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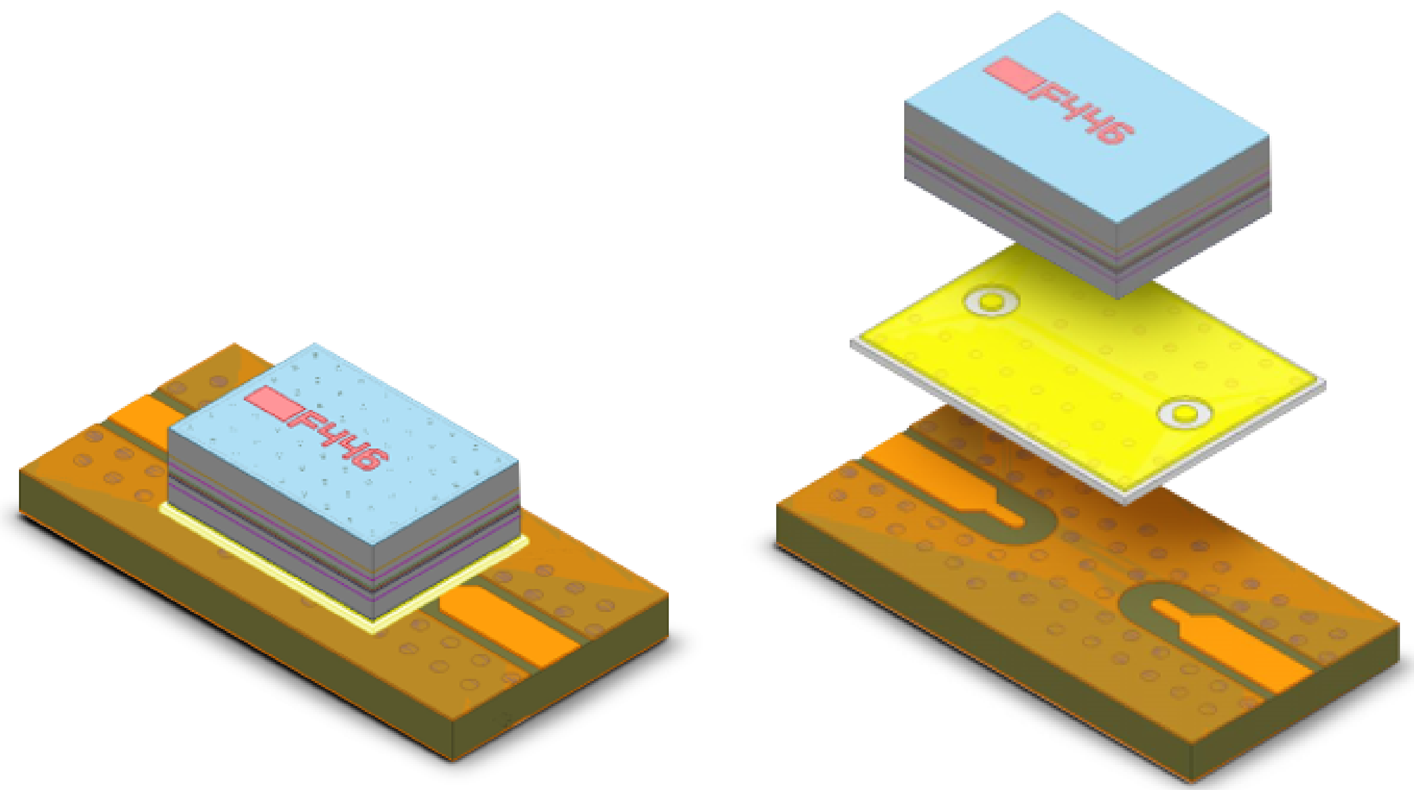
Optimizing High-Rejection LTCC Filter Performance in Co-Planar Waveguide Implementations



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Mini-Circuits' BFHK-series of high-rejection LTCC filters have been characterized with stopband rejection floors on the order of 90 dB and higher with a combination of size, reliability, and cost currently unmatched by other filter technologies with comparable performance. Performance in the customer's system, however, can vary depending on the specific implementation. The unique design of these devices features coaxial input and output pins on the bottom surface of the structure requiring blind vias to the conductive layer of a stripline circuit board. While many PCB manufacturers have developed the capability to build surface-mount assemblies with blind vias reliably, some designers still prefer to use coplanar waveguide (CPW) wiring boards where the contact between the conductive trace and the device ports is exposed on the top layer. In addition to avoiding any concerns about blind vias, in certain use cases, CPW allows soldering of other surface-mount components in shunt or series to the signal trace as well as fine-tuning of the trace width and characteristic impedance for optimal matching conditions. To this end, Mini-Circuits has developed the BFHKI series of CPW-compatible filters by on a pick-and-place-ready platform, consisting of a sub-assembly with the LTCC component and an interposer substrate, which converts the coaxial launch of the LTCC into a CPW interphase.

This paper describes the physical differences between stripline and coplanar waveguide implementations of Mini-Circuits' high-rejection LTCC filters and related effects on performance. Channelization is proposed as an effective technique to achieve comparable performance to stripline implementations in CPW environments. Real test data from a leading customer's evaluation of the new BFHKI series of these filters on interposer boards in a channelized housing is then presented as proof of concept.

PCB Layouts in Stripline vs. Coplanar Waveguide Implementations

Because the land pattern of the BFHK-series filter package features conductive plating across the bottom surface as shown in Figure 1, simply soldering the unit to the exposed trace of a CPW board would cause functional issues due to shorting between the conductive metallizations on the PCB and the bottom surface of the filter.

