

Comparing Automotive Radar RF Bandpass Filter Implementations (Part 3)

When it comes to planar technologies for mmWave filtering in automotive radar applications, the fabrication technology makes a difference in terms of performance. This multi-part article delves into those differences.

In [Part 1](#) of this multi-part series, we analyzed 3D electro-magnetic (EM) simulations in the frequency domain of two of six implementations of a 5th-order, Chebyshev-type RF front-end bandpass filter for automotive radar applications in the mmWave band from 76 to 81 GHz. Those implementations were rectangular metallic waveguides with H-plane iris and cylindrical posts, respectively. In [Part 2](#), we continued our analyses with microstrip and stripline implementations. Part 3 will shift to analyses of substrate-integrated waveguide implementations and wrap up with some conclusions.

SIW Bandpass Filters

Let's take a look at substrate-integrated waveguide (SIW) implementations of the same bandpass filter we've examined in other implementations in Parts 1 and 2. SIW technology has been well-established as a technology^{1,3,4,5} over the last decade. It mimics the structure and performance of the metallic waveguide technology but with miniaturized dimensions. The miniaturization of the dimensions depends on the dielectric constant of the material in play.

In fact, SIW technology is a printed-circuit-board (PCB) technology with some advanced design rules, especially when implementing structures in the mmWave bands. In this article, we'll examine the implementation of a SIW bandpass filter with H-plane iris and with metallic posts. The design procedure in both cases is the following:

1. Design the metallic waveguide filter equivalent.
2. Transfer that design to a metallic waveguide filter filled with the dielectric material that will be used during the PCB process.
3. Replace the transverse walls of the metallic waveguide filter with ground vias of the proper geometry (diameter,

pitch of vias).

4. Implement a proper microstrip-to-SIW transition.²

The general geometry of a SIW structure and its equivalent to a metallic waveguide¹ is shown in *Figure 1*.

The TE₁₀-mode related frequency region of interest is defined by:

$$p > d \quad (1a)$$

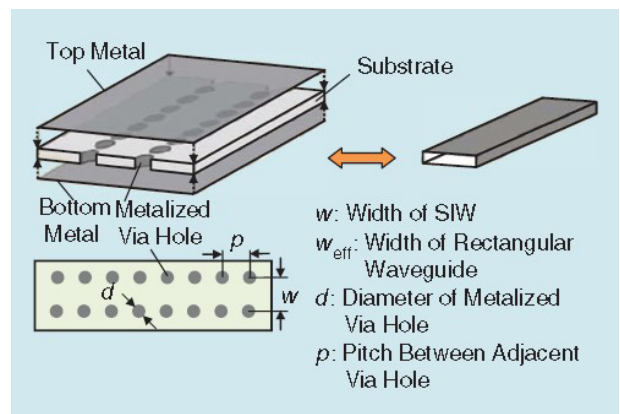
$$p/\lambda_c < 0.25 \quad (1b)$$

$$\alpha/k_0 < 10^{-4} \quad (1c)$$

$$p/\lambda_c > 0.04 \quad (1d)$$

where α is the total loss and k_0 is the wave number in free space.

The condition (1a) states that the period length must be larger than the cylinder diameter so that the circuit is physi-



1. This image illustrates the general geometry of a SIW structure and its equivalent to a metallic waveguide.

cally realizable, and (1b) is required to avoid any bandgap in the operating bandwidth of the TE₁₀ mode and other related guided-wave modes (if involved). To be negligible, the leakage losses must respect (1c). A more restrictive and general condition for negligible leakage losses is $p \leq 2d$.

