Design and Demonstration of Integrated Passive Components Test Vehicle for 5G and mm-Wave Applications

Students: Muhammad Ali, Atom Watanabe, Tong-Hong Lin
Faculty: Prof. Raj Pulugurtha, Prof. Manos Tentzeris, Prof. Rao. R. Tummala, Prof. M. Swaminathan
Industry Partners: Samsung, Qualcomm, AGC, Ajinomoto, Taiyo, Corning

Goals and Objectives

Model, design, fabricate and characterize high-performance, miniaturized and integrated passive components for 5G and mm-wave applications (28 and 39 GHz bands) with next generation of package substrates such as laminated glass

- Filters and Power Dividers
- Diplexers and Couplers

The research objectives for diplexers are given below:

	Objectives	Prior Art	Challenges	Tasks to Address Challenges
Task-1: Design	• Filter Design: Doubly-Terminated • Passband: <3 dB • Return Loss: <15 dB	• Filter Design: Singly-Terminated	• Design doubly-terminated filters and configure them as diplexers	• Design filters to achieve lower in-band insertion loss and higher out-of-band rejection using advanced structures and high-Q resonators • Achieve optimum trade-off between filter performance and footprint in simulation. Optimize for diplexer design
Task-2 Miniaturization	• Overall Size: $<0.5\lambda_0^2$	• Overall Size: $>2\lambda_0^2$	• Precise linespace features required for excellent model-to-hardware correlation	• Achieve optimum tradeoff between process capability, footprint and performance

Prior Work

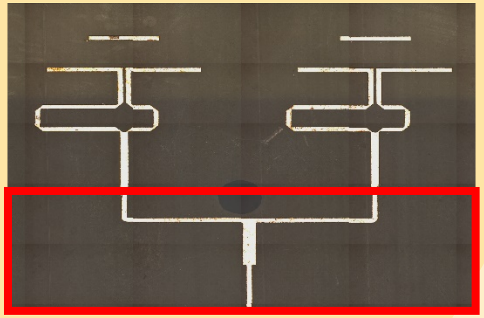
Power Dividers for 28 GHz 5G band

Objectives: Model, design, fabricate and characterize power dividers with small footprint for 5G and mm-wave applications on advanced materials such as glass.

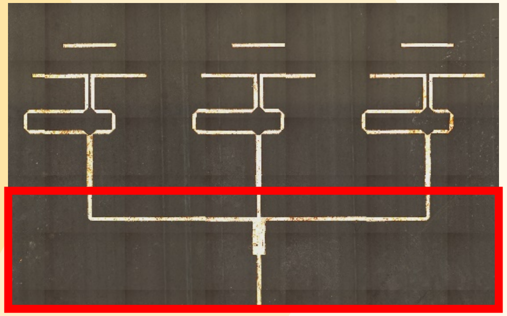
Results: Power Dividers configured as Yagi-Uda antenna arrays are demonstrated in two equal-split ratios: two- and three-way with corresponding antenna arrays

- Added insertion loss of 0.45-dB for two-way and 0.65-dB for three-way T-Junction based power dividers with return loss <15-dB in the passband
- Two-way power divider has a footprint smaller than $<\lambda_0 \times \lambda_0$ with just 147-μm z-height.