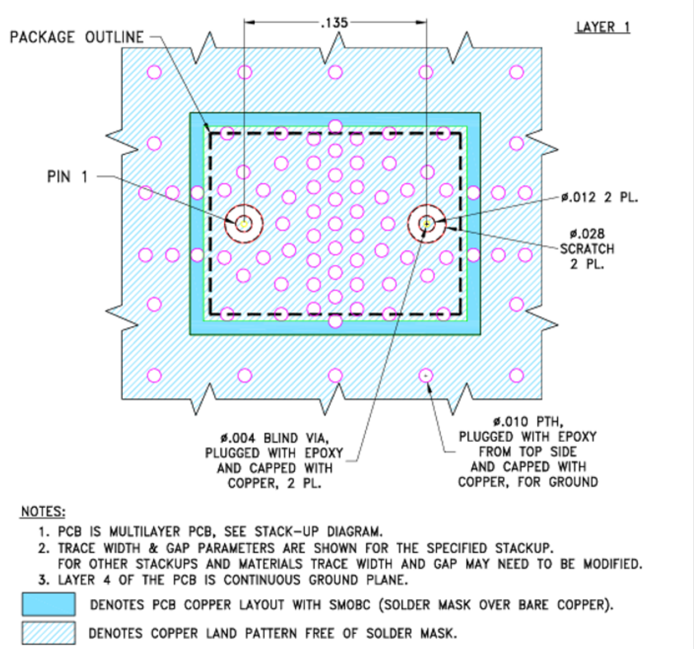


***Figure 1**: Stripline PCB layout for a BFHK-series high-rejection LTCC filter.*

Mini-Circuits developed the BFHKI series of filters incorporating a novel interposer board to allow drop-in use on CPW launches to facilitate integration on the user's end (Figure 2). The LTCC filter is pre-mounted on a stripline base designed for coaxial mating between the top-layer metallizations on the customer's PCB and the filter input and output ports as shown in Figure 3.

The interposer board enables surface mount assembly of Mini-Circuits' high-rejection LTCC filters on coplanar waveguide substrate, but as with everything in the RF world, it comes with caveats and requires due consideration in the design and assembly process.

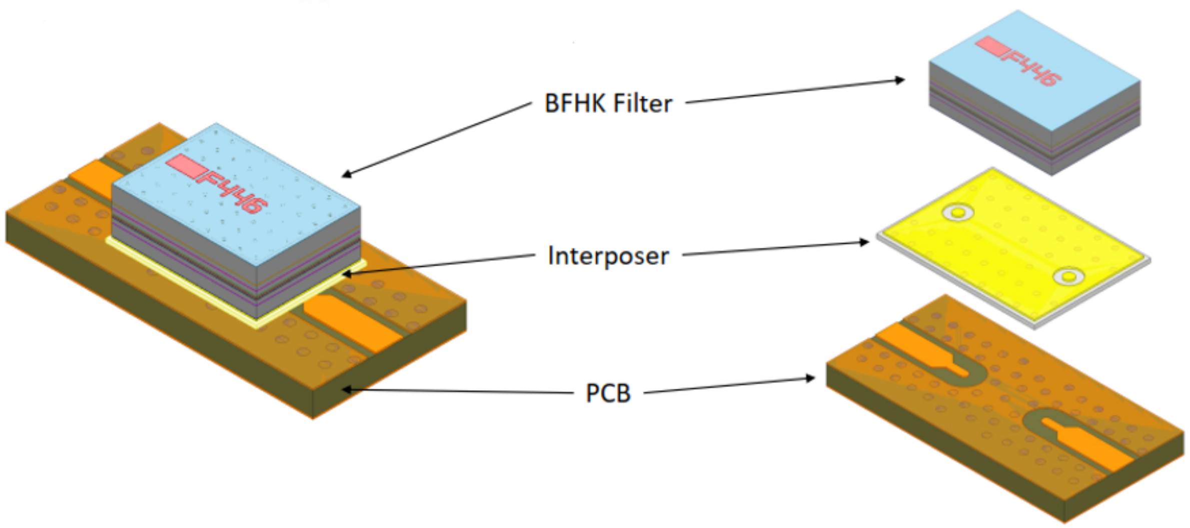


Figure 2: BFHKI-series LTCC filters feature an interposer between the filter and the customer's PCB, allowing easy use with top-layer transmission line.

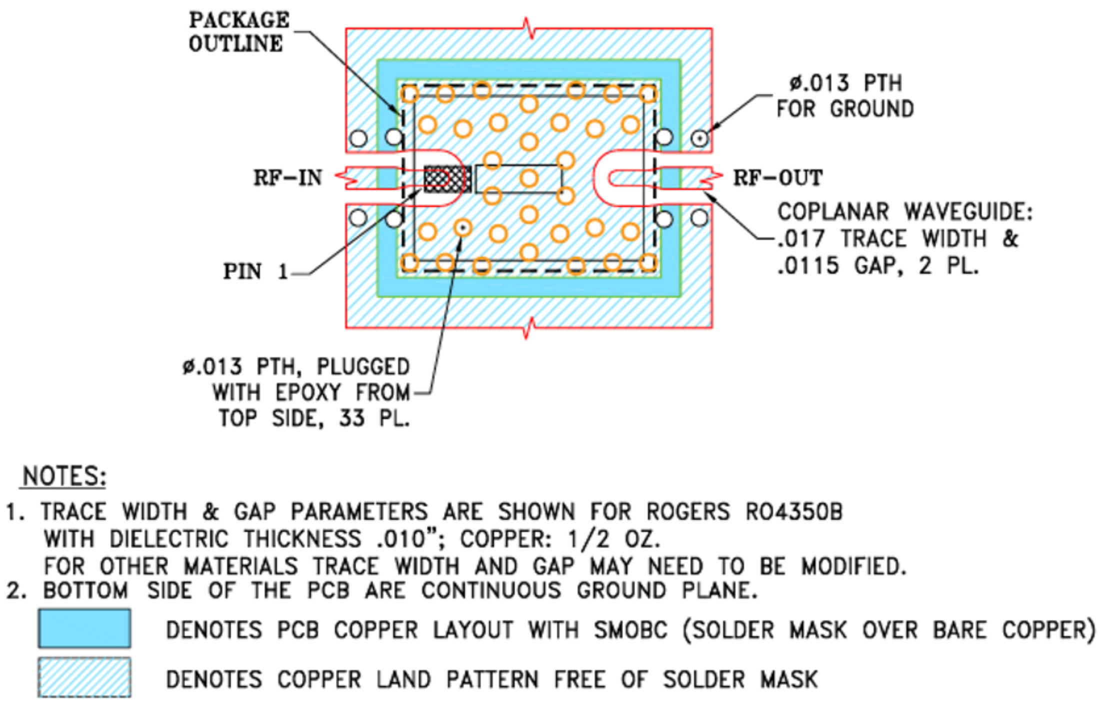


Figure 3: Suggested PCB layout for BFHKI-series LTCC high-rejection band pass filter on coplanar waveguide launches.

