Design of a compact, planar triplexer covering DC to 9 GHz implemented on low cost softboard

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Agenda

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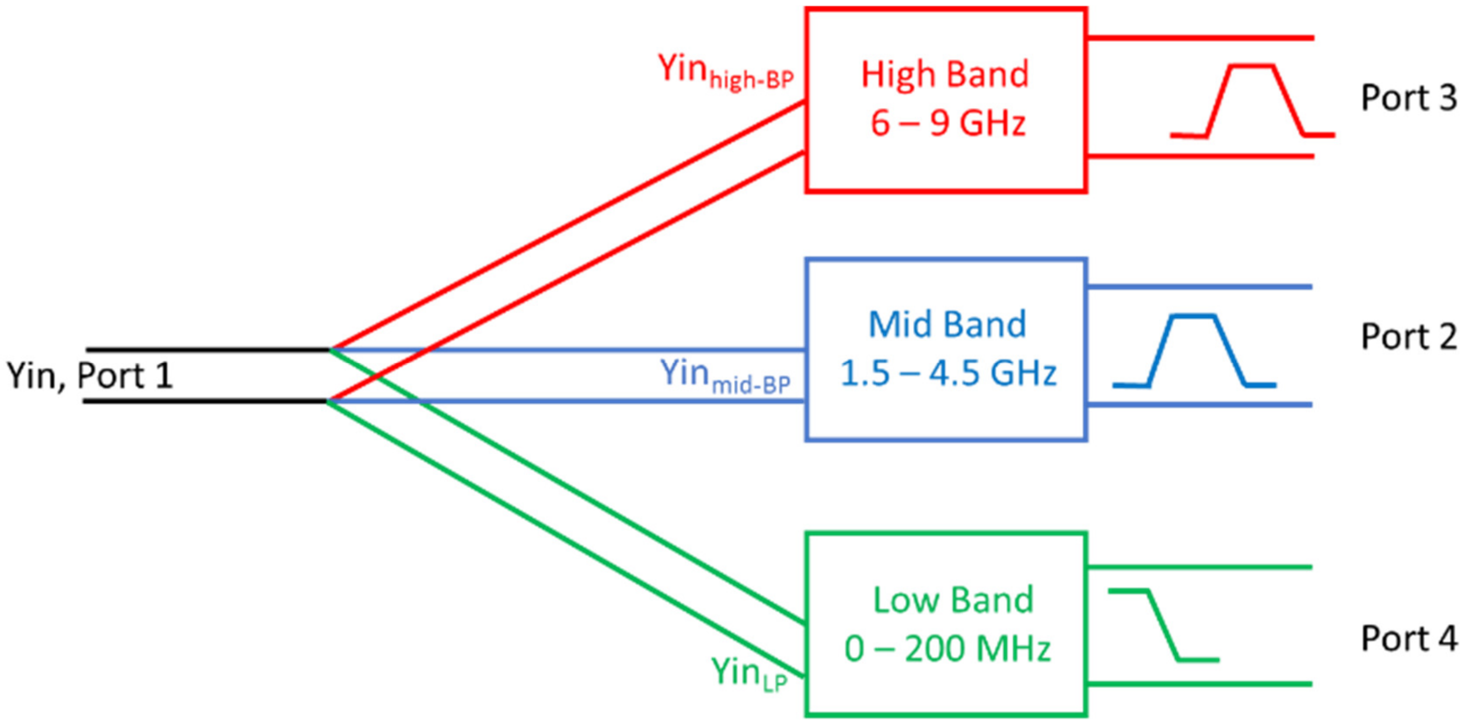
- Introduction
- Filter Design
- Simulation and Optimization
- Fabrication
- Measured Results
- Summary

Motivation

Requirements:

1. Triplex 3 separate frequency bands thus saving 2 pairs of connectors and 2 cables.
2. Easily integrated into a standard planar Microstrip or CPW design flow.
3. Compact and inexpensive.
4. Have acceptable conversion loss and rejection in the required bands.

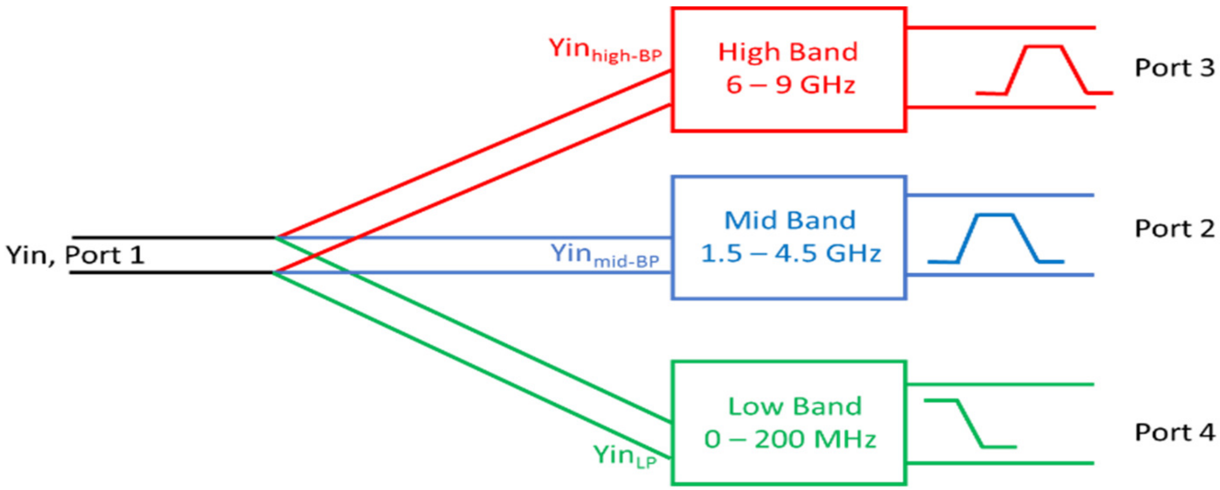
Introduction



1. 3 Bands are:
   a. Low band: 0 – 200 MHz.
   b. Mid band: 1.5 – 4.5 GHz.
   c. High band: 6 – 9 GHz.