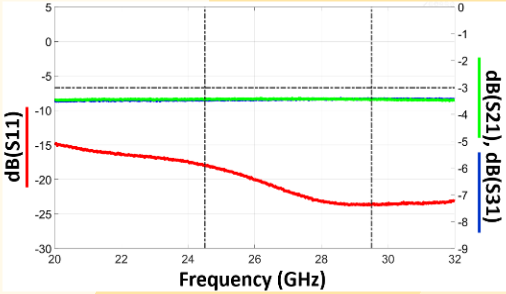
Two-way Power Divider



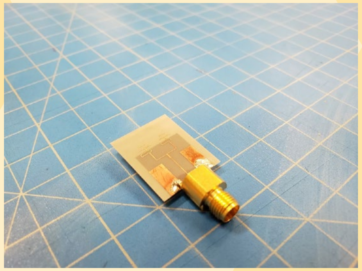
Three-way Power Divider



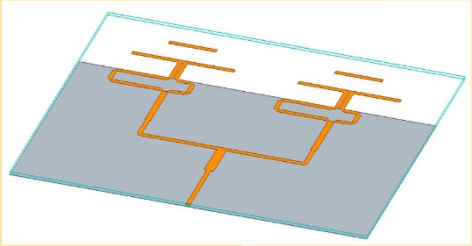
S-Parameters – Two-Way Power Divider



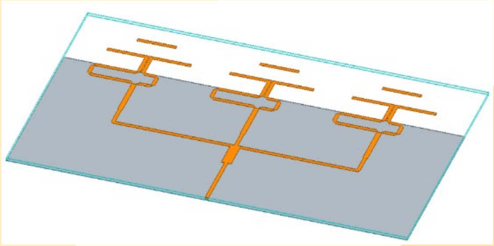
Fabricated Coupon with SMA Connector



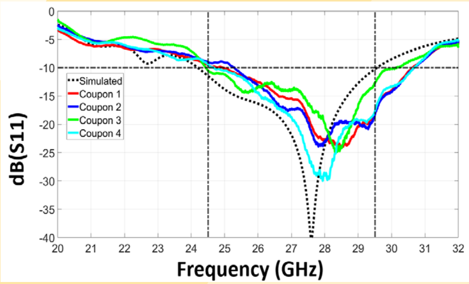
2×1 Antenna Array



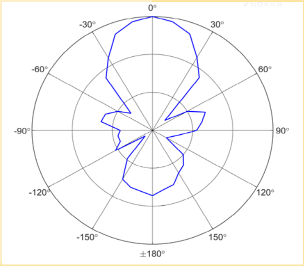
3×1 Antenna Array



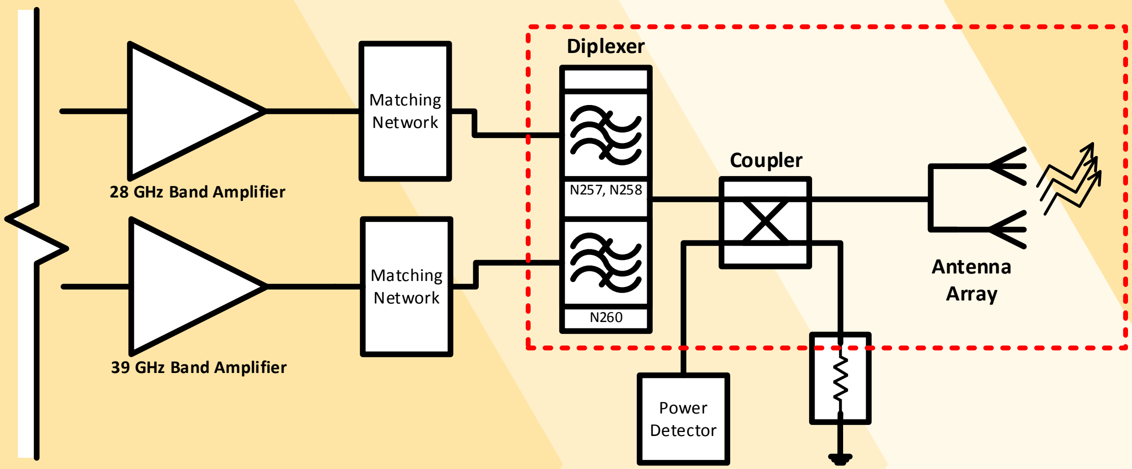
S-Parameters – 2×1 Antenna Array

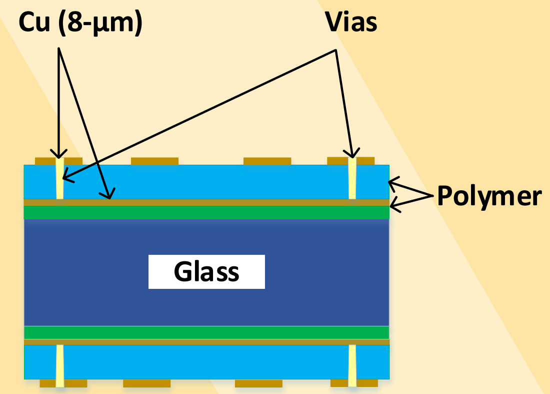


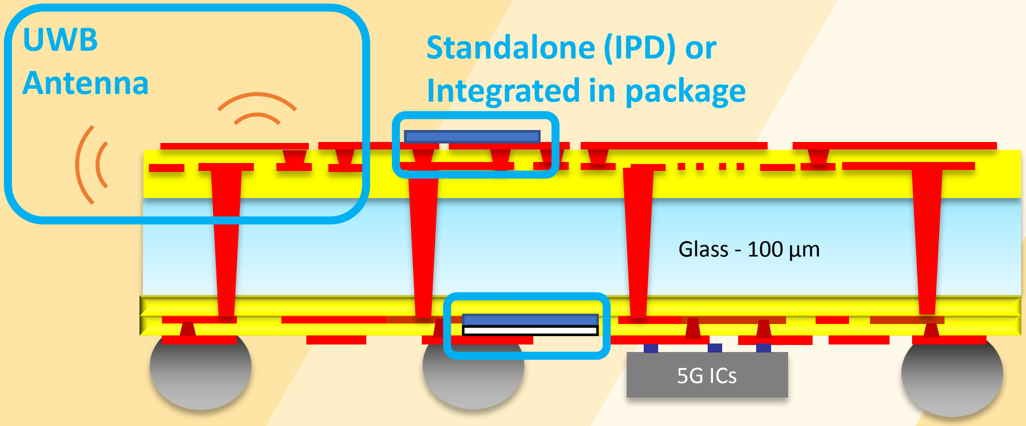
Measured Radiation Pattern - 2×1 Antenna Array



Technical Approach







Layer	Details
M4 (Top)	Microstrip Passive Components
Dielectric-4	Taiyo Zaristo (71-µm)
M3	GND, Via Antipads, Dicing Clearance
Dielectric-3	Taiyo Zaristo (15-µm)
Core-Glass	AGC EN-A1 (100-µm)
Dielectric-2	Taiyo Zaristo (15-µm)
M2	GND, Via Antipads, Dicing Clearance
Dielectric-1	Taiyo Zaristo (71-µm)
M1 (Bottom)	Microstrip Passive Components