Effects on Performance

The specified rejection performance of BFHK-series filters is characterized on stripline test boards where the line to and from the filter is shielded from cross-coupling, buried in the PCB stackup. By contrast, in a CPW implementation, the exposed launch from the PCB to the device creates leakage, which affects rejection performance. For illustration, consider Figure 4. The filter response for BFHK-8501+ is shown on the left exhibiting a rejection floor of about 100 dB. The response for BFHKI-8501+, the same filter mounted on the interposer, exhibits typical rejection of about 70 dB in the lower stopband and 50 dB in the upper stopband.

Note that in the test fixture for the BFHK-series model, the filter is mounted directly to stripline substrate, while the BFHKI-series model is characterized with the interposer mounted on an open CPW test board. It's important to qualify that the variation in rejection performance between the two models is a function of the quality of the launch from the PCB to the filter rather than an intrinsic property of the filter itself.

An ideal solution would replicate the insulation provided by the top layer of a stripline PCB in a CPW environment. Fortunately, this can be achieved by making use of the LTCC's conformal metallic coating and industry-standard channelization techniques, yielding a response similar to that of the BFHK-series mounted directly on stripline.
What follows will present data measured by a leading customer in the test and measurement field evaluating the performance of Mini-Circuits' BFHKI-series filters on CPW substrate in channelized housings. The results will demonstrate performance parity between the baseline case of a filter mounted directly to stripline and the CPW use case with the interposer board and channelization.

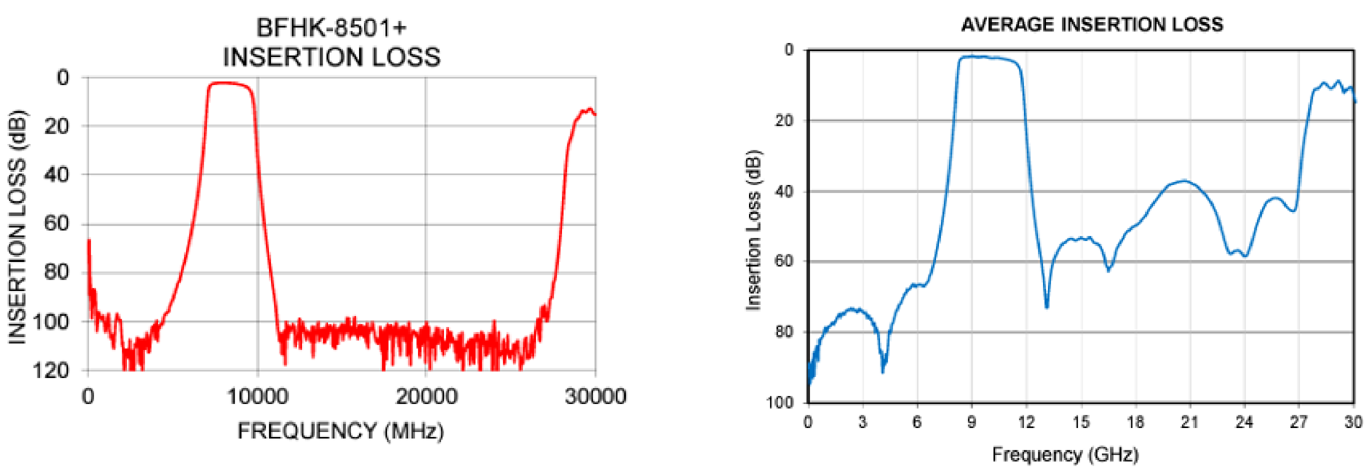
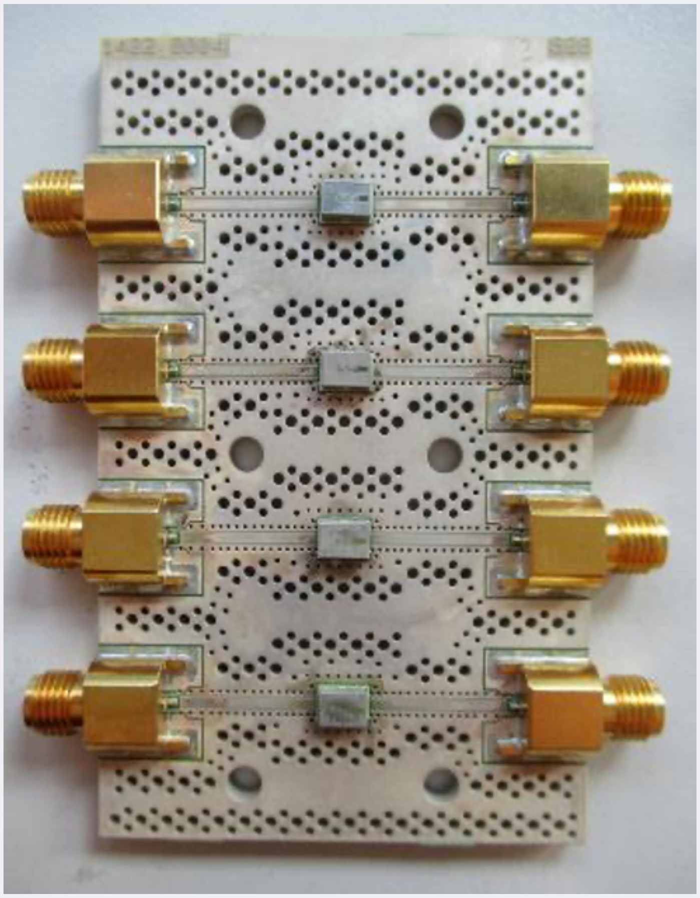


