Microstrip Filters

Can Lower Q Resonators Produce Better Filters?

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With the exception of Superconducting Filters, no one uses microstrip filters in the expectation of getting leading edge filter performance. Microstrip filters are used for reasons of Cost, Convenience and Size.

However, is it possible to deliberately reduce the Q-factor of the resonators used in order to achieve a better filter?

In order to compare realistic filters as they might be made for a real application we designed them using Rogers RO4350B material at 0.508mm thick with half ounce copper.

The value of Er used for the filter design is 3.66

The value of Tan∂ is 0.0031

The filter design will be a 4-pole filter covering 1.95GHz to 2.0GHz passband. We will compare insertion loss, and rejection for a range of microstrip filter designs.

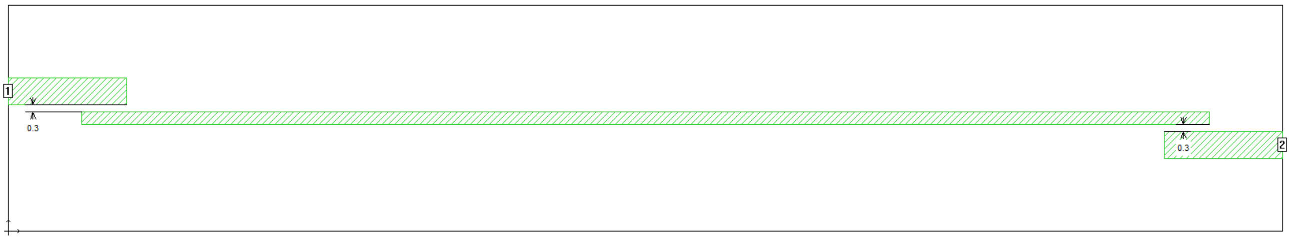
We used Nuhertz FilterSolutions 2017 to synthesise the filter from basic requirements and then Sonnet Software to electromagnetically simulate the filter and optimise the layout to achieve the final performance.

The design started with the largest, highest Q version of a microstrip resonator and progressively used smaller resonators to see what the impact was on performance.

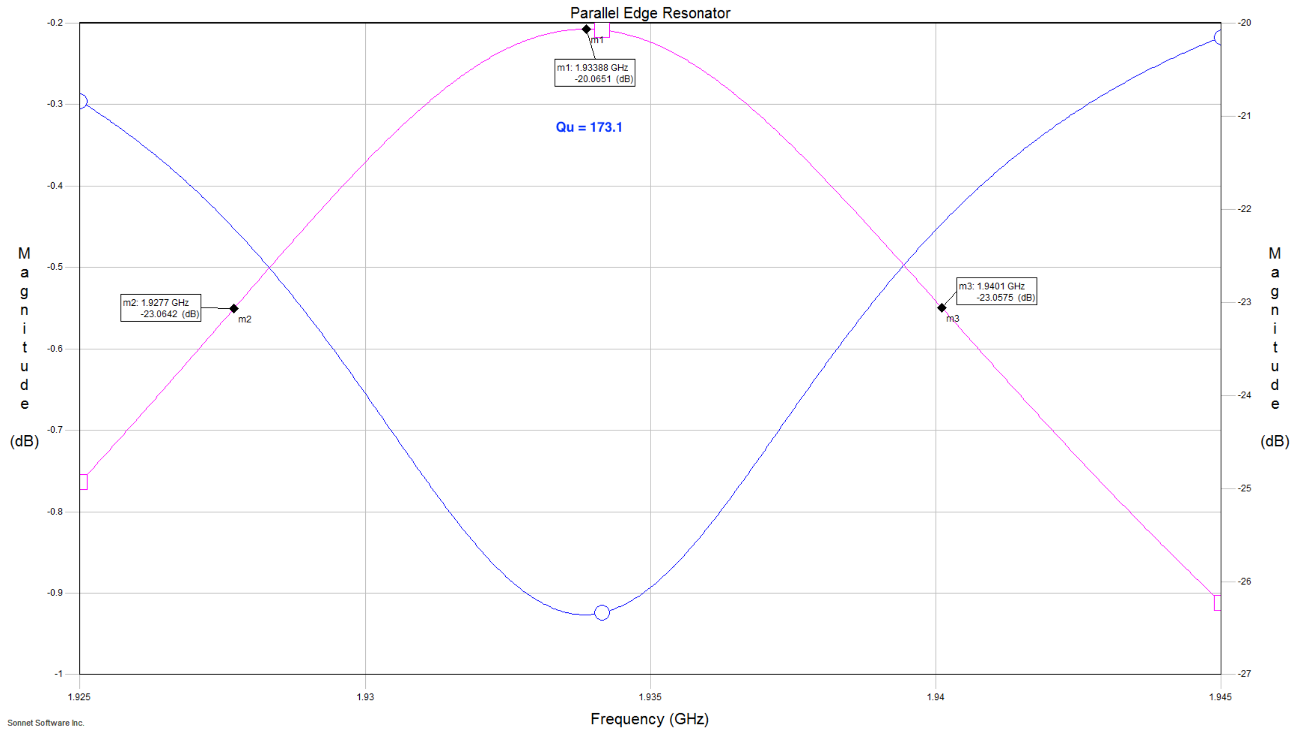
Parallel Edge Coupled Filter

This is the standard form of microstrip filter that is most easily designed and laid out

The typical resonator section would look as follows:

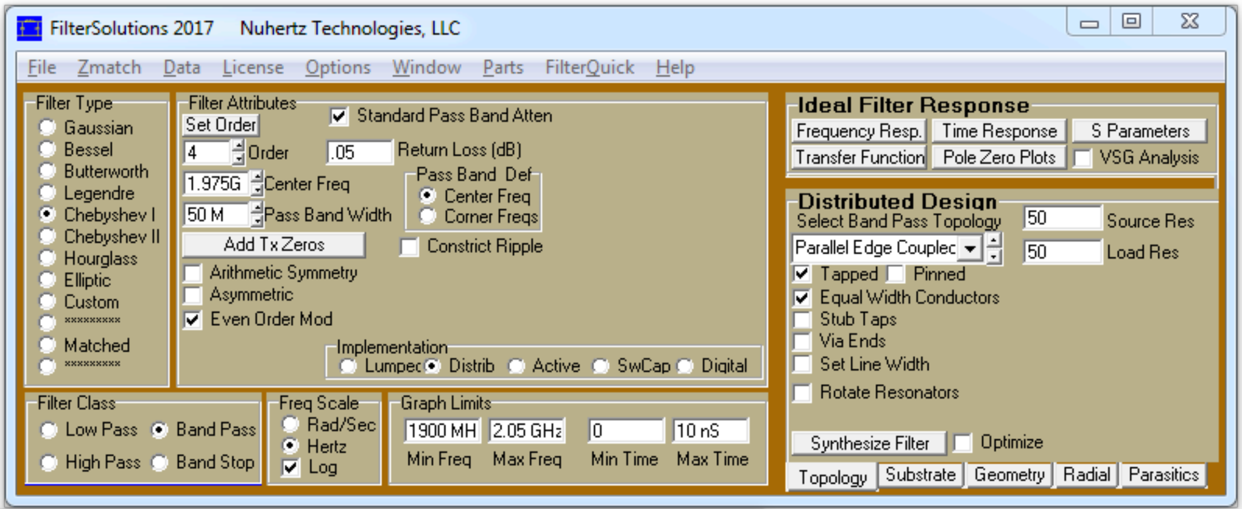


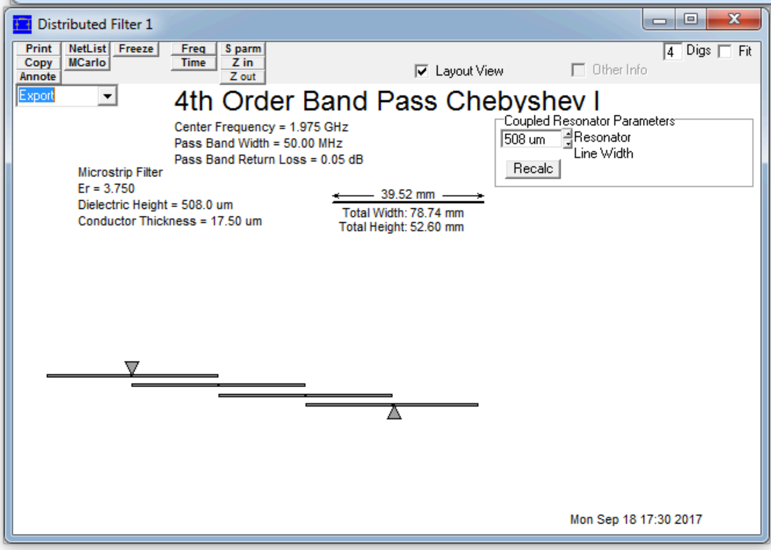
The Q-factor of this resonator is:



The Unloaded Q-factor, Qu = 172

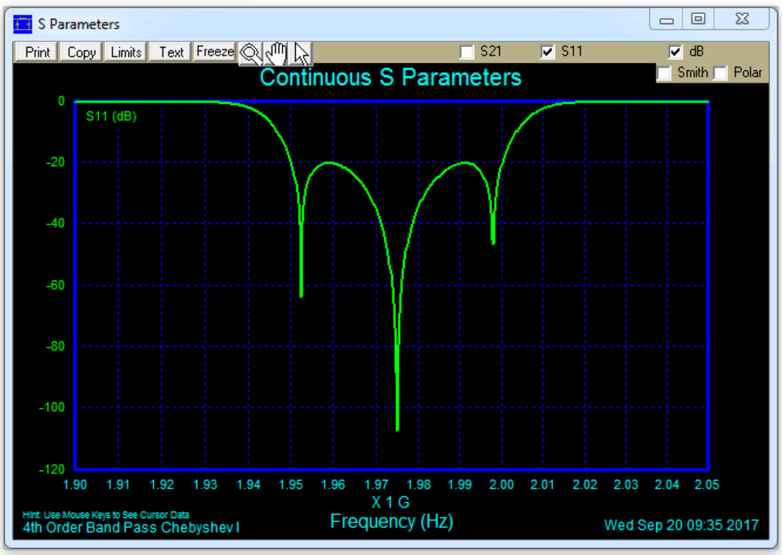
The Filter Synthesis set up is as follows:



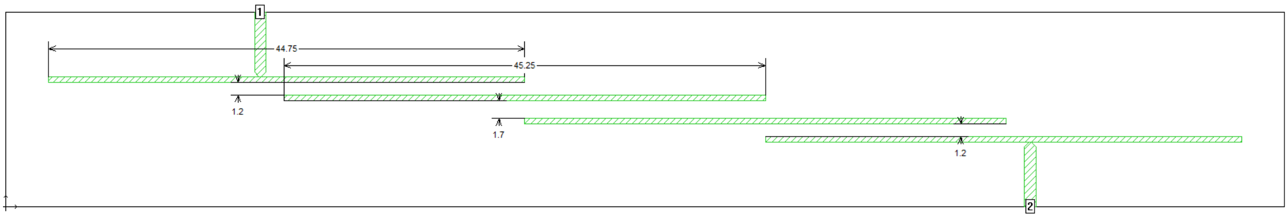


The predicted return loss is -20dB across the passband.

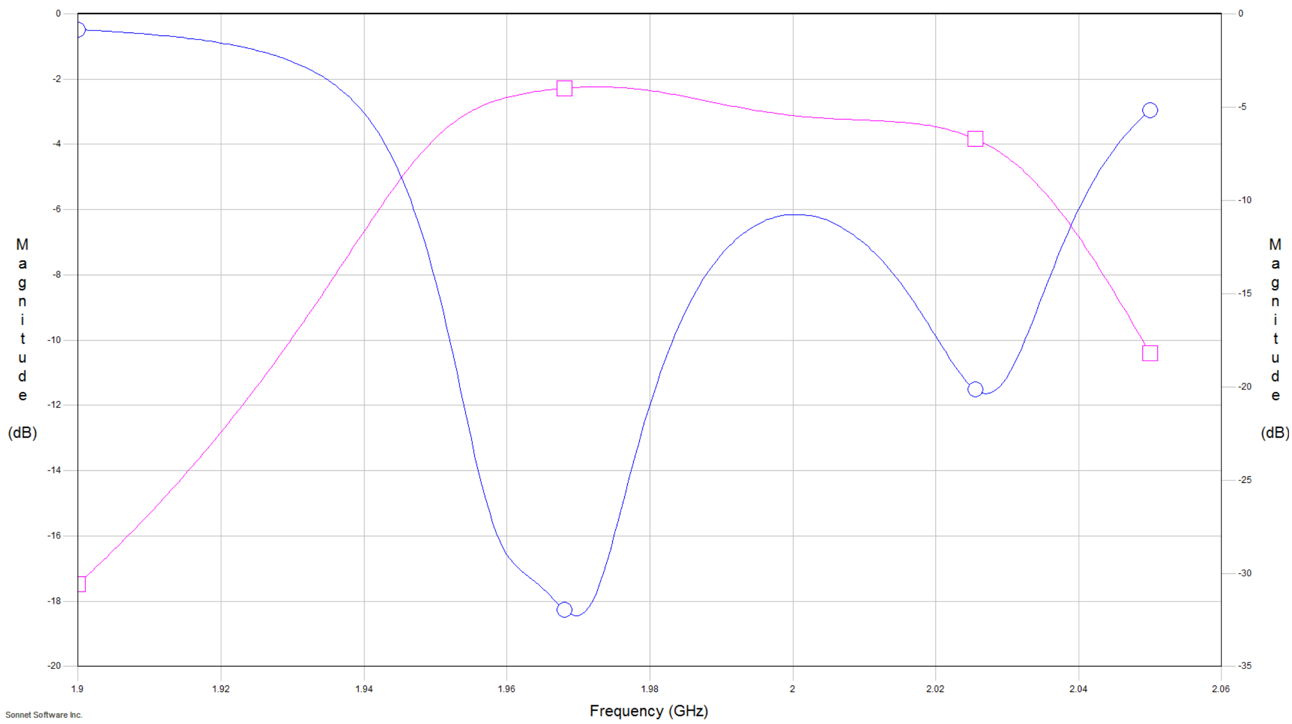
The filter layout is exported directly into Sonnet for em-simulation and optimisation.



The exported layout :

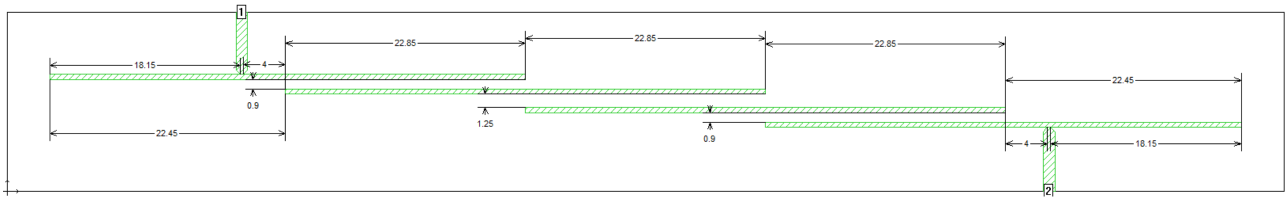


The initial simulated response:



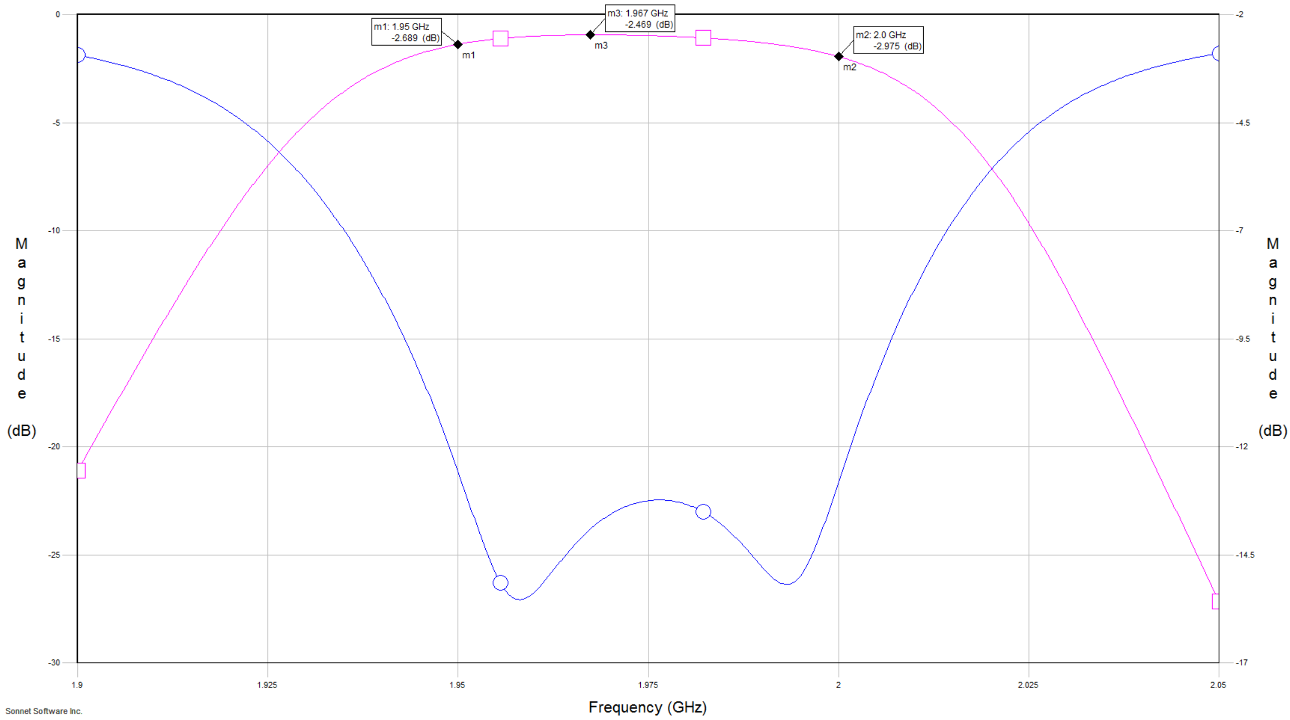
Each simulation takes about 10 minutes and about an hour's work is required to optimise the filter to the following response:

Optimised Layout:



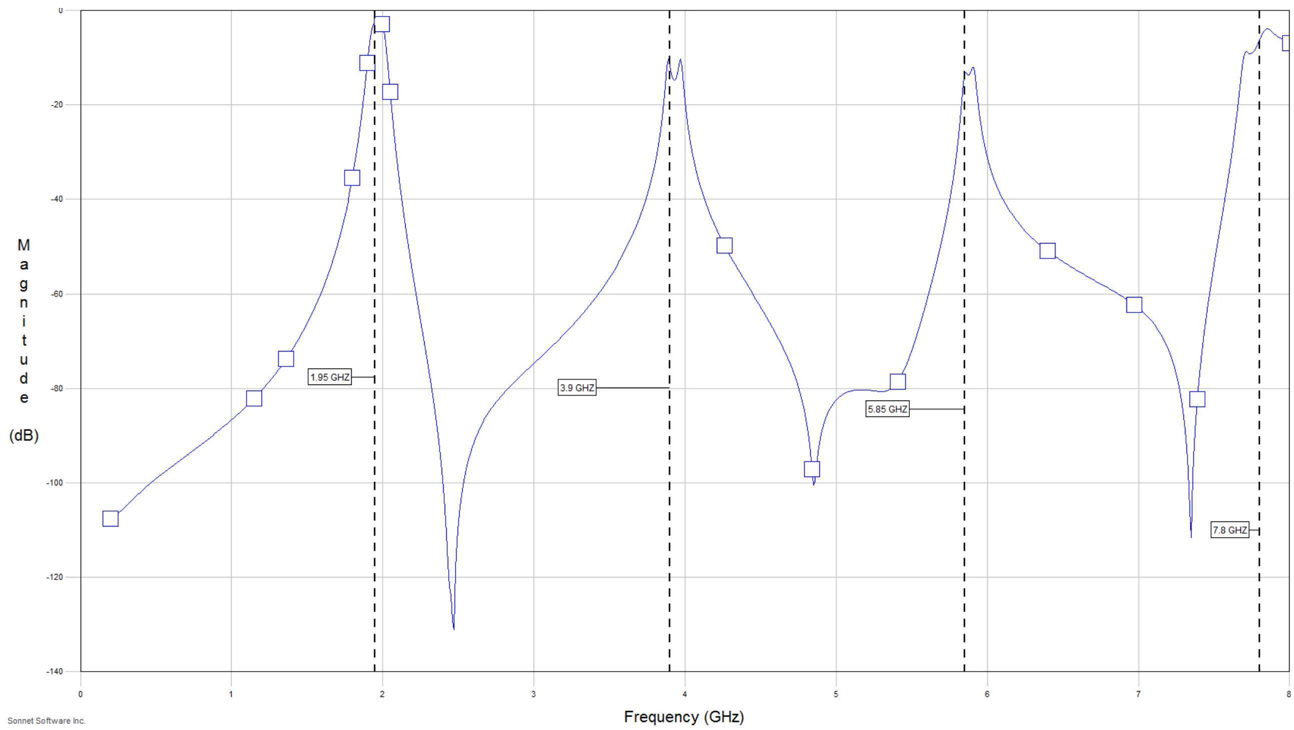
The coupling gaps are slightly narrower and the resonators are slightly longer, however the synthesised layout reduced the design time enormously.

Passband response:



Insertion Loss from 2.47dB to 2.98dB with return loss of -20dB.

Wideband response:

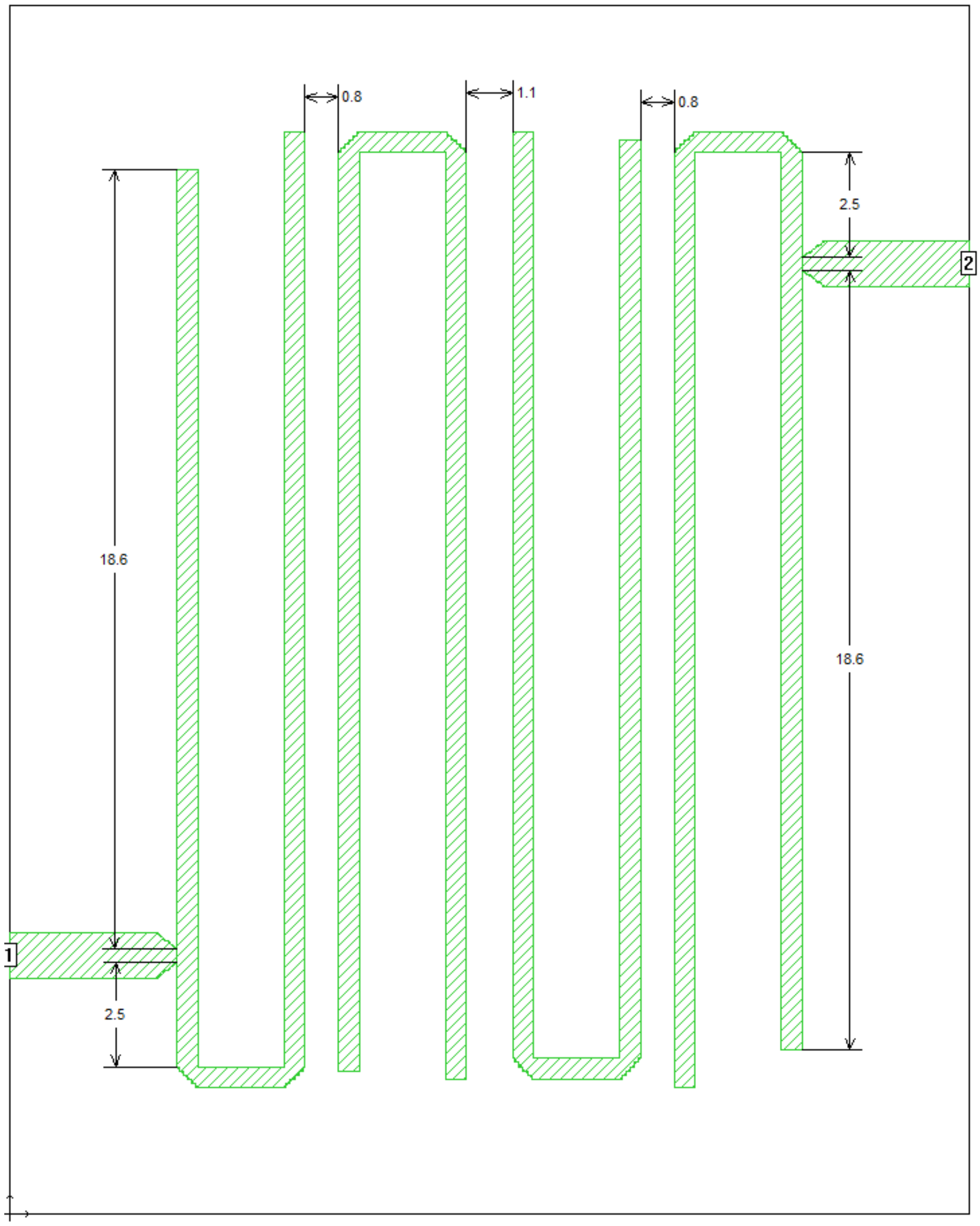


It can be seen that every harmonic has its own passband. If the harmonic bands are important then a low pass filter will also be required to clean up the reject band and this will add more insertion loss.

The total board area required for this filter is 121.5mm x 17.05mm = 2,071 mm^2
The insertion loss is < 3dB across the passband

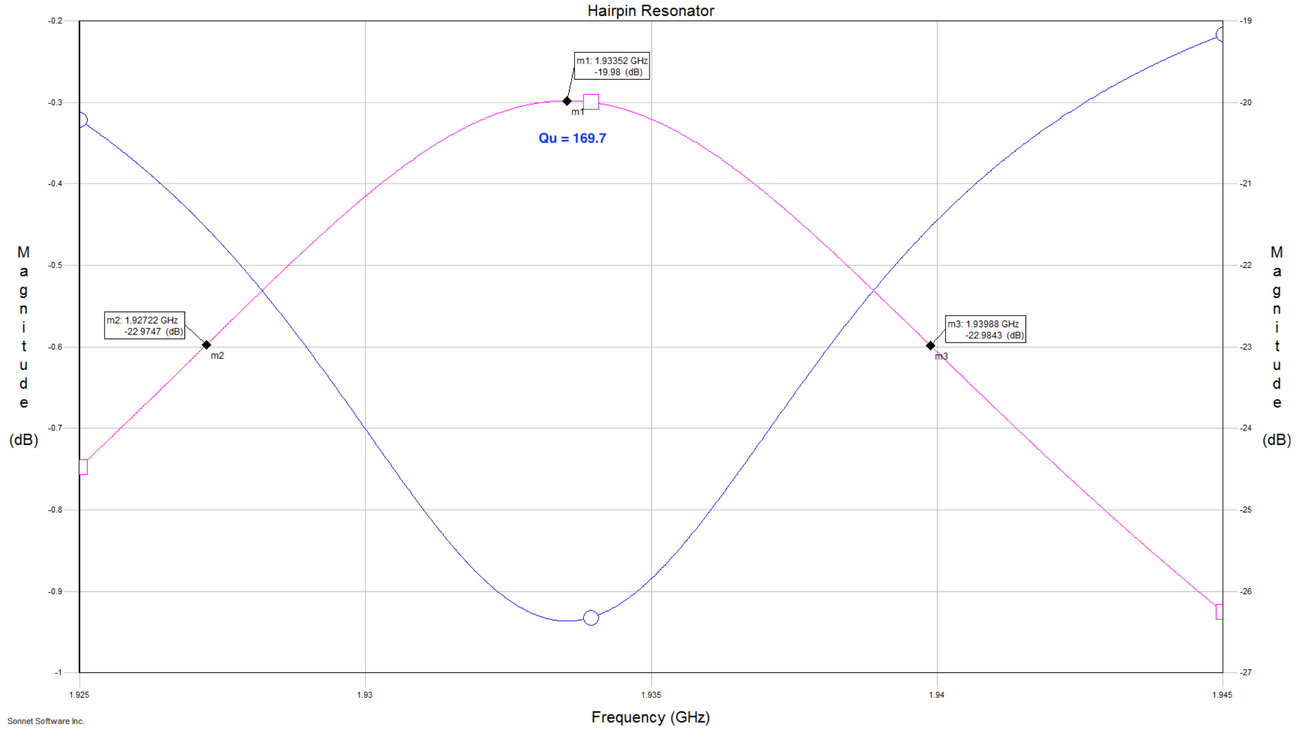
Hairpin Filter:

The first stage of miniaturisation is the Hairpin Filter, which folds the straight resonator into a U-shape. This produces the following result :

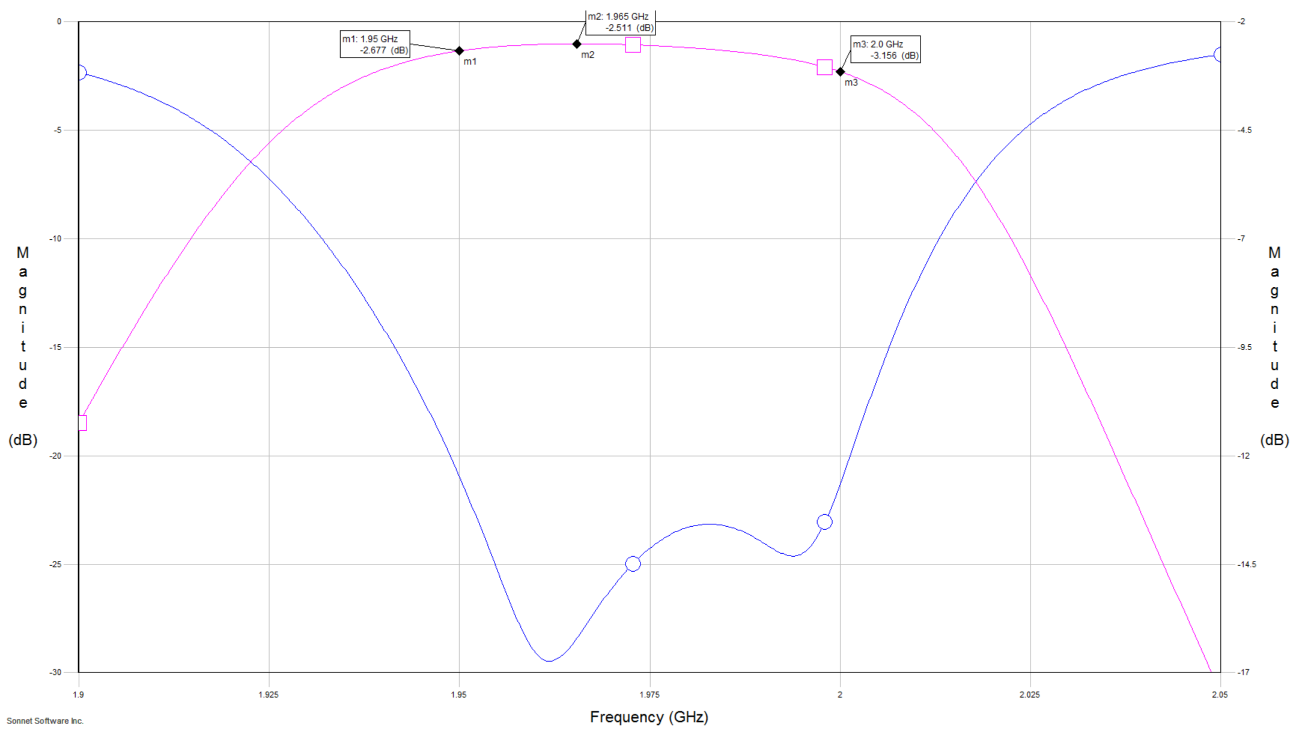


The surface area of the filter is 22.9mm long x 28.8mm wide = 660mm^2

The Unloaded Q, Qu = 169. This almost as good as the straight resonator.



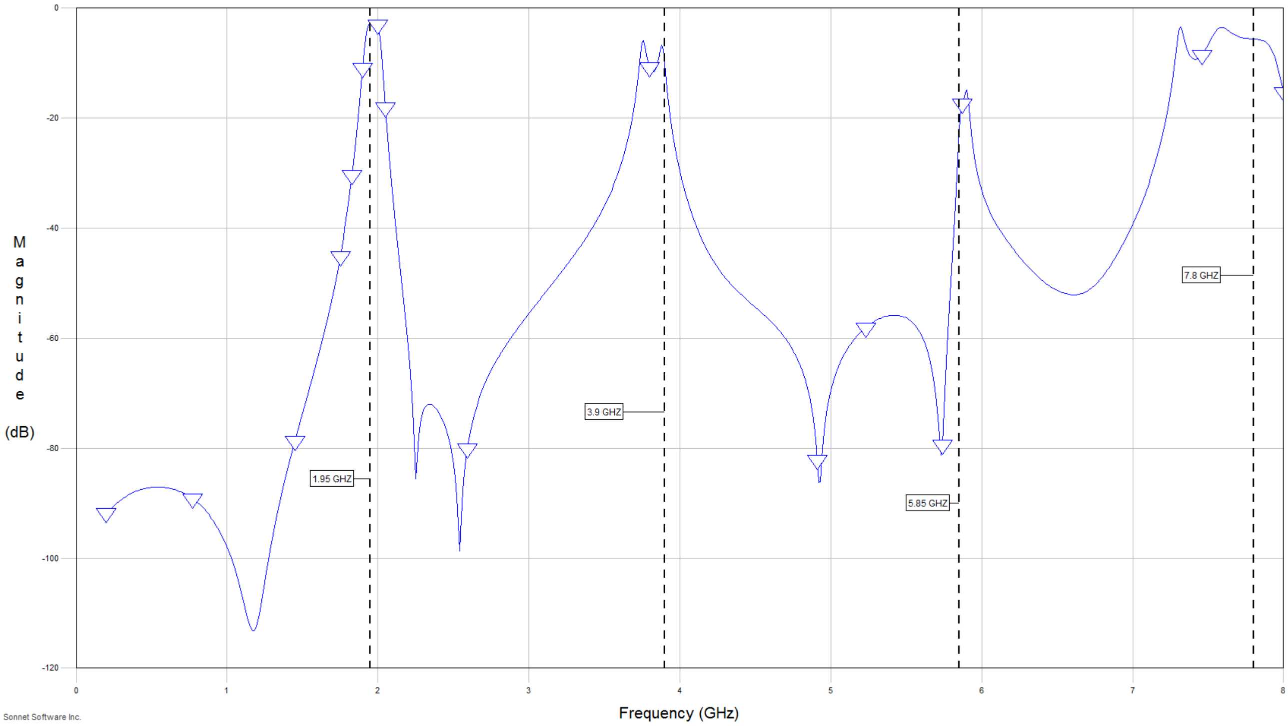
Hairpin Passband Response:



Insertion loss from -2.51dB to -3.16dB

The insertion loss is up to 0.2dB worse than for the parallel edge coupled filter.

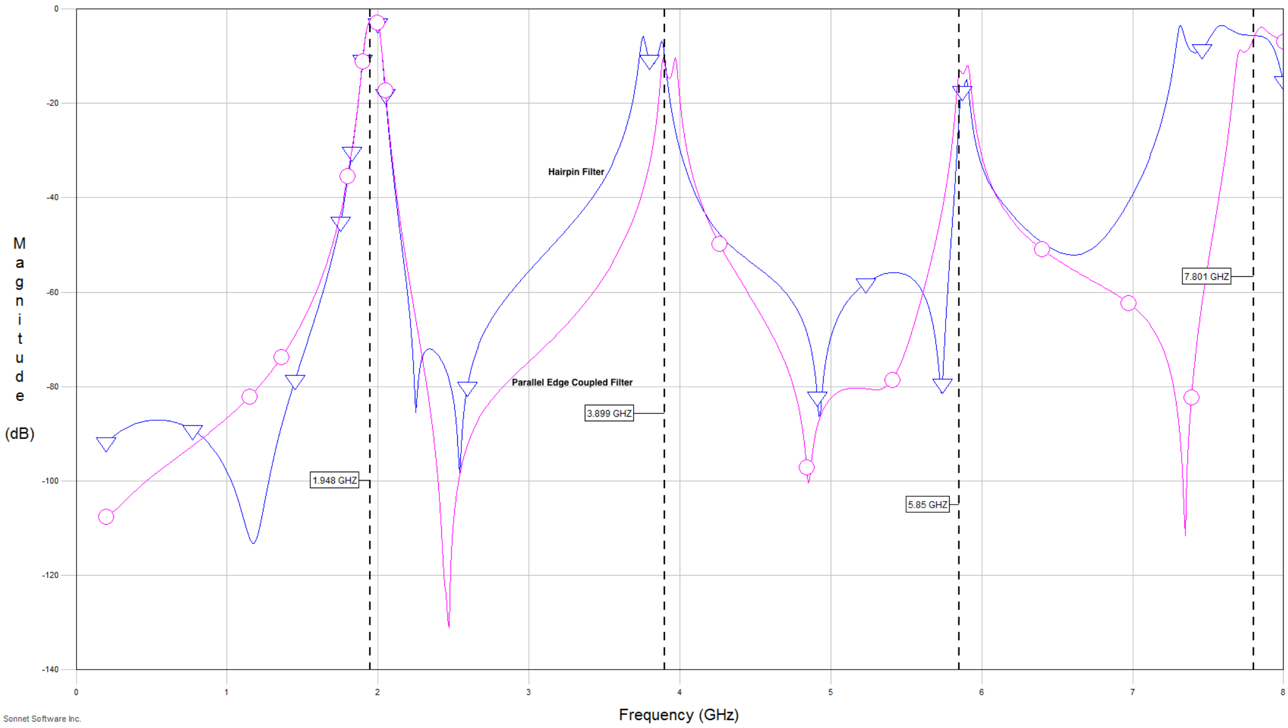
Hairpin Wideband Response:



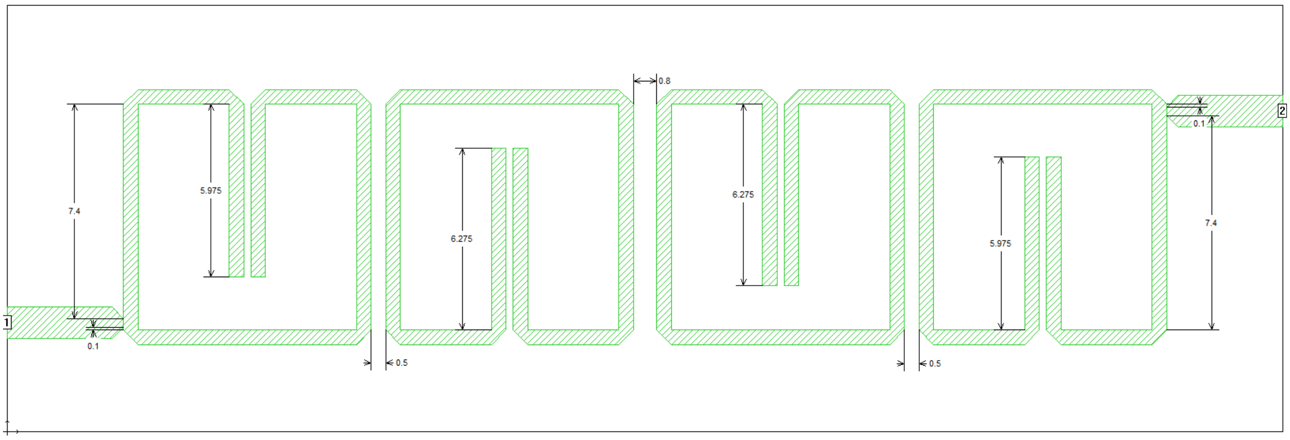
Comparison of Hairpin versus Parallel Edge Coupled Filter:

The close in rejection is very similar to the parallel edge coupled filter.

The higher order passbands are almost harmonically related, but the even order harmonics are shifted and spread across a wider band.

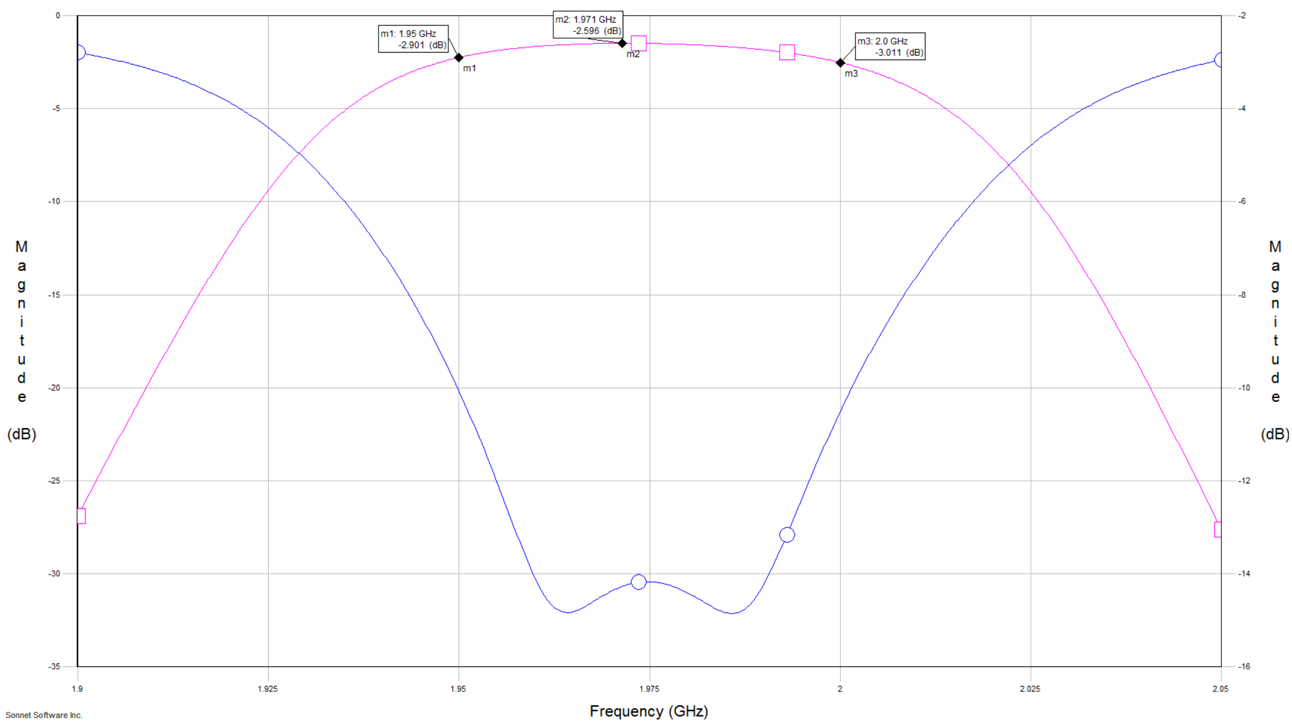


Miniature Hairpin Filter:
The second stage of size reduction folds the hairpins in on themselves



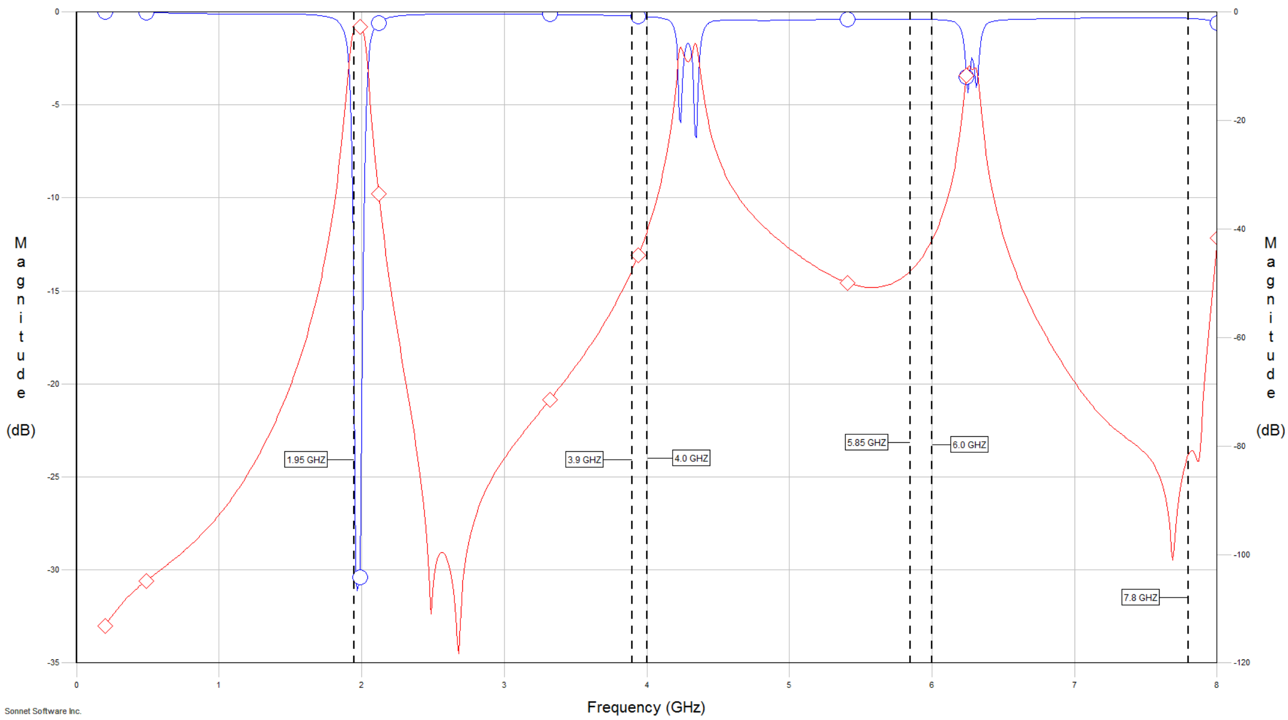
The surface area of the filter is 44.0mm long x 12.7mm wide = 559mm^2
The Unloaded Q, Qu = 172 which matches the straight resonator.

