WHITEPAPER

Tolerance and Size Analysis for mmWave Filter Manufacturing

One of the questions we get asked regularly is *“Why not just integrate a filter in the board stack?”*

Besides overall filter performance concerns, our answer to this comes in two parts: First there are manufacturing tolerances to consider, and second there is size.

Manufacturing tolerance for any filter will contribute to a filter’s performance and can make for some interesting discussions about what was planned for vs the realized filter performance. At mmWave frequencies, tolerance impacts can become significant and can potentially impact the total cost of an implementation.

Size is also a cost of implementation consideration – allocating board space or layers to a filter implementation can take up areas that could be used for other functionality or devices and may further complicate implementation.

To look at these factors, we examined different 26GHz filter manufacturing approaches with the following design goals:

- Center Frequency: 26GHz
- 3dB Bandwidth: 4x800MHz
- Insertion Loss: 2dB
- Stopband 1: -35 dB within DC-22 GHz
- Stopband 2: -35dB within 30-68 GHz

IMPACT OF MANUFACTURING TOLERANCE ON FILTER PERFORMANCE

For manufacturing tolerances, we used our own experience in fabricating filters across a range of substrate materials. For the comparison, we selected three filter implantation approaches – an integrated Microstrip approach, an integrated Stripline approach, and one of our own Thin Film Dielectric component designs.

NOTES ON TOLERANCE ANALYSIS

The approach we take is a simplified worst case analysis. Discussion in the public domain [1] use a monte-carlo based approach to reach essentially the same conclusion for Microstrip on PCB. In general, we would observe that the tolerances used in these prior analyses is very aggressive compared to the typical tolerances that can be held in production.

Tolerance	Stripline on RO3003	Microstrip on RO4350B
Thickness	30mil ±1.5mil	10mil ± 1mil
Etching Tolerance	±0.5mil	±2mil
DK Tolerance	3 ±0.04	3.66 ±0.05

Table 1. Manufacturing tolerances used in this work (worse case analysis)

MICROSTRIP

As first pass, we had a look at a Microstrip filter. We found a close match to the design targets above was to implement a 6th order edge coupled topology on 10mil of RO4350B. Metallization was 2oz Electrodeposited (ED) Copper.

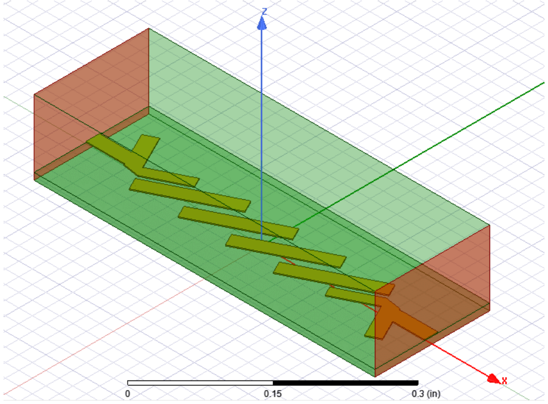

Figure 1. Microstrip Implementation of 26GHz BPF

Due to the inherent transmission zeros produced by the edge coupled Microstrip filter, the nominal design passes the close-in rejection requirements with margin, and while the passband shows less margin the design could be adjusted to provide some additional space. The high side harmonic response is less than favorable, but for the sake of this analysis we decided not to tune the design any further since adding complexity would drive up insertion loss and sensitivity to tolerances.

Std-Dev	Microstrip on 3.4 low loss laminate
Thickness	15um, 0.6mil
Line width	8um, 0.3,mil
Permittivity	3.4 ±0.02

Table 2. Manufacturing tolerances used in [1] (monte carlo analysis)

To look at tolerance impact on this hypothetical Microstrip filter, we ran a worst case analysis over 8 variations of the design, using variations of substrate thickness, etching tolerance, and dielectric constant tolerance.

