



Dual-band Microstrip Ferrite Circulator

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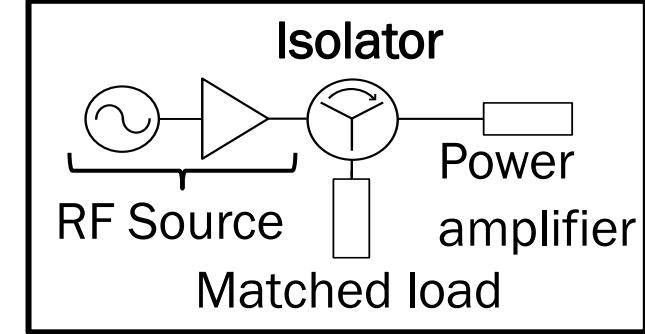
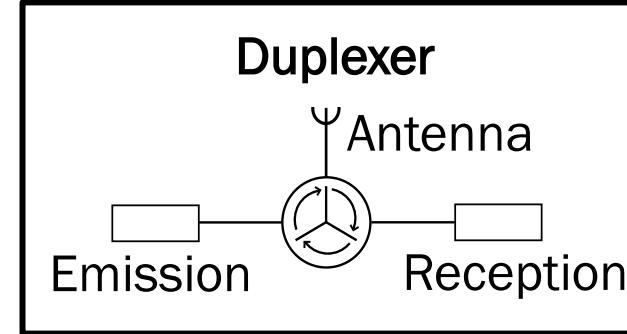
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Introduction

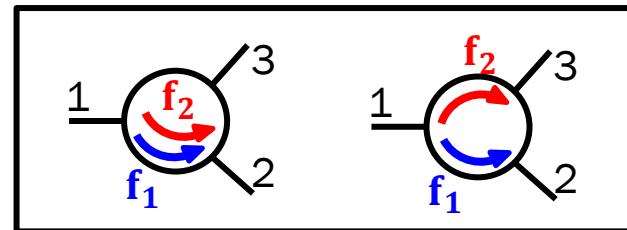
- Circulators in RF systems

Single-band functions



Expansion to multi-band systems

→ Dual-band circulators

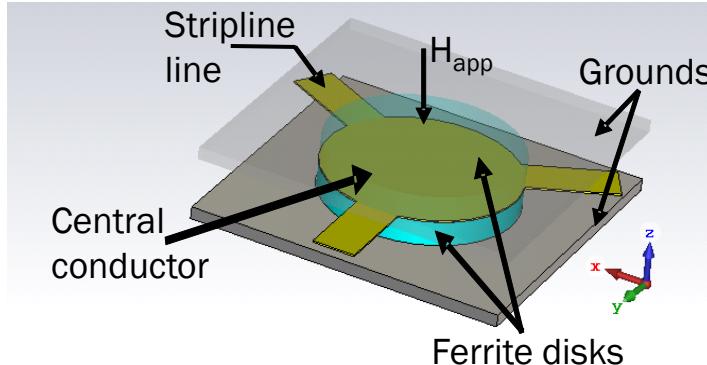


Main advantages →

- Size miniaturization
- Multi-applications systems

- I. CONTEXT AND BIBLIOGRAPHY
- II. CIRCULATOR DESIGN
- III. MEASUREMENTS
- IV. CONCLUSION

- Ferrite circulator structure



Two ferrite disks loaded by three access lines and biased by magnets.

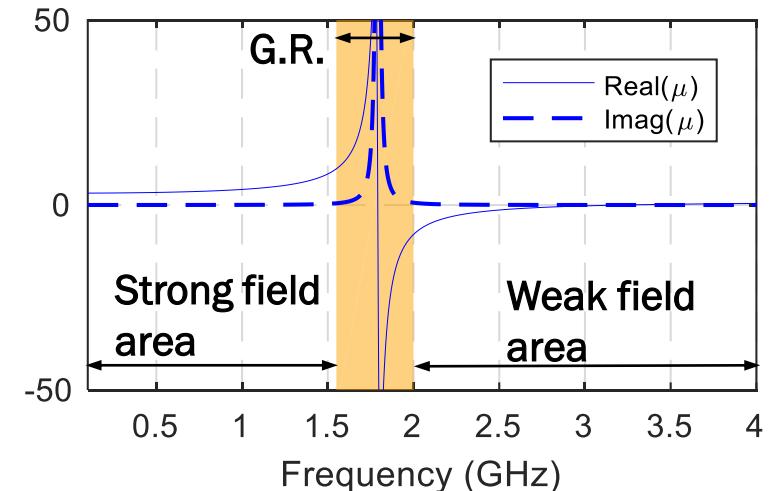
- EM properties of Biased Ferrites : Anisotropic material

Saturated ferrites \longrightarrow Polder Permeability Tensor

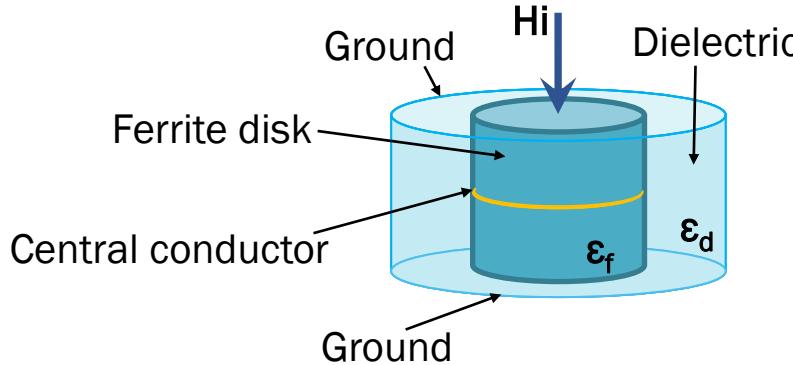
$$\mu = \mu_0 \bar{\mu} = \mu_0 \begin{bmatrix} \mu & -j\kappa & 0 \\ j\kappa & \mu & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\mu = 1 + \frac{\omega_m \omega_0}{\omega_0^2 - \omega^2} \quad \kappa = \frac{\omega_m \omega}{\omega_0^2 - \omega^2} \quad \omega_0 = \gamma \mu_0 H_i + j \alpha \omega \quad \omega_m = \gamma \mu_0 M_s$$

