ADVANCES IN RF PLANAR FILTER TECHNOLOGIES

Prof. Jiasheng Hong, **DPhil (Oxford) IEEE Fellow**

Heriot-Watt University, UK

2021

Backgrounds

R&D of advanced RF planar filters are driven by applications -

- **Wireless communications**
- **Wireless sensor/radar systems**
- **.......**

In connection with technologies -

- **Planar (PCB, LTCC, LCP, …)**
- **Micromachining, additive manufacturing, …**
- **Functional materials (semiconductor, ferroelectric, …)**
- **.......**

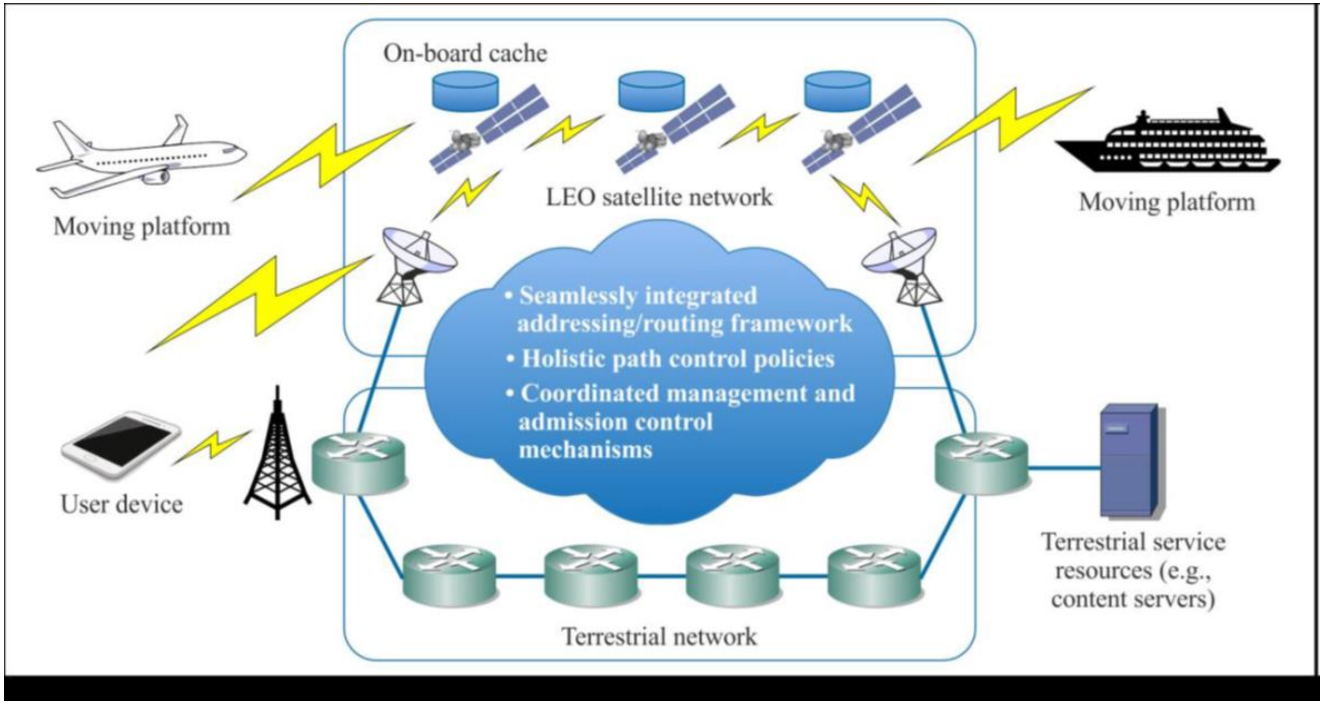
J.Hong@hw.ac.uk

Backgrounds

Satellite communications will be an essential part of the 6G infrastructure to ensure seamless access to any telecommunications service anytime and anywhere. Service providers will need to provide seamless connectivity between terrestrial and satellite.

Example of LEO satellites and terrestrial Internet integration

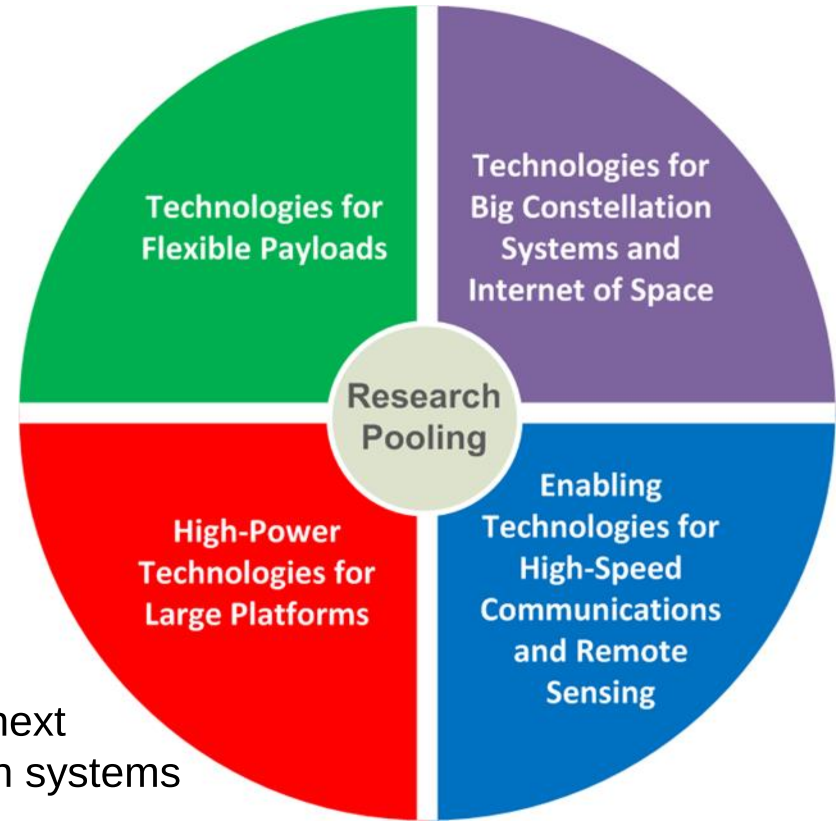
From: ITU-T, "Focus group on technologies for network 2030: Representative use cases and key network requirements," February 2020.