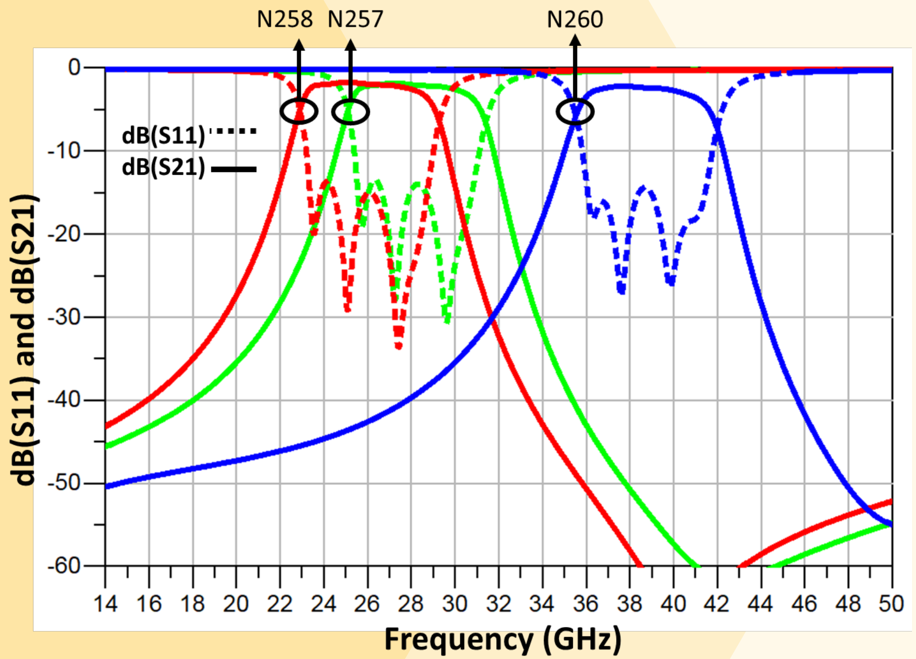
Results & Key Accomplishments

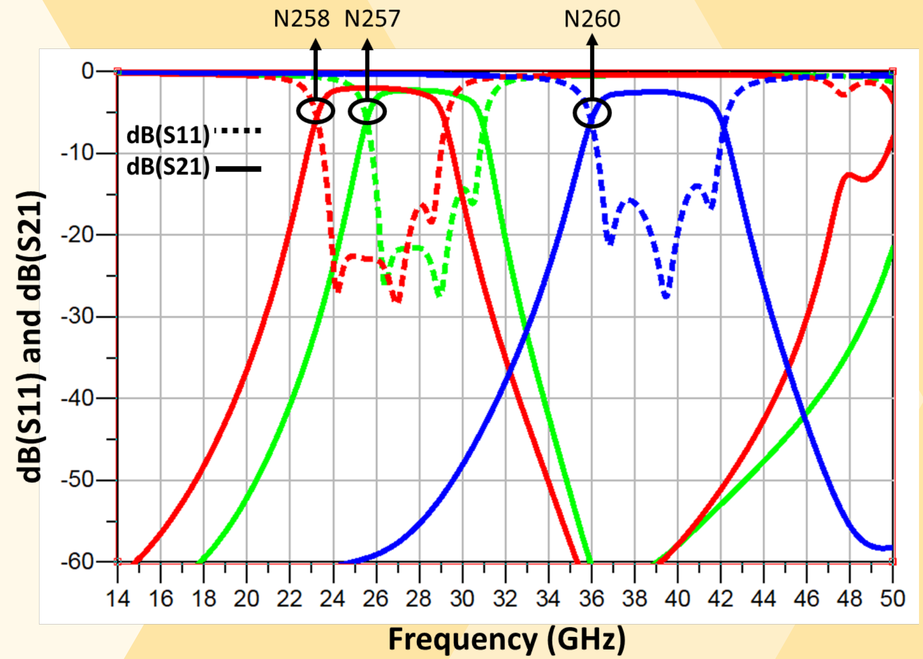
List of Structures

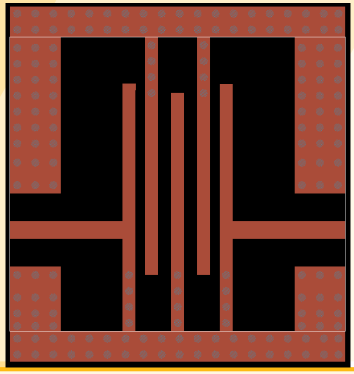
- Band Filters (5th Order)
  - Hairpin and Interdigital for band N257 (26.50-29.50 GHz, 10.71%), N258 (24.25-27.50 GHz, 12.6%) and N260 (37.00-40.00 GHz, 7.8%)
- Diplexer
  - Hairpin and Interdigital N257 & N260
  - Hairpin and Interdigital N258 & N260
- Couplers covering 24.25-40.00 GHz
  - Branch-Line
  - Coupled-Line