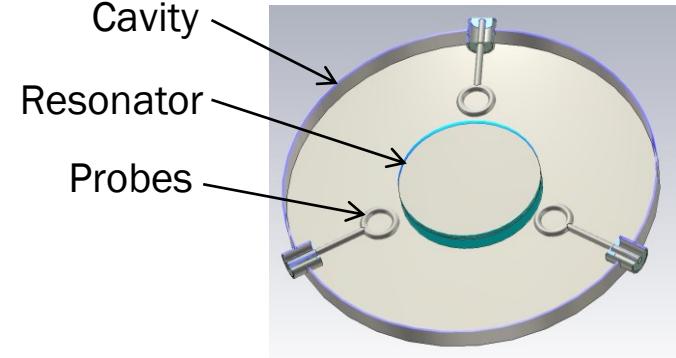
H_i : DC magnetic field
 M_s : Saturation magnetization
 ω_0 : Larmor Frequency
 ω_m : Gyroscopic frequency
 α : Damping factor



- Eigenmodes on ferrite cavities

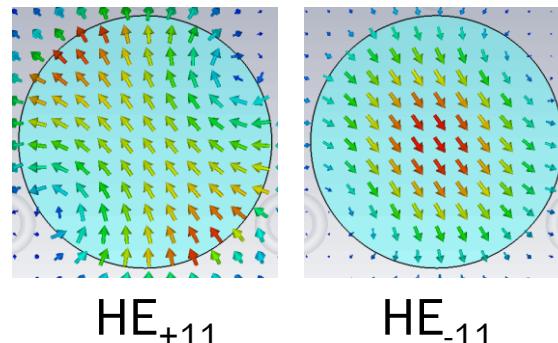


Numerical model with magnetic probes

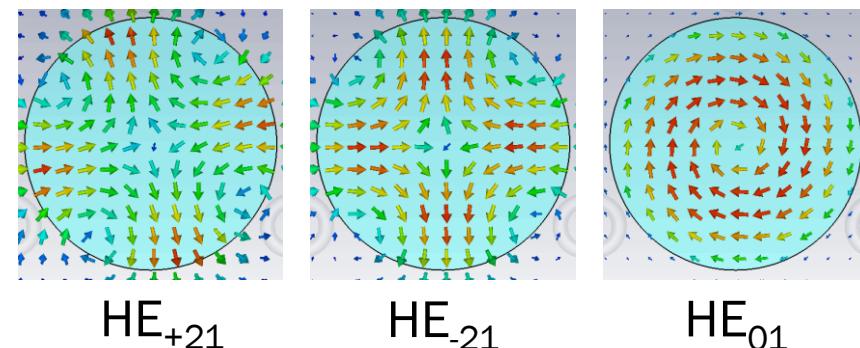


Identification of counter-rotating eigenmodes: H field mapping

Fundamental modes : HE₊₁₁ and HE₋₁₁

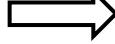


Upper Modes : HE₊₂₁, HE₋₂₁ and HE₀₁

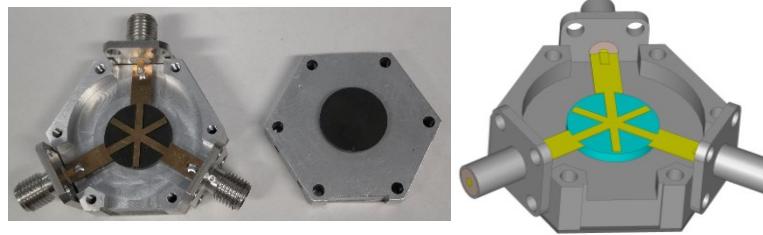


I. CONTEXT AND BIBLIOGRAPHY

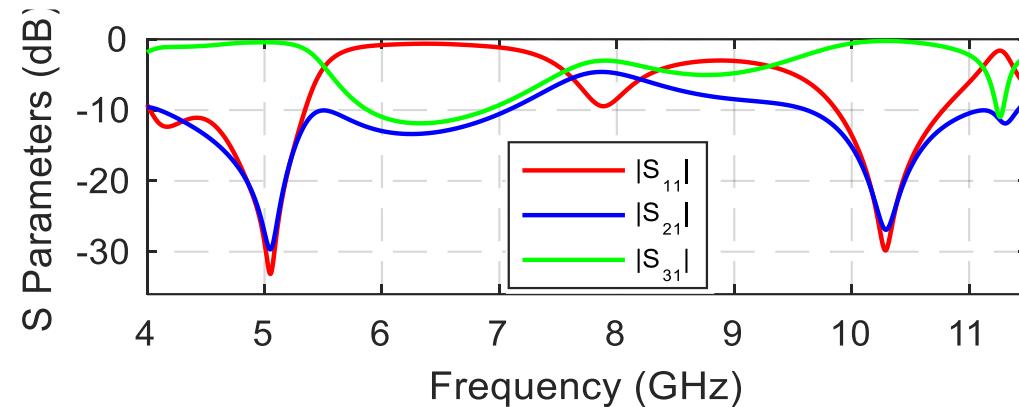
- Dual-band ferrite circulators in literature

