

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

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**Abstract**— This paper presents a uniplanar microstrip triplexer implemented on softboard. The triplexer consists of Chebyshev band-pass sections implemented using microstrip interdigital (High-band: 6-9 GHz), quasi-lumped (mid-band: 1.5-4.5 GHz) and quasi-lumped (0-200 MHz) sections. The primary motivation is to reduce the number of RF/microwave connectors and cables needed to transfer multi-band signals between modules. The triplexer was implemented on 8-mil RO4003C PCB. Passband losses are limited to ~2-3 dB while adjacent band rejection is better than 30 dB. This triplexer design can be incorporated as part of a standard microstrip design flow.

**Keywords**—triplexer, diplexer, filter, softboard, planar, broadband, microstrip, PCB, microwave.

## I. INTRODUCTION

Diplexers are frequency selective circuits that are used to combine and separate multiple frequency bands in a common transmission medium. This results in savings in terms of cables, connectors and circuit space. This is designed to transfer three separate bands, namely a reference signal at 10 MHz and two information bands at 1.5 – 4.5 GHz and 6-9 GHz, across a single cable between two microwave modules thus eliminating two sets of cables and associated connectors. The triplexer is compact, easily fabricated, have low insertion loss (<2 dB) in the pass-band and high rejection (> 30 dB) in the reject bands. This is achieved by designing a planar microstrip triplexer that combines distributed interdigital and quasi-lumped sections bandpass and lowpass sections.

Fig. 1 shows a triplexer realized by paralleling a lowpass filter and 2 bandpass filters at a common junction. The complex input admittance of the triplexer is given by the following equation:

$$Y_{in} = Y_{inLP} + Y_{inBP-mid} + Y_{inBP-high} \quad (1)$$

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

$$Y_{in} = Y_0, \quad (2)$$

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

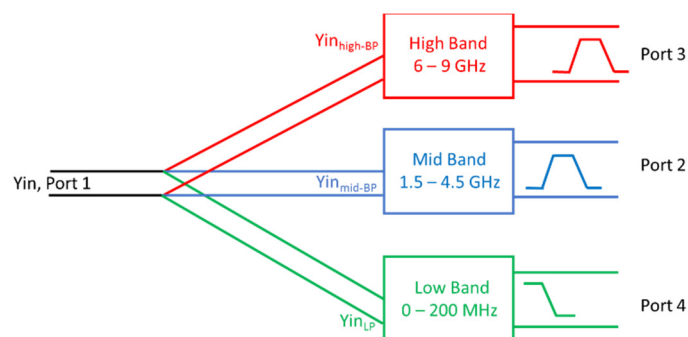


Fig. 1. Block Diagram of a parallel-connected triplexer

$$\text{Re}(Y_{inLP}) + \text{Re}(Y_{inBP-mid}) + \text{Re}(Y_{inBP-high}) = Y_0 \quad (3)$$

$$\text{Im}(Y_{inLP}) + \text{Im}(Y_{inBP-mid}) + \text{Im}(Y_{inBP-high}) = 0 \quad (4)$$

A detailed treatment for the same can be found in [1]. The next section details the design of the three filters and the triplexer response optimization after combination.

## II. FILTER DESIGN

The three filters are designed separately after which the triplexer response is optimized so that the transmission zeros of one band do not lie in the passband of the other bands. Admittance inverter equations are used in conjunction with AWR Microwave Office to design all three filters. Targeted design specs for the triplexer are detailed in the table in Table 1.

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

Table 1. Design Specifications

### A. 0 – 200 MHz Lowpass Filter

This section consists of a 3<sup>rd</sup> 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. The layout of this filter is shown in Fig 2.

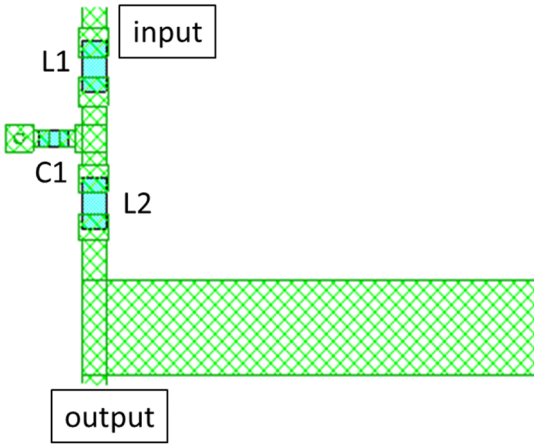


Fig. 2. Layout of the Lowband section.