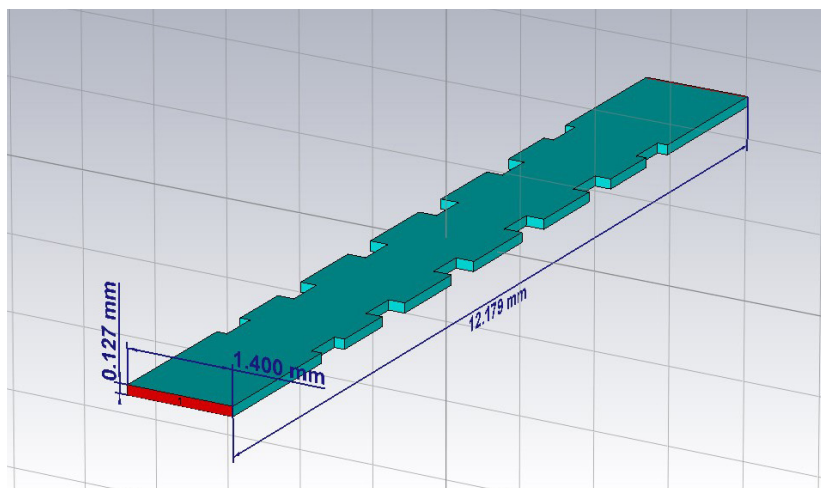
Finally, a nonessential but desirable condition for the manufacturing process is for “d” to be comparable to the substrate thickness. These via cylinders are usually mechanically drilled and chemically electroplated or plasma-deposited, and the production time is directly related to the choice of a processing technique.

If the length of the period is very small with respect to the guided-wave wavelength, the mechanical rigidity is adversely affected. The number of cylinders should therefore not exceed 20 per wavelength, as stated in (1d). In the next two sections, we’ll present the 3D electromagnetic simulation results for the two SIW implementations of the bandpass filter (BPF).

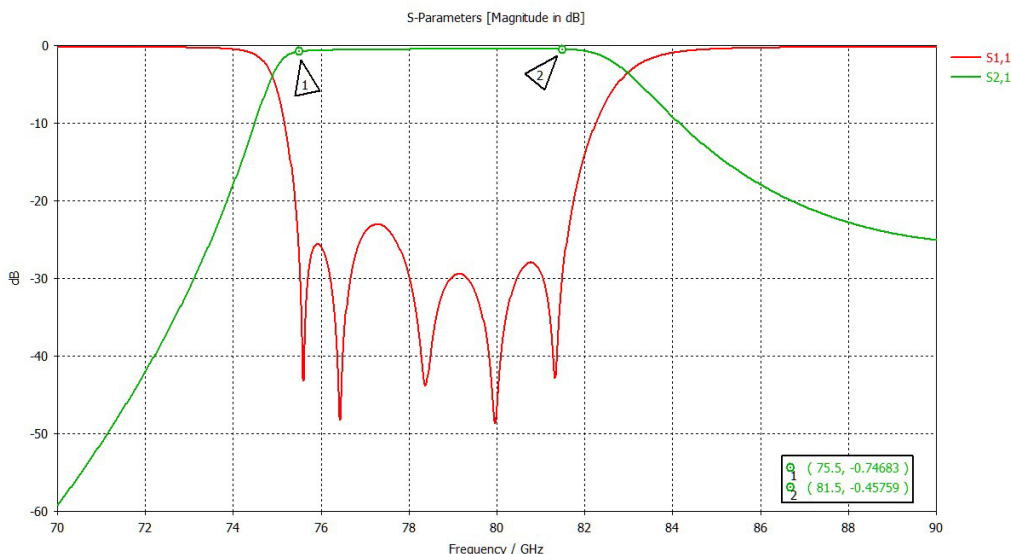
SIW Bandpass Filters with H-Plane Iris

As described in the previous section, the first steps in the design procedure are to design the metallic waveguide equivalent and then transfer the design to an equivalent metallic waveguide filled with the proper dielectric. In this case, it is Rogers RO3003G2 PTFE laminate with $\epsilon_r = 3.07$. We chose a dielectric thickness of 0.127 mm. Figure 2 depicts the ideal 3D geometry.

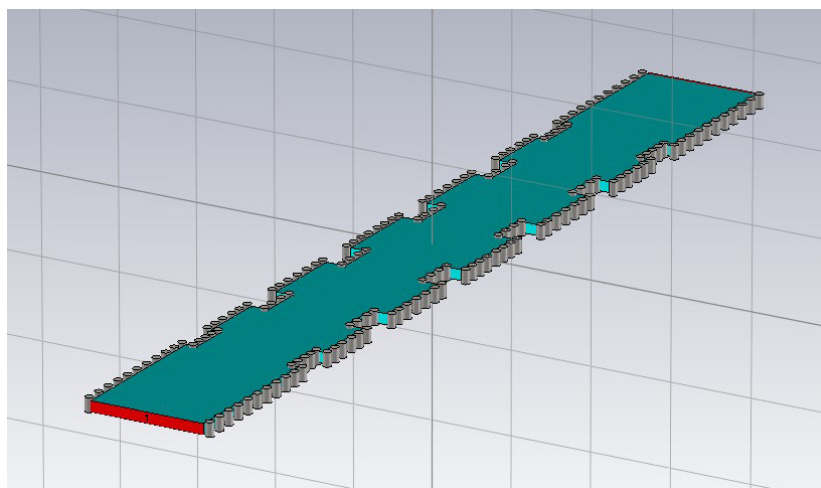
The RF performance of this filter with respect to S-parameters appears in Figure 3. The insertion loss compared to the pure metallic waveguide counterpart is increased by about 0.4 dB. The