2019  First proof of concept on stripline structure

2020  New methodology allowing the control of F2/F1 frequency ratio



5 and 10 GHz dual-band
ferrite circulator

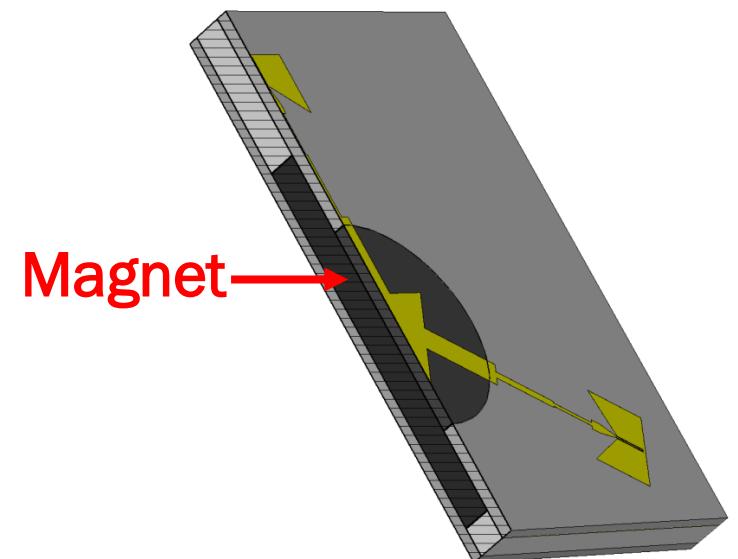
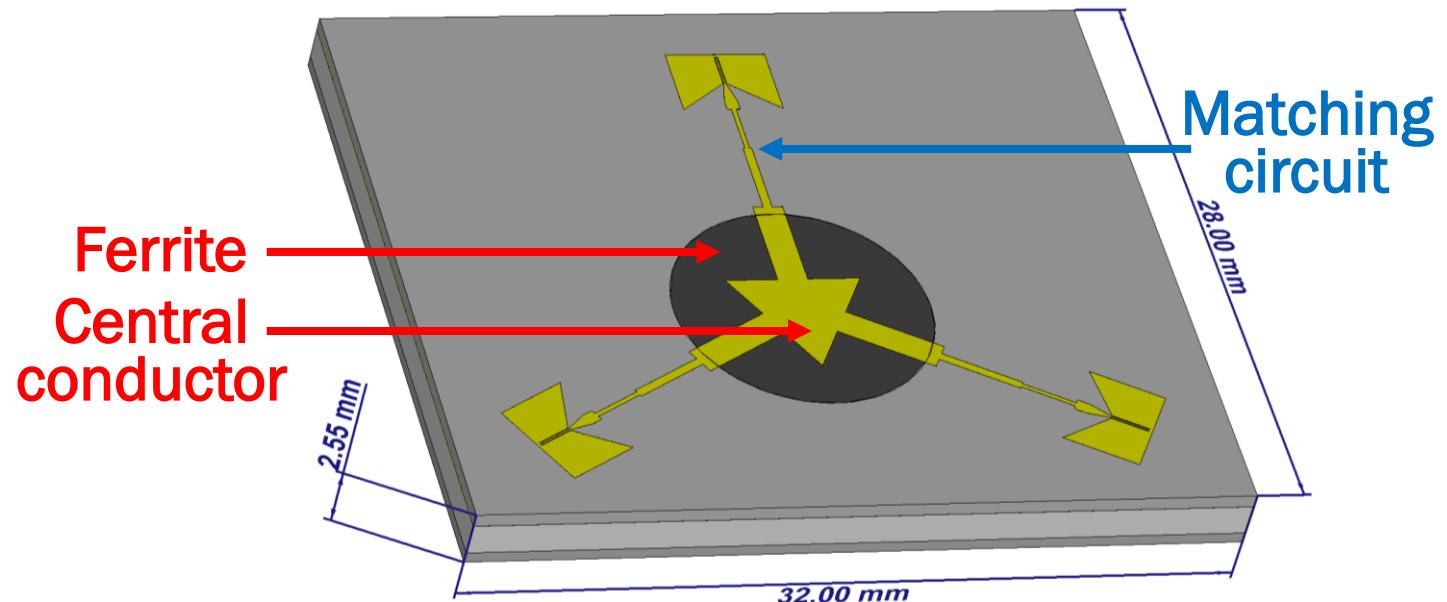
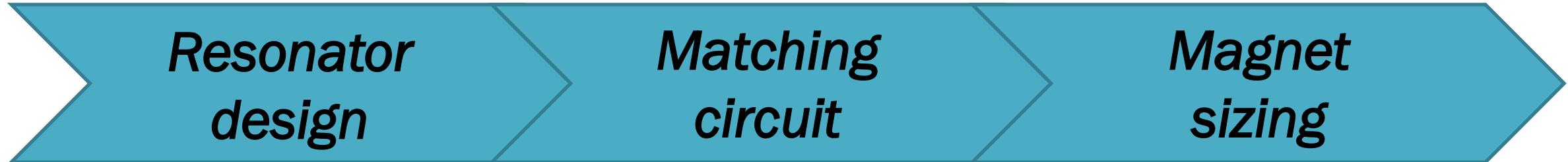


