# Characterization of a Metamaterial-Enabled Waveguide Diplexer for Ka-Band Satellite Communication Systems


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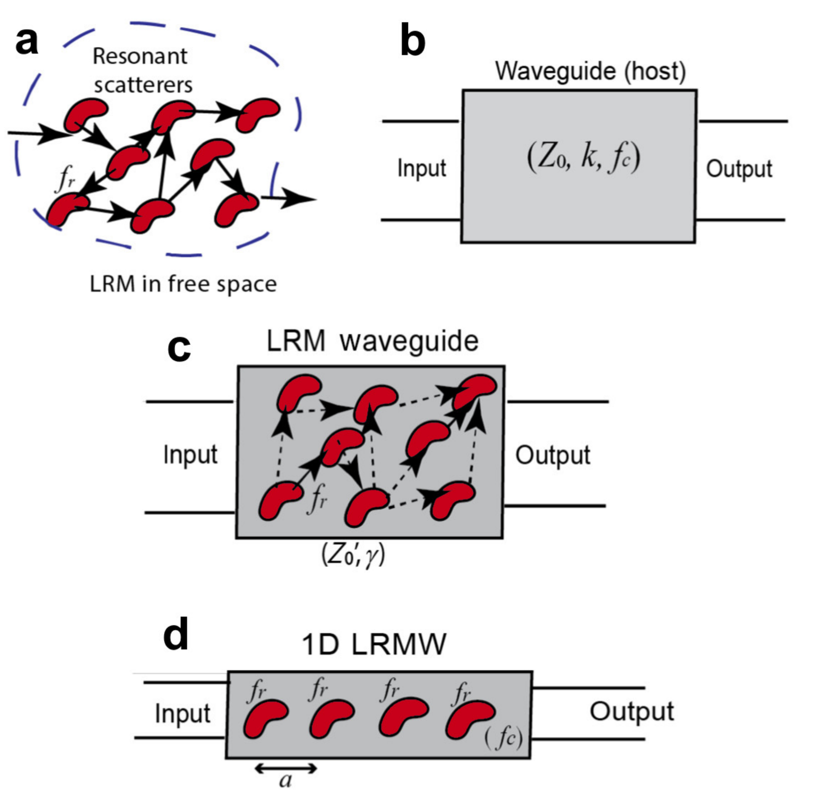
## Abstract

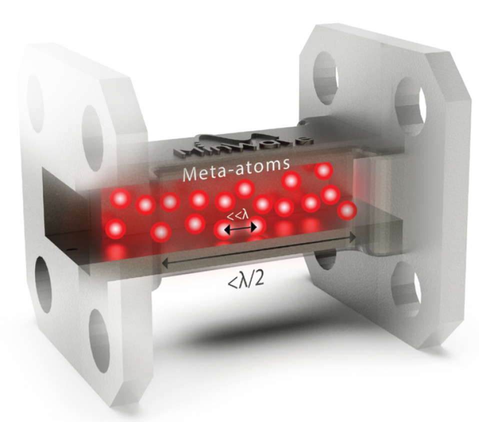

We present a novel **miniaturized metamaterial-enabled diplexer**, together with **measurement methodologies to characterize noncontiguous channels**, within a waveguide structure. The studied diplexer efficiently separates receive (17.3 – 20.2 GHz) and transmit (27 – 31 GHz) Ka-band satellite communication channels utilizing a design approach that integrates **locally resonant metamaterials (LRMs) and an evanescent mode junction**. This integration allows for high rejection and low loss in an ultra-small volume, effectively showcasing the capabilities of the diplexer. We precisely measure the passband and stopband of both the receive and transmit channels and compare the results with simulations.


## Metamaterial Filters

(a) Locally resonant metamaterials consist of **electrically small resonators** placed with sub-$\lambda$ separations
(b) A standard waveguide with $Z_0$, $k$, $f_c$ is used as a host
(c) Scattering of incident fields induce an opposing phase shift and lead to the formation of a **hybridization bandgap (HBG)** in a waveguide below cutoff [1], [2]
(d) Simplified structure as a 1D periodic array




*Concept of locally resonant metamaterial waveguides (LRMWs), reproduced from [1]*