Backgrounds

TESLA (https://tesla-itn.hw.ac.uk/) a consortium of 8 academic universities,11 industrial partners,15 Early Stage Researchers with EC funding of ~4 million Euro, focus on R&D of the *Advanced **T**echnologies for future **E**uropean **S**ate**l**lite **A**pplications* from 2019-2022.

Project Coordinator: Prof. Jiasheng Hong



R&D topics include –

- Integrated beamforming network based on Active Phased Array
- Millimeter wave hardware for the next generation satellite communication systems
- Novel technologies for miniaturized passive components and sub-systems with tuning capabilities
- …..

European Commission

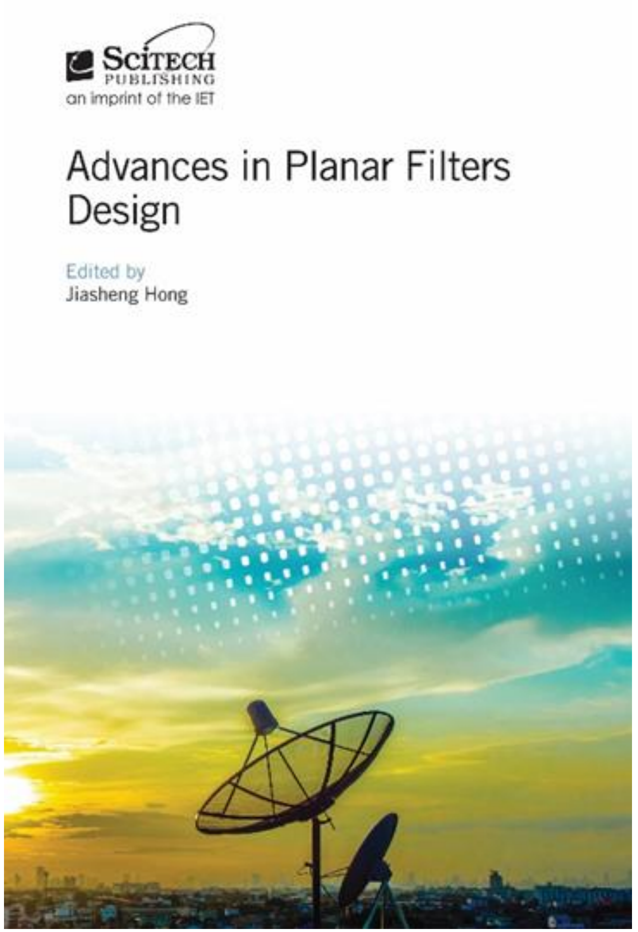
Backgrounds

Challenges for RF Planar Filters –

✓Small footprint ✓High performance

✓Low cost ✓More functionalities

To meet these challenges for a specific application, in addition to a proper technology, novel design and implementation are also required.



Advanced Planar Filters I

ESA Contract Frame:

Basic Technology Research Programme (TRP)

Subject Title:

Techniques for ultra wide stopband IF filter

Project Objective:

To develop new design techniques, concepts and filtering configurations for IF filters with compact footprint, ultra-wide stopband as well as equivalent high-Q performance (i.e. low insertion loss variation and high selectivity by using low-Q resonators).

Advanced Planar Filters I

ESA SoW IF Filter Specifications

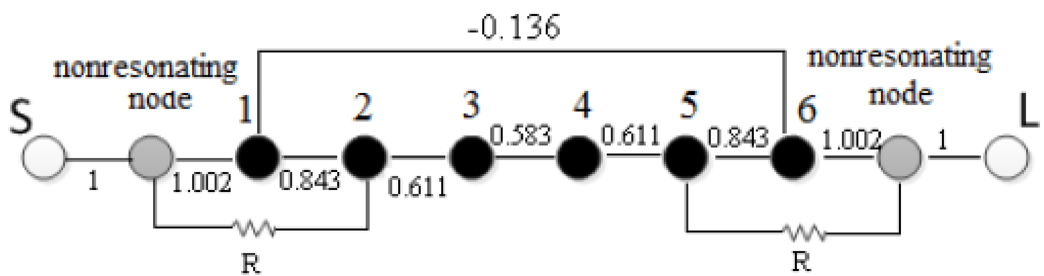
Challenging!!

- Low insertion loss variation
- High selectivity
- Ultra-wide stopband
- Compact size and low weight

BB1 _250MHz			
PARAMETERS	REQ.	UNIT	COMMENTS
Central Frequency (C_{IF})	1000	[MHz]	
Channel Bandwidth	250	[MHz]	
Insertion Loss at C_{IF}	TBA	[dB]	
Insertion Loss versus Frequency			
C_{IF}±70 MHz	<0.25	[dBpp]	<0.15
C_{IF}±100 MHz	<0.6	[dBpp]	<0.3
C_{IF}±120 MHz	<1.5	[dBpp]	<1.0
Narrowband isolation			
C_{IF}±150 MHz	>20	[dB]	
C_{IF}±400 MHz	>40	[dB]	
Group Delay Variation			
C_{IF}±70.0 MHz	<2.0	[nspp]	
C_{IF}±100.0 MHz	<6.0	[nspp]	
C_{IF}±120 MHz	<20.0	[nspp]	
Out-of-band rejection C_{IF}+400 MHz to C_{IF}+1500 MHz	>30	[dB]	>40
C_{IF}+1500 MHz to C_{IF}x10	>40	[dB]	
Input Return Loss C_{IF}±120 MHz	TBD	[dB]	Goal – 20 dB
Output Return Loss C_{IF}±120 MHz	TBD	[dB]	Goal – 20 dB
Non-Operating Temperature Range	[–40, +75]	[°C]	
Operating Temperature Range	[–10, +60]	[°C]	
Footprint	20x20	mm	To be minimized
Mass	15	g	To be minimized
Interface		-	TBD