Design principles and equations for the same can be found in [2]. 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

Table 2. Component values of lowband section.

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

### B. 1.5 – 4.5 GHz Midband Bandpass filter

This section consists of a 6<sup>th</sup> degree Chebyshev inductively coupled cap- $\pi$ i 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. The passband of this section is 6 – 9 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. Layout of the same is shown in Fig 3.

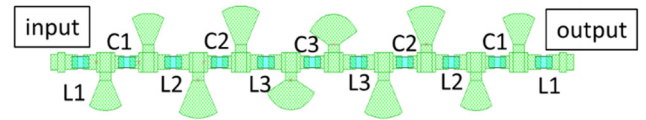


Fig. 3. Layout of the Midband section.

The values of the inductors and capacitors used in this section in the table in Table 3.

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

Table 3. Component values of midband section.

The section is 750 mils long and 125 mils wide.

### C. 6 – 9 GHz Highband Bandpass filter

This section consists of a 7<sup>th</sup> degree Chebyshev tapped input distributed interdigital bandpass filter. Layout of the filter is shown in Fig 4. The passband of this section is 6 – 9 GHz with an insertion loss less than -3 dB and return loss better than 12dB. This section is 205 mils long and 272 mils wide.

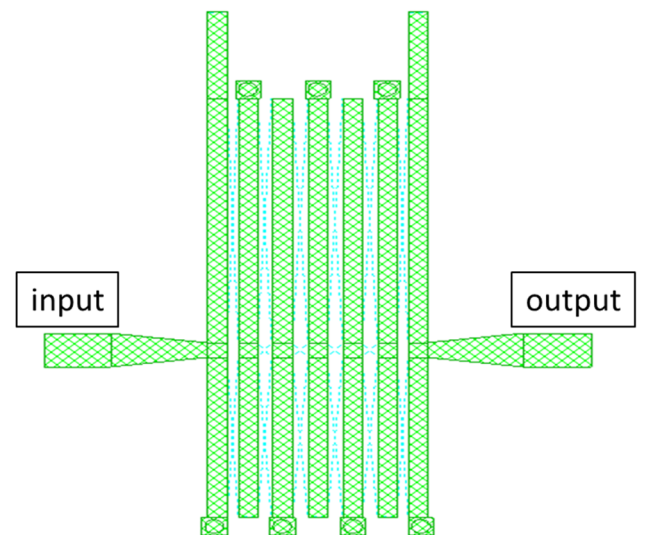


Fig. 4. Layout of the Highband section.

Theory and design principles utilized for this design can be found in [3].

### D. Triplexer Optimization

Once basic simulation of the individual sections has been completed, three sections were combined in a phased manner, one section at a time. 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. 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. After each addition, the combined sections were re-simulated and optimized using the AWR Microwave Office Axim and Analyst EM simulators. The complete layout of the triplexer is given in Fig 5.

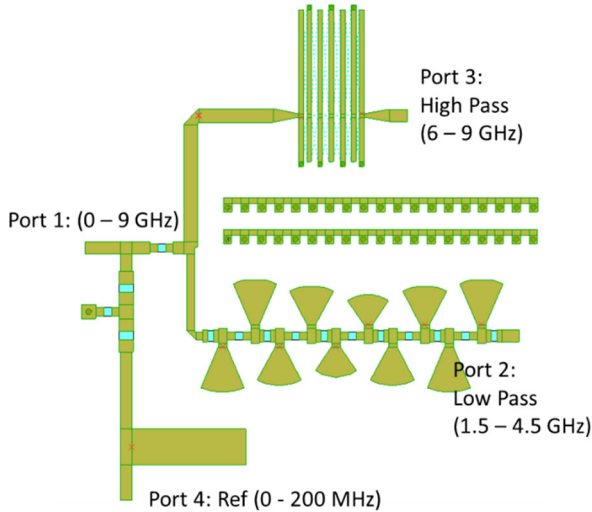


Fig. 5. Full layout of the triplexer.