2. The triplexer is realized by paralleling a lowpass filter and 2 bandpass filters at a common junction.

Triplexer Specifications



Parameter	Attenuation (dB)
|S11|, |S22|, |S33|, |S44|	< -12 dB
|S21|, |S31|, |S41|	> -3 dB
|S32|, |S42|	< -30 dB

Design Flow

The 3 filters in the triplexer are designed separately. The design steps are given here:

1. Admittance inverter equations are used in conjunction with AWR Microwave Office to design the 3 filters.

2. Design is optimized to ensure that transmission zeros of one band do not lie in the passband of the other bands.

3. The 3 sections are connected and optimized to ensure full band performance.

Triplexer Design Equations

The complex input admittance of the triplexer is given by the following equation:

$$Y_{in} = Yin_{LP} + Yin_{BP\text{-}mid} + Yin_{BP\text{-}high} \qquad (1)$$

To realize a perfectly matched input for all the required bands, the complex input admittance of the triplexer must satisfy the following condition:

$$Y_{in} = Y_0 \qquad (2)$$

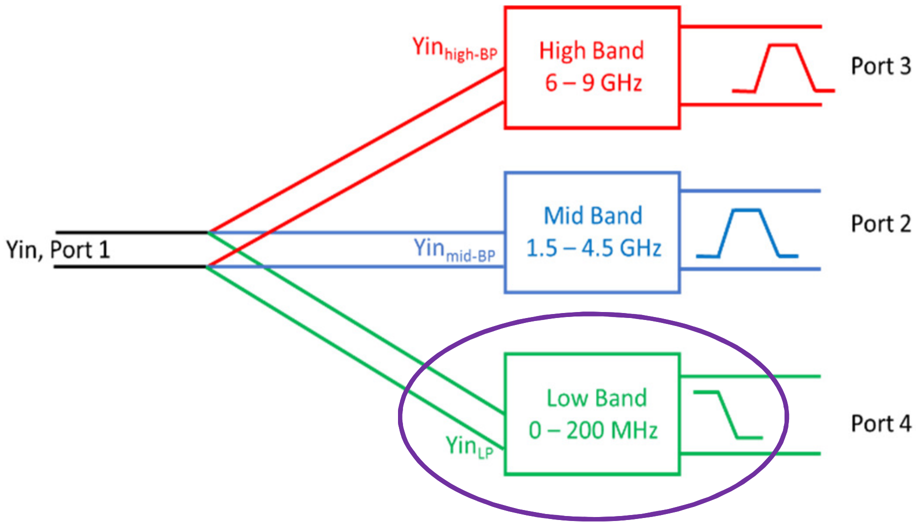
where Y_0 is the real characteristic admittance of the system and is equal to 0.02 siemens. Yin can be rewritten in terms of its real and imaginary components as:

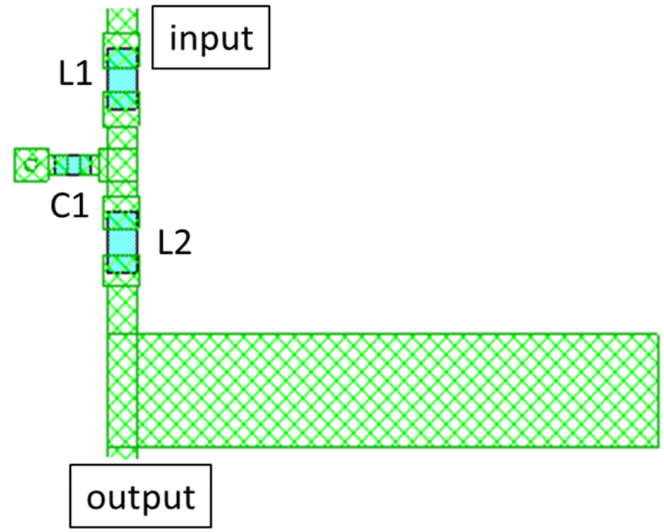
$$Re(Yin_{LP}) + Re(Yin_{BP\text{-}mid}) + Re(Yin_{BP\text{-}high}) = Y_0 \qquad (3)$$

$$Im(Yin_{LP}) + Im(Yin_{BP\text{-}mid}) + Im(Yin_{BP\text{-}high}) = 0 \qquad (4)$$

Low Band LPF Design (0 – 200 MHz)

- This section consists of a 3rd degree Chebyshev lumped element L-C-L lowpass filter with a RF quarter-wave stub added to improve rejection at the higher bands.



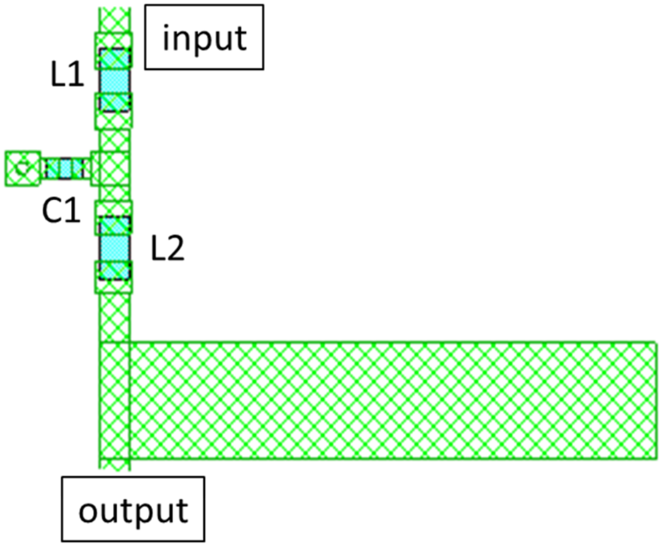


- The passband is from 0 – 200 MHz with an insertion loss less than 3 dB and return loss better than 12dB.

Low Band LPF Design (0 – 200 MHz) – contd.