Advanced Planar Filters I

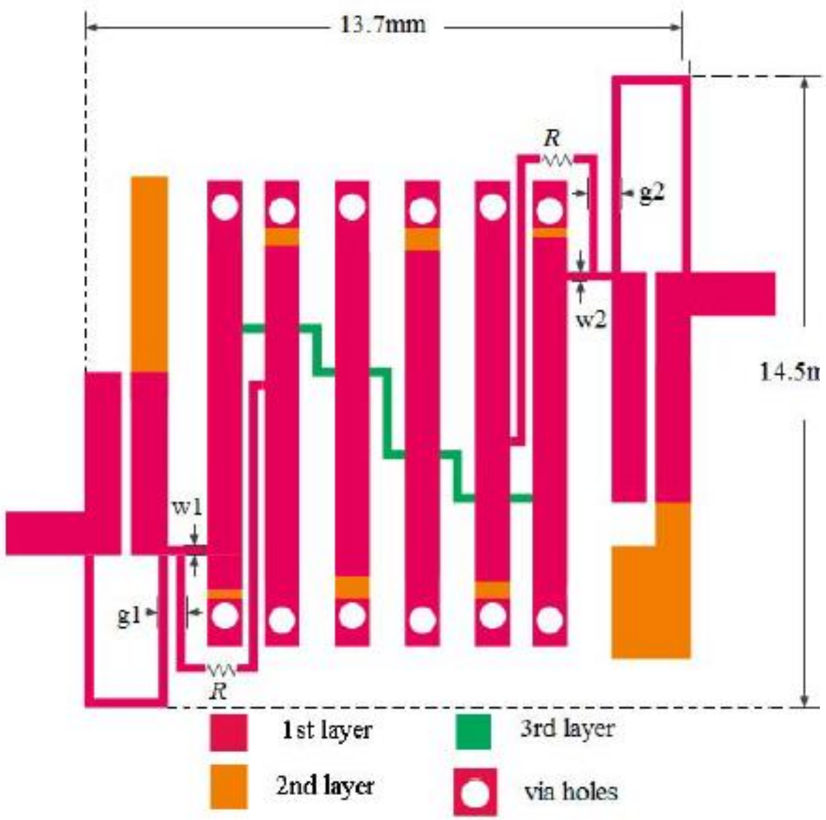
Novel design:



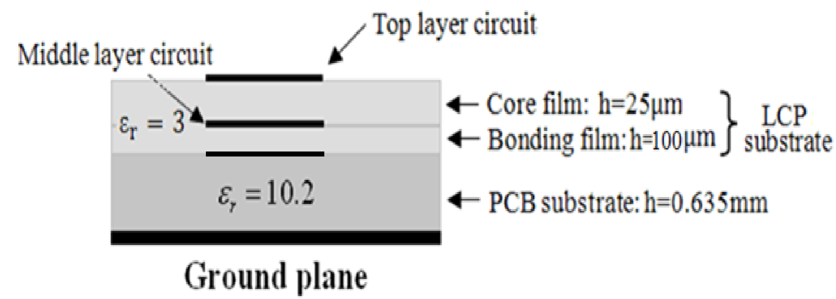
- ✓Double-layer strongly coupled miniature resonators: for size reduction as well as harmonic suppression.
- ✓Interdigital couplings between adjacent resonators: to realize a wide passband bandwidth.
- ✓Cross coupling: to create transmission zeros near the passband to improve the selectivity.
- ✓Resistive cross coupling (RCC) : to reduce the passband insertion loss variations.

Advanced Planar Filters I

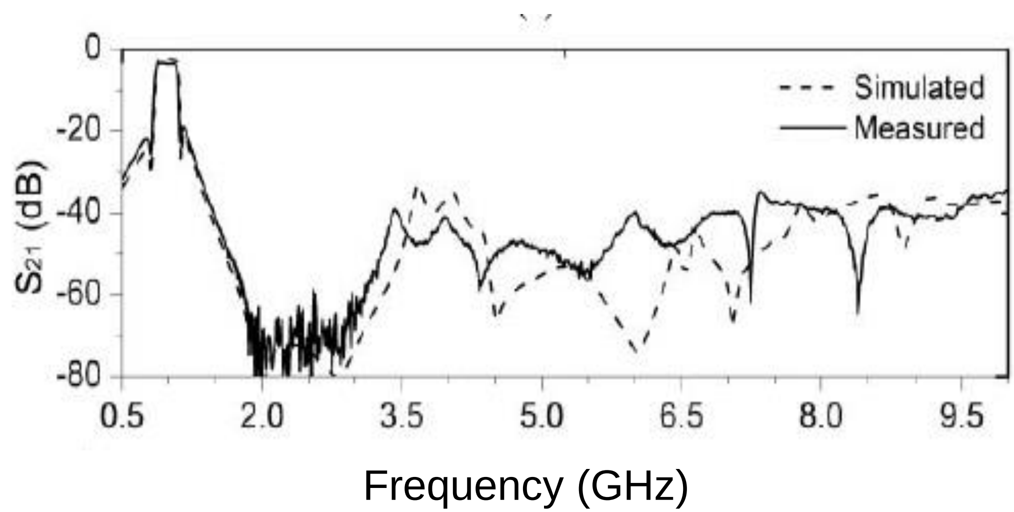
Novel implementation:



Footprint < 15 mm by 15 mm

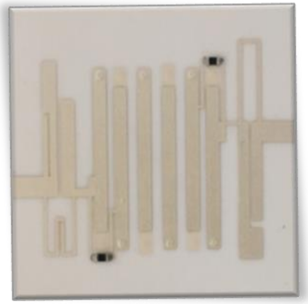


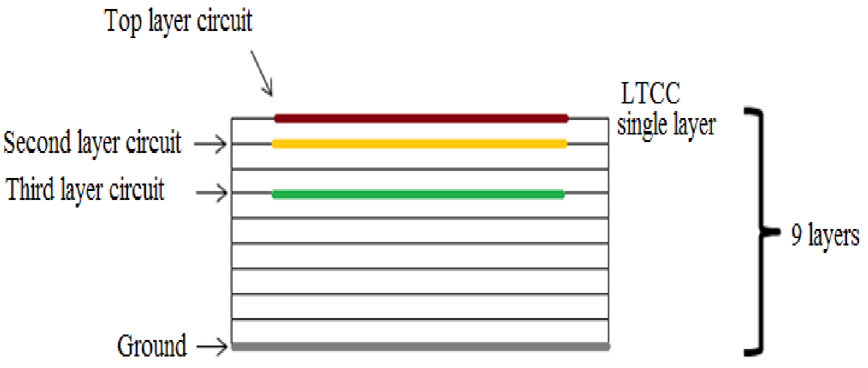
LCP boned PCB multilayer (< 1mm)



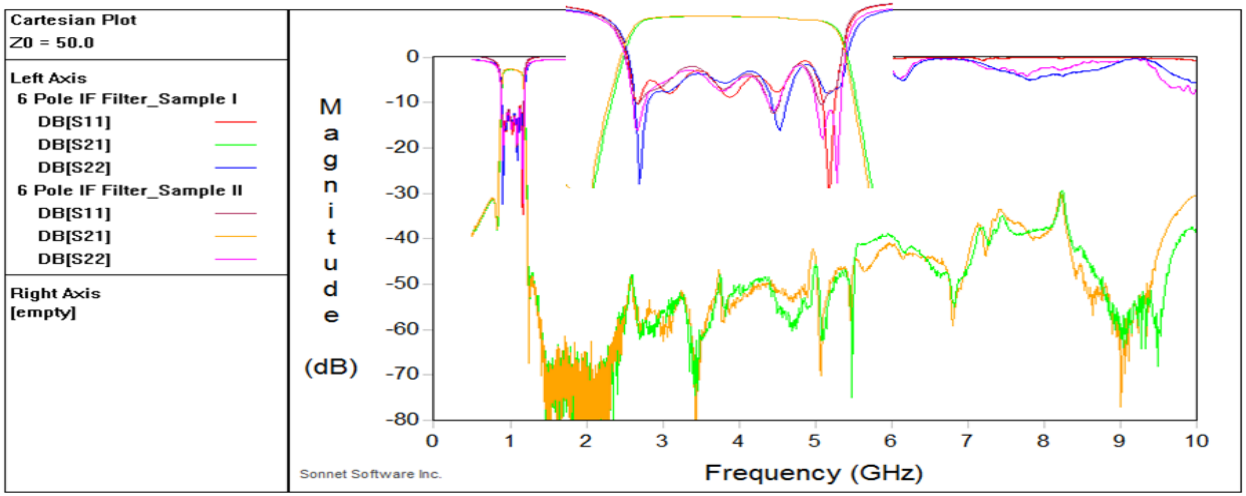
Advanced Planar Filters I

Novel implementation on LTCC:





Footprint < 15 mm by 15 mm. thickness < 1mm



Measured performance

Advanced Planar Filters II

ESA Contract Frame:

Basic Technology Research Programme (TRP)

Subject Title:

Compact Tunable IF Filter

Project Objective:

To develop new design techniques, concepts and filtering configurations for tunable IF filters with compact footprint, wide bandwidth tuning range as well as equivalent high-Q performance (i.e. low insertion loss variation and high selectivity by using low-Q resonators).

Advanced Planar Filters II

Challenging!!

Wide bandwidth tuning range (14:1)

Low insertion loss variation

High selectivity

ESA SoW *Compact Tunable IF Filter* Specifications

PARAMETERS	PRO.	UNIT	COMMENTS
Central frequency (C_{IF})	TBD	MHz	
Channel Bandwidth	From 36 to 500MHz	MHz	
Insertion Loss at C_{IF}	TBA	dB	
Insertion loss versus Frequency			
$C_{IF} \pm 30\% BW$	<0.4	dBpp	
$C_{IF} \pm 40\% BW$	<0.6	dBpp	
$C_{IF} \pm 50\% BW$	<1	dBpp	
Narrowband isolation			
$C_{IF} \pm 70\% BW$	$C_{IF} \pm 80\% BW$ >20	dB	
$C_{IF} \pm 160\% BW$	>40	dB	
Group Delay Variation			
$C_{IF} \pm 30\% BW$	<2	nspp	
$C_{IF} \pm 40\% BW$	<6	nspp	
$C_{IF} \pm 50\% BW$	<15.0	nspp	
Input Return Loss $C_{IF} \pm 50\% BW$	TBD	dB	GOAL -20dB
Output Return Loss $C_{IF} \pm 50\% BW$	TBD	dB	GOAL -20dB
Operating Temperature Range	[-10, 65]	℃	
Footprint	TBA	mm	To be minimized
Mass	TBA	g	To be minimized
Interface			TBD

Advanced Planar Filters II

Novel design

- ✓Centrally loading resistors: flatten the passband insertion loss (patented) and/or absorb harmonic resonances.
- ✓Combinations of Pin and varactor diodes offer a wide range of coupling coefficient for bandwidth tuning
- ✓Cross coupling between the second and fifth resonators: create transmission zeros near the passband to improve the selectivity and could be switched on/off at different states
- ✓Pin diode attenuator is used to offer tunable resistance to flatten the passband at different bandwidth