***Figure 4**: Characteristic response of BFHK-8501+ (left) vs. BFHKI-8501+ (right).*

The Test Setup

The customer used a 20 mil test board with four positions for BFHKI filters of identical layout using PC 2.92mm connectors. Input and output lines were grounded CPW types. Ground vias were made through the whole PCB stackup. Additionally, there was a TRL Calibration Board not shown here, which allowed de-embedding of the measurements excluding effects from PC 2.92mm connector and CPW line to the BFHKI unit. The test board and PCB layout are shown in Figure 5:



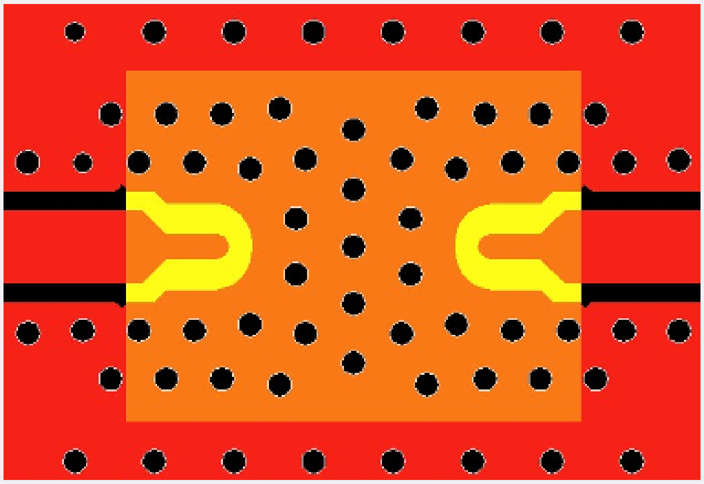


***Figure 5**: Test board and PCB layout for the customer's measurement of BFHKI filters.*

Additionally, as an experiment, a conductive die attach adhesive (Ablebond 84-1LMI) was applied around the interposer except at contacts with RF lines. The adhesive application is pictured in Figure 6:

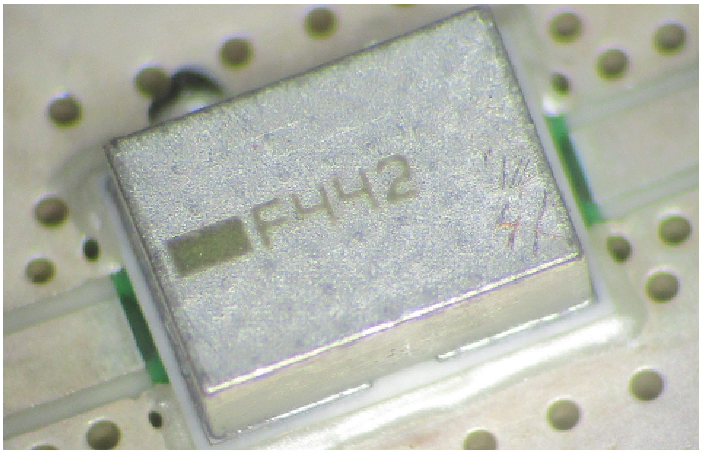


***Figure 6**: Conductive die attach adhesive was applied around the edge of the interposer board as a measure to maximize rejection.*

Channelization with a Silver-Plated Conducting Cover

To test the filters in a channelized environment, a silver-plated conductive cover was used. The cover (pictured in Figure 7) contained single chambers for each of the four BFHKI filter positions on the test board. Note that the dimensions of the chambers were not optimized for the BFHKI filters specifically because the cover was built for use with devices of various sizes.

Figure 7*: Silver-plated conductive cover used with the test board for 4x BFHKI filters.*

The top cover contained a conductive sealing cord, and the device chambers were fitted with a compressible material to create a firm electrical contact with the top face of the BFHKI filter package. This so-called "EMI D-Profile" is built with a foam core covered with metallic woven fabric (2.0 x 6.4mm, LAIRD 4202-AE-221-07900), and must be mounted transverse to the channel. Otherwise, there may be a crosstalk path through the non-conductive foam core. 3x3mm pieces of damping material (0.76mm thick LAIRD Eccosorb GDS) were glued into the input and output channels to further suppress any crosstalk (Figure 8).

The strong imprints from the BFHKI units in Figure 8, indicate a good electrical contact to the top of the filter package, although the chamber depth may be a little low as dimensions were not optimized for these filters specifically.

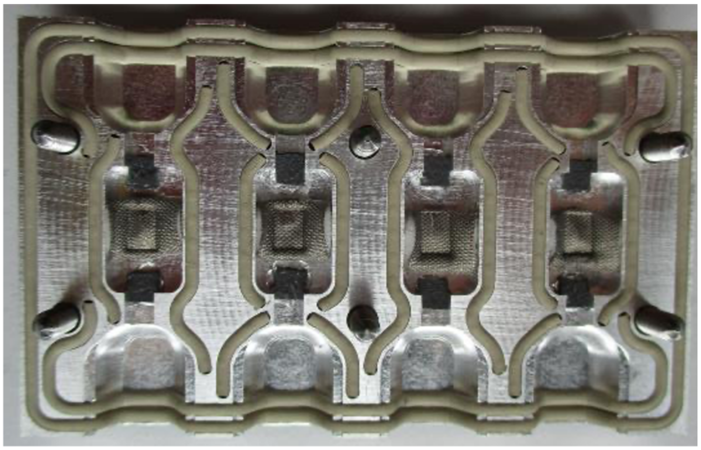


Figure 8*: Cover pictured with compressible EMI D-Profile mounted in device chambers and damping material glued to input and output channels.*

Measurements

Multiple BFHKI models were measured in the test setup described above using a Rohde & Schwarz [ZNA43 2-port vector network analyzer](#) (Figure 9). Calibration was performed, and the DUT was de-embedded to the outer edge of the component footprint. The taper from the CPW line width to the pad's width is therefore still included in the measurement.