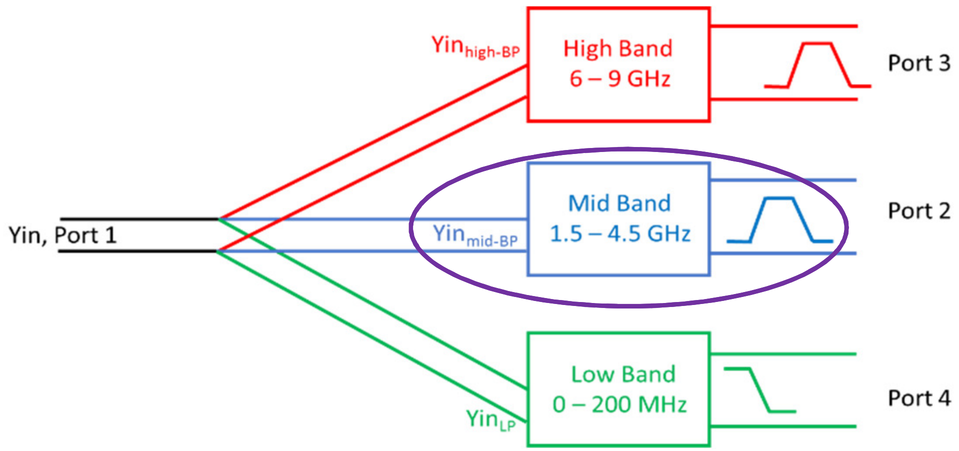
- Table 2 gives the capacitor and inductor values, case types and dimensions of the stub.

Component	Value	Case type
L1	3.6 nH	0402
L2	8.2 nH	0402
C1	8.2 pF	0201
Width of Stub	73 mils	NA
Length of Stub	345 mils	NA



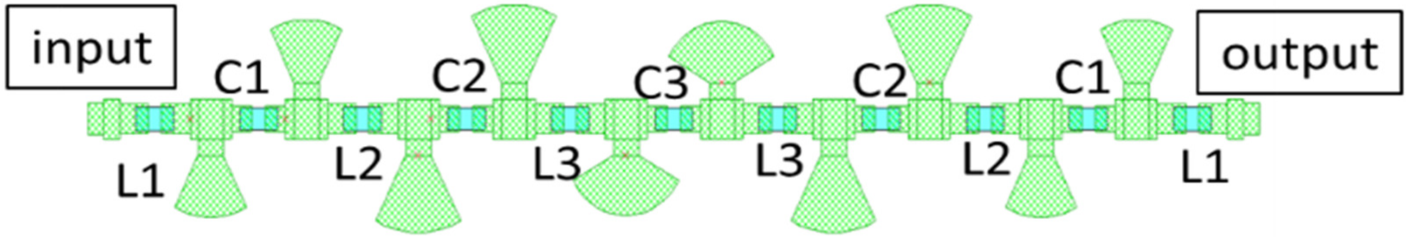
- The section is 300 mils long and 425 mils wide, mainly due to the long stub.

Mid Band BPF Design (1.5 – 4.5 GHz)



- This section consists of a 6th degree Chebyshev inductively coupled cap-pi quasi-lumped lowpass section realized using discrete 0201 inductors and capacitors in addition to distributed features.
- The passband is from 1.5 – 4.5 GHz with an insertion loss less than 3 dB and return loss better than 12dB.
- The shunt capacitors, being very low valued, are replaced by radial stubs, to avoid tolerance issues associated with low valued lumped elements.

Mid Band BPF Design (1.5 – 4.5 GHz) – contd.

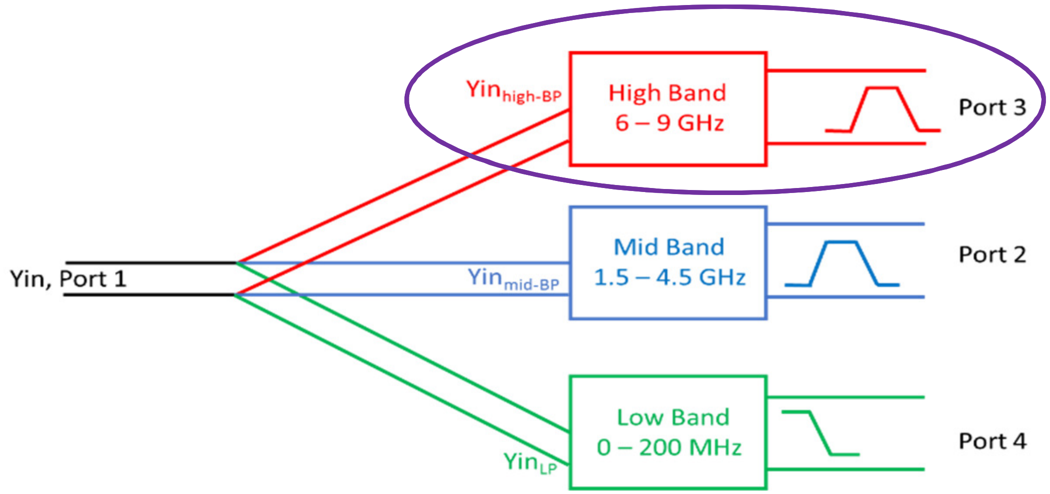


The values of the inductors and capacitors used in this section in the table below.