2. Shown is the 3D geometry of the ideal H-plane iris-based SIW filter.



3. Here, we see the RF performance of this filter plotted with respect to S-parameters. The insertion loss compared to the pure metallic waveguide counterpart increases by about 0.4 dB.



4. This image depicts the 3D geometry of the H-plane iris-based SIW filter with the transverse walls of a metallic waveguide filter replaced by posts serving as ground vias.

return loss is better than 22 dB. The dimensions, though, are miniaturized by a factor of 10 in the vertical dimension and by a factor of 2.5 in the horizontal dimension.

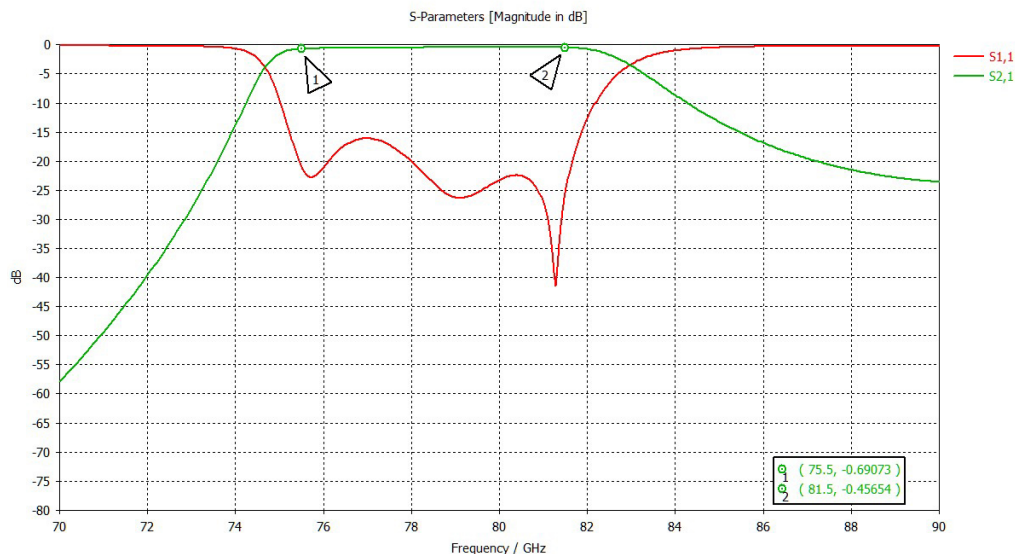
Then, according to the design procedure discussed above, the transverse walls of the waveguide are replaced by proper ground vias as shown in Figure 4. The diameter of the posts is $d =$

0.1 mm and the pitch is $p = 0.2$ mm. To obtain these values for the via diameter, we used pitch-optimization techniques to obtain the best possible S_{11} in the passband and, simultaneously, the best rejection for the out-of-band areas. The RF performance of the 3D geometry of Figure 4 is shown in Figure 5.