Results

Band Filters – Interdigital and Hairpin

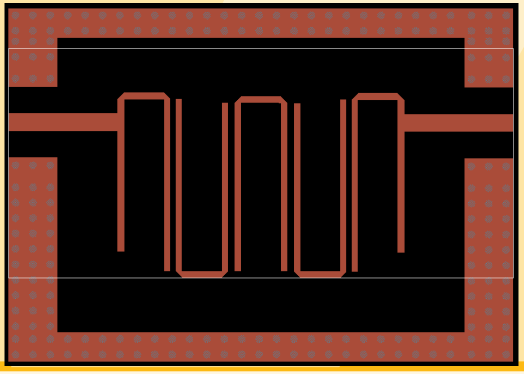






<u>Maximum in-band Insertion Loss</u>

Interdigital and Hairpin: 2.7 dB

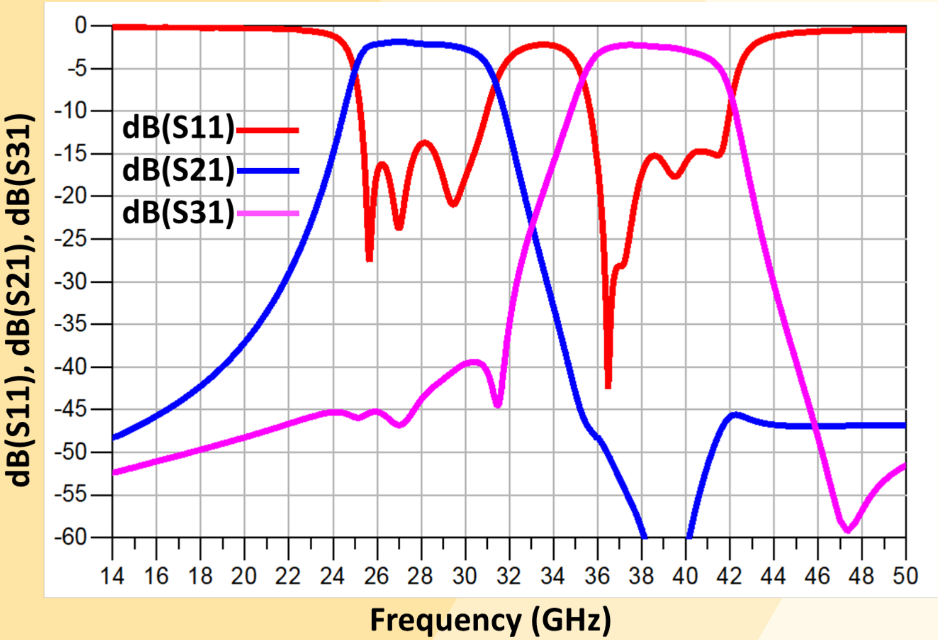


Results (Cont'd)