Advanced Planar Filters II

Novel technique for flatting passband

A RADIO FREQUENCY PASS-BAND FILTER

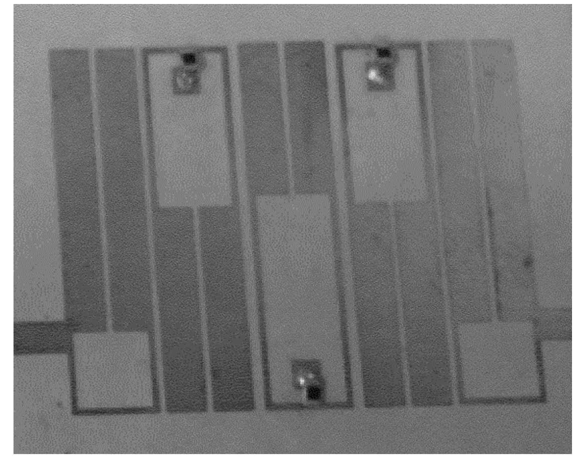
WIPO | PCT

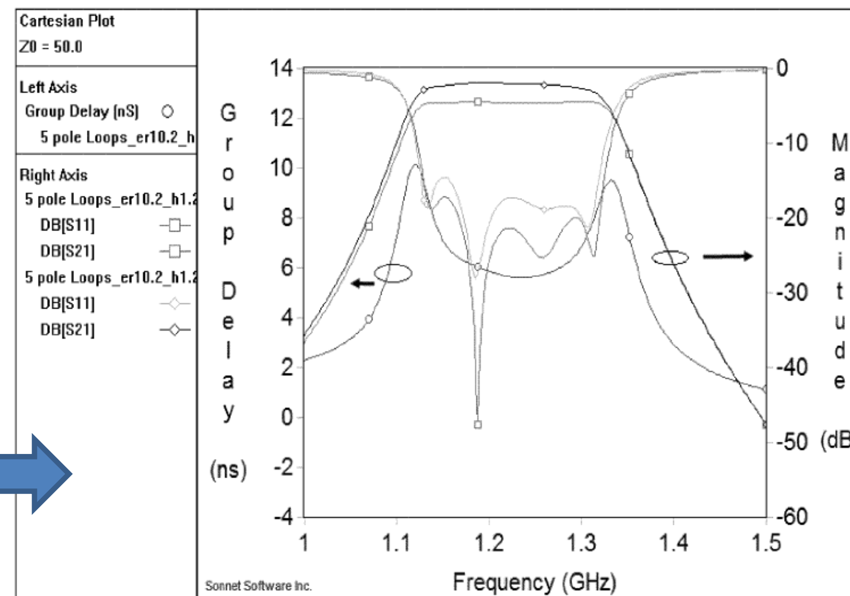
(10) International Publication Number
WO 2020/057722 A1

Applicant: EUROPEAN SPACE AGENCY [NL/NL]; Technology Transfer Programme Office, Keplerlaan 1, 2200 AG Noordwijk (NL).

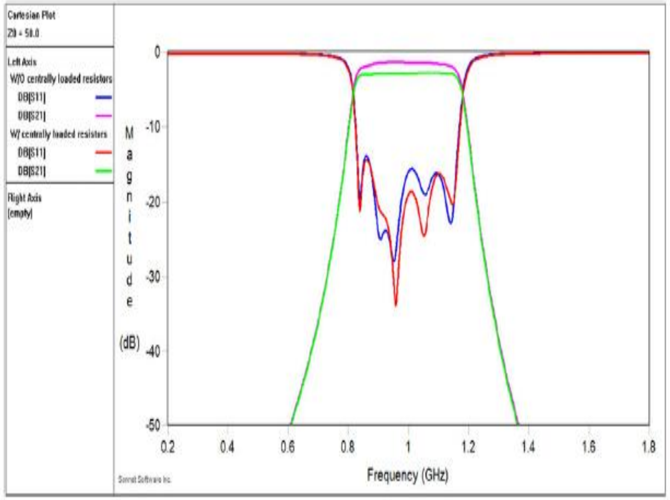
Inventors: HONG, Jiasheng; School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh EH14 4AS (GB). **NI, Jia**; School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh EH14 4AS (GB). **MARTIN-IGLESIAS, Petronilo**; C/o European Space Agency, Keplerlaan 1, 2200 AG Noordwijk (NL).

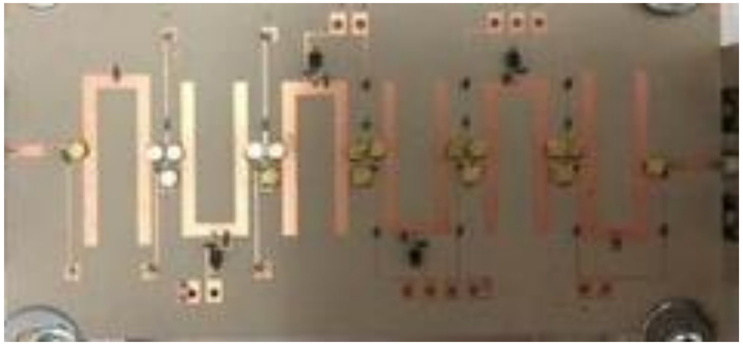
With an average unloaded quality factor Qu of 100, the flattened passband response shape has an equivalent Qu of 600.