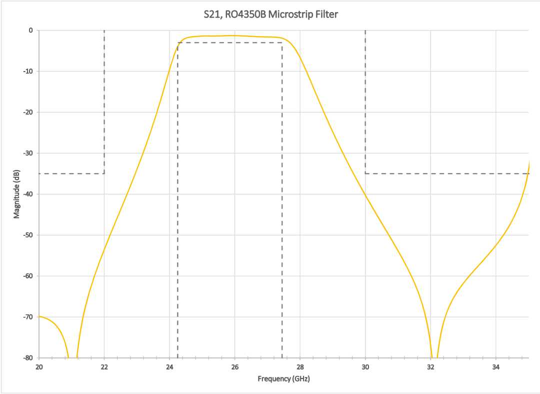

Figure 2. Simulated S21 from Microstrip Implementation of 26GHz BPF, with limit lines

For this design, we selected the following manufacturing parameters knowing they would be considered reasonably tight without being outside the realms of available manufacturing capability:

- RO4350B Thickness = 10mil ± 1mil
- Etching Tolerance = ±2mil
- DK Tolerance = 3.66 ±0.05

Using a simple worst case analysis, we observe a significant shift in the filters low side performance for both rejection and 3dB point. The 35dB low side rejection point is shifting by over 2GHz. Based on this simplified analysis, unless significant margin is added to the target specification such a filter would be unusable in manufacturing – being part of the PCB this variation over tolerance would render the entire board out of specification before performance variations from other components or due to factors like temperature stability come into play.

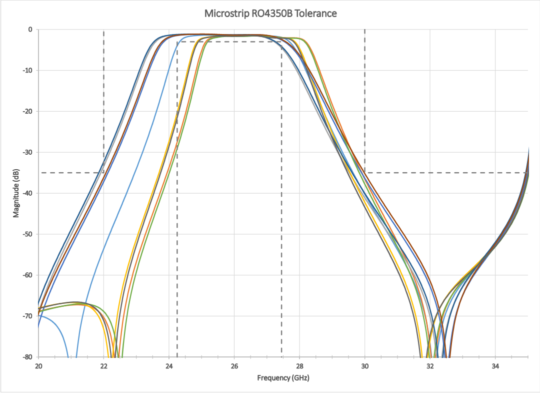

Figure 3. Simulated S21 over 8 manufacturing runs of Microstrip Implementation of 26GHz BPF, with limit lines

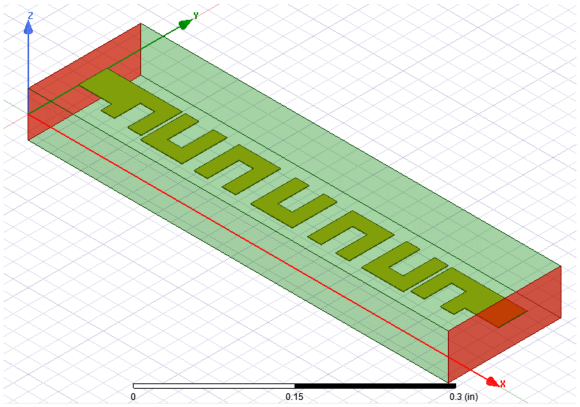

Figure 4. Stripline Implementation of 26GHz BPF

STRIPLINE

Next up, we will take a look at a stripline approach. For this simulation, the following design comes close to the target specifications we are working with:

- 7th Order Hairpin
- 30mil RO3003 Top and Bottom
- 0.5oz Rolled (RA) Copper

This hairpin stripline design does not have quite as steep a skirt as the edge coupled microstrip implementation, and we find the same harmonic performance challenges on the high side of the stop-band as seen with the microstrip filter.

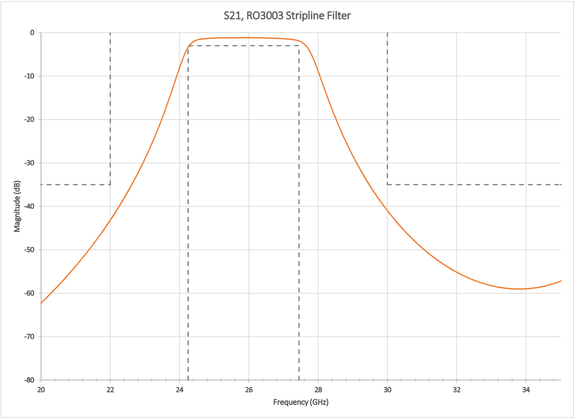

Figure 5. Simulated S21 from Stripline Implementation of 26GHz BPF, with limit lines

For tolerance analysis, we took a similar approach looking at 8 variations across substrate thickness, etching tolerance and dielectric material tolerance.