Component	Value	Case type
L1	1.2 nH	0201
L2	3.3 nH	0201
L3	3.3 nH	0201
C1	3 pF	0201
C2	10 pF	0201
C3	6.8 pF	0201

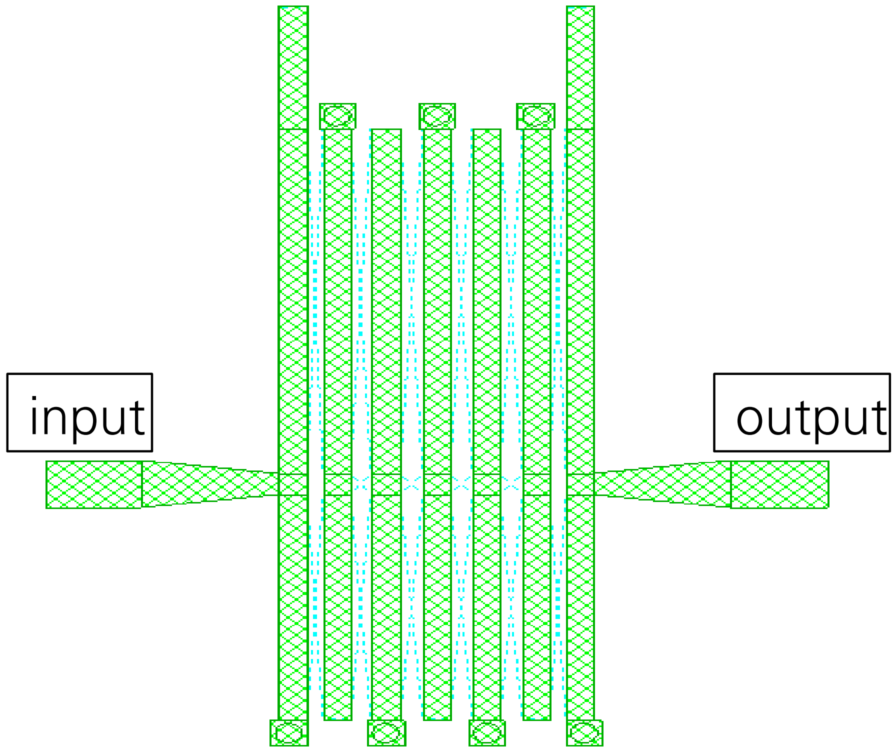
The section is 750 mils long and 125 mils wide.

High Band BPF Design (6 – 9 GHz)



- This section consists of a 7th degree Chebyshev tapped input distributed interdigital bandpass filter.
- The passband is from 6 – 9 GHz with an insertion loss less than 3 dB and return loss better than 12dB.
- Linewidths were kept above 7 mils, line gaps above 4.75 mils.

High Band BPF Design (6 – 9 GHz) – contd.



This section is 205 mils long and 272 mils wide.

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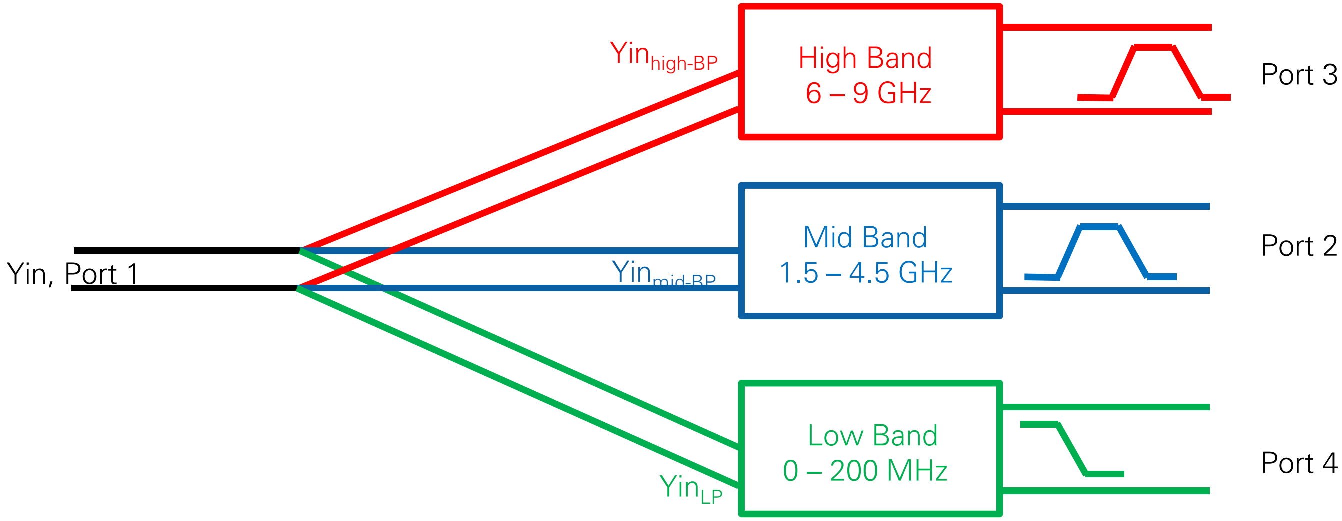
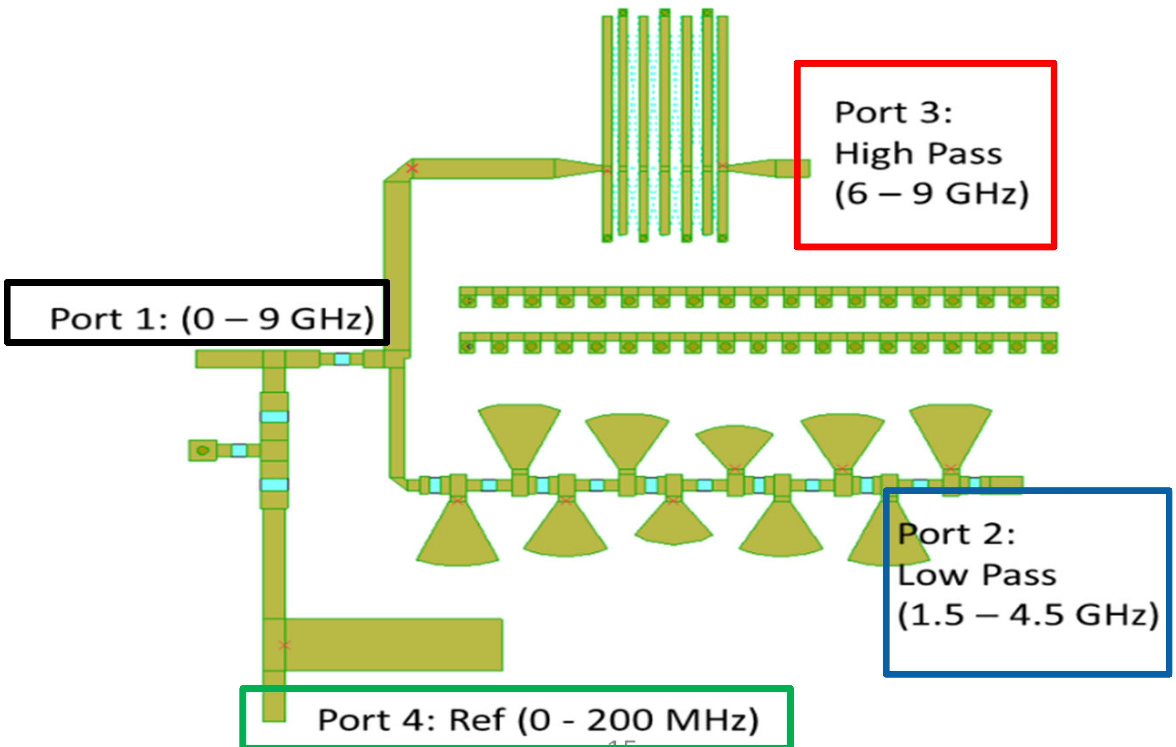
Triplexer Optimization