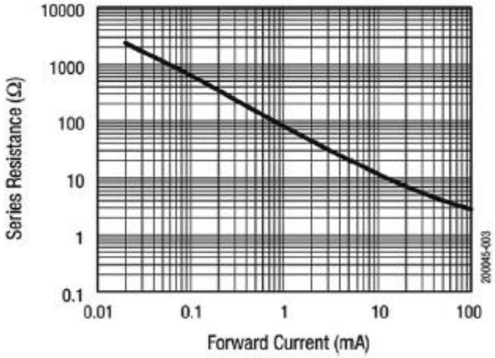
Advanced Planar Filters II

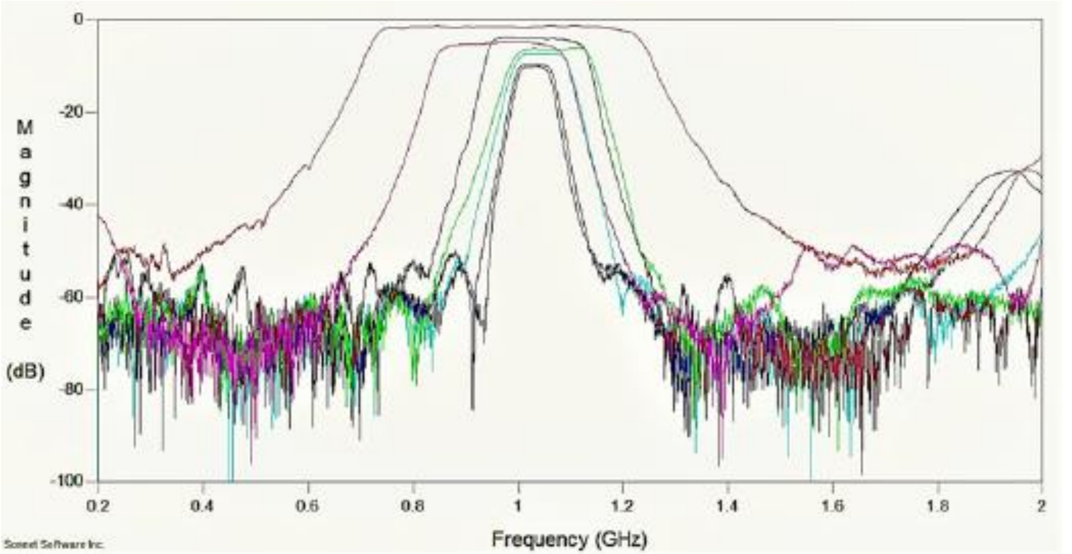




Circuit size 70x32 (mm)

Centrally loaded variable resistors (pin) on improving passband flatness of the proposed tunable filter





Measured tunable bandwidth performance

J.Hong@hw.ac.uk

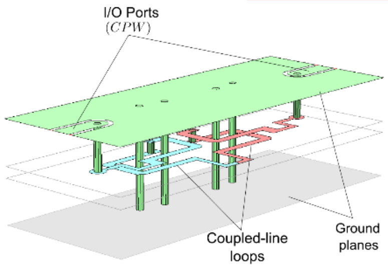
Advanced Planar Filters III

What needed from-
ESA Advanced Technology Statement of Work
Substrate embedded filters
for microwave equipment

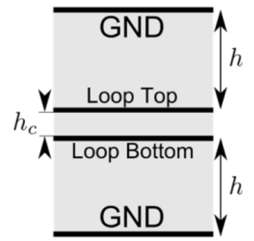
The size of the RF module is often limited by the physical size of the filters that are needed to remove all of the unwanted signals. The objective of this activity is to design, develop and test L- to Ka-band filters directly embedded in the substrate (PCB and/or LTCC) of microwave equipment.

