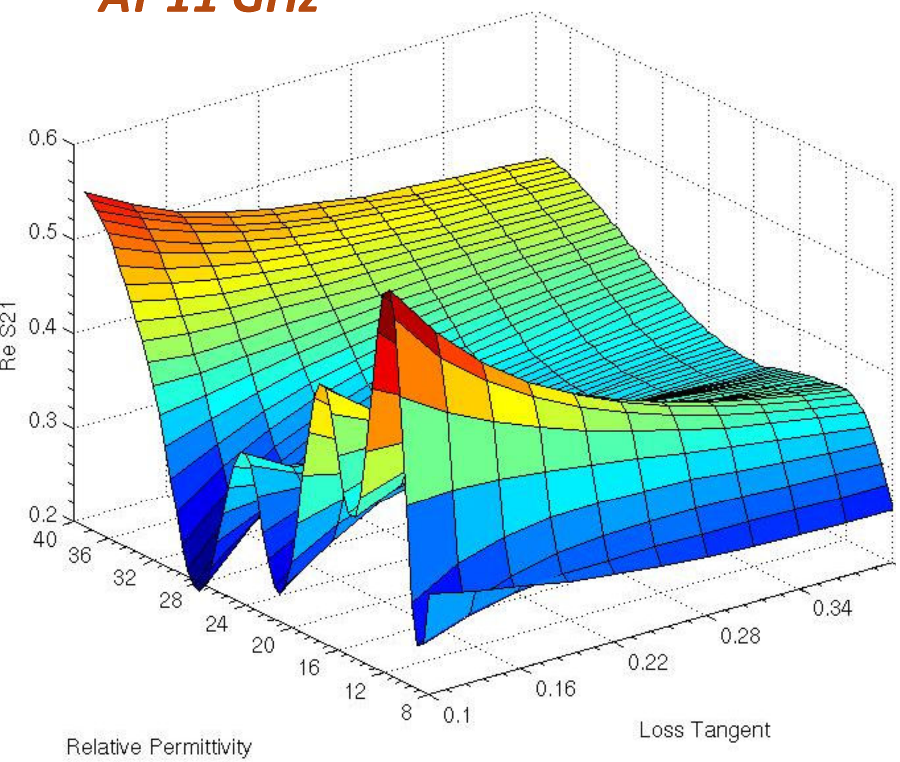
AT 10GHz ReS21= -0.178 and ImS21= 0.064
Goals come from measurements