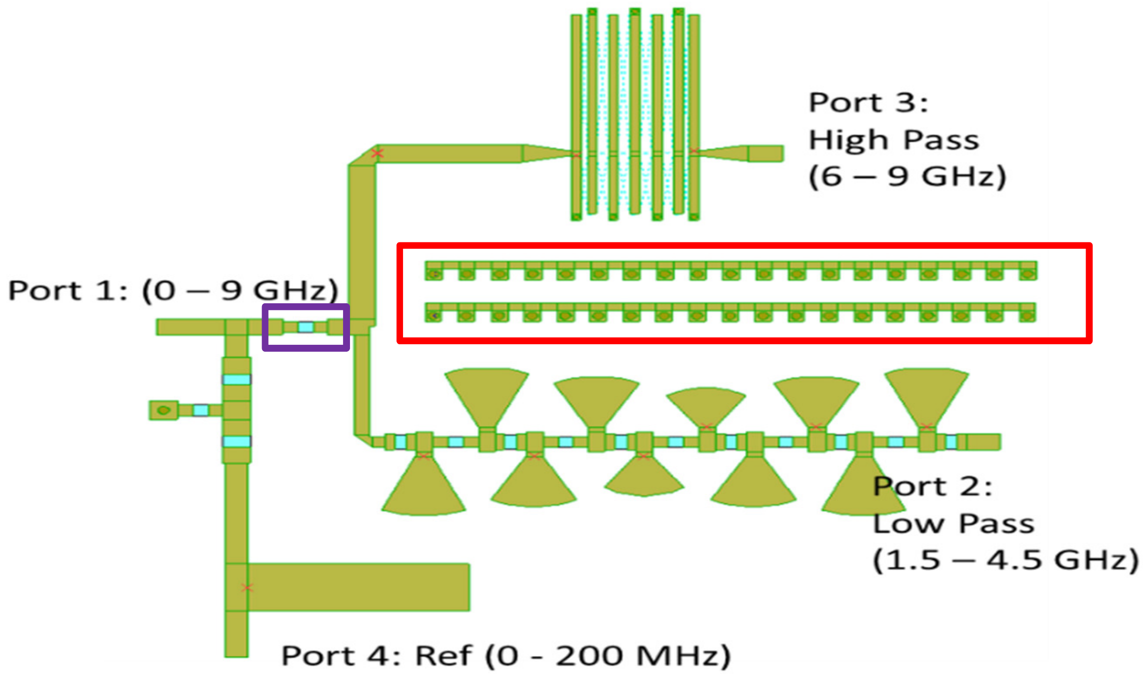
- The 3 sections were combined in a phased manner, one section at a time.
- After each addition, the combined sections were re-simulated and optimized using the AWR Microwave Office Axiem and Analyst EM simulators.
- The widths and lengths of the pair of transmission lines leading from the junction to each section is adjusted to ensure that the transmission zeros of each band are optimally suited.

Triplexer Optimization – contd.