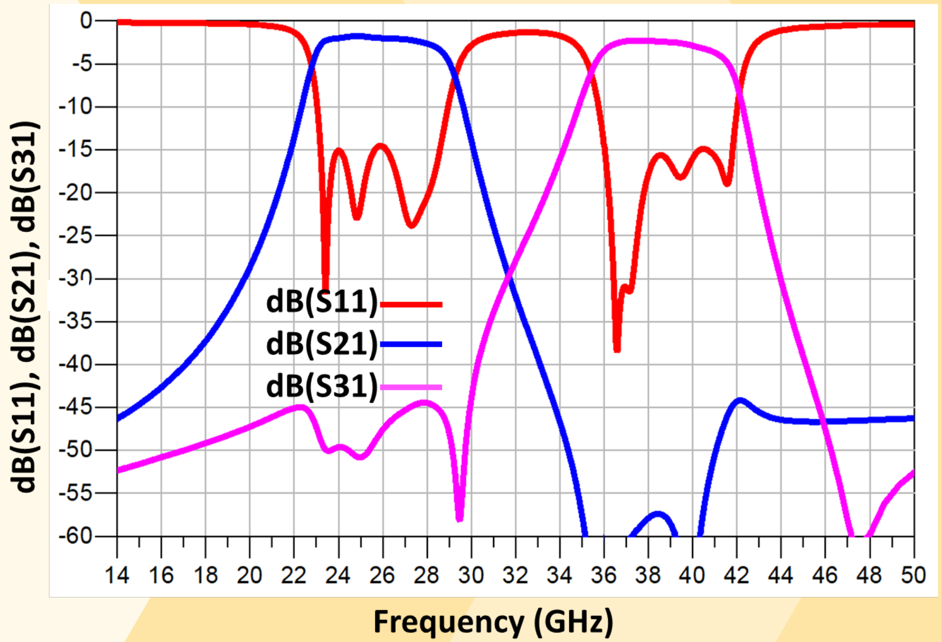
Diplexers using Interdigital Filters

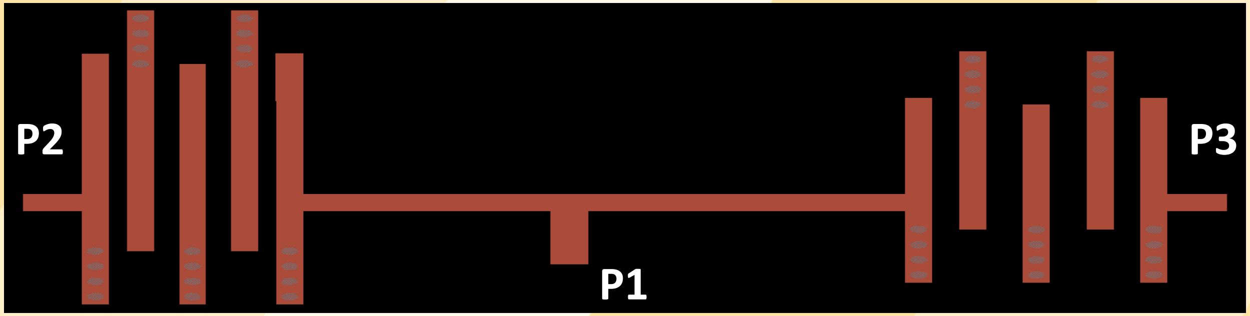
Maximum in-band Insertion Loss: 3.0 dB

N257 and N260



N258 and N260



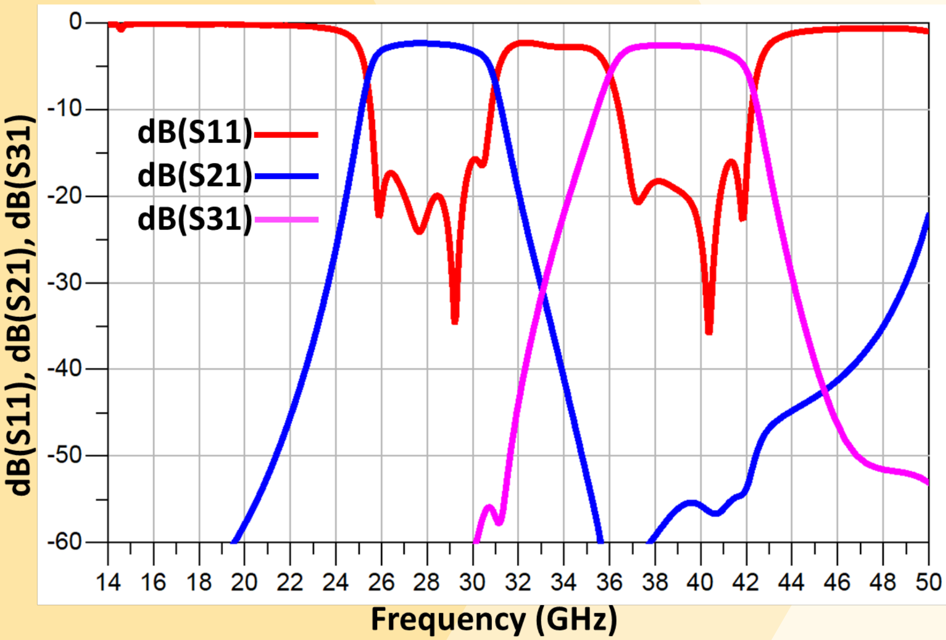


Results (Cont'd)