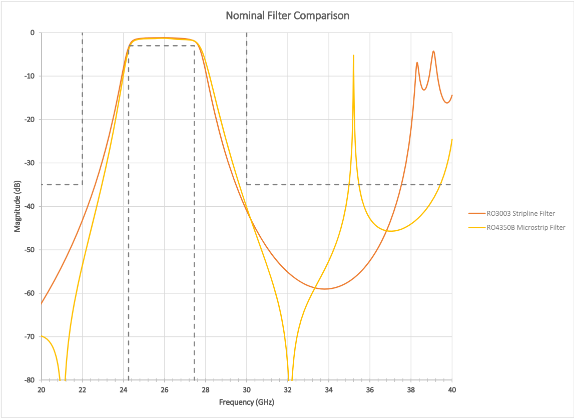

Figure 6. Comparison of nominal design performance, Microstrip and Stripline

- RO3003 Thickness = 30mil ±1.5mil
- Etching Tolerance = ±0.5mil
- DK Tolerance = 3 ±0.04

From the worst case analysis, we observe a smaller shift in filter performance. However, margins would still need to be added to the design to allow for the variation in frequency response. For example, on the low side the 35dB point is varying by ~1GHz.

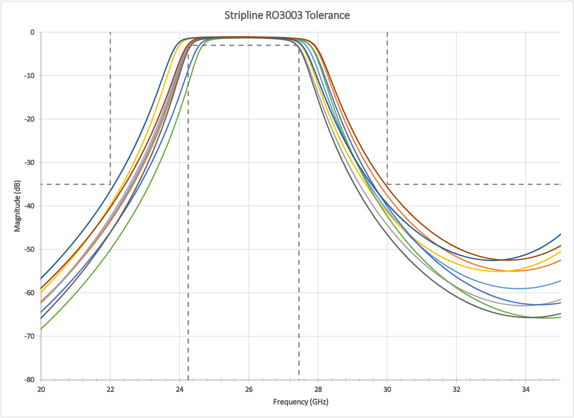

Figure 7. Tolerance simulations for the Stripline Filter

KNOWLES PRECISION DEVICES CATALOG FILTERS

For comparison, we will look at the simulated tolerance shift in our one of catalog filters – the B259MC1S. We can't get into topology and material details here, but we can show nominal simulated design performance and simulated tolerance response to the same three variables.

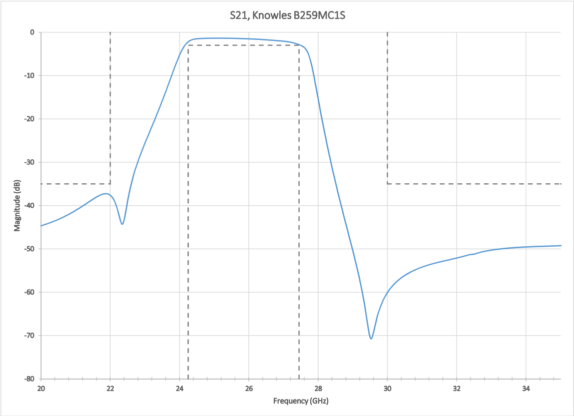

Figure 8. Nominal design performance – B259MC1S.

If we subject the simulated version of the catalog filter to the same worst case analysis across just three design variables, we can see a much smaller sensitivity to manufacturing tolerances. Simulated 35dB attenuation shift at the low end is approximately 130MHz and the simulated filters do not threaten the stop bands. We observe a small shift vs the static passband. Also given that these devices are discrete surface mount components (rather than implemented within the PCB) and we screen the filters by 100% RF test, any devices that did not meet the performance goals would not ship to the end user.