Passband Response:



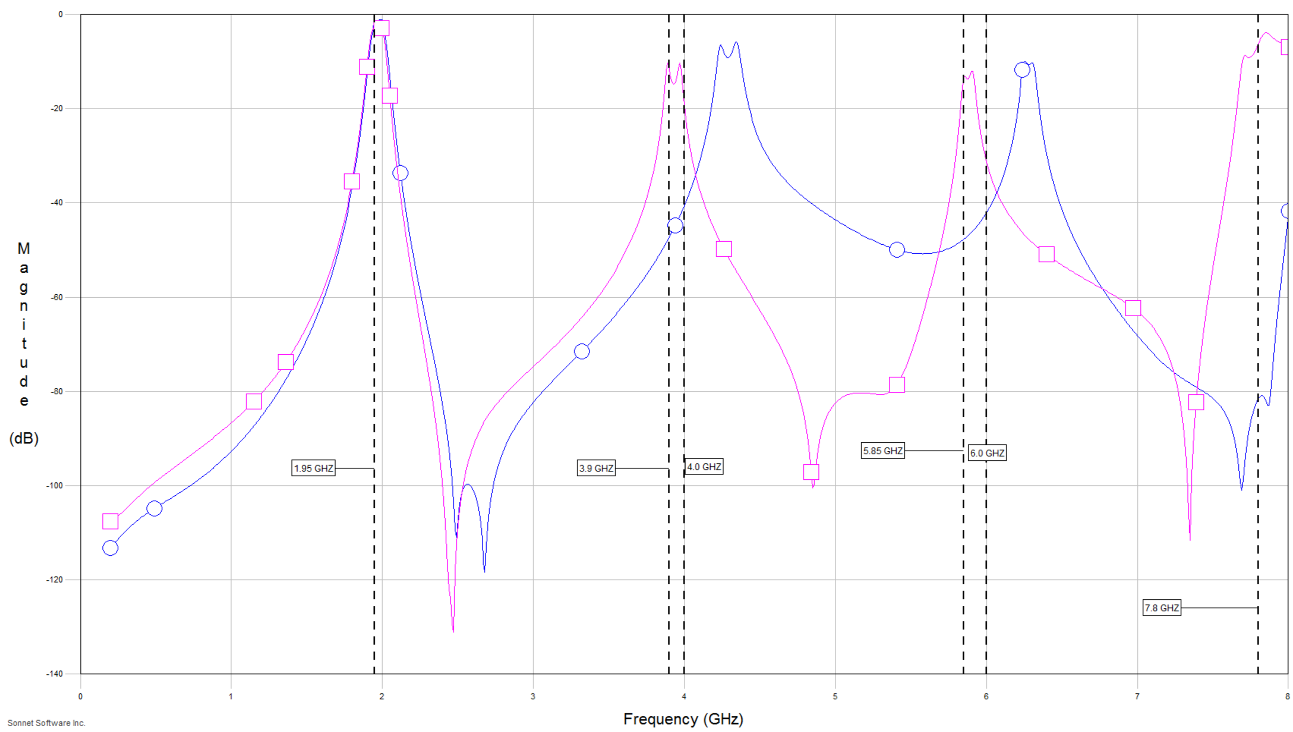
Insertion loss from -2.6dB to -3.01dB
The insertion loss is within measurement error of the parallel edge coupled filter.

Miniature Hairpin Wideband Response:



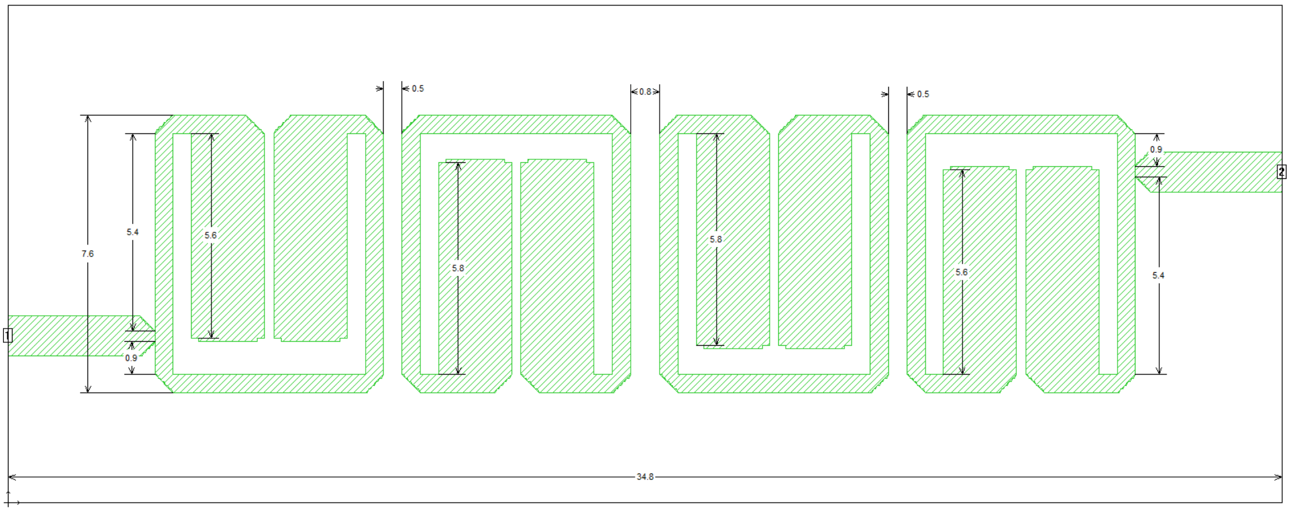
The higher order passbands have been shifted up in frequency providing useful rejection in the harmonics of the wanted passband.

Comparison of Miniature Hairpin with Parallel Edge Coupled Filter:



Harmonic Hairpin Filter:

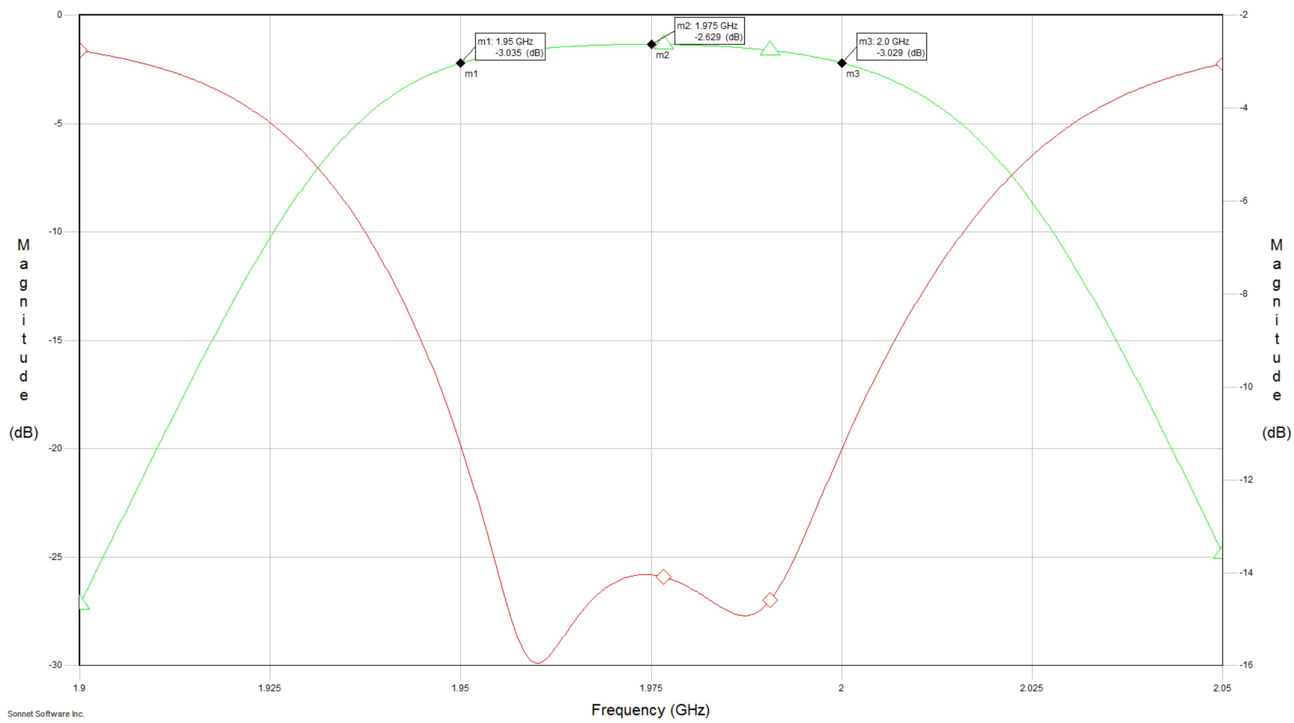
The third stage of size reduction is the use of stepped impedance within the folded hairpin to produce an extremely compact resonator that is is deliberately designed to move the harmonic resonances as far as possible up the frequency band.



The surface area of the filter is 34.8mm long x 11.6mm wide = 404mm^2

The Unloaded Q, Qu = 160 which is 7% lower than the straight resonator.

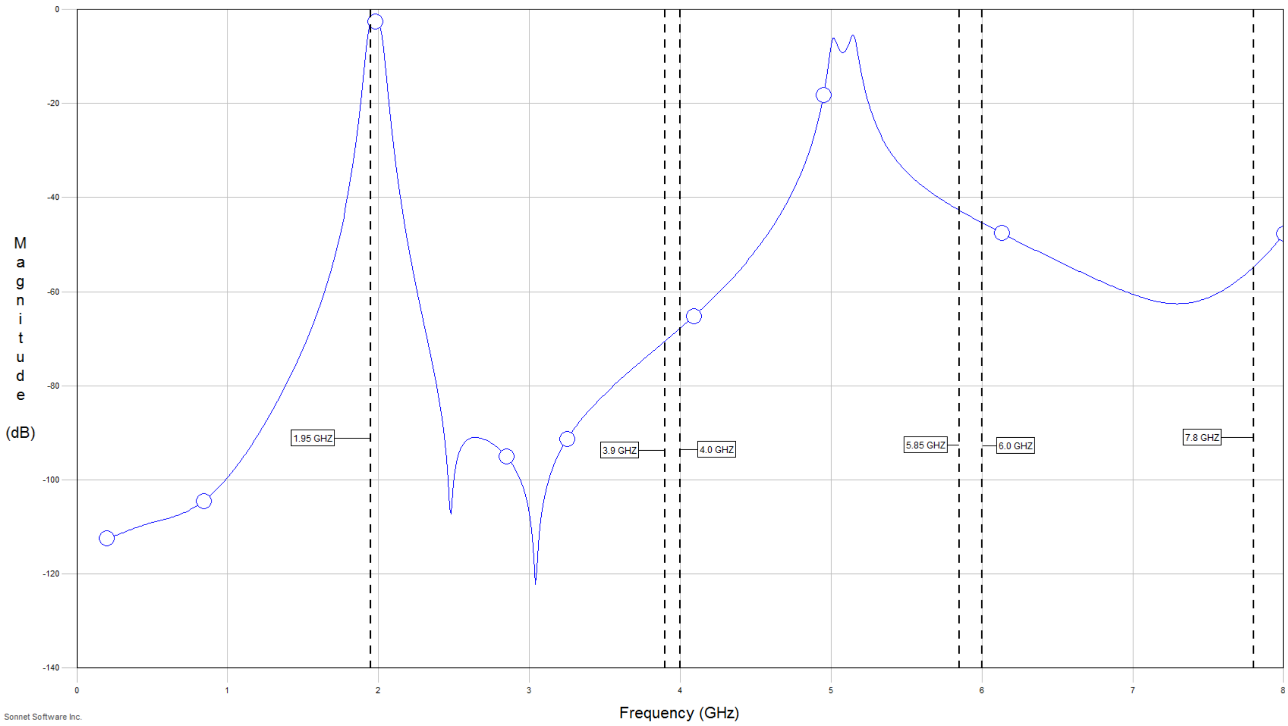
Passband Response:



Insertion loss from -2.63dB to -3.03dB

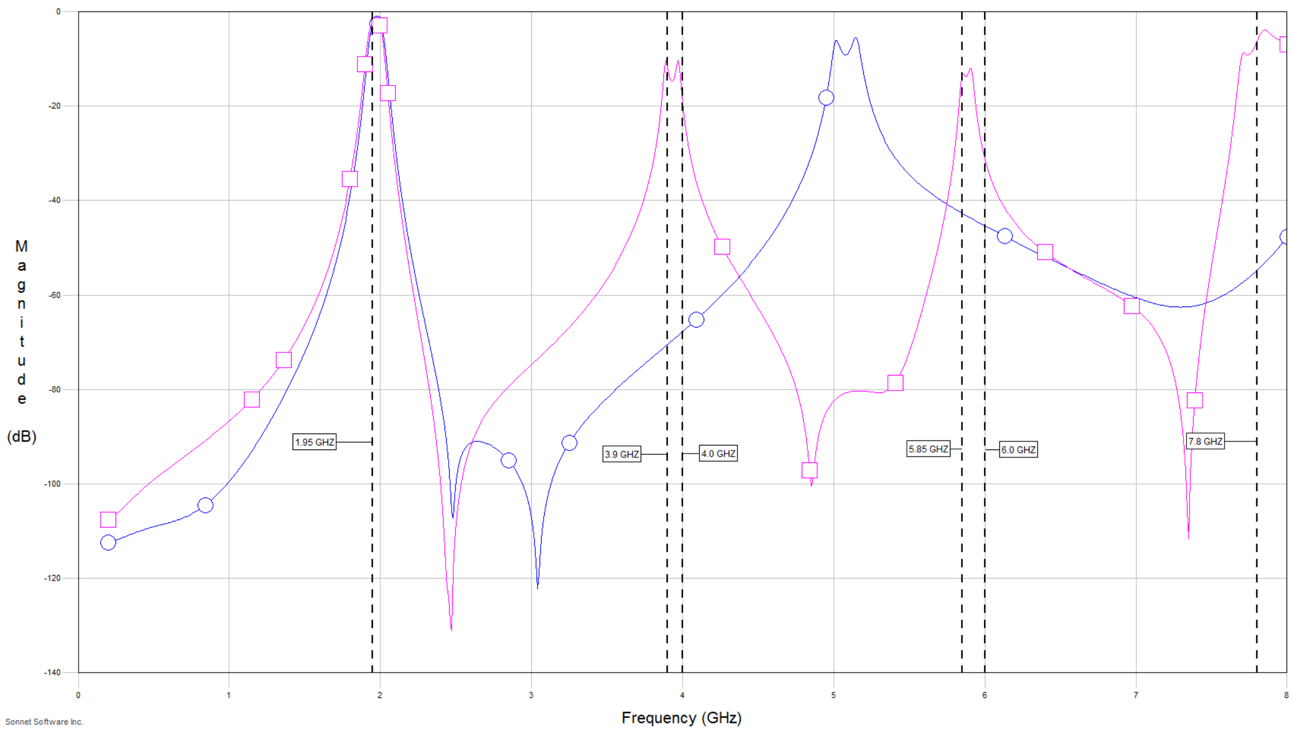
The insertion loss is within measurement error of the parallel edge coupled filter.

Harmonic Hairpin Wideband Response:



There is now only one higher order passband, with the 2nd Harmonic having better than 60dB rejection, and both the 3rd and 4th harmonic better than 40dB rejection.

Comparison of Harmonic Hairpin with Parallel Edge Coupled Filter:



The Harmonic Hairpin filter has better close in rejection below the passband than the Parallel Edge Coupled, while the Parallel filter is slightly better close in above the passband.

If the system requirements only relate to close in rejection and to the harmonic passbands then this Harmonic Hairpin Filter has met the requirements, while the Parallel Edge Coupled Filter would need to have an additional Low Pass Filter to clean up the harmonic bands. This would increase the size of the Parallel Edge Coupled Filter even more and would add insertion loss.

By most definitions then the Harmonic Filter is a better filter than Parallel Edge Coupled Filter as it is smaller, with very similar insertion loss and more rejection.

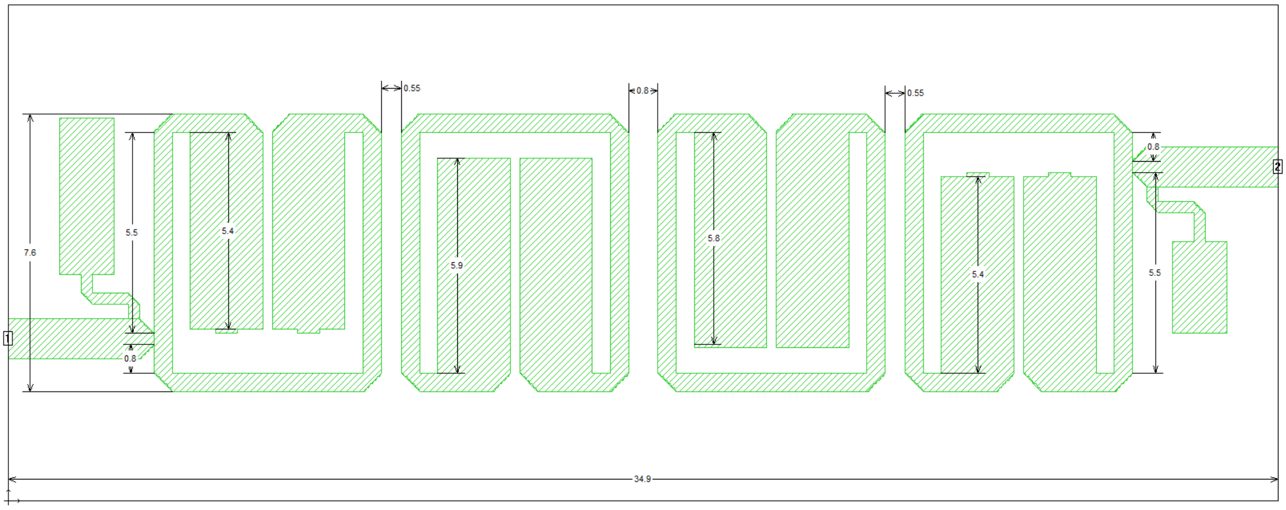
This does leave one question though; what if the system requirement is for continuous rejection out to 8GHz with no re-entrant passbands?

One option would be to add a low pass filter to the Harmonic Hairpin to pull down the re-entrant band at 5GHz, this would be a smaller low pass than required for the Parallel Edge Coupled as the needed attenuation is at a higher frequency.

However, there is another option:

As there is only one re-entrant passband to remove it is possible to add resonant notches to the Harmonic Hairpin to reject that narrow band. The result is as follows:

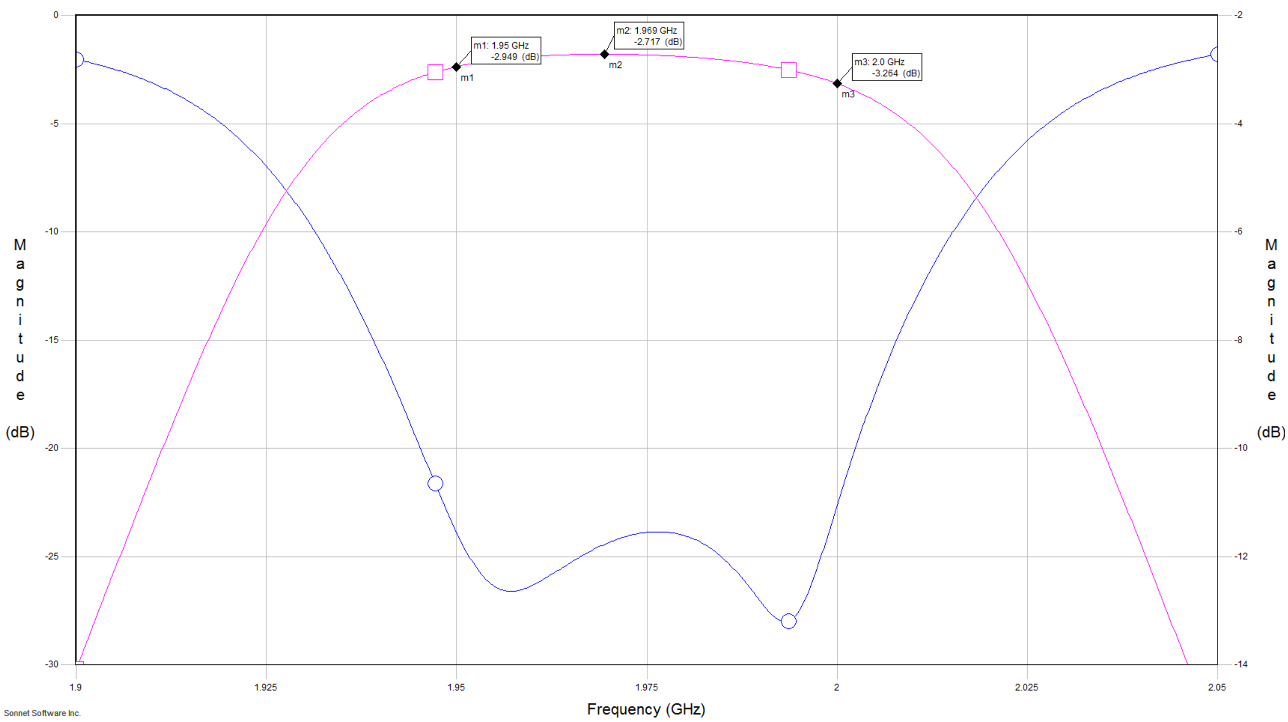
Harmonic Hairpin Filter with Notch:



The surface area of the filter is 34.9mm long x 11.6mm wide = 405mm^2

The coupling of the outer resonators has been adjusted very slightly to account for the effects of the extra notches.

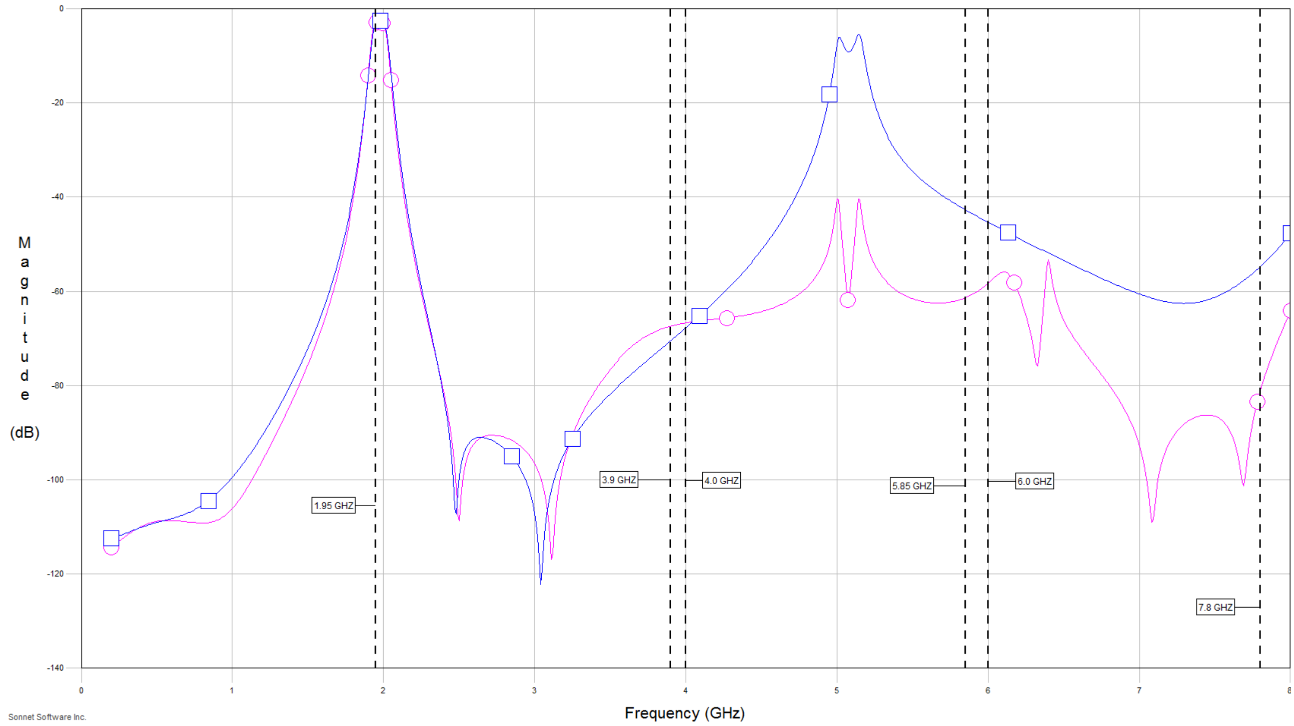
Passband Response:



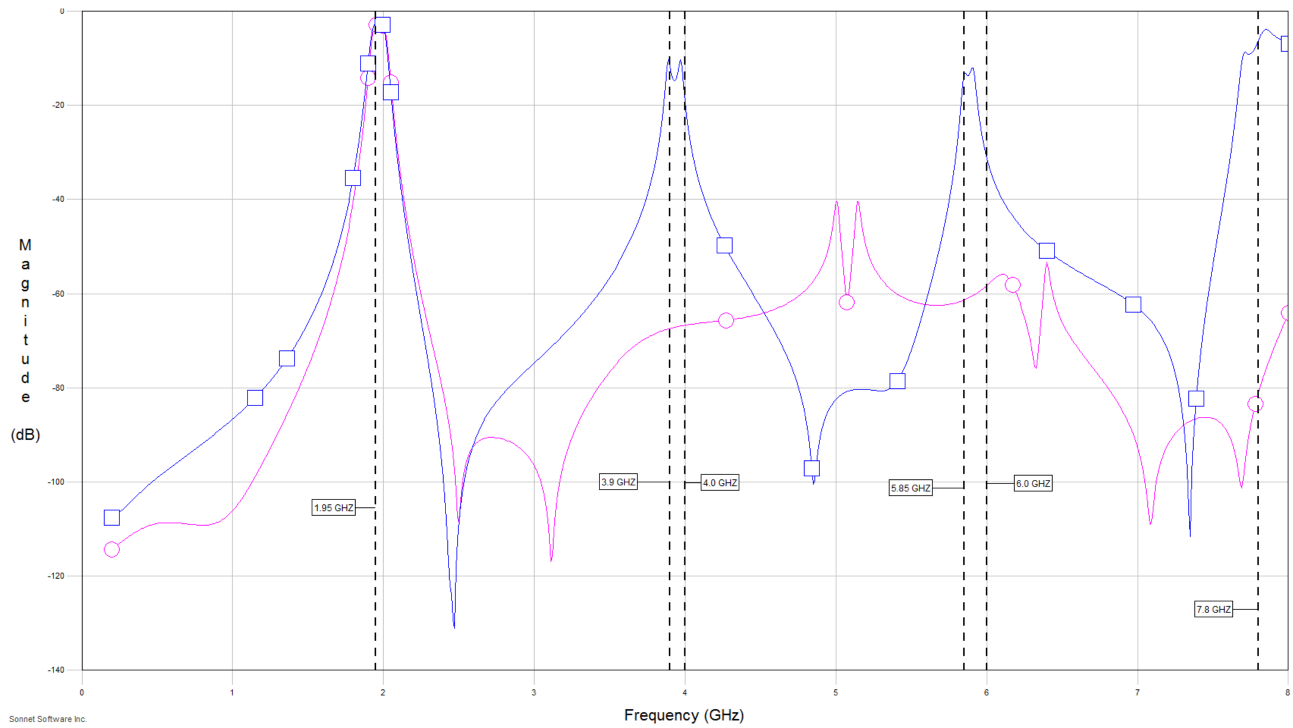
Insertion loss from -2.72dB to -3.27dB

The insertion loss is c.0.25dB worse with the notches, but a Low Pass Filter would add more loss than this.

Harmonic Filter with Notch compared with the Harmonic Hairpin:



Harmonic Filter with Notch compared with Parallel Edge Coupled Filter:



The benefits of the additional notch resonators are very apparent.

Table of Filters and Parameters:

Filter Type	Board Area	Insertion Loss	Resonator Qu	First Coupling Gap	Second Coupling Gap
Parallel Edge	2,071mm^2	2.98dB	173	0.9mm	1.25mm
Hairpin	660mm^2	3.16dB	169	0.8mm	1.1mm
Miniature Hairpin	559mm^2	3.01dB	172	0.5mm	0.8mm
Harmonic Hairpin	404mm^2	3.03dB	160	0.5mm	0.8mm
Harmonic with Notch	405mm^2	3.27dB	160	0.55mm	0.8mm

The first surprise is that the Qu of the smaller resonators does not reduce as much as expected.

The second surprise is that the insertion loss of the filters does not increase, or not by much as the resonator Qu does reduce.

The key reason for this better than expected insertion loss can be seen by looking at the coupling gaps between the resonators. As the resonators shrink so does the length of gap between them to achieve the same coupling value and, therefore, there is less circuit board material between the resonators to absorb the RF energy.

The main determinant of insertion loss in a microstrip filter is the circuit board material.

Conclusion

Lower Q resonators can indeed offer better filters when the reduction in Q-factor is offset by a corresponding reduction in loss in the coupling sections. Further more, if size is a critical factor then lower Q resonators can offer a much better filter.
In terms of the reject band, the smaller resonators have inherent advantages.

Nuhertz Filter Solutions can be used to synthesise these small filters and the layouts can be fed to Sonnet for electromagnetic simulation and optimisation for a very efficient filter design process.