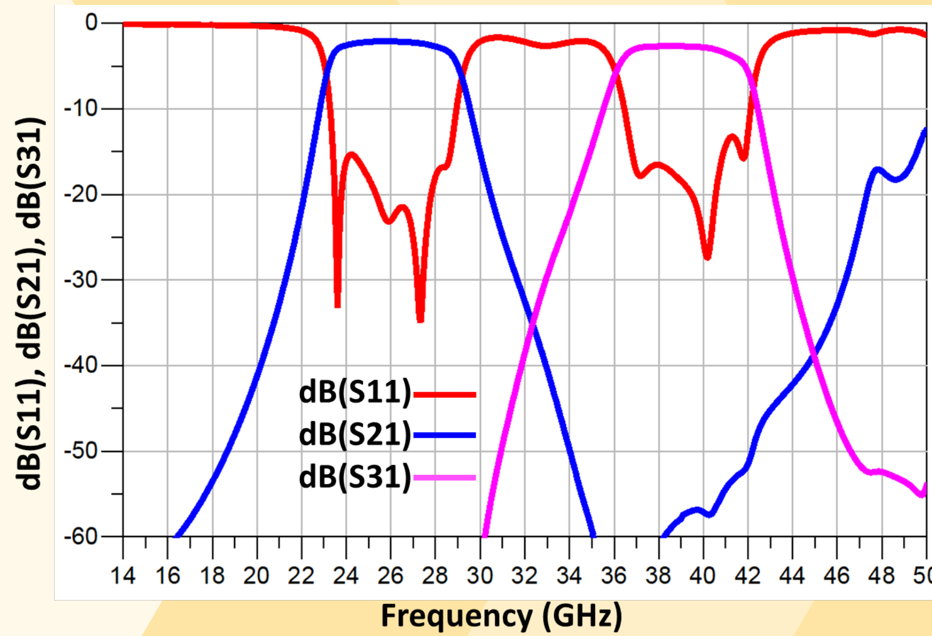
Diplexers using Hairpin Filters

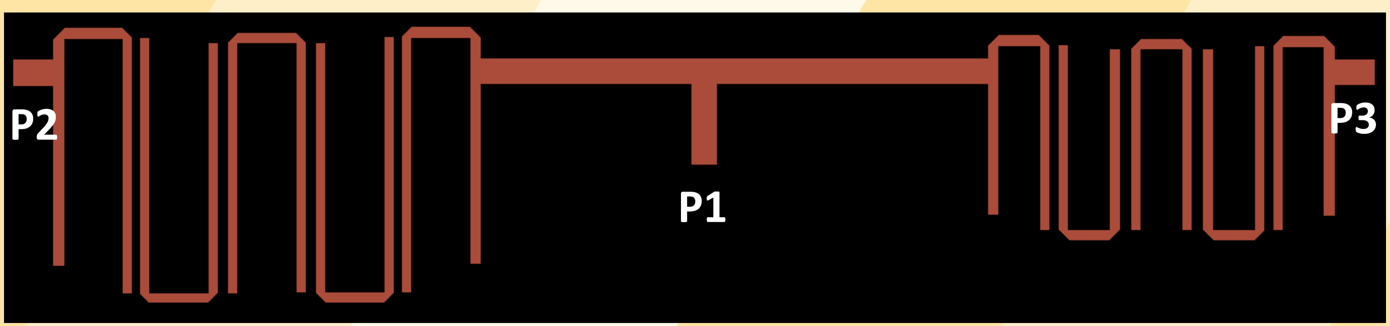
Maximum in-band Insertion Loss: 2.9 dB

N257 and N260



N258 and N260

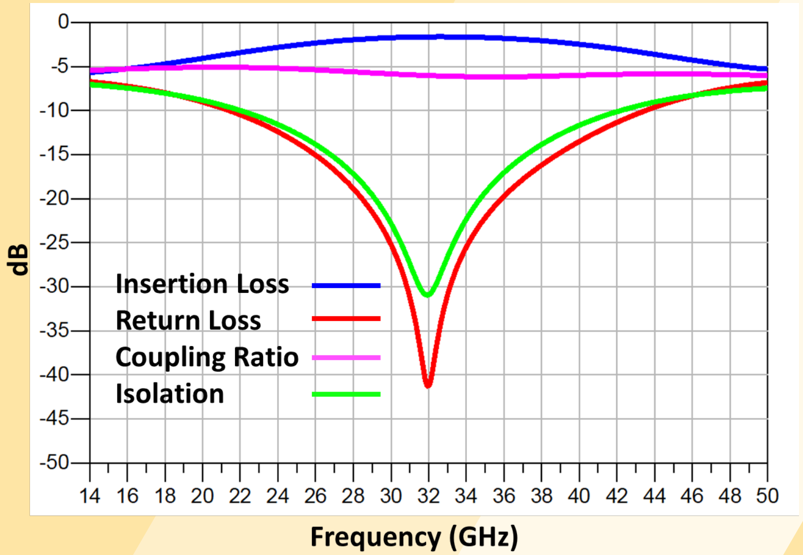




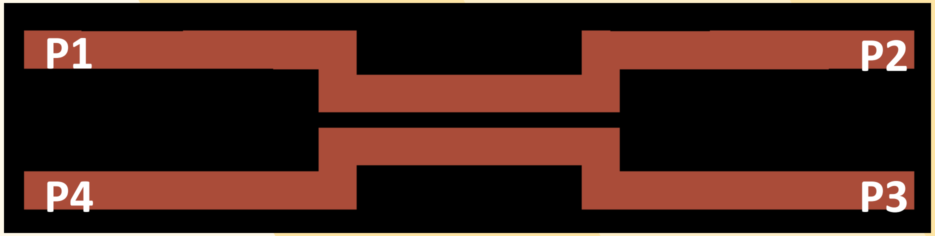
Results (Cont'd)