*Schematic representation of an LRM waveguide host*

## Further Reading

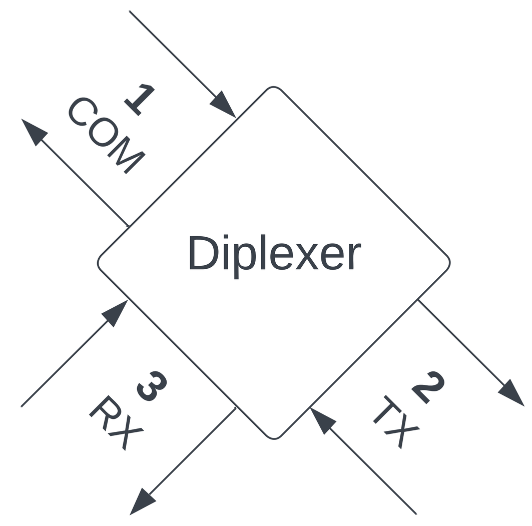
This work was developed on the basis of a Master's thesis at École Polytechnique Fédérale de Lausanne (EPFL), Switzerland, consult the full report:

*R. F. Bonny "RF Measurements of Unconventional Miniaturised Filters and Diplexers"*
`https://infoscience.epfl.ch/record/306796`

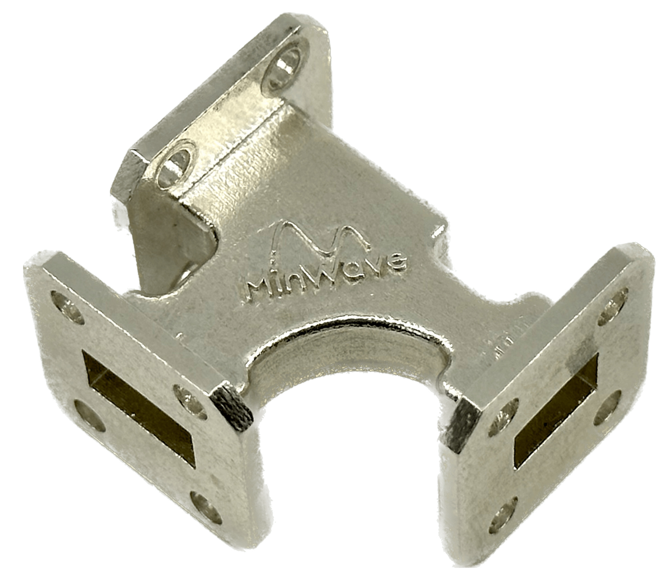
## Diplexer Overview

| Parameter | RX passband | TX passband |
|---|---|---|
| Peak amplitude | -0.26 dB | -0.32 dB |
| Peak frequency | 18.53 GHz | 29.01 GHz |
| 1 dB bandwidth | 3.83 GHz | 4.47 GHz |
| Lower freq. bound | 17.19 GHz | 27.45 GHz |
| Upper freq. bound | 21.02 GHz | 31.92 GHz |
| Typical insertion loss | 0.64 dB | 0.58 dB |
| Rejection | 68.48 dB | 67.91 dB |
| RX/TX isolation | 66.34 dB | 64.61 dB |