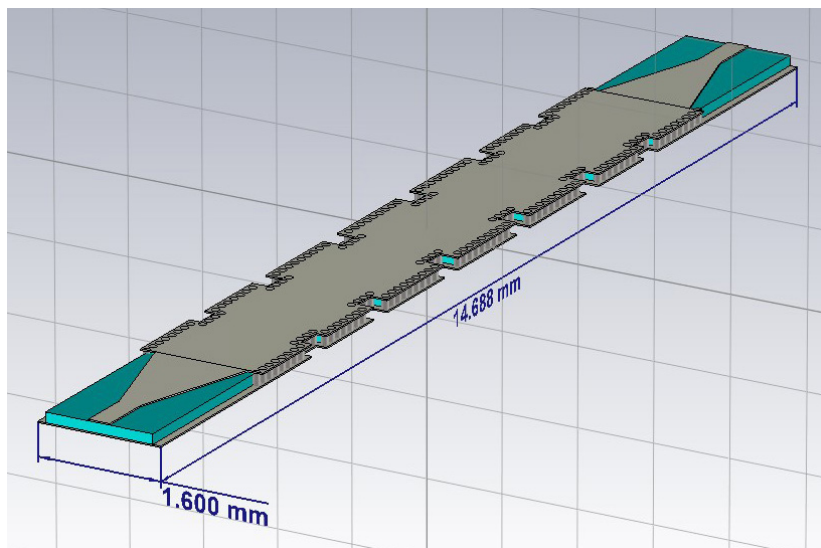
In comparing Figures 3 and 5, the insertion loss of the filter isn't affected. However, the return loss is impacted, but it remains well above 16 dB. The main reason for the deterioration of return loss is the radiation leakage due to the limited pitch of the ground vias. The pitch is kept to a minimum of $p = 0.2$ mm so that one may fabricate the circuit with a normal PCB process. The final step is to implement the microstrip-to SIW transition. That geometry appears in Figure 6.

Comparing Figures 2 and 6 reveals that the additional length for each of the microstrip-to-SIW transitions is about 1.25 mm. Several types of transitions could be used,² but the simple tapered type is most easily fabricated.

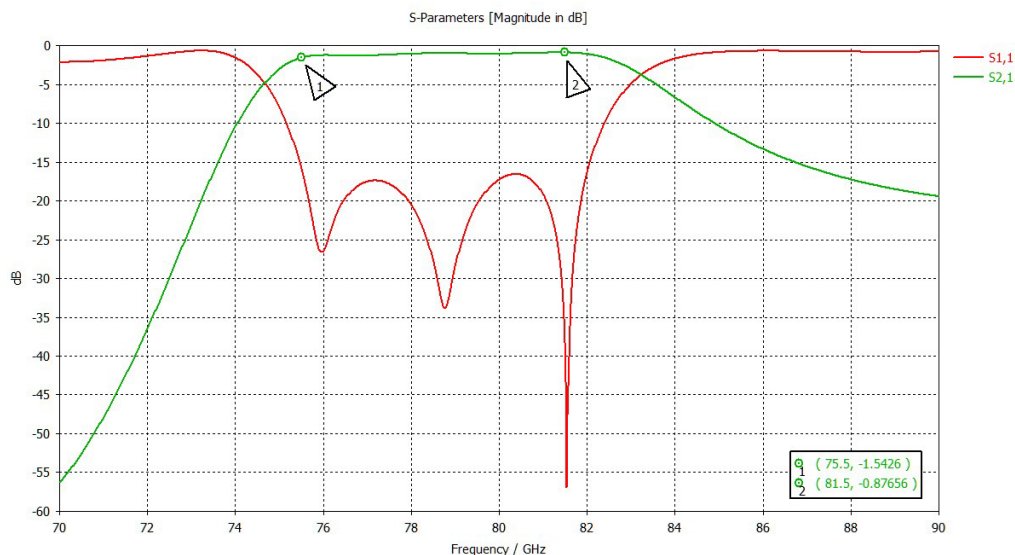
7. Here, we plot the RF performance of the H-plane iris-based SIW filter with posts and microstrip-to-SIW transitions.



5. Here, we plot the RF performance of the H-plane iris-based SIW filter with posts.



6. Shown is the 3D geometry of the H-plane iris-based SIW filter with posts and microstrip-to-SIW transitions.



The RF performance of the final geometry shown in Figure 6 is presented in Figure 7.

The insertion loss increases by 0.5 dB at mid-band compared to the non-transition case; the return loss as well as the out-of-band rejection remain about the same.