- New goal : Microstrip ferrite circulator

➤ Design and measure of a 5 and 10 GHz microstrip ferrite circulator

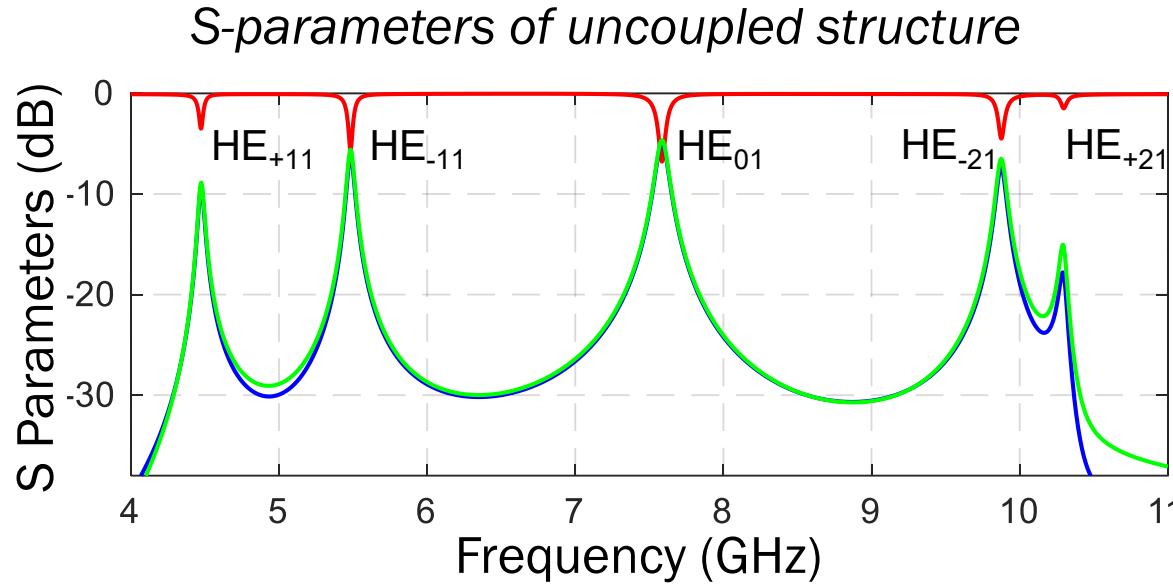
II. CIRCULATOR DESIGN

- Design steps



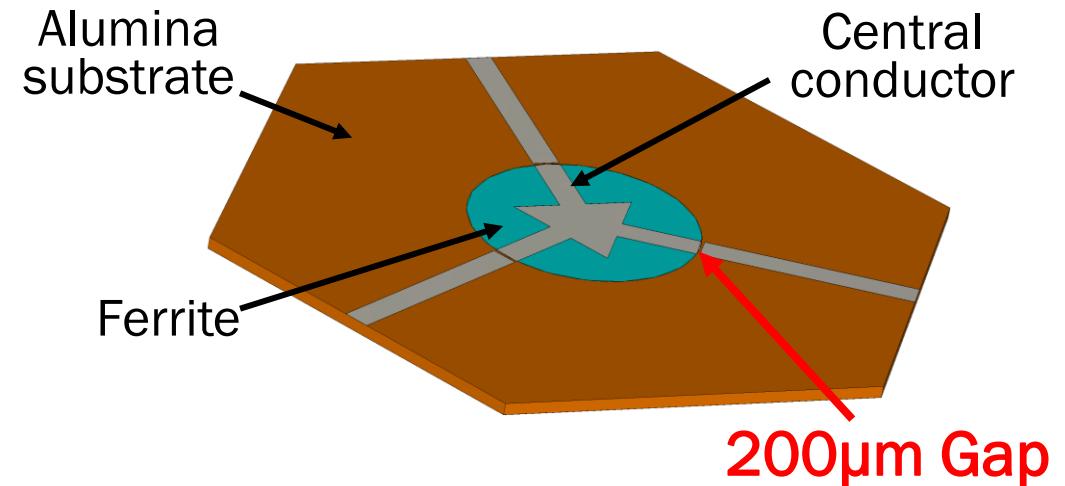
II. CIRCULATOR DESIGN

- Eigenmodes on microstrip ferrite cavities



- HE_{+11} modes around 5 GHz
- $\text{HE}_{\pm 21}$ modes around 10 GHz

Triangular central conductor

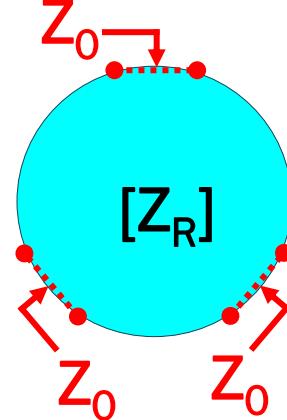


Ferrite Y210

$M_s = 1000 \text{ G}$, $\epsilon_r \text{ fer} = 14.2$;
 $R_{\text{fer}} = 5.35 \text{ mm}$; $H_i = 28 \text{ kA/m}$;
 $\epsilon_r \text{ sub} = 9.6$