Different materials different measured values

HFSS scan give at a different frequency

Different Re and Im of S21

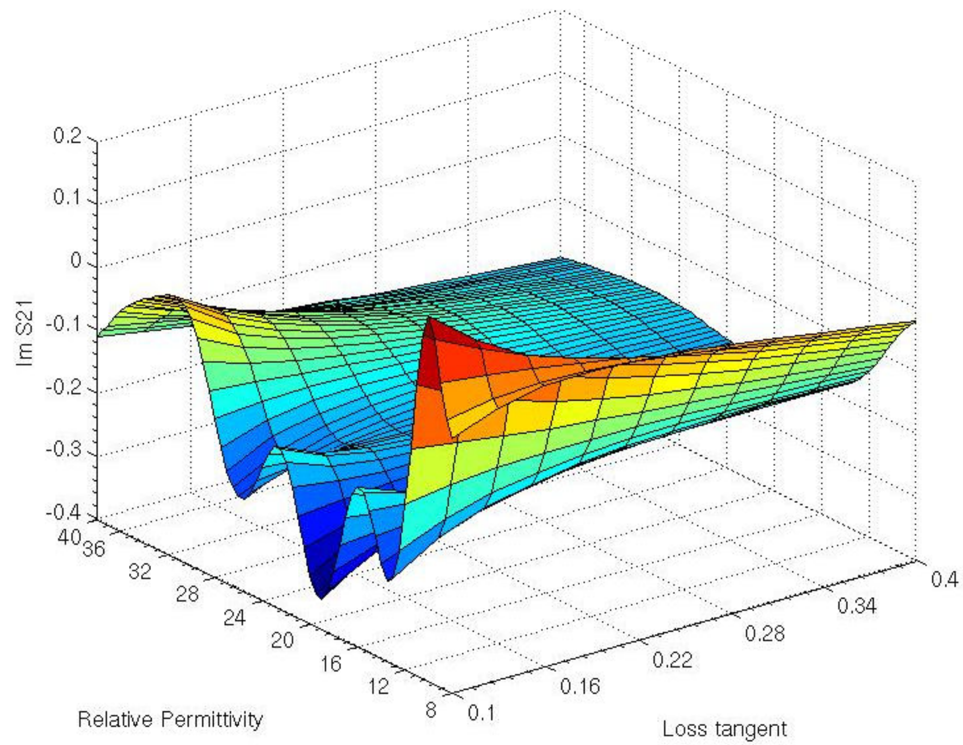
AT 11 GHz



Measurements give at different freq

Different transmission coefficients

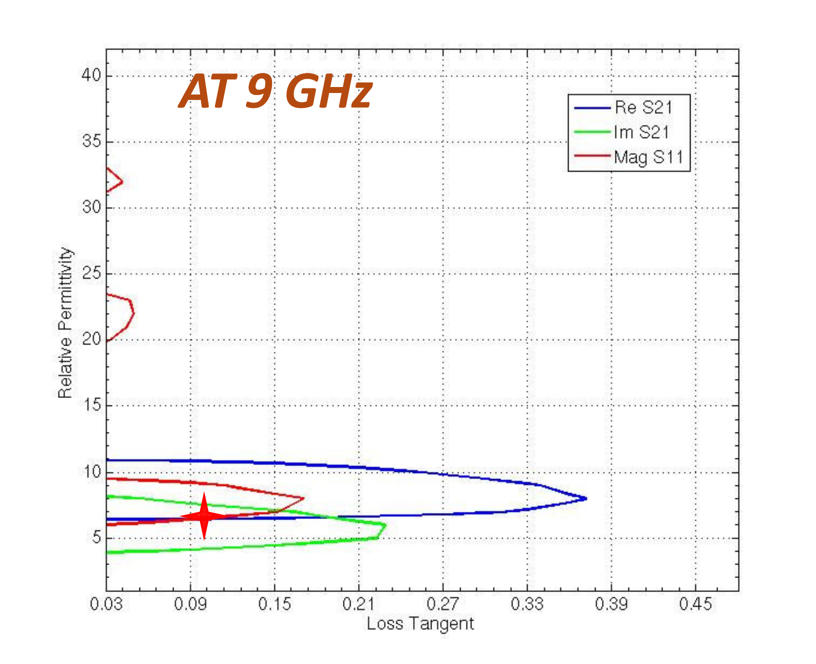
ReS21= 0.5 and ImS21= 0.12

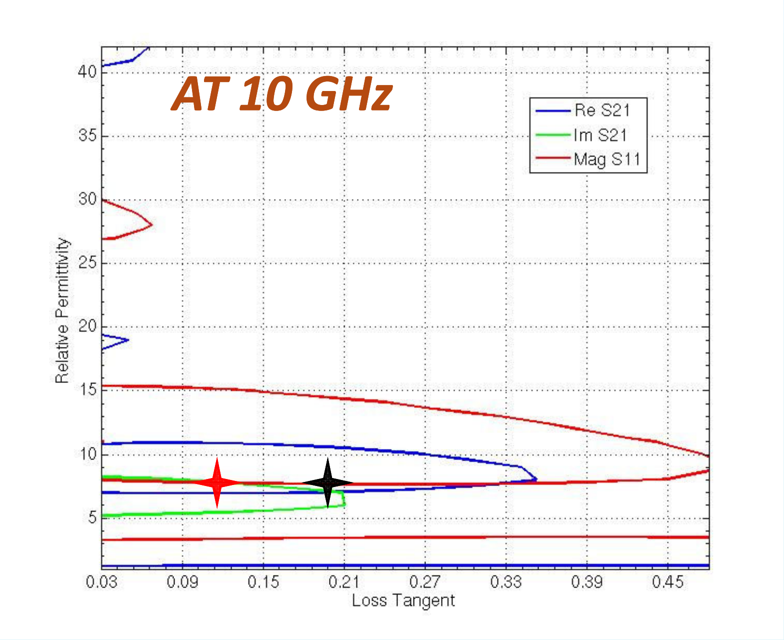


Measurements + simulations

Different Contour Lines

Comparing Contour Plots Physics Result