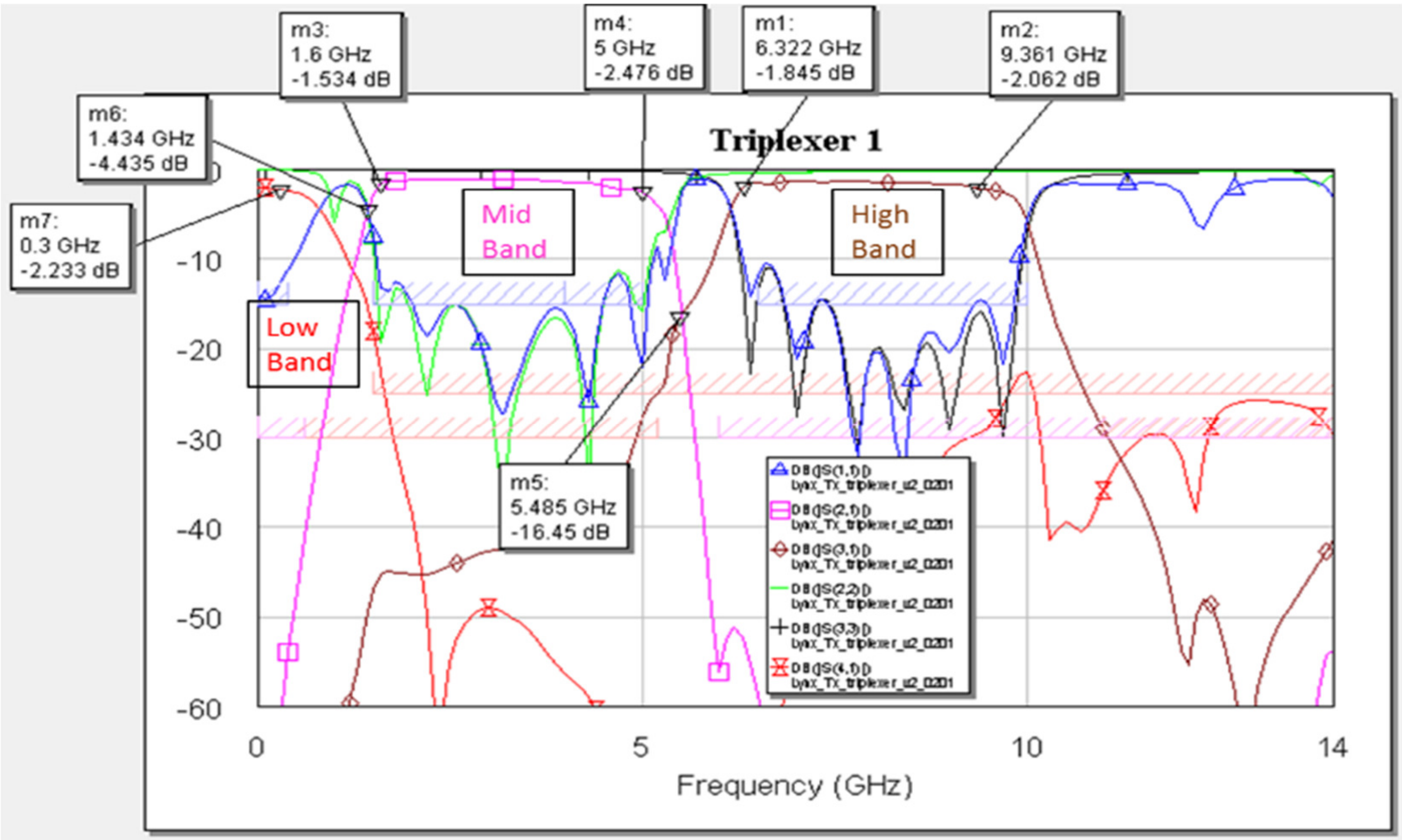
Triplexer Optimization – contd.



- An additional double layer of ground vias has been added to improve substrate leakage between the mid-band and high-band sections.

- An additional microwave capacitor was added between the lowpass sections and the other two sections. This capacitor couples the two higher bands to the input and also acts as a DC-block.

Triplexer – simulated results

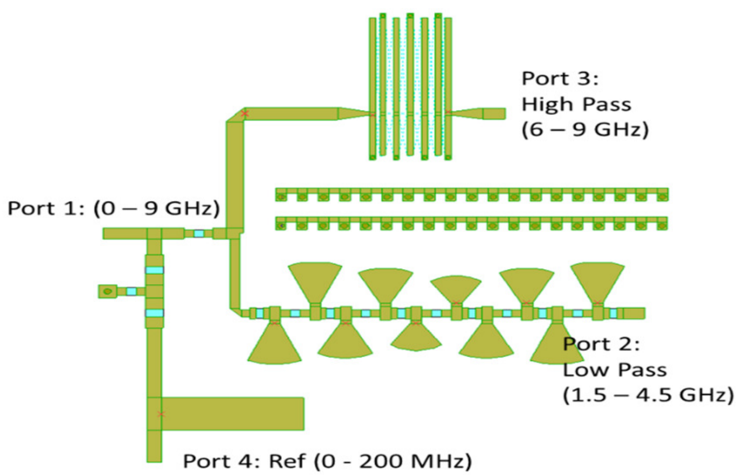


S41 - Low Band IL

S31 – High Band IL

S21 – Mid Band IL

S11 – Input RL



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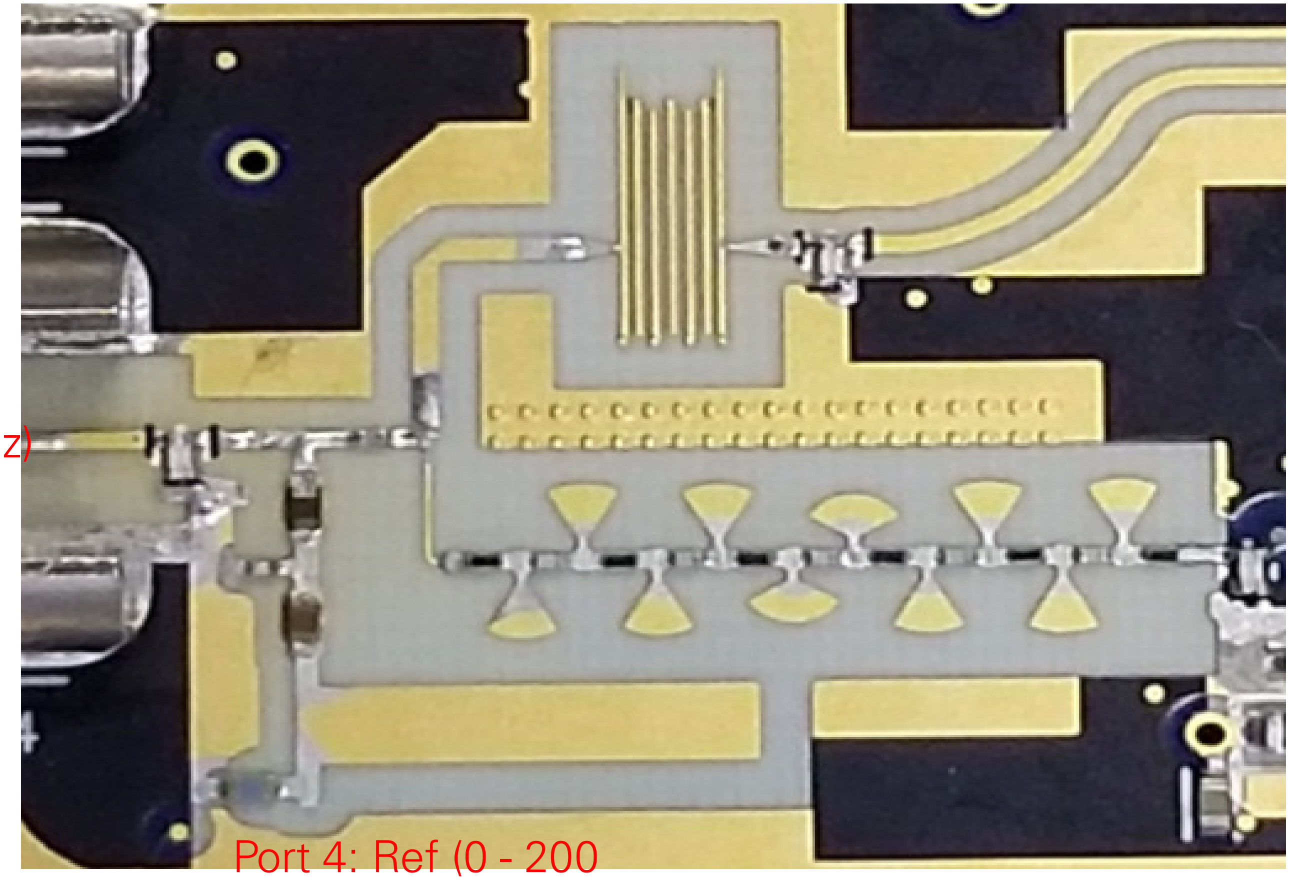
Fabrication and related issues