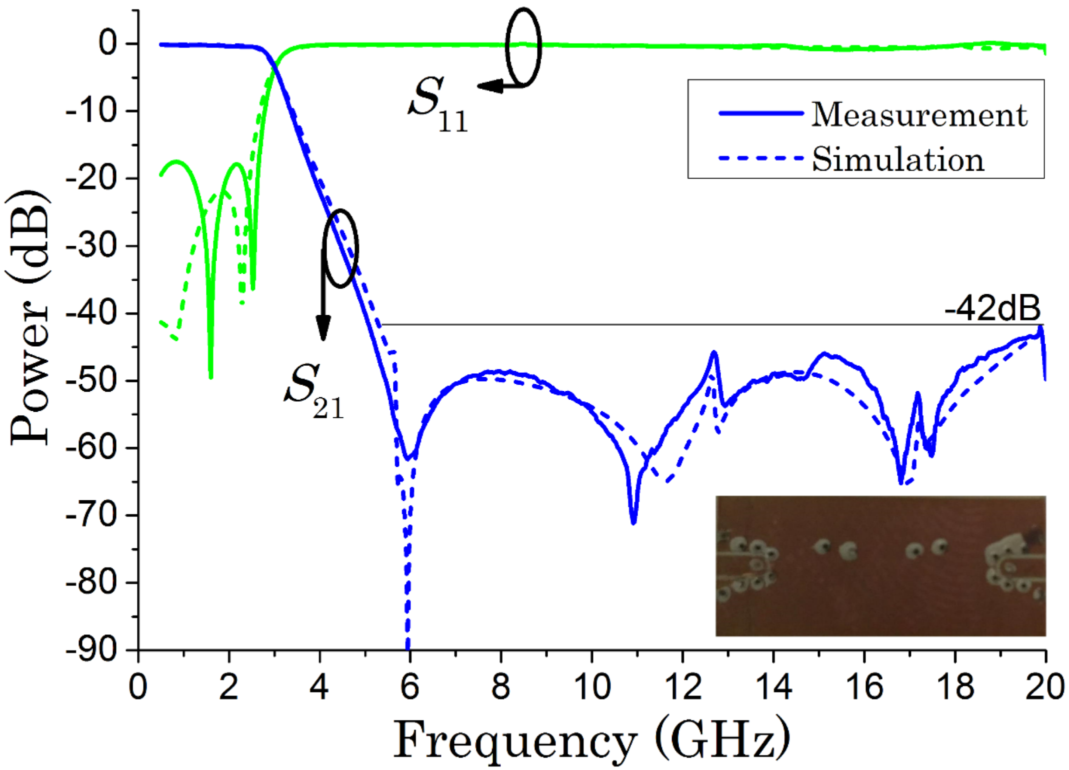
Advanced Planar Filters III

Self-Packaged Lowpass Filter



hc = 25 μm
h = 0.2 mm





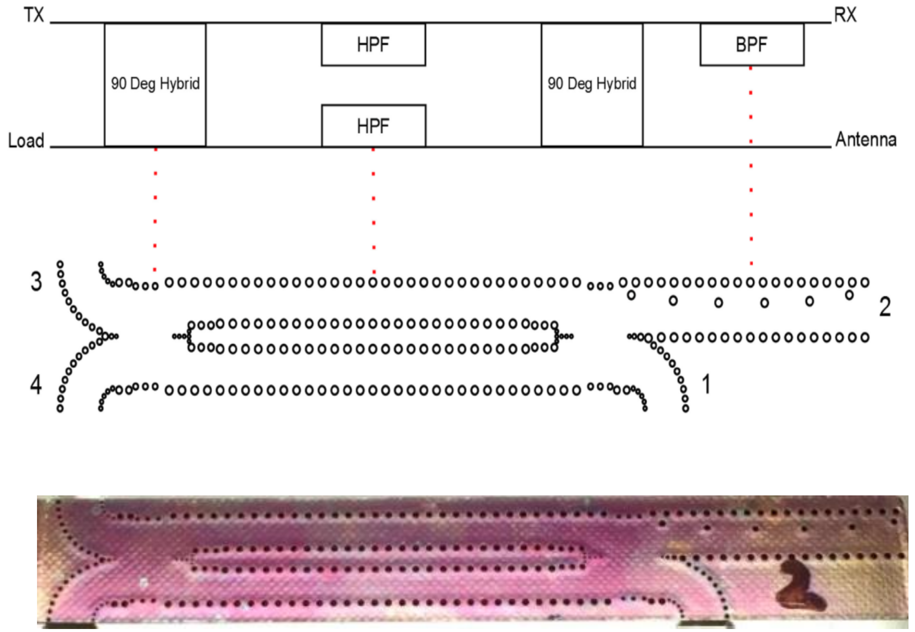
Response parameters	
Cut-off frequency (f_c)	3 GHz
Ripple Bandwidth (15dB)	2.7 GHz
Return Loss	>17.6 dB
Insertion Loss @2.5GHz	0.33 dB
Rejection Bandwidth (42dB)	5.1- >20 GHz (5.1- 23 GHz)*

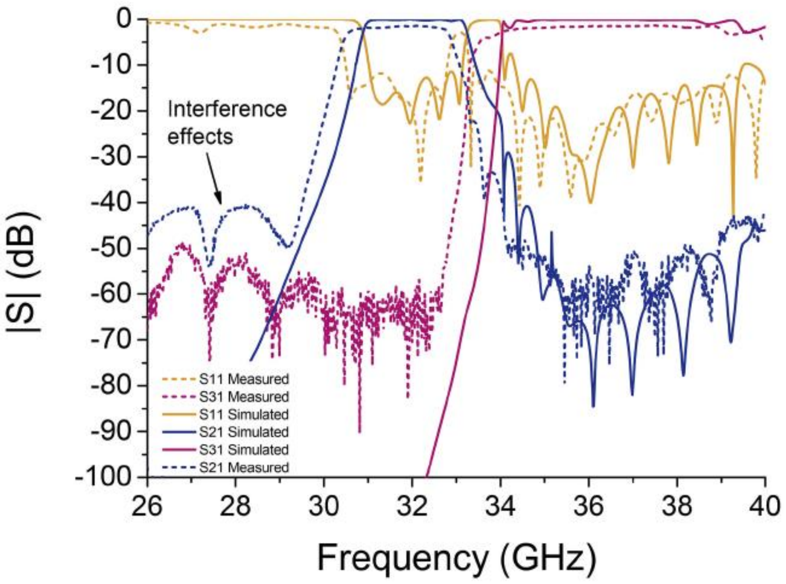
Mechanical parameters	
Filter size	8.4x4.2 mm^2
Filter size (w/packaging)	16.4x6.6 mm^2
Weight	0.12 g.
Thickness	0.45 mm

J.Hong@hw.ac.uk

Advanced Planar Filters III

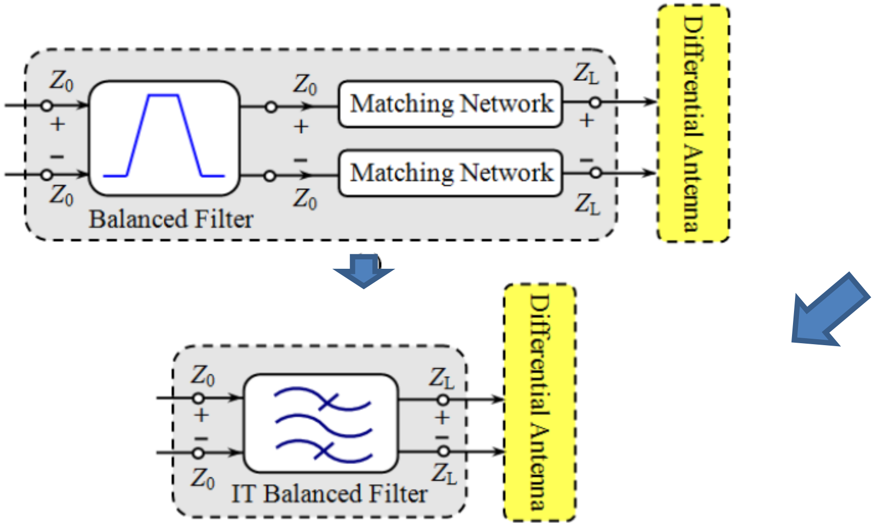
Substrate-Integrated Waveguide (SIW) Ka-band Diplexer