***Figure 9**: Measurement was performed using a Rohde & Schwarz ZNA43 2-port vector network analyzer.*

For each model of interest, S11 and S21 were swept over the full operating bandwidth under the following conditions:

- Open CPW test board without cover
- DUTs channelized with silver-plated conductive cover
- Channelized with cover and conductive die attach adhesive on outer edge of interposer

These measurements were compared to S-Parameters for the BFHK-series counterpart of each model as a baseline reference to study any deviations in each implementation of the BFHKI model on CPW. The S-Parameters were taken from the Mini-Circuits website and were measured on stripline test boards. The data presented below are compiled from the different measurements and superimposed on the same set of axes to easily compare the filter response under the different conditions tested.
Color Key:

- Red = Open
- Blue = With Cover
- Green = Cover + Adhesive
- Gray = BFHK on stripline (Mini-Circuits S-Parameters)

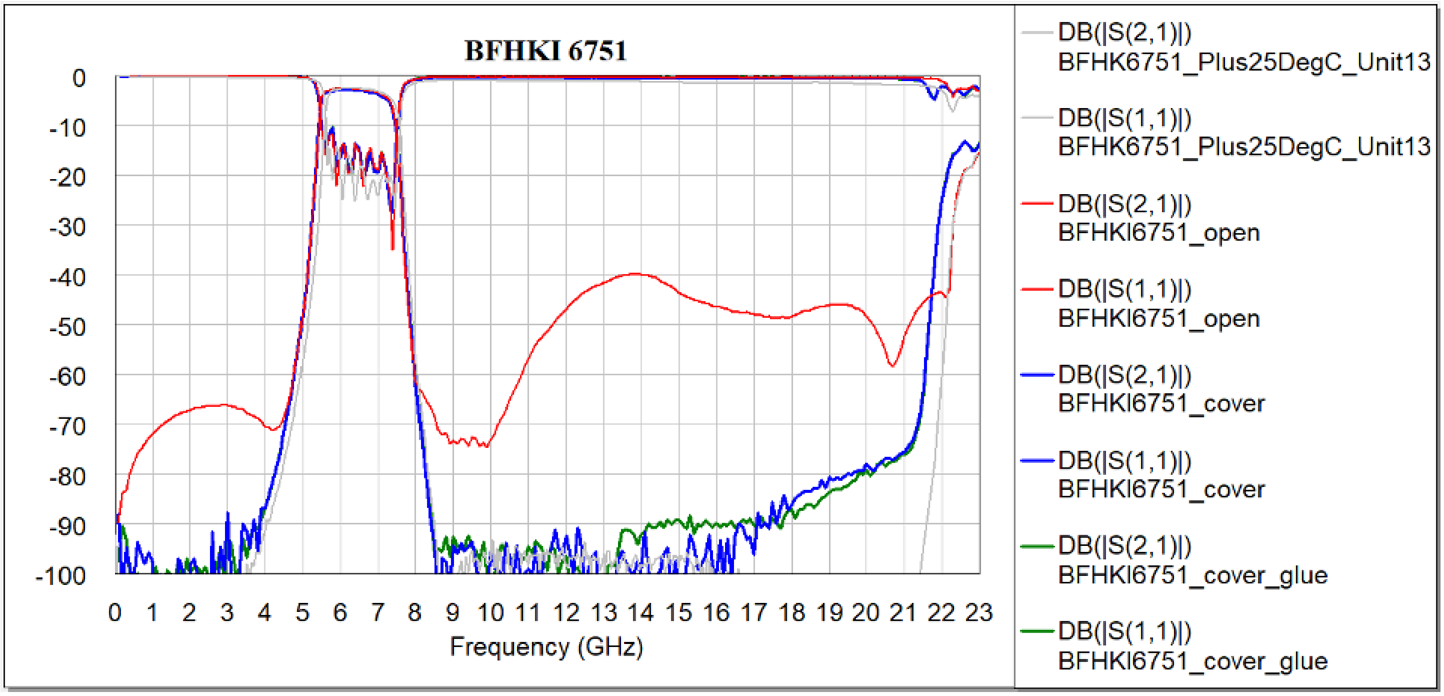


***Figure 10**: S11 and S21 plots for BFHKI-6751+ and BFHK-6751+ under various test conditions.*

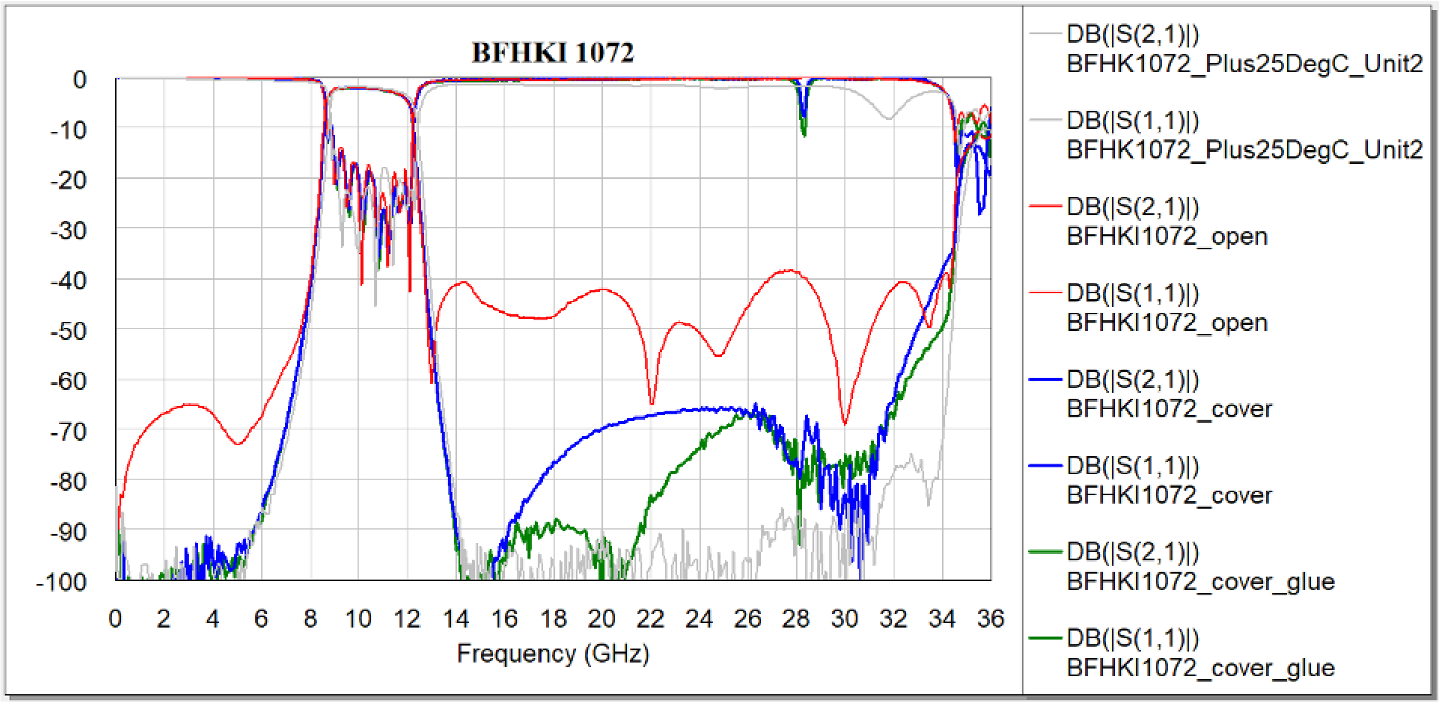


***Figure 11**: S11 and S21 plots for BFHKI-1072+ and BFHK-1072+ under various test conditions.*

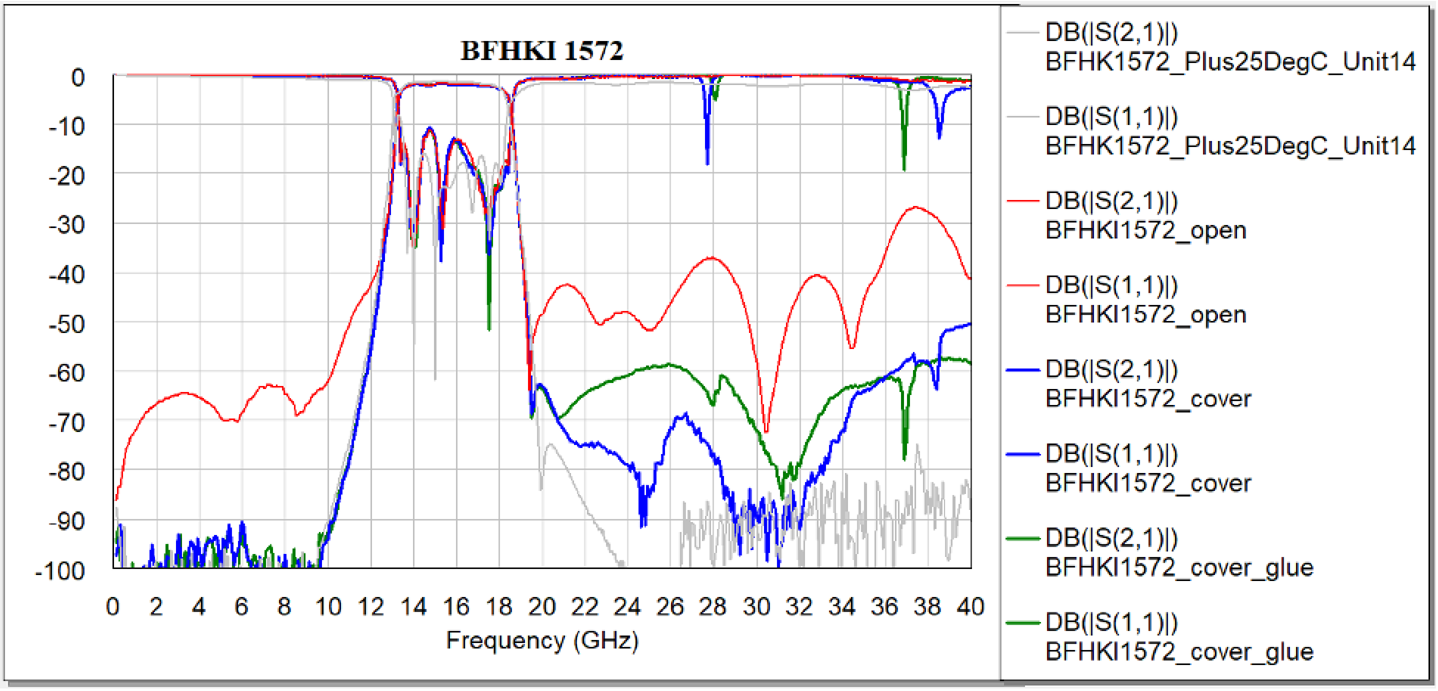


***Figure 12**: S11 and S21 plots for BFHKI-1572+ and BFHK-1572+ under various test conditions.*

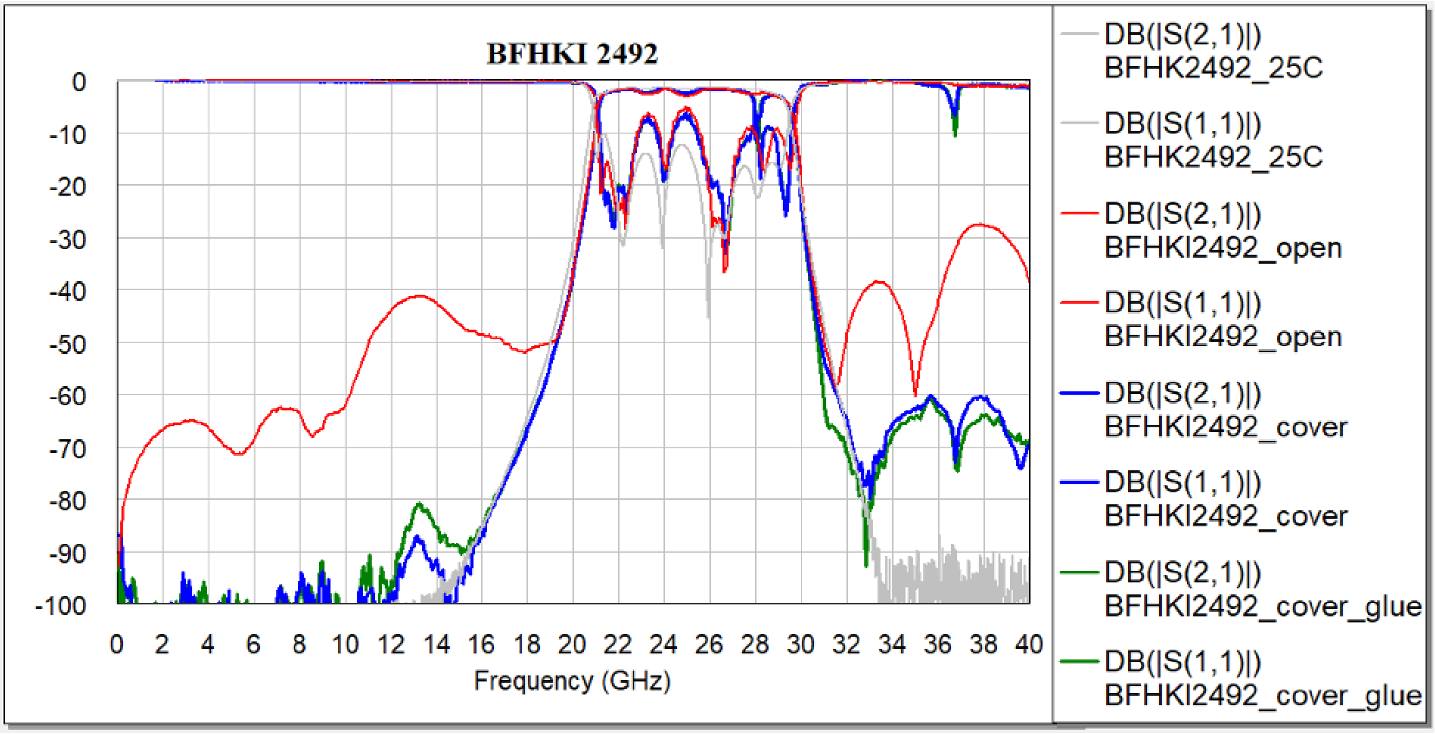


***Figure 13**: S11 and S21 plots for BFHKI-2492+ and BFHK-2492+ under various test conditions.*
The dip in the passband at 28 GHz is caused by the cover.