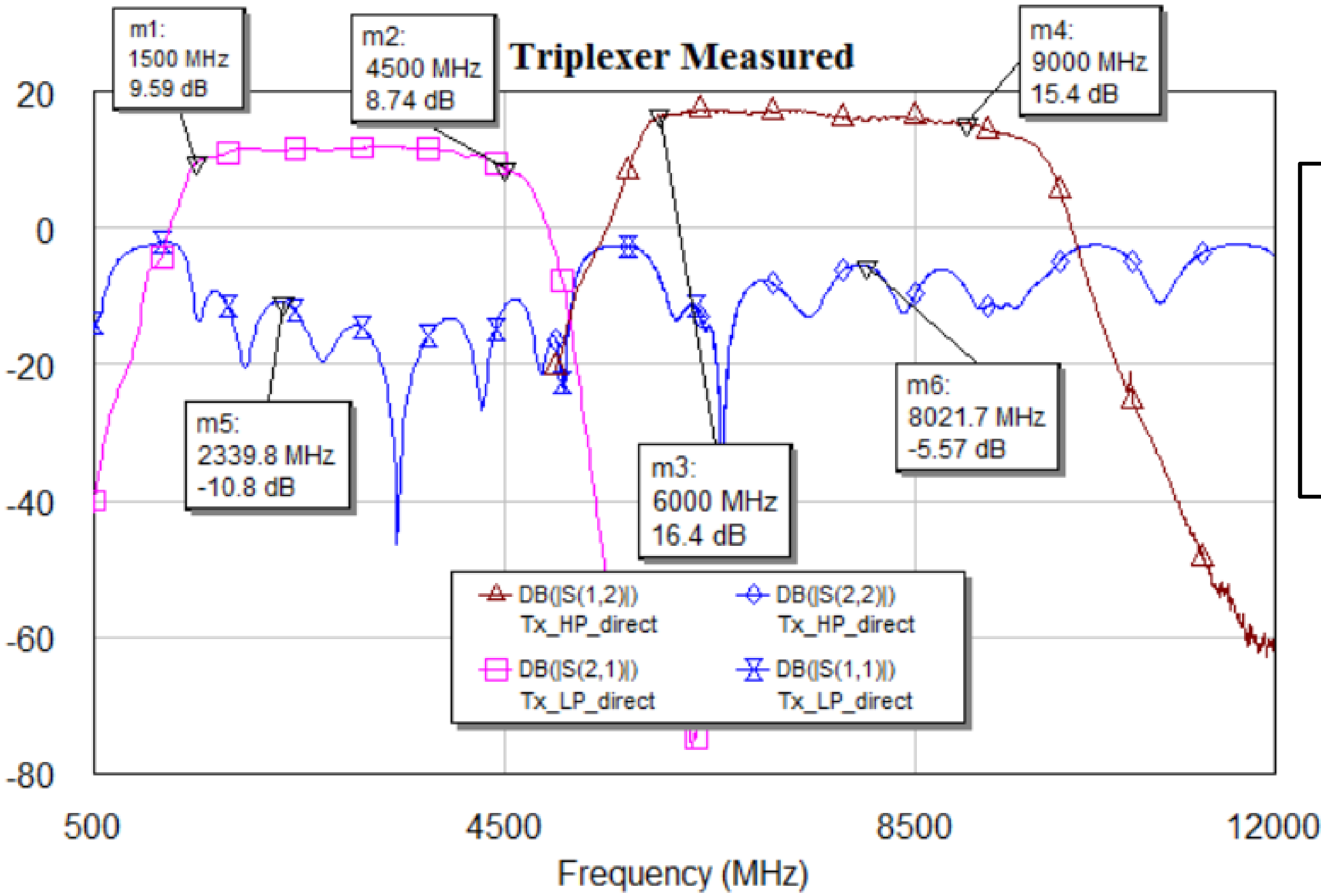
- The triplexer was constructed on a hybrid multilayer PCB.
- The top RF layer consists of 8-mil thick Rogers RO4003C material. The bottom layers were made from lower cost FR-370HR material of varying thicknesses.
- Half-ounce copper was used for all RF signal traces. Therefore, linewidths are kept above 7 mils, via diameter above 8 mils and gaps between conductors above 4.75 mils.
- The copper traces were plated using Electroless nickel immersion gold (ENIG) to protect from oxidation. While ENIG treatment does cause an increase in losses with increasing frequency of operation, this was considered an acceptable trade-off below 10 GHz.