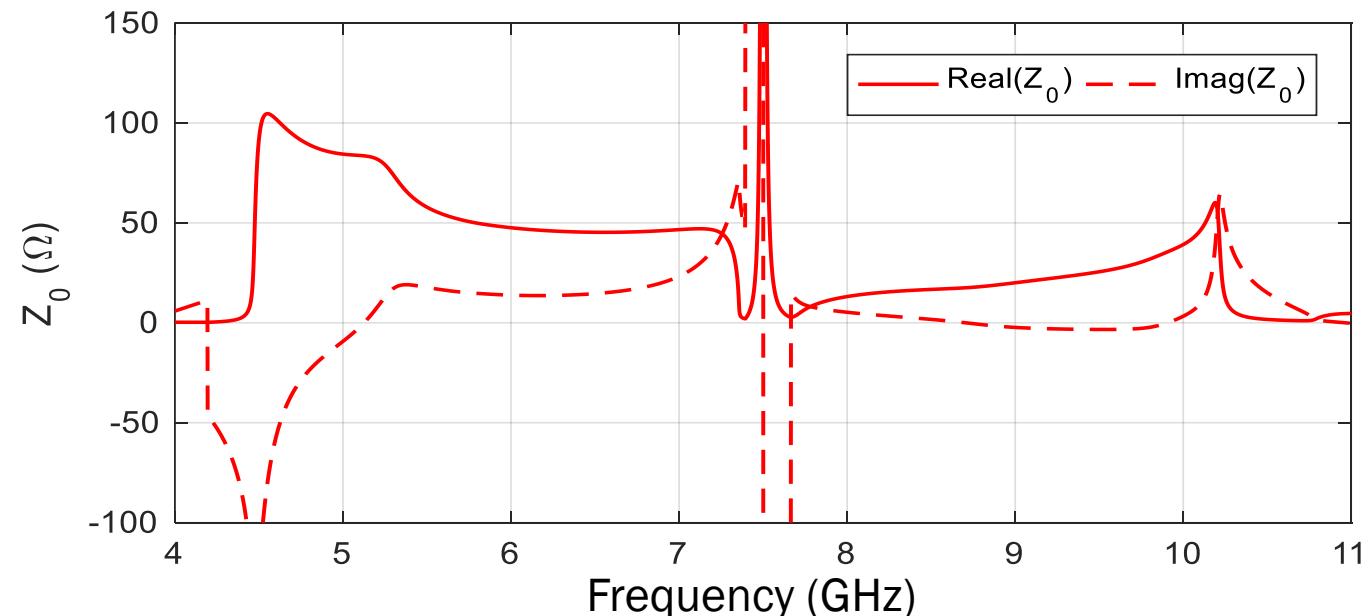
II. CIRCULATOR DESIGN

- Search for impedance to apply



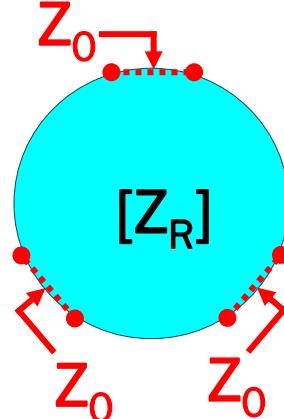
Following : V. Olivier et al., "General Coupling Method for Stripline Ferrite Circulators" *IEEE T-MTT*, Jul. 2022 :

$$0 = (-Z_0 - Z_{R11})^3 + 2Z_{R11}(-Z_0 - Z_{R11})^2 + Z_{R21}Z_{R31}(-Z_0 - Z_{R11}) + Z_{R21}^3 + Z_{R31}^3 - 2Z_{R11}Z_{R21}Z_{R31}$$



II. CIRCULATOR DESIGN

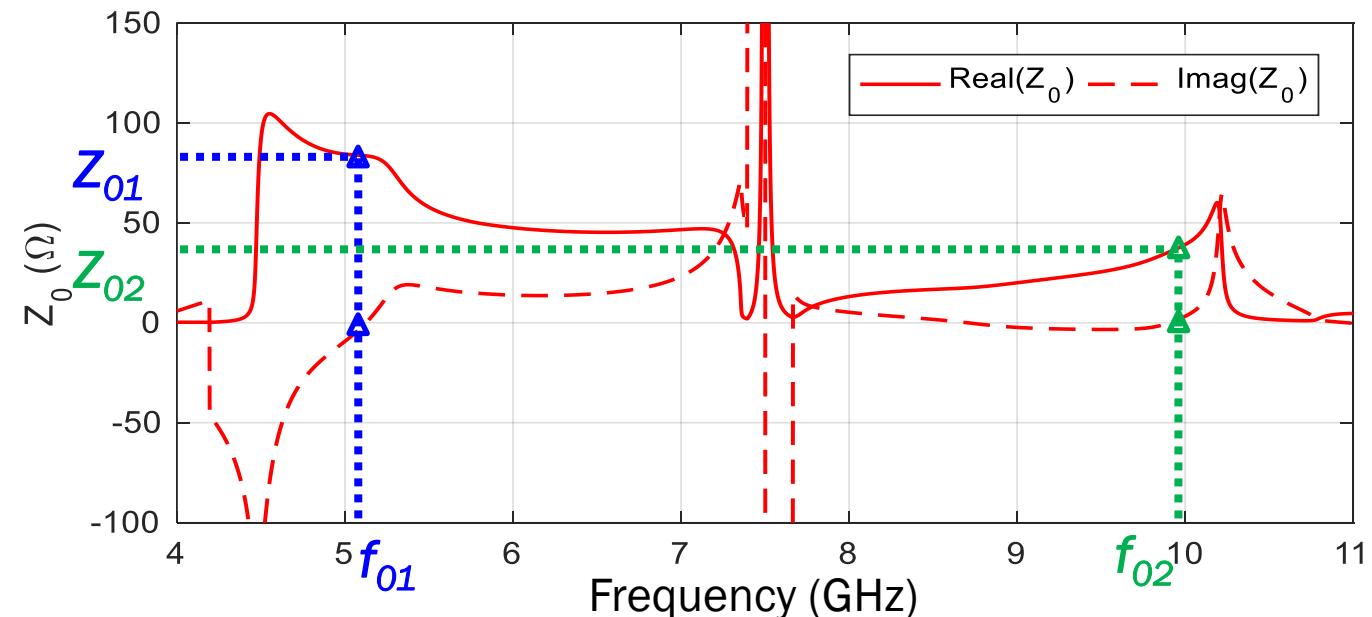
- Search for impedance to apply



Perfect circulation conditions reached if : $\Rightarrow \text{Imag}(Z_0) = 0$

Two identified solutions:

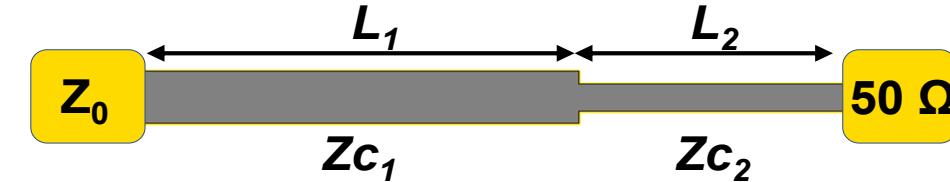
- $Z_{01} = 83\Omega$ at $f_{01} = 5.10$ GHz
- $Z_{02} = 37\Omega$ at $f_{02} = 9.95$ GHz



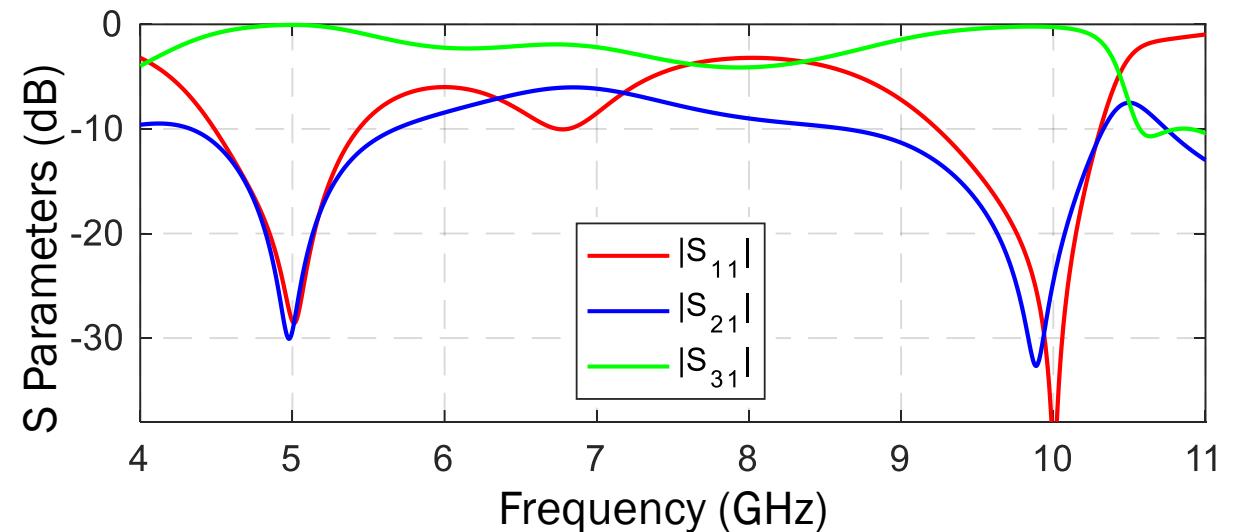
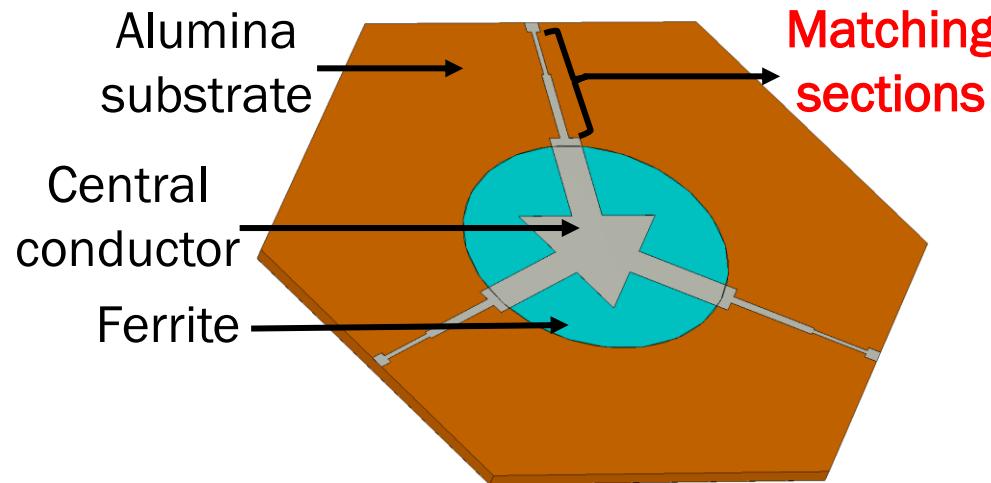
- Coupling and matching

To match from Z_0 to 50Ω : Two line sections

- $Z_{01} = 83\Omega$ at $f_{01} = 5.10$
- $Z_{02} = 37\Omega$ at $f_{02} = 9.95$