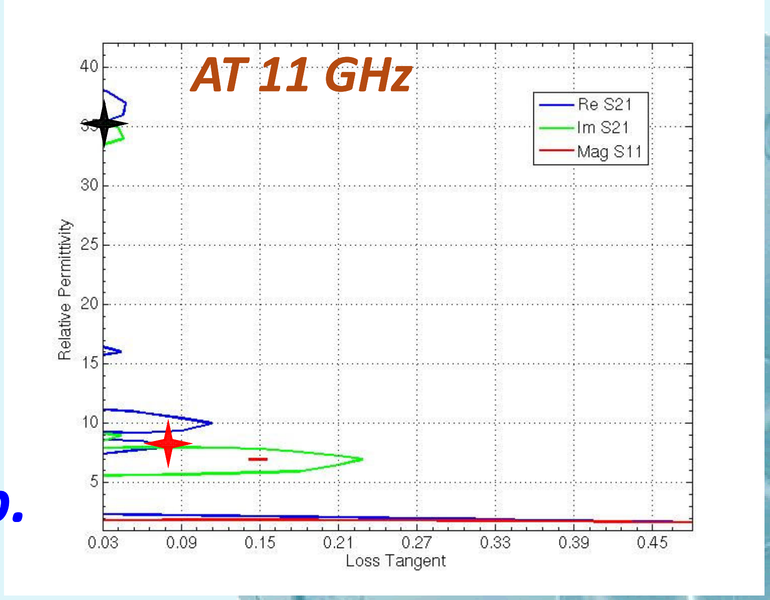




Measurements + simulations

Different Contour Lines

For this case ε_r = 11 and tgδ = 0.09
Is possible solution at all frequencies



SiC-ALN Material from Argonne Nat. Lab.

News:

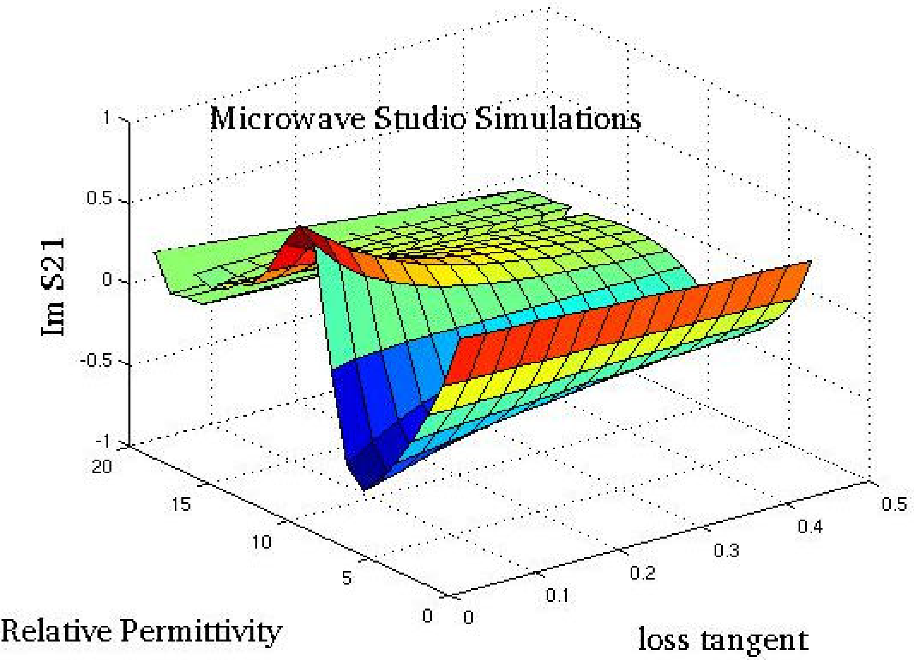
- We found the SiC 100® we lost track of, now mainly used for telecommunication applications (telescopes) company changed name: BOOSTEC Inc.