An additional double layer of ground vias has been added to improve substrate leakage between the mid-band and high-band sections. The simulation results for all three bands are shown in Fig 6. A detailed treatment of multiplexer design and analysis can be found in [4].

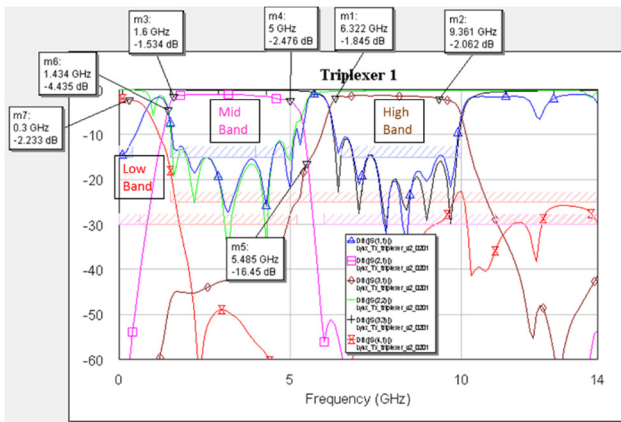


Fig. 6. Simulation Results.

### III. FABRICATION

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. It was considered important to achieve consistent performance and avoid tolerance related issues in serial production. 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. An image of the fabricated triplexer is shown in Fig. 7.

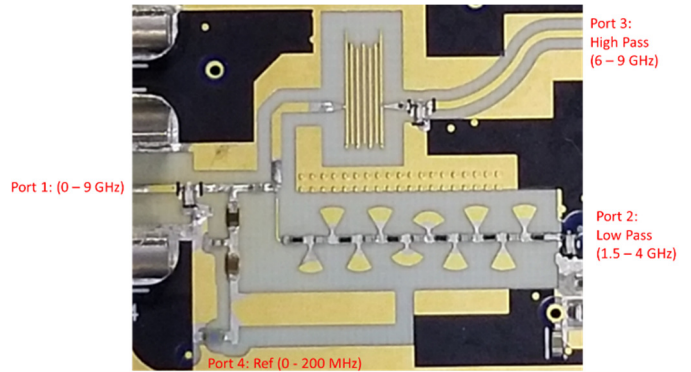


Fig. 7. Fabricated Triplexer.

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.

### IV. MEASURED RESULTS

The fabricated triplexer was designed as part of a larger integrated PCB based circuit consisting of amplifiers, attenuator pads and mixers. The frequency response, though, is primarily dependent on the triplexer. The combined response for the mid and high bands is given in Fig 8.

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. Once compensated for the contributions (loss and gain) of the additional components, the measured performance of the triplexer closely matches the simulated response. Average measured insertion loss is better than 3 dB while average isolation measured greater than 35dB.

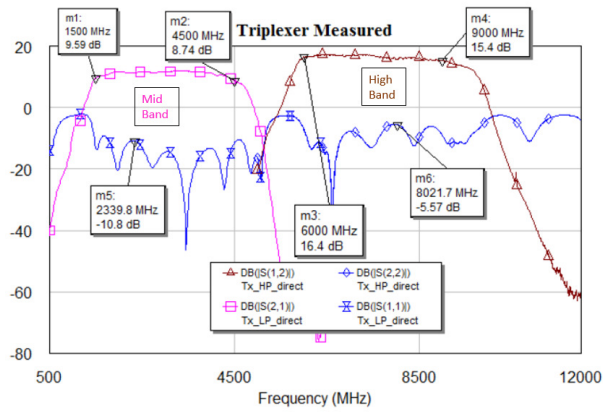


Fig. 8. Measured Results.

## V. CONCLUSION

A compact, uniplanar, microstrip triplexer discriminating 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.

## VI. ACKNOWLEDGEMENTS

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## VII. REFERENCES

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