*Properties of the measured diplexer*




*Port numbering scheme and nomenclature*



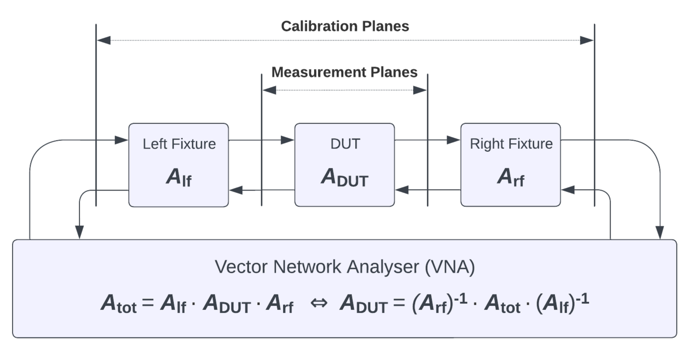
*Fabricated diplexer prototype*

## Methods & Techniques

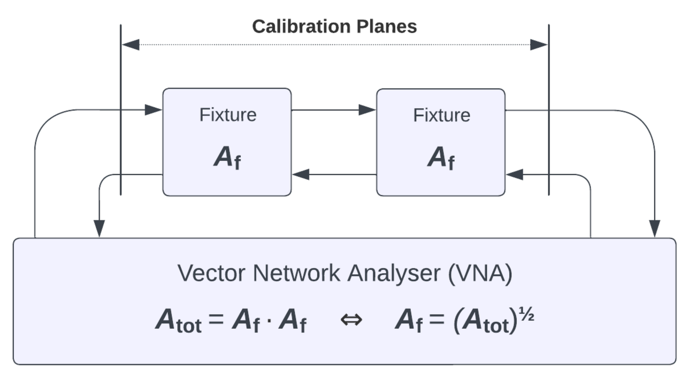
Three major measurement challenges were addressed: **multi-port networks** (measuring a three-port device in a two-port measurement setup), **non-standard flanges** (adapting proprietary waveguide dimensions to standardized values), and **asymmetric networks** (different waveguide dimensions for different ports).

### De-Embedding & Unterminating

- To isolate the DUT, the contribution of the **test structure must be de-embedded** [3]
- The $S$-parameters of the test structure can be determined via a **2x-thru measurement** [4]



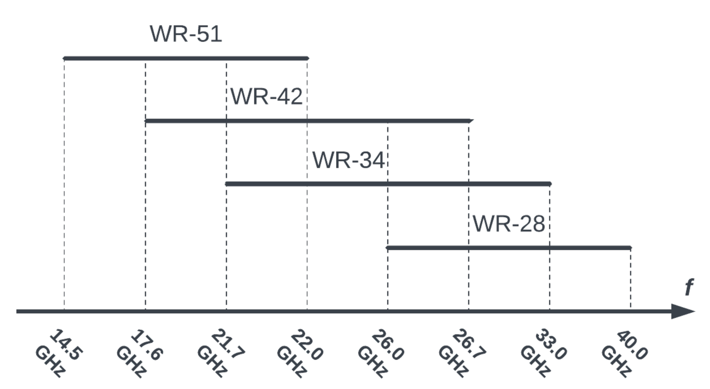

*De-embedding measurement with DUT*




*Unterminating with 2x-thru measurement*

### Frequency Fusion

- Using multiple waveguide standards requires frequency fusion techniques
- The embedding structure must be properly characterized for each employed waveguide
- **Continuity of measurements** indicate proper calibration
- Overlapping regions are combined via **geometric means** across measurements




*Waveguide operating frequency ranges*

### Port Augmentation

- Integrating a three-port device into a two-port measurement setup requires **proper termination**
- Appropriate techniques include **impedance renormalization** [5] and **wave identification** [6]
- The diplexer can be simplified by taking advantage of the port isolation