SIW Bandpass Filters with Metallic Posts

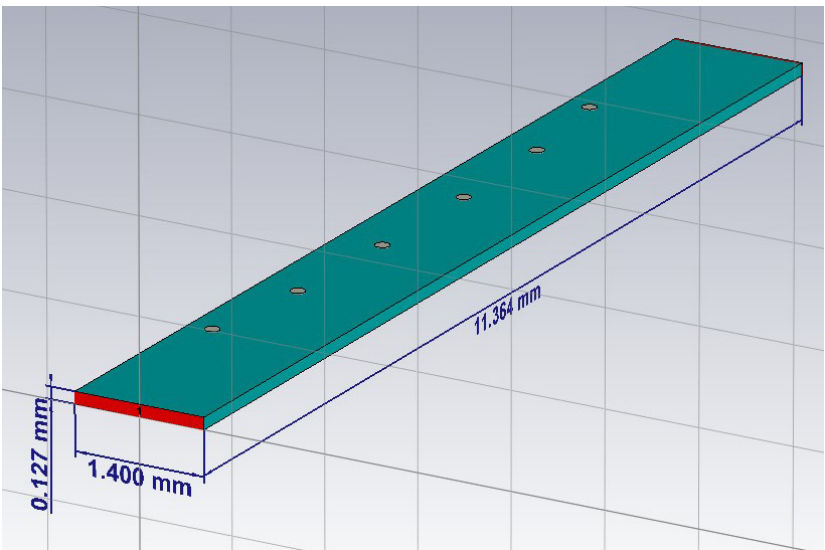
An alternative SIW implementation approach is based on metallic posts instead of an H-plane iris.

This approach is more robust from the fabrication point of view because the locus of the ground vias is much simpler. The dielectric material used is the same as in the previous section. We show the ideal 3D geometry in Figure 8.

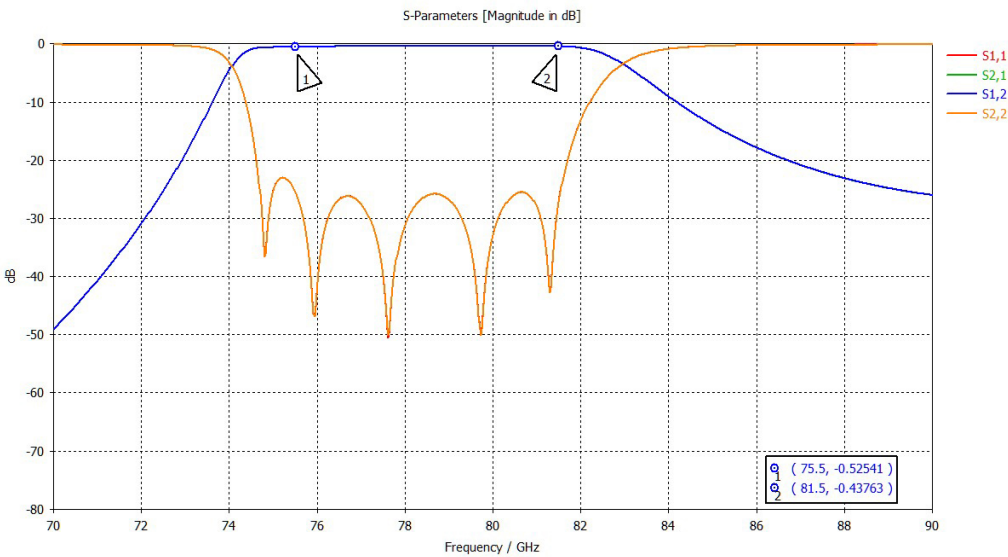
This filter's RF performance with respect to S-parameters is shown in Figure 9. The insertion loss compared to the pure metallic waveguide counterpart is increased by an amount of about 0.3 dB. Return loss is better than 22 dB. As with the iris-based implementations, the dimensions are reduced by a factor of 10 in the vertical dimension and by a factor of 2.5 in the horizontal dimension.

Then, as in the design procedure followed for the H-plane iris-based implementation, the transverse walls of the metallic post-based waveguide are replaced by proper ground vias (Fig. 10).