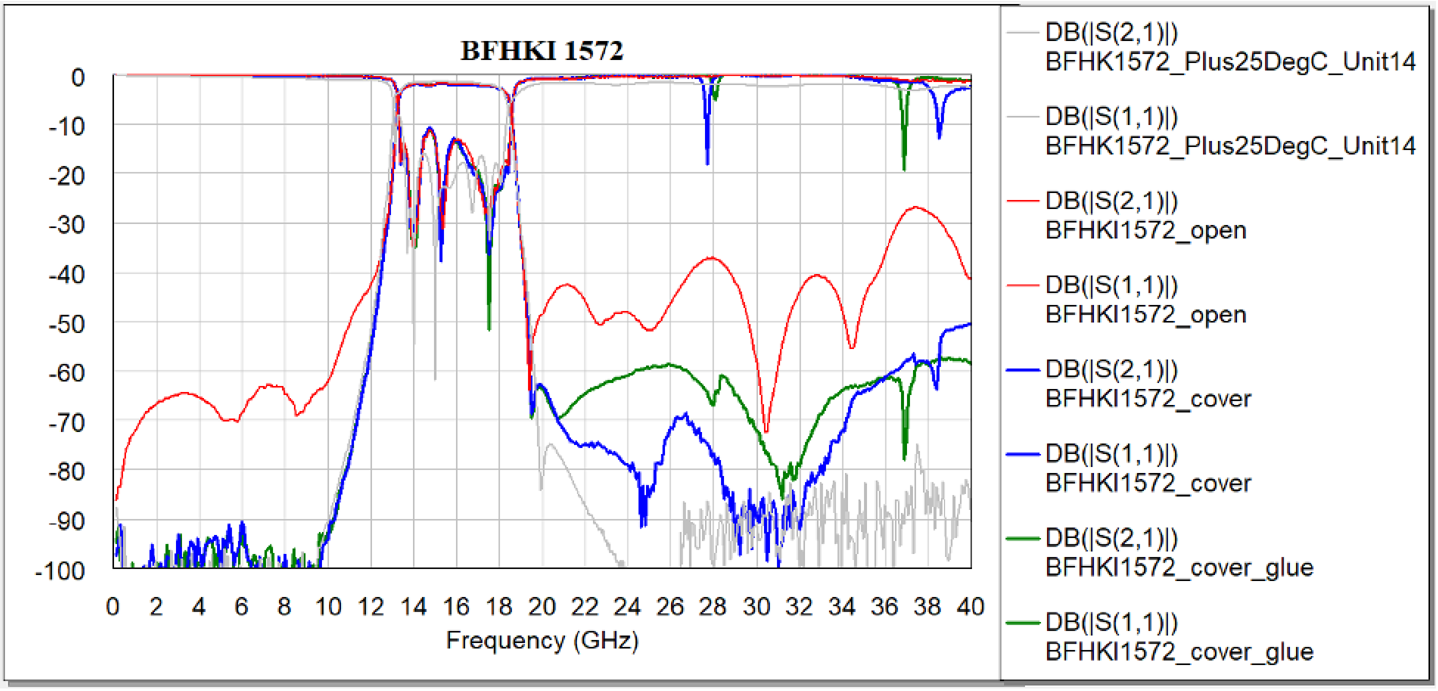


***Figure 14**: S21 plots for all BFHKI models tested on open CPW.*

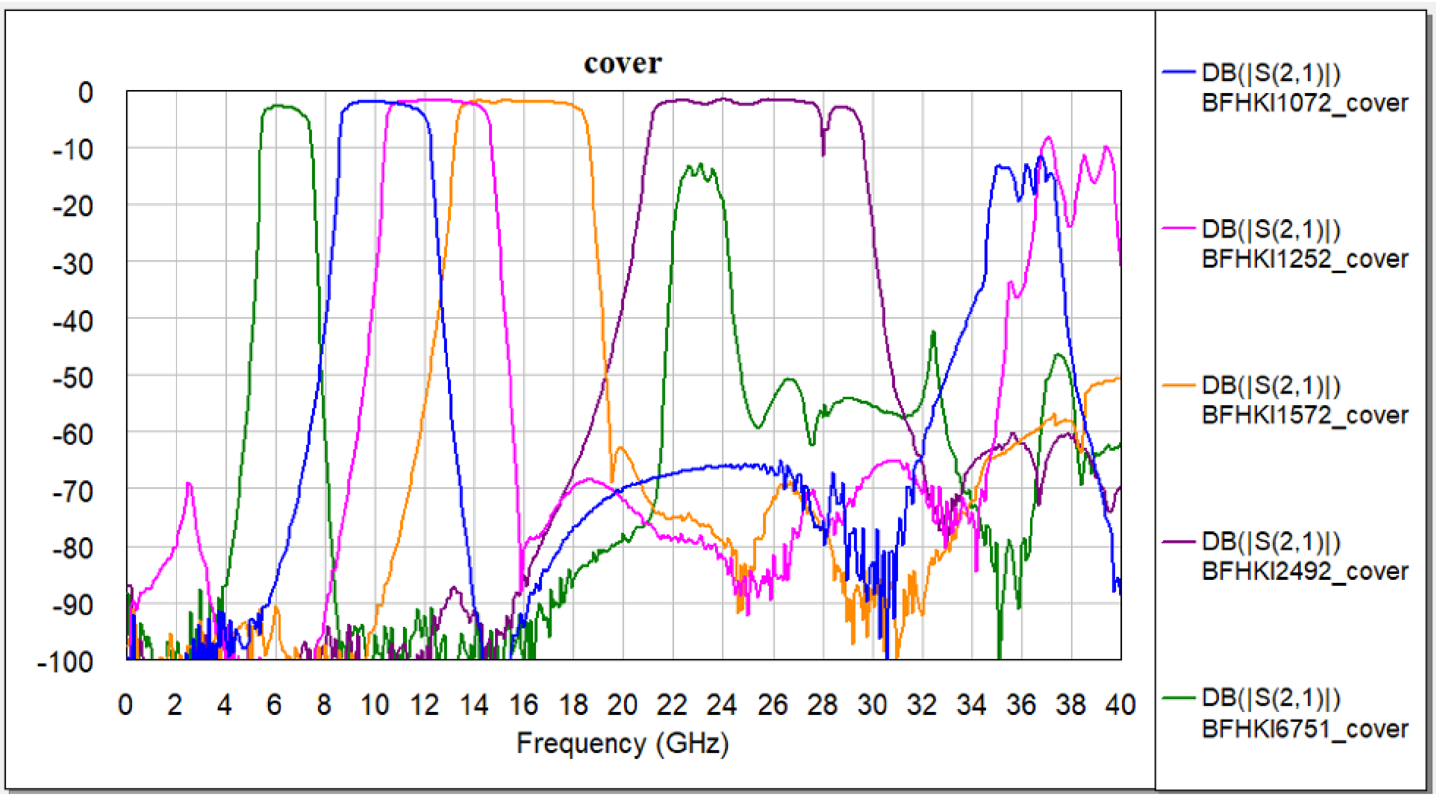


***Figure 15**: S21 plots for all BFHKI models tested with cover.*
Observe the dip at 28 GHz caused by the cover.

Discussion

In all cases, the addition of a channelized cover resulted in significant improvement in stopband rejection compared to the open CPW test case. Measurements of the BFHKI-series filters with the cover exhibited a response more closely approximating the reference case of the BFHK filter mounted directly on stripline with 90+ dB rejection floor in the lower stopband and upper stopband rejection ranging approximately from 60 to 90 dB depending on the model and the frequency of the upper stopband. More deviation was evident in the upper stopband, particularly at higher frequencies, but the channelized implementation still exhibited 60 to 70 dB rejection even at millimeter-wave range.

Application of conductive die attach adhesive achieved additional improvement in rejection in some cases, but caused resonances in others (e.g. BFHKI-1572+) resulting in poorer rejection. The cover may also cause resonances for higher passband frequencies, and a cover with chambers optimized to the dimensions of the BFHKI filter would presumably yield even better results.

Lastly, the measurements presented here exhibit poor return loss for passbands with higher center frequencies. A 10 mil test board rather than the 20 mil test board used here for filters with Fc higher than 18 GHz would likely correct this effect but was not included in this evaluation.

Conclusion

Mini-Circuits' BFHKI-series high-rejection LTCC filters with an interposer board were developed to extend the revolutionary capability of the BFHK series to CPW implementations with top-layer RF traces. While specifications on the datasheet exhibit degradation in rejection performance due to characterization on an open CPW test board, customers have demonstrated performance comparable to that of the BFHK filter on stripline PCB with channelization.
The channelization techniques presented in this paper are well-understood and widely used in the industry, making this a practical solution for customers using high-rejection LTCC filter technology in coplanar waveguide implementations.

[Explore Mini-Circuits' High-Rejection LTCC Filters]

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