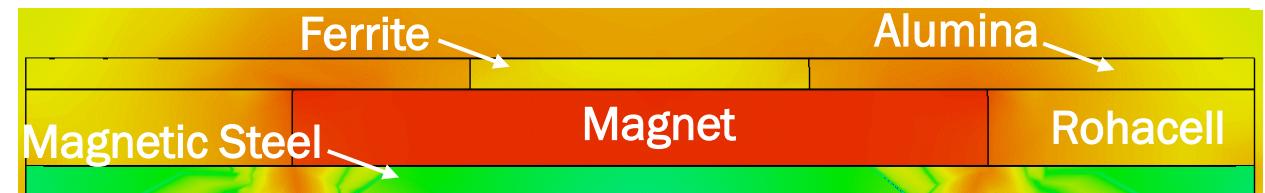
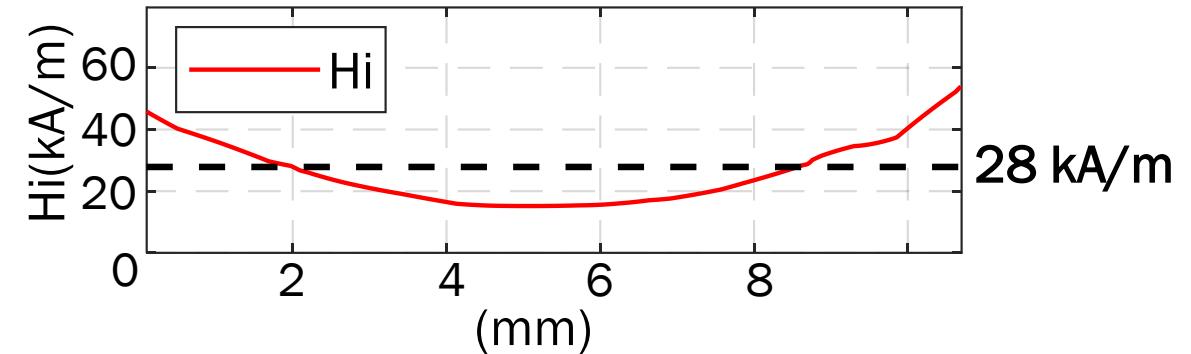
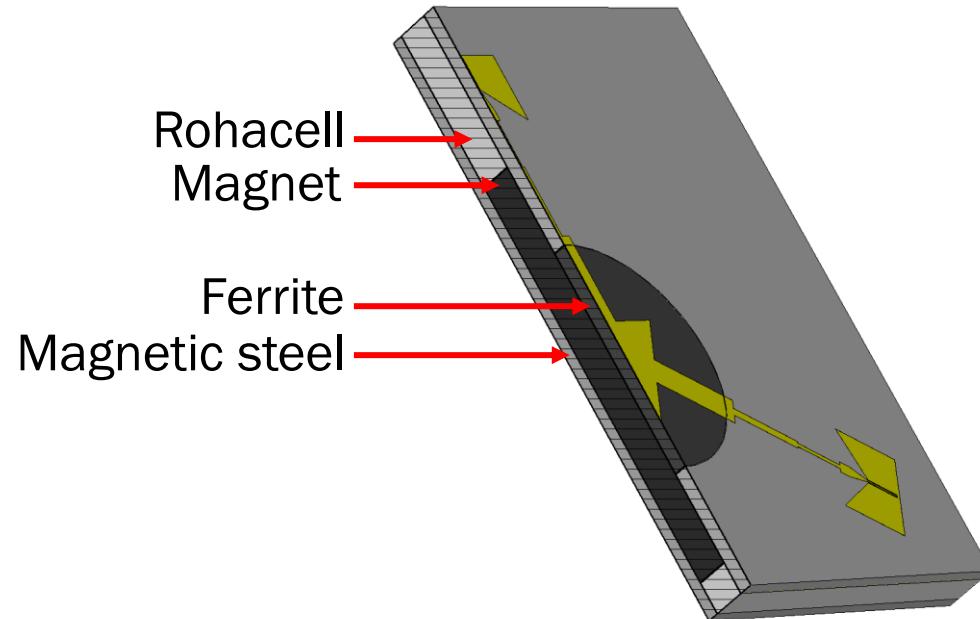


Circulator with matching sections:



- Magnetostatic study

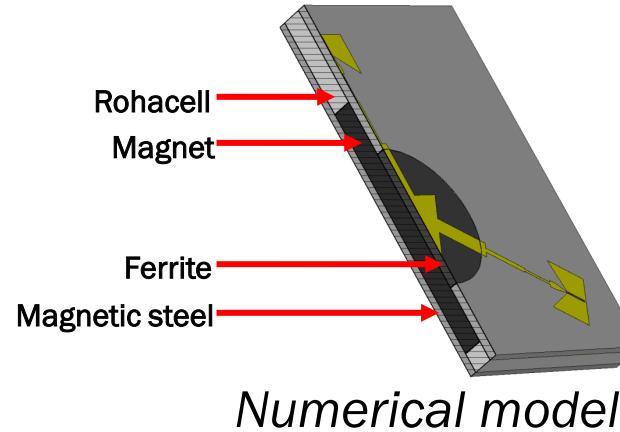
Goal of the study: Find the appropriate magnet to provide a magnetic field with good homogeneity and near 28kA/m inside ferrite



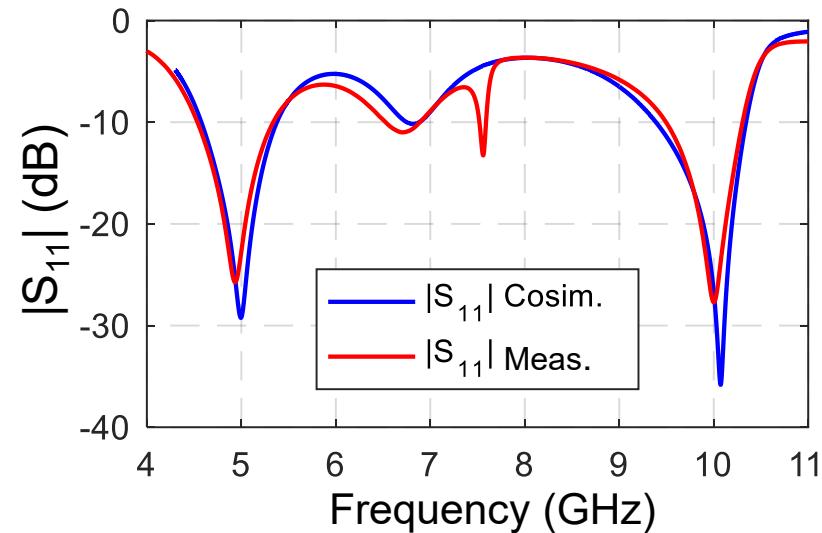
Magnet used :