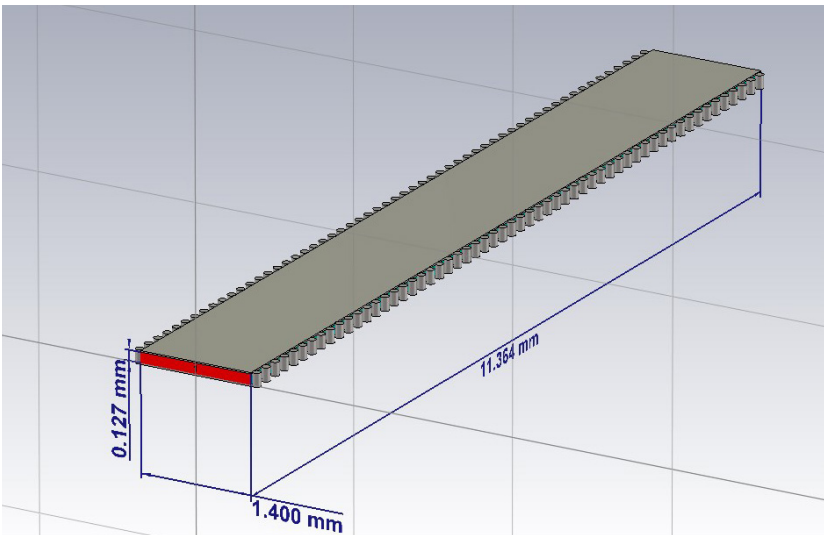
The diameter of the posts is $d = 0.1$ mm, and the pitch is $p = 0.2$ mm. To obtain these values for the via diameter, we employed pitch-optimization techniques to obtain the best possible S_{11} in the passband as well as the best rejection for the out-of-band areas. The tuning posts inside the SIW structure are placed symmetrically and their



8. This is the 3D geometry of the ideal metallic post-based SIW filter.



9. This plot shows the RF performance of an ideal metal post-based SIW filter.



10. Here's a depiction of the 3D geometry of the metal post-based SIW filter with the transverse walls of a metallic waveguide filter replaced by posts serving as ground vias.

diameter is 0.15 mm. The RF performance of the 3D geometry of Figure 10 appears in Figure 11. The dimension of this filter implementation compared to the H-plane iris based is smaller by about 0.9 mm.

Comparing Figures 9 and 11 shows that the filter's insertion loss has increased by 0.3 dB at mid-band. Although the return loss is affected, it remains well above 15 dB. Next, we implement the microstrip-to-SIW transition to finalize the design (Fig. 12).

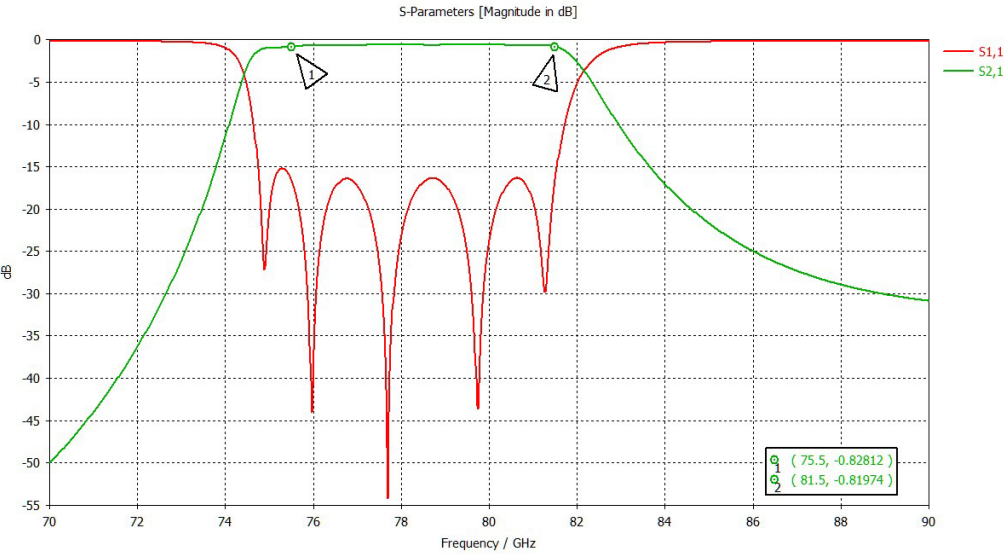
If we compare Figures 10 and 12, the additional length for each of the microstrip-to-SIW transitions is about 1.45 mm. Again, the simple tapered type of transition makes for the easiest fabrication.² Figure 13 shows the RF performance of the final geometry shown in Figure 12. While the insertion loss is increased at mid-band by 0.5 dB compared to the non-transition case, the return loss and the out-of-band rejection are unchanged.