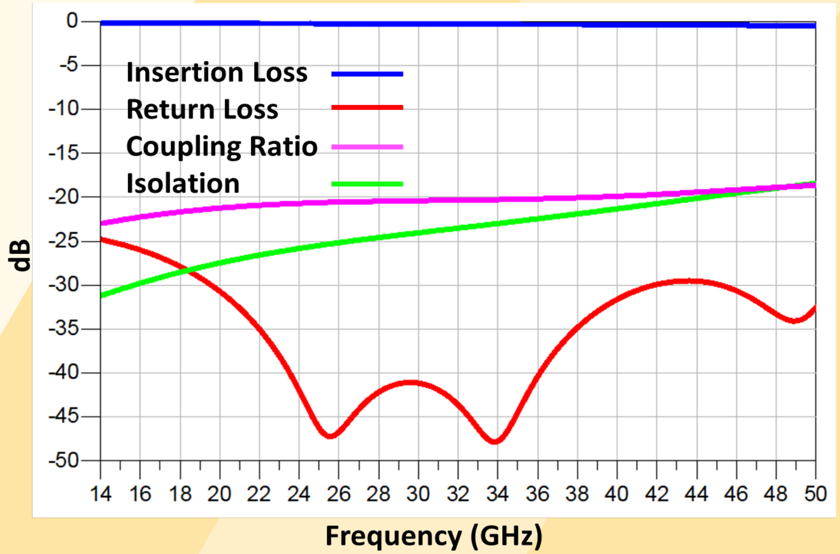
Couplers

6-dB Branch-Line Coupler



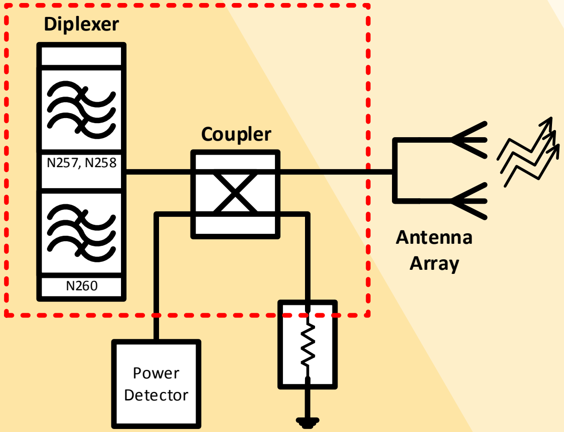
20-dB Coupled-Line Coupler

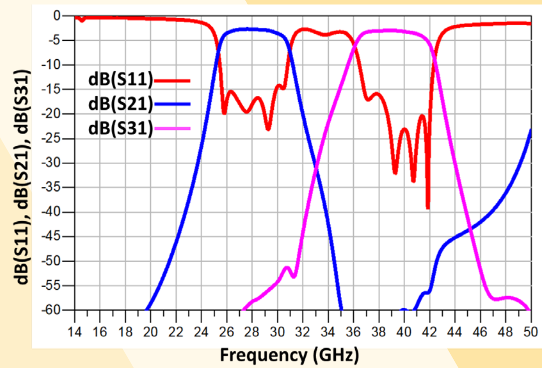


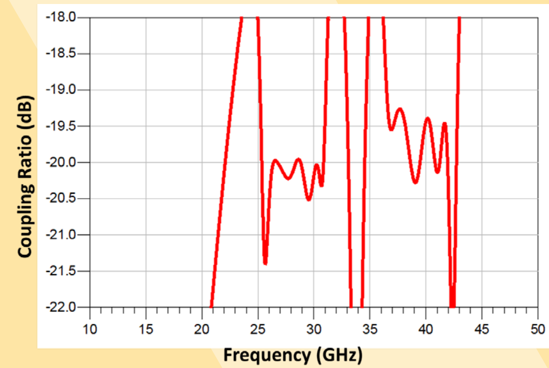


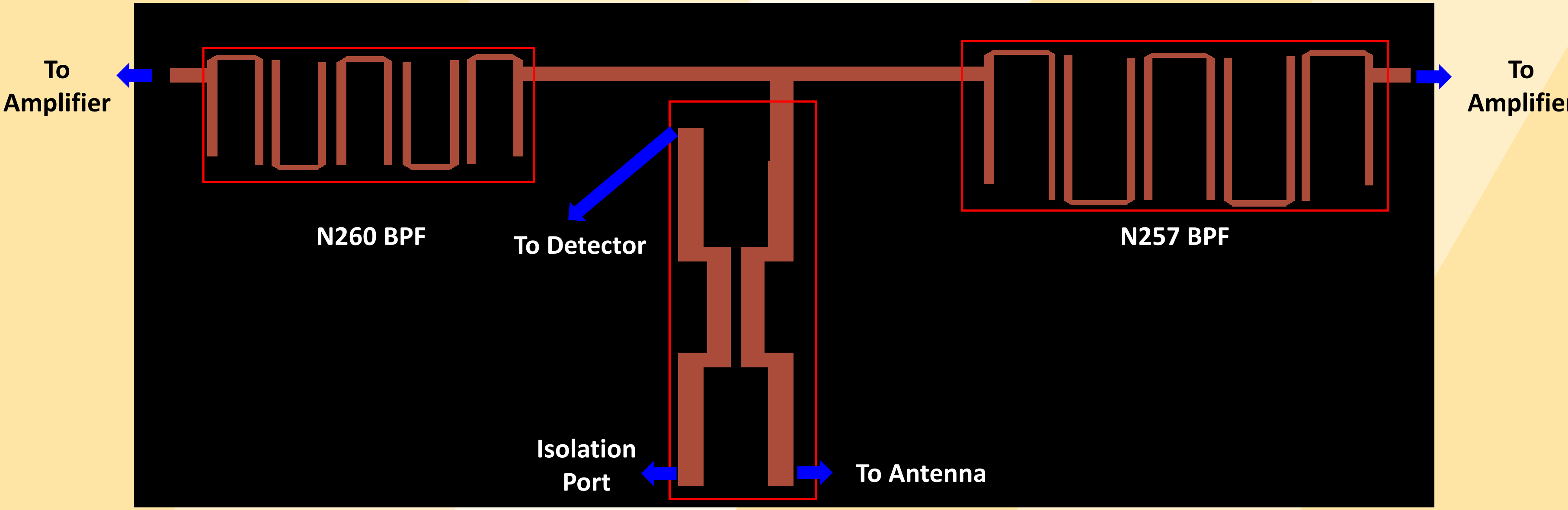
Results (Cont'd)

Layout









Results (Cont'd)

Design-level Dimensional Analysis

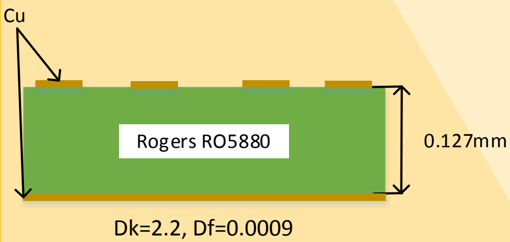
Structure	Physical Dimensions (mm^3)	Electrical Dimensions (λ_0^3)
Hairpin Filter for N257	4.64×2.11×0.202	0.43×0.20×0.019
Hairpin Filter for N258	4.75×2.20×0.202	0.44×0.21×0.019
Hairpin Filter for N260	4.14×1.72×0.202	0.54×0.22×0.026
Interdigital Filter for N257	2.98×2.62×0.202	0.28×0.34×0.019
Interdigital Filter for N258	2.94×2.76×0.202	0.27×0.26×0.019
Interdigital Filter for N260	3.12×2.17×0.202	0.41×0.28×0.026
Diplexer - Hairpin N257 & N260	8.42×1.70×0.202	0.90×0.18×0.022
Diplexer - Hairpin N258 & N260	8.71×2.02×0.202	0.93×0.22×0.022
Diplexer - Interdigital N257 & N260	5.09×2.62×0.202	0.54×0.28×0.022
Diplexer - Interdigital N258 & N260	5.10×2.77×0.202	0.55×0.30×0.022
Branch-Line Coupler	4.24×1.86×0.202	0.45×0.20×0.022
Coupled-Line Coupler	3.91×0.78×0.202	0.42×0.08×0.022

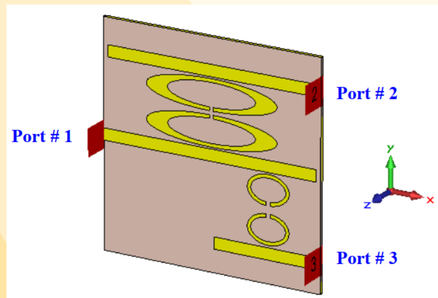
Note:

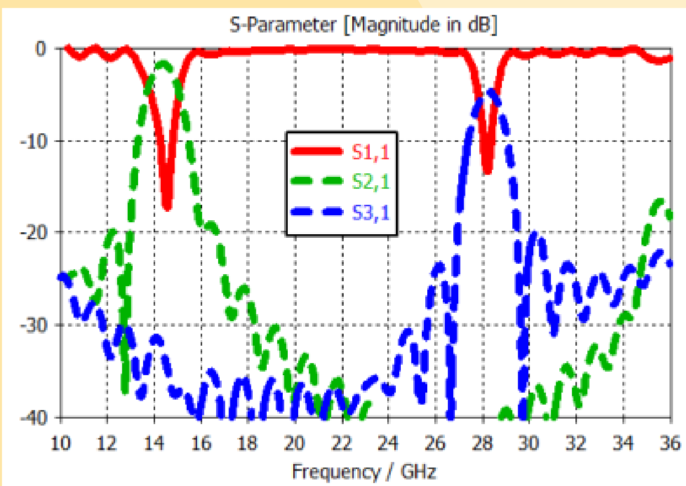
1. For the filters, physical dimensions are normalized by the wavelength corresponding to band frequency of 28 and 39 GHz. The corresponding wavelengths are 10.71 mm and 7.7 mm, respectively.
2. For diplexers and couplers, the physical dimensions are normalized by the wavelength corresponding to 32.125 GHz (center of 24.25-40 GHz). The corresponding wavelength is 9.34 mm.