- Composition : NdFeB
- Size : Radius 19,1mm, Thickness 1,45mm
- Field Br : 11600G

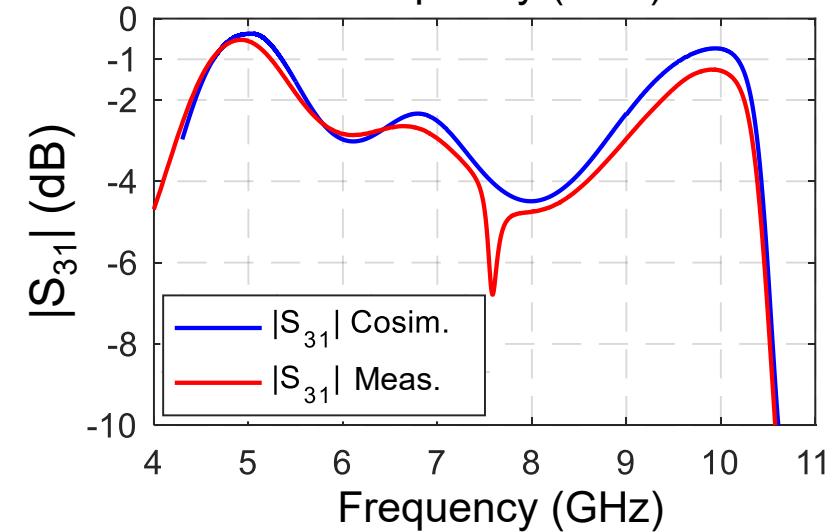
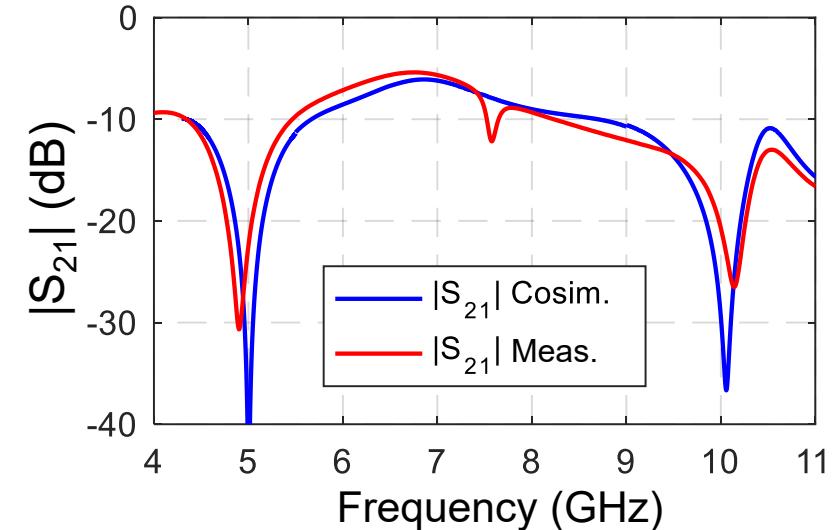
III. MEASUREMENTS



Metallization : Xlim clean room
Etching : LPKF ProtoLaser U4



GSG Probes measurement

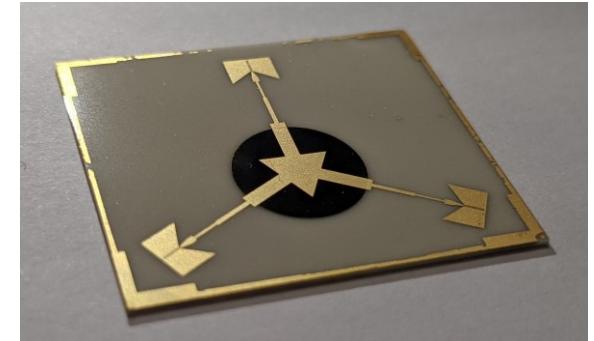


III. MEASUREMENTS

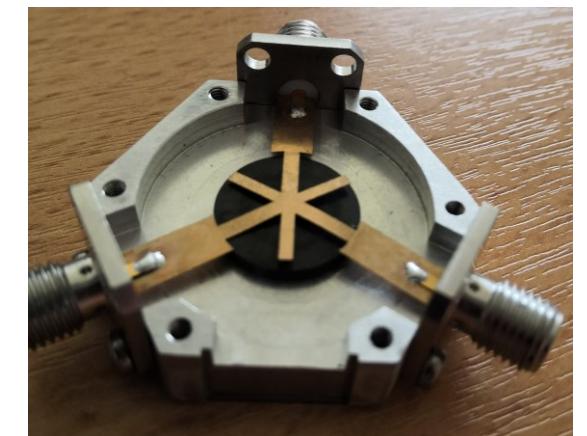
- Microstrip and stripline comparison

Circulator	Microstrip (this work)	Stripline (previous work)	
Central frequency	4,9 GHz	10.1 GHz	5,0 GHz
I.L. max (dB)	0,65	1,3	0,78
BW(%) (Iso >20dB)	5,5	2,8	4,0
Size (mm)	32*28*2,55	35*30*15	

- Comparable performance to stripline
- Size reduction



Composite substrate of the microstrip circulator



Bottom part of the stripline circulator (previous work)

IV. CONCLUSION

- Design and measurement of the first dual-band microstrip ferrite circulator
- Two chosen and controlled frequencies : 5 and 10 GHz
- Very good simulation/measurements agreement
- Comparable performances to stripline
- Better integration and dimensions



Thank you for your attention

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