Conclusions

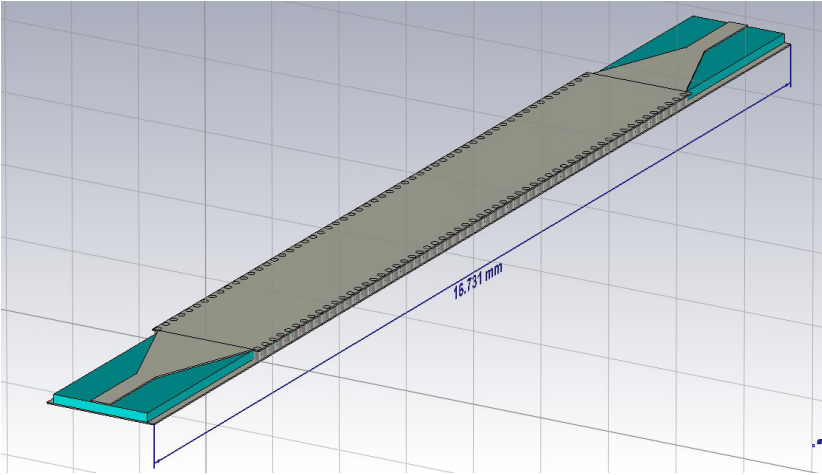
Our simulations show that metallic-type filters offer far better performance compared to their planar-technology counterparts as expected. Specifically, the microstrip filter delivers the worst performance due to radiation effects that exist in microstrip-technology implementations.

The table compares the various filter technologies in terms of manufacturing complexity, size/weight, cost, and RF performance. The lowest cost—and lowest performance—is found in the microstrip implementation, while the best performance at higher cost comes with the metallic waveguide filters.

In general, depending on the application, different approaches offer advantages and disadvantages.



11. A plot illustrates the RF performance of the metal post-based SIW filter with posts.



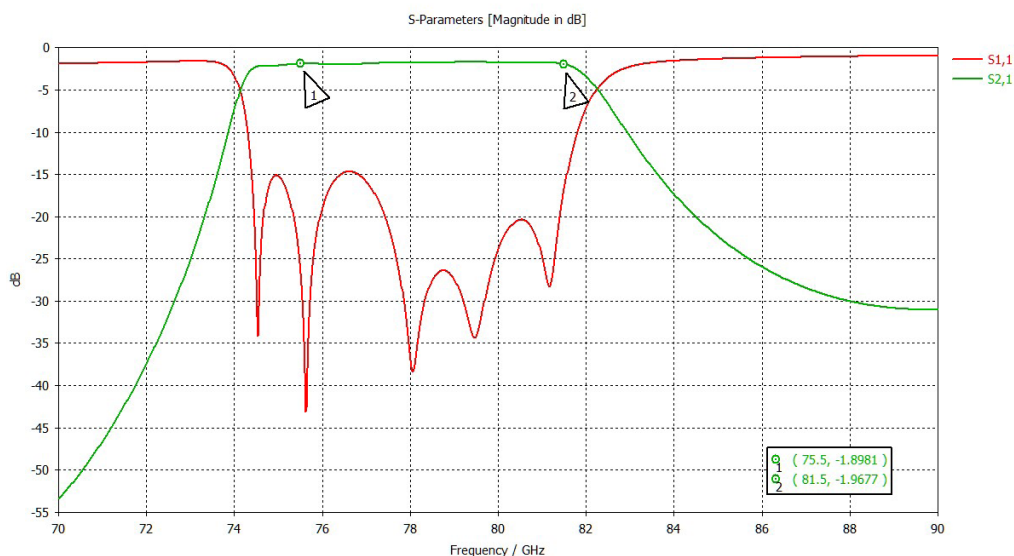
12. In this drawing, we see the 3D geometry of the metal post-based SIW filter with posts and microstrip-to-SIW transitions.

COMPARISON OF VARIOUS FILTER TECHNOLOGIES				
Technology	Complexity	Size/Weight	Cost	Performance
Iris-based metallic waveguide	High	High	High	High
Post-based metallic waveguide	Medium	High	Medium	High
Microstrip	Low	Low	Low	Low
Stripline	Medium	Low	Medium	Medium

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Yorgos E. Stratakos earned his diploma in Electrical and Computer Engineering in 1992 from the National Technical University of Athens, and his PhD from the same university



13. Here's a look at the RF performance of the metal post-based SIW filter with posts and microstrip-to-SIW transitions.

in 1995. He is a senior researcher on the faculty of Electrical and Electronics Engineering of the University of West Attica. His main research interests are RF and microwave design of analog passive and active circuits and systems.

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