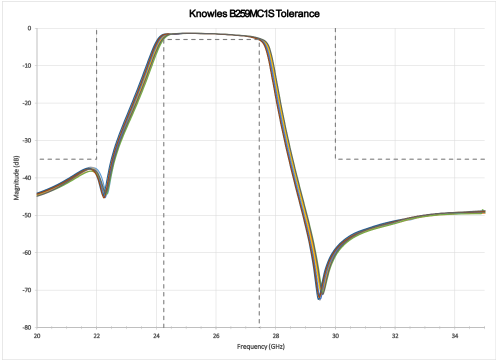

Figure 9. Knowles B259MC1S – simulated performance variation across 3 variables

Adding fully tested surface mount filters with known repeatable performance is a cost saver over integrated board level implementations in microstrip or stripline when one considers the total cost in rejecting non-conforming board level assemblies.

It is also a potential space saver, which is an aspect we can look at next.

FILTER SIZE COMPARISON

Let's take a look at the dimensions of each design as simulated:

- Microstrip Design Size: 505 x 170 x 10mils, or 12.8 x 4.3 x 2.5 mm
- Stripline Design Size: 560 x 160 x 60mils, or 14.2 x 4.0 x 1.5mm
- Knowles B259MC1S Size: 216 x 90 x 64mils, or 5.5 x 2.3 x 1.6 mm

Looked at another way, we can look at the nominal performance comparison again and overlay the filter surface area to scale.

Considering performance for footprint, a compact SMT filter takes up less than a quarter of the space that would be allocated to the Microstrip and Stripline filters built to the same target specification.

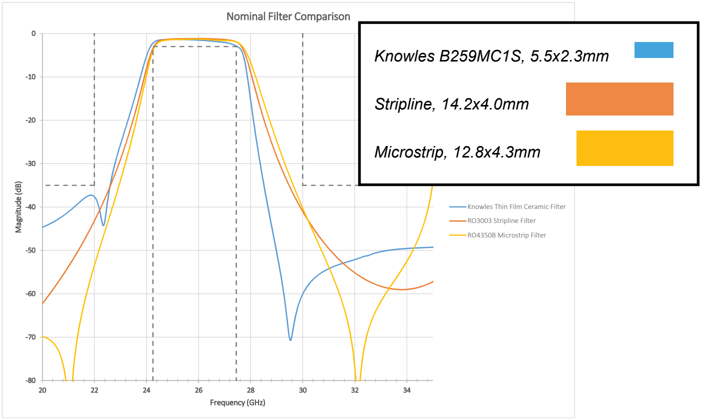

Figure 10. Nominal design performance and Filer Area

Looking next at where the filters actually fit into a system, we need to remember that antenna spacing in phased array systems will be of the order of λ/2, where λ is the free space wavelength of the radiation that the antenna will transmit and or receive.

At 26GHz λ/2 is approximately 5.7mm, smaller than the largest dimension of the two PCB implementations we looked at.

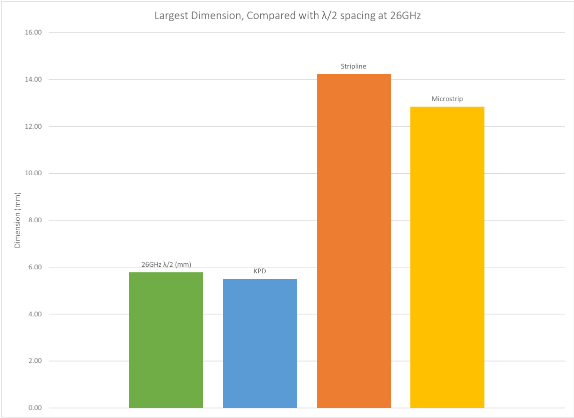

Figure 10. Longest dimension compared to λ/2 at 26GHz

OBSERVATIONS

- At mmWave frequencies manufacturing tolerances can make significant contributions to a filters performance.
- If you are implementing filters on (or in) board, consider the lot to lot repeatability and allow for this in your target specifications.
- Guard bands can eat into available bandwidth, undoing some of the gains for using mmWave frequencies originally.
- Tolerance is a cost to implement driver if one considers the cost of rejection no-conforming boards, and the physical size of the filter implementation is another potential cost consideration.

References

[1] On mm-wave filters and requirement impact, 3GPP TSG-RAN WG4 meeting #85, R4-1712718

ABOUT KNOWLES

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