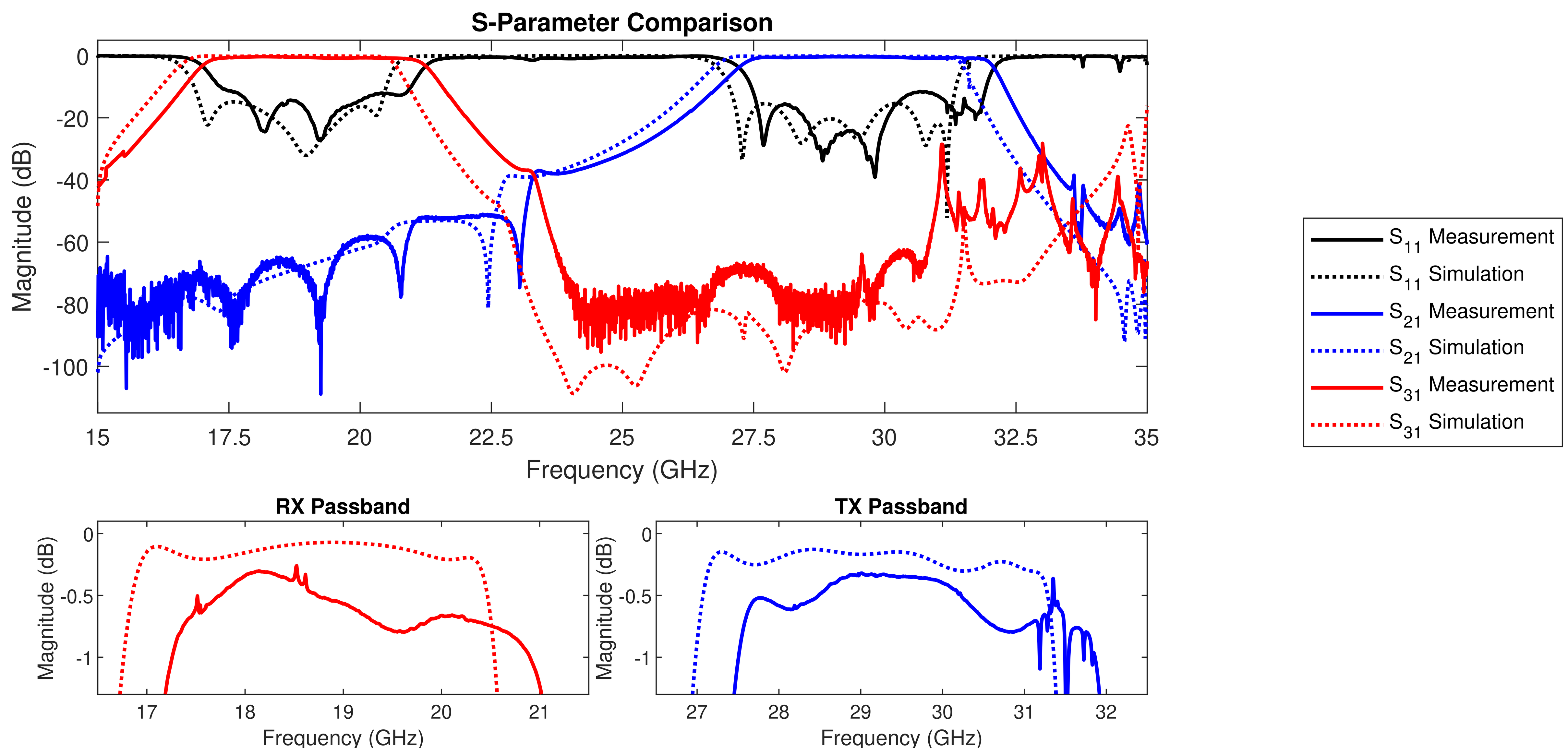
$$\begin{bmatrix} \cdot \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} \cdot & \cdot & \cdot \\ \cdot & S_{22} & S_{23} \\ \cdot & S_{32} & S_{33} \end{bmatrix} \begin{bmatrix} \cdot \\ a_2 \\ a_3 \end{bmatrix} \quad \text{Port 1 terminated}$$

$$\begin{bmatrix} b_1 \\ \cdot \\ b_3 \end{bmatrix} = \begin{bmatrix} S_{11} & \cdot & S_{13} \\ \cdot & \cdot & \cdot \\ S_{31} & \cdot & S_{33} \end{bmatrix} \begin{bmatrix} a_1 \\ \cdot \\ a_3 \end{bmatrix} \quad \text{Port 2 terminated}$$

$$\begin{bmatrix} b_1 \\ b_2 \\ \cdot \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdot \\ S_{21} & S_{22} & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \cdot \end{bmatrix} \quad \text{Port 3 terminated}$$

$$\Rightarrow \begin{bmatrix} S_{11}|S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22}|S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33}|S_{33} \end{bmatrix}$$

## Measurements




*Comparison between processed measurements and simulation results*

## References


[1] M. K. Moghaddam and R. Fleury, "Subwavelength Meta-Waveguide Filters and Meta-Ports," *Physical Review Applied*, 2021. DOI: `10.1103/PhysRevApplied.16.044010`.
[2] M. K. Moghaddam and R. Fleury, "Slow light engineering in resonant photonic crystal line-defect waveguides," 2019. DOI: `10.1364/OE.27.026229`.
[3] R. Bauer and P. Penfield, "De-Embedding and Unterminating," 1974. DOI: `10.1109/TMTT.1974.1128212`.
[4] H. Barnes and J. Moreira, "Verifying the accuracy of 2x-Thru de-embedding for unsymmetrical test fixtures," 2017. DOI: `10.1109/EPEPS.2017.8329760`.
[5] J. Tippet and R. Speciale, "A Rigorous Technique for Measuring the Scattering Matrix of a Multiport Device with a 2-Port Network Analyzer," 1982. DOI: `10.1109/TMTT.1982.1131118`.
[6] I. Rolfes and B. Schiek, "Multiport method for the measurement of the scattering parameters of N-ports," 2005. DOI: `10.1109/TMTT.2005.848823`.