Comparison with Prior Art

Millimeter-Wave Microstrip Diplexer using Elliptical Open-Loop Ring Resonators



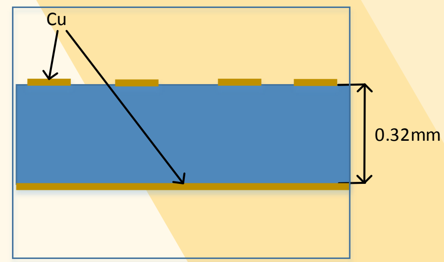


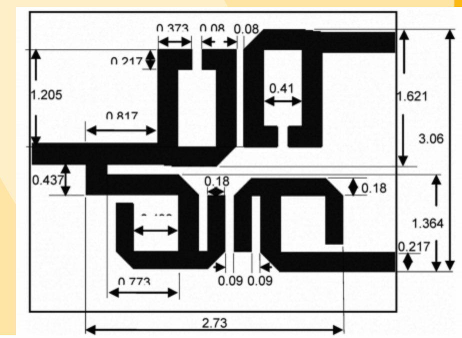


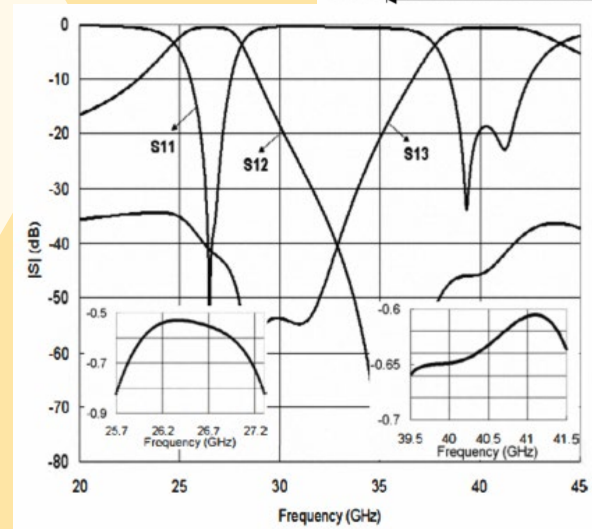
<u>Frequency Bands:</u> 14 and 28 GHz (<3% FBW)
<u>Insertion Loss:</u> 1.9 and 4.7 dB
<u>Size:</u> 7.82 mm ×7.82 mm

(Source: H. Shamam et. al, IEEE MMS 2014)

Compact Diplexer using Modified Hairpin Filters





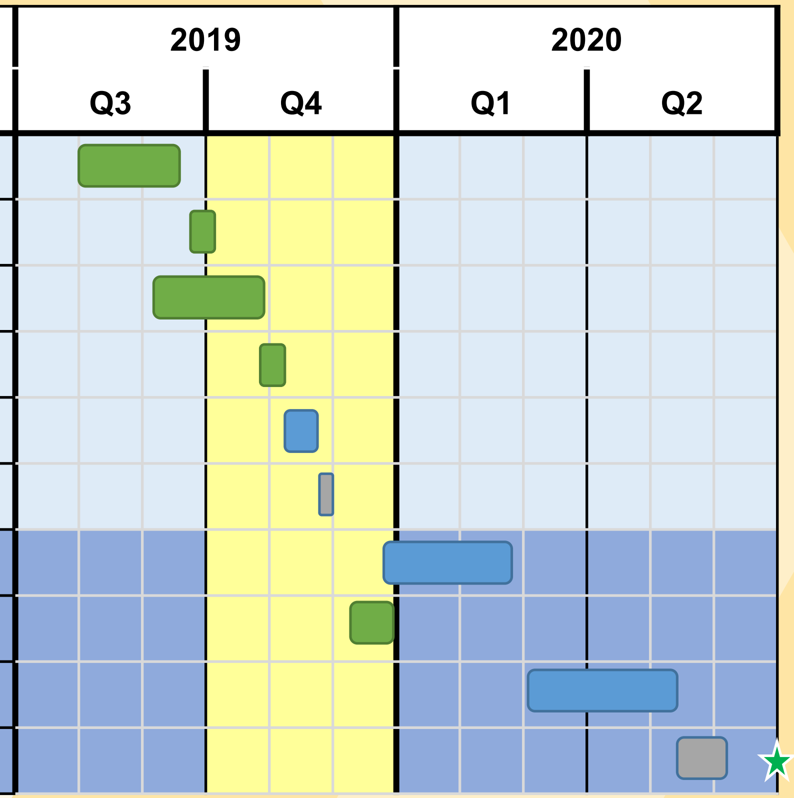


<u>Frequency Bands:</u> 26.5 and 40.5 GHz (<6.6% FBW)
<u>Insertion Loss:</u> <1.5 dB and <1 dB
<u>Size:</u> 2.73 mm ×3.06 mm

(Source: N. He et. al, IEEE APEMC 2010)

Schedule

Done	1 – Filter Design
Done	2 – Diplexer Design
Done	3 – Coupler Design
In Progress	4 – Integrated Components Optimization
In Progress	4 – Fabrication of Test Vehicle (TV) without TGVs
	5 – Characterization
	7 – TGV Fabrication
	8 – Antenna Design
	9 – Fabrication of Test Vehicle (TV) with TGVs
	10 – Characterization



Light blue: TV w/o TGVs
Dark blue: TV w/ TGVs
Light Yellow: Current time window

Electrical Design and Optimization
Fabrication
Characterization and Correlation
★ Graduation