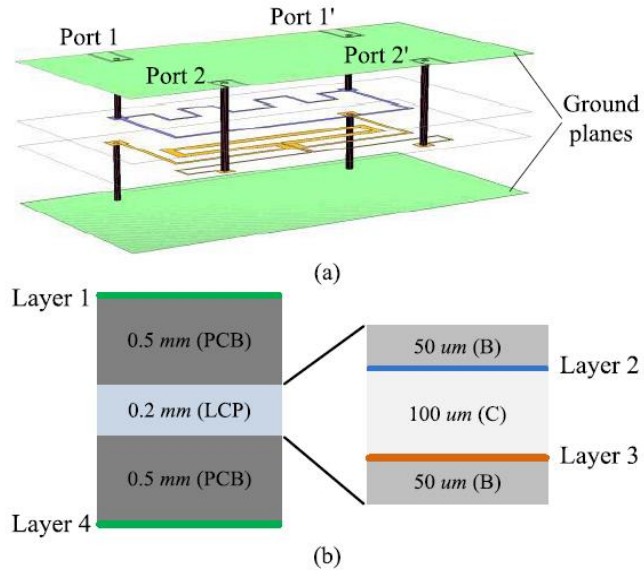


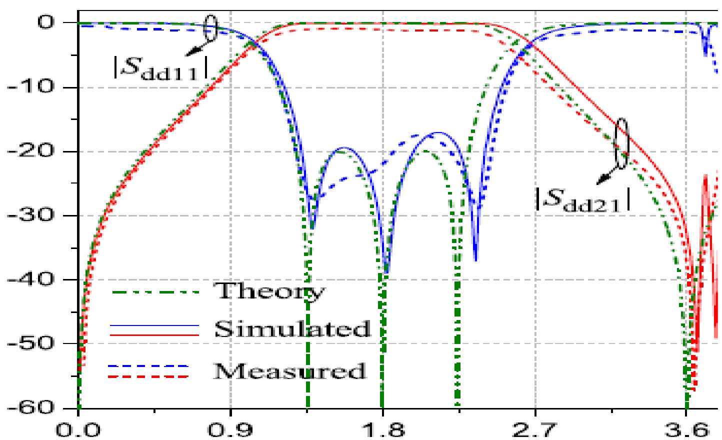


Advanced Planar Filters IV

Self-Packaged Balanced Bandpass Filters With Impedance Transformation Characteristic



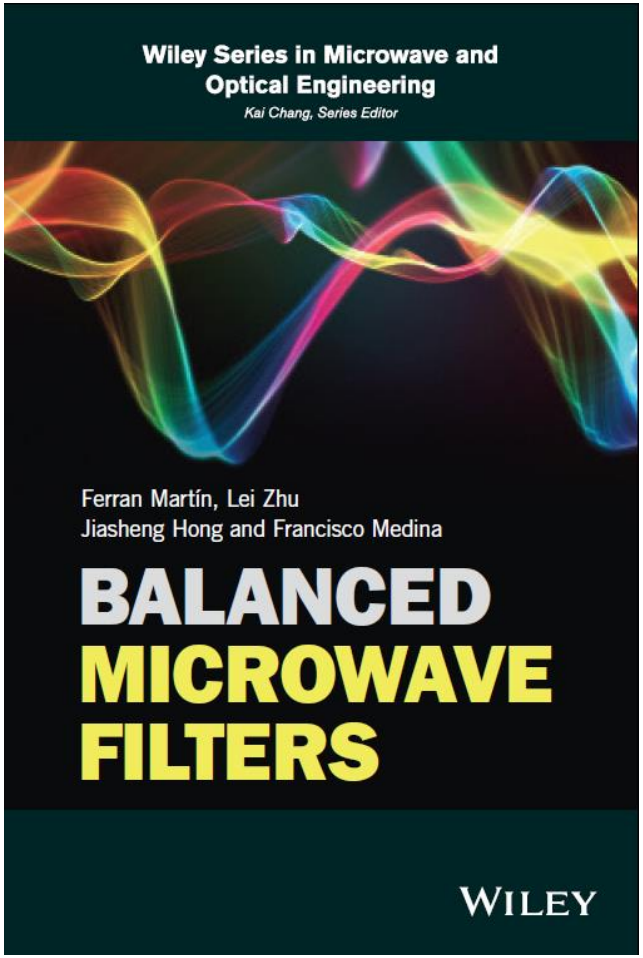




85% 3-dB bandwidth at the central frequency of 1.8 GHz with 50–200 impedance transformation and more than 30 dB common-mode rejection. The size is 0.19x0.37 (λg) at the centre frequency

J.Hong@hw.ac.uk

Advanced Planar Filters IV



This new book presents and discusses strategies for the design and implementation of common-mode suppressed balanced microwave filters, including narrowband, wideband, ultra-wideband and multiband filters.

Thank you !

References

[1] J. Hong, *Microstrip Filters for RF/Microwave Applications, 2rd ed., Wiley, 2011.*
[2] J. Ni ; J. Hong ; P. M. Iglesias, "Compact Microstrip IF Lossy Filter With Ultra-Wide Stopband", IEEE Transactions on Microwave Theory and Techniques, Vol.66, No. 10, 2018
[3] J. Ni ; J. Hong ; P. M. Iglesias, "Compact bandwidth tunable IF filters for reconfigurable converters", International Journal of Microwave and Wireless Technologies 1–12. https://doi.org/10.1017/S1759078721000714, 2021
[4] J. R. Aitken and J. Hong, "Millimetre wave SIW diplexer with relaxed fabrication tolerances", Ch. 12 in *Advances in Planar Filters Design*, Jiasheng Hong (Ed), IET 2019
[5] Huang, F., Aliqab, K., Wang, J., Hong, J. & Wu, W., "Self-packaged balanced bandpass filters with impedance transformation characteristic", IEEE Transactions on Microwave Theory and Techniques. 67, 11, p. 4353-4361, 2019