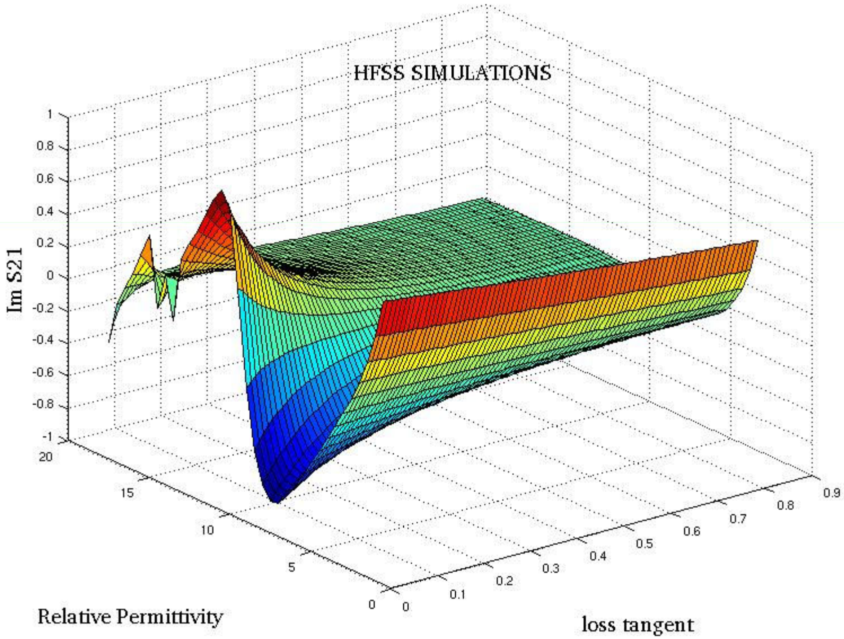
- We ordered samples to verify the material quality and material for PETS loads to be ready for high power test at SLAC

- People from SPS impedence team (Rumolo, Zannini and Salvant) interest in characterizing Ferrites with Wave Guide method

Using Surface and Contour method Comparing Microwave Studio (time domain) and HFSS (frequency domain)