Fabrication and related issues – contd.



- The lumped elements used in the design are 0402 and 0201 type components with high self-resonant frequency values (>12 GHz) and high Q-values from different manufacturers.

Measured Results

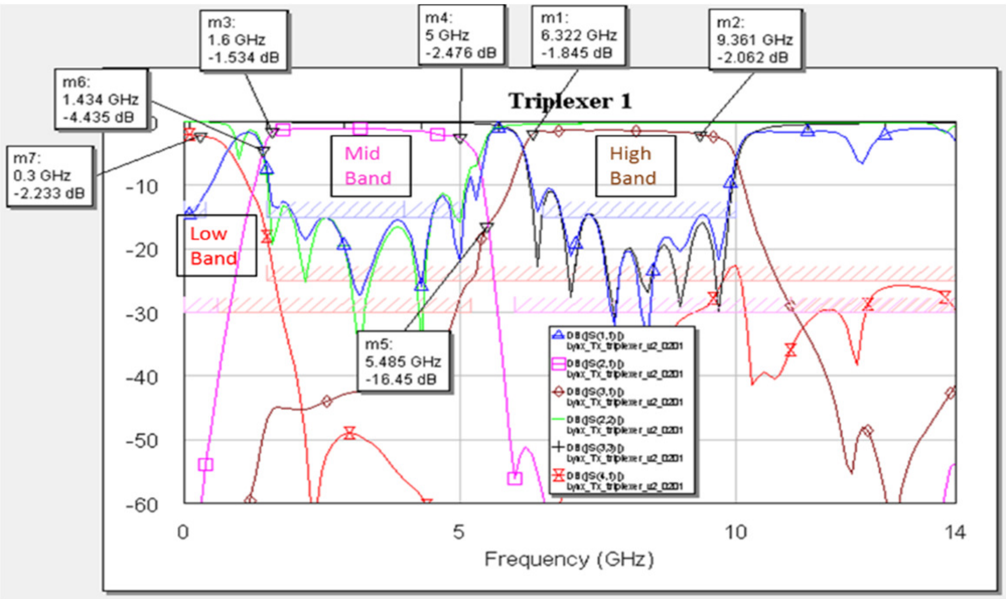


S31 – High Band IL

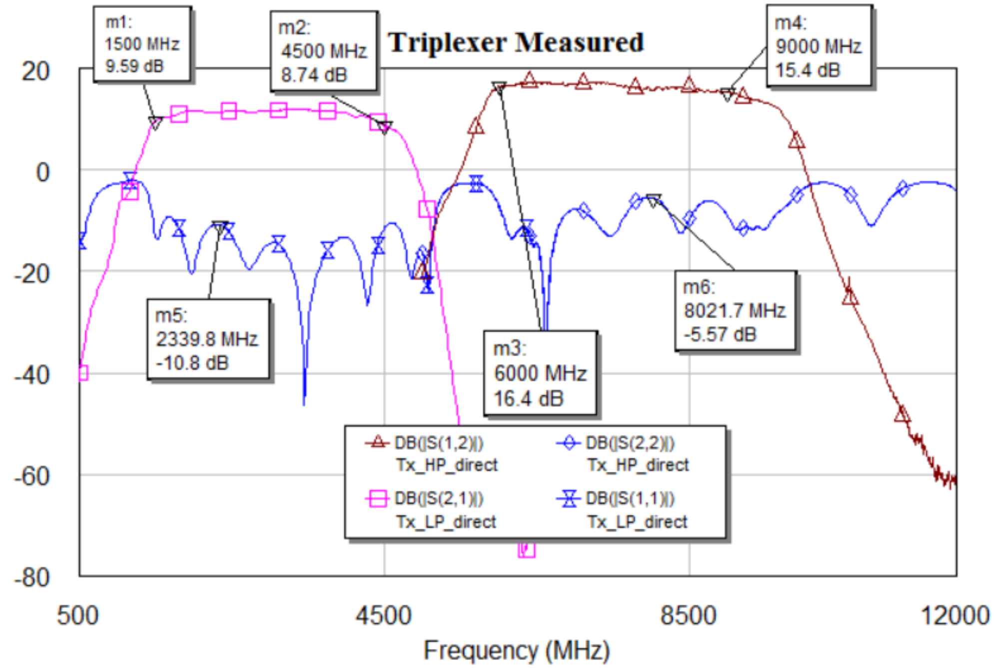
S21 – Mid Band IL

S11 – Input RL

Measured vs Simulated Results



SIMULATED



MEASURED

- The fabricated triplexer was designed as part of a larger integrated PCB based circuit consisting of amplifiers, attenuator pads and mixers.

- The measured response shifted lower by 200 MHz in the mid-band and 300 MHz in the high-band. This is due to many factors including but not limited to fabrication tolerances, additional components and cavity effects.

- Average measured insertion loss is better than 3 dB while average isolation measured greater than 35dB.

References

- [1] J. Hong and M. Lancaster, "Microstrip filters for rf/microwave applications" First Edition, John Wiley & Sons, Inc., 2001, pp. 29-74.
- [2] J. Hong and M. Lancaster, "Microstrip filters for rf/microwave applications" First Edition, John Wiley & Sons, Inc., 2001, pp. 109-120.
- [3] P. Jarry and J. Beneat, "Advanced design techniques and realizations of microwave and rf filters" First Edition, John Wiley & Sons, Inc., 2008, pp. 131-149.
- [4] G. Matthaei et al, "Microwave filters, impedance-matching networks and coupling structures" First Edition, McGraw Hill, Inc., 1964, pp. 355 – 409.

Summary

- A compact, planar, inexpensive microstrip triplexer discriminating 3 bands in the range of 0 – 9 GHz has been implemented on RO4003C softboard.

- The successful design of this triplexer provides considerable savings in terms of board space, cables and connectors.

Acknowledgements

The authors would like to thank all members of the NI Microwave Components Group who contributed with their advice and insights to this design.

Questions?