Good Agreement between simulations with HFSS and Microwave Studio



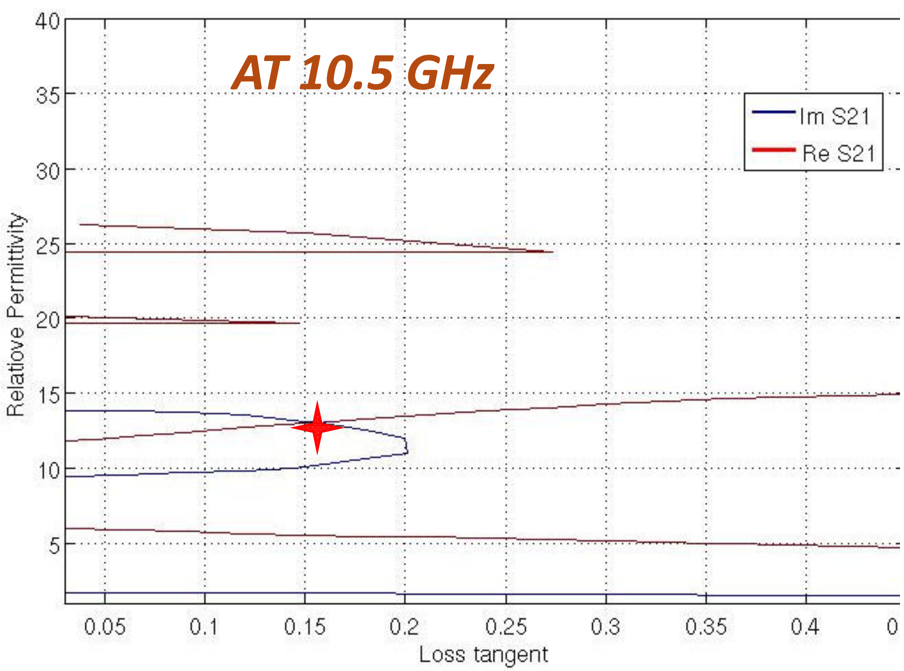


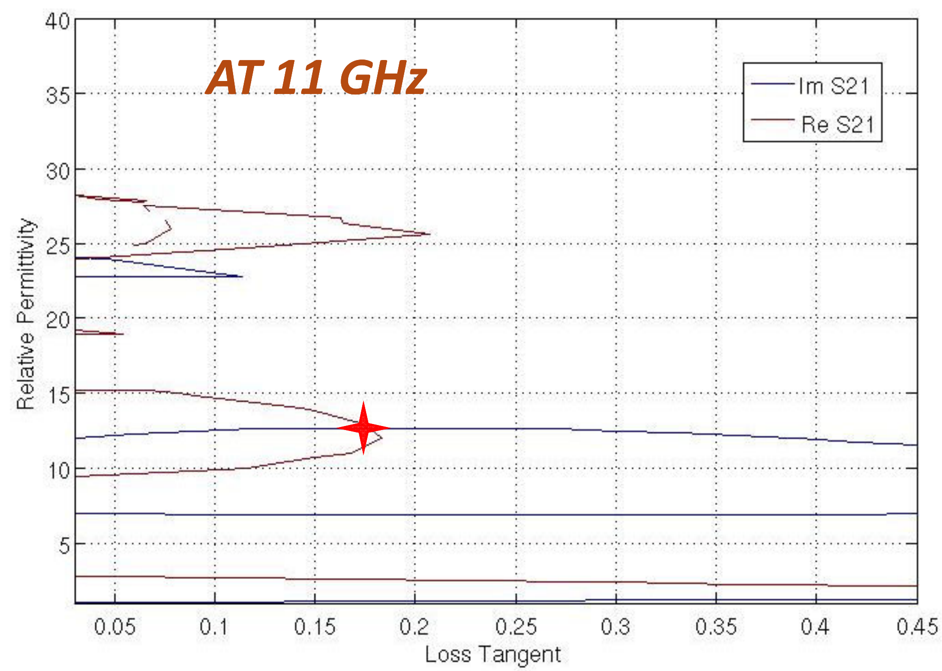
Microwave Studio Simulations: C. Zannini

Preliminary results with different steps in loss tangent and relative permittivity

First Measurements [7-12GHz]:

Contour method applied at S21 and measurements on SiC-100 give as follow





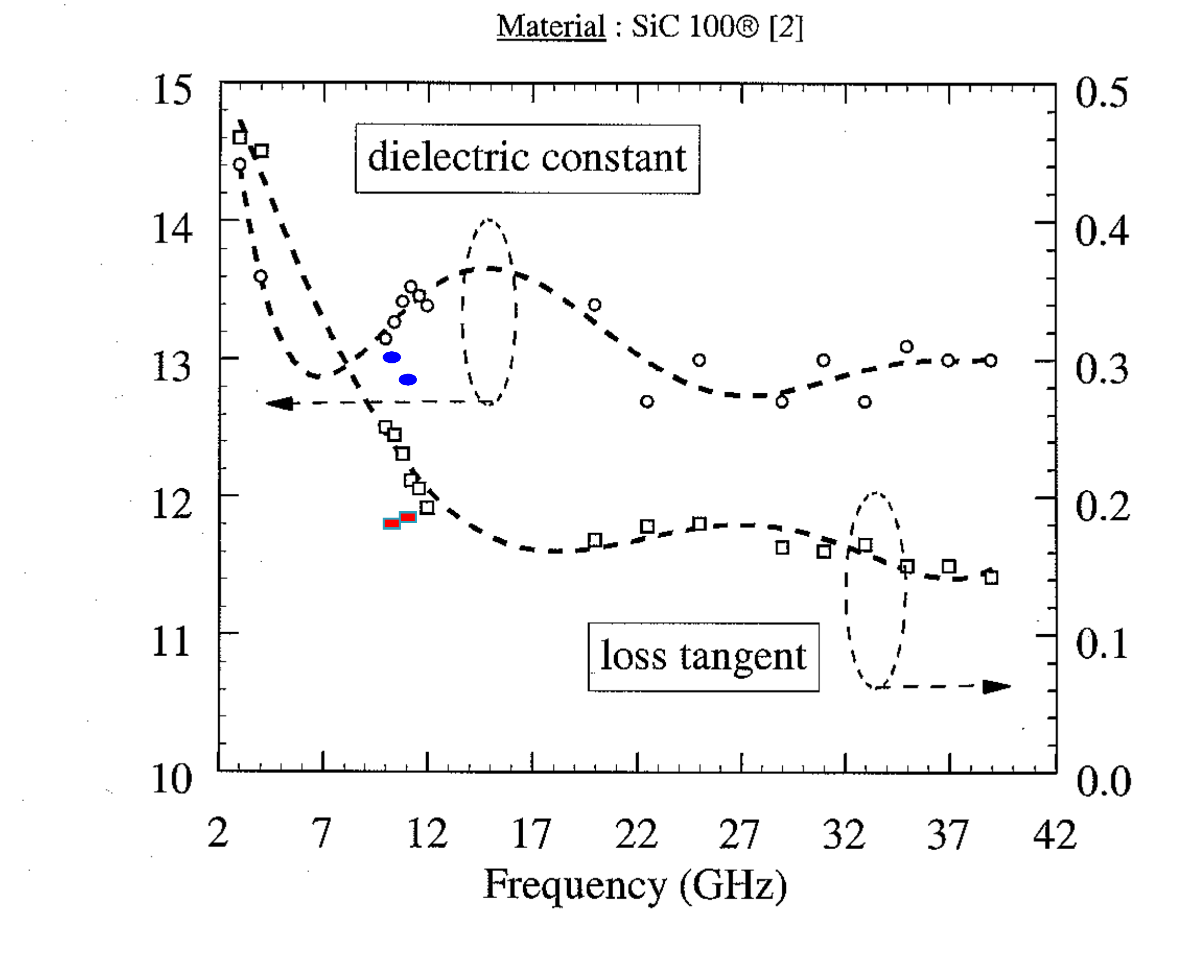
ε_r = 13 and tgδ = 0.16

ε_r = 12.8 and tgδ = 0.175

Microwave Studio Simulations: C. Zannini

SiC-100 from BOOSTEC Inc

- Microwave Studio (time domain) and HFSS (frequency domain) benchmark give same results
- SiC-100 material today give same relative permittivity and loss tangent as measured by Luong
- Fast Technique to define relative permittivity and loss tangent



Further cross checks at high frequencies for Accelerating Structures

- Higher frequencies with wave guides and surface method
- EPFL – LEMA Group at Lausanne can measure up to 50 GHz complex permittivity of solid materials with different set-ups
- Agilent Inc suggest commercial probe (High Performance Probe) to measure complex permittivity for 0.1MHz-50 GHz

Summary

- Material survey have produced large number of promising materials (20 different materials and around 300 pieces to be tested)
- Complete characterization will be performed and data available for future applications of ceramics for loads and ferrite for SPS kickers and PS2 project
- Fast Technique to determine material complex permittivity had been defined using two different simulation models HFSS (frequency domain) and Microwave Studio (time domain)
- Resistivity measurements are part of the material characterization

Conclusions

- Permittivity measurements: three different methods applied to keep track of material properties
- Measurements are of interest for different groups (CLIC-RF, SPS impedence team, PS2 and Col. Phase II)
- **SiC-100 still in production at BOOSTEC Inc with exactly same GOOD characteristics as in 1999**
- **Nevertheless defining other suitable materials can/will avoid to depend on one single supplier**