APPLICATION **NOTE**

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Design and Implementation of a Miniature X-Band Edge-Coupled Microstrip BPF Using AWR Software

Microwave bandpass filters (BPFs) are the fundamental component used in many RF/microwave applications to eliminate interference from signals operating at nearby frequencies. This application note presents a straightforward and largely nonmathematical method for designing an edge-coupled bandpass filter for X-band operations (8.4- 9.3GHz). The flow combines filter synthesis, closed-form edge-coupled transmission-line models, and electromagnetic (EM) analysis using the Cadence® AWR® Microwave Office® circuit simulator within Cadence AWR Design Environment® software.

Design Overview

A miniature X-band, edge-coupled microstrip bandpass filter design example demonstrates this flow. The filter was implemented using edge-coupled microstrip lines on a Rogers RO4003 substrate material with Er = 3.66 and H = 8 mil. The temperature coefficient of dielectric constant was among the lowest of any circuit board material, and the dielectric constant was stable over a broad frequency range, specifically at X-band frequencies. The simulated results showed good filter response characteristics with the passband insertion loss approximately 5 dB and return loss greater than 12dB over the pass bandwidth of 900MHz.

Bandpass Filter Construction

A BPF can be constructed from resonant structures, such as a waveguide cavity or open-circuit transmission lines (i.e., stubs). An important parameter in filter design considerations is the fractional bandwidth, which is defined as the ratio of the passband bandwidth to the geometric center frequency. The inverse of this quantity is called the Q-factor. If ω1 and ω2 are the frequencies of the passband edges, then

bandwidth $\Delta\omega = \omega 2 - \omega 1 \Delta\omega = \omega 2 - \omega 1$

geometric center frequency $\omega 0 = \sqrt{\omega 1 . \omega 2}$

and $Q = \frac{\omega 0}{\Delta\omega}$

Parallel-coupled line are another popular topology for PCB filters. While these resonant structures can be based on shorted or open-circuited parallel lines, open-circuit lines are the simplest to implement since the manufacturing does not require making a connection to the ground plane, often achieved through the use of vias. The design consists of a row of parallel λ/2 resonators that couple to each of the neighboring resonators, forming the topology shown in Figure 1. Wider fractional bandwidths are possible with this type of filter than with the capacitive gap filter implementation, which is formed with an in-line row of transmission lines separated by a small gap between line segments.

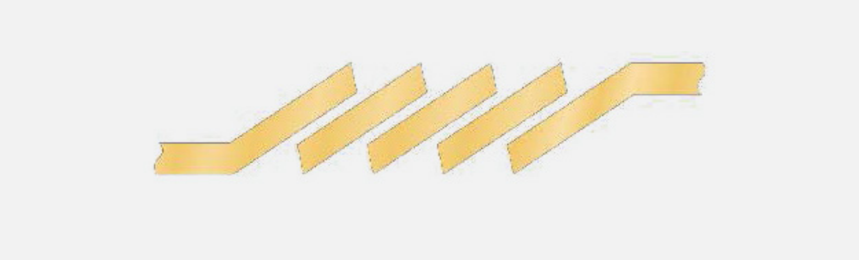


Figure 1: Filter with parallel edge-coupled lines.

Conventional Chebyshev design equations were used as follows:

J-inverters

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi * FBW}{2 * g_0 g_1}} \quad (1)$$

$$\left.\frac{J_{j,j+1}}{Y_0} = \frac{\pi * FBW}{2 * g_j g_{j+1}} \quad j = 1 \quad to \quad n-1 \quad (2) \quad \right\}$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi * FBW}{2 * g_n g_{n+1}}} \quad (3)$$

where

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0} \quad (4)$$

Equations used for the even and odd impedance of the coupled lines were:

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad j = 0 \quad to \quad n \quad (5)$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad j = 0 \quad to \quad n \quad (6)$$

The widths, spaces, and lengths of the coupled line were calculated with the TX-LINE calculator within the AWR Design Environment. An equivalent circuit was developed for derivation of the design equations for the BPF using admittance parameter equations from Pozer [1]. Figure 2 shows the layout of (a) an N+1 section coupled line BPF, (b) equivalent circuit for each coupled line section, and (c) the equivalent circuit for transmission lines with a length of 2θ. Figure 3 shows (d) the equivalent circuit for the admittance inverter, (e) the results of (c) above and (d) for the *N* = 2 case, and (f) the lumped-element circuit for the BPF for *N* = 2.

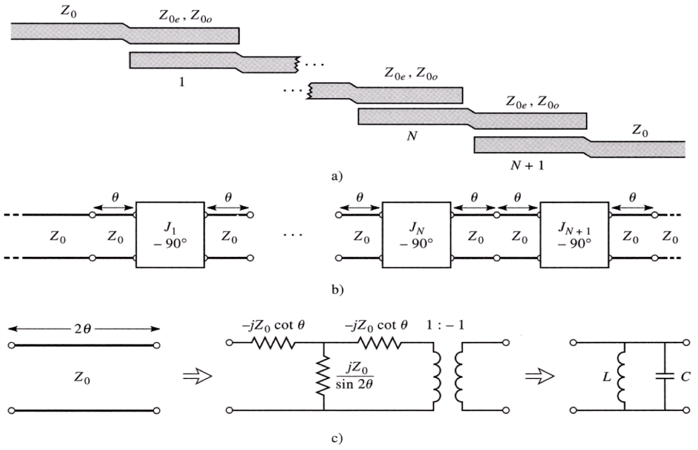


Figure 2: Development of an equivalent circuit for derivation of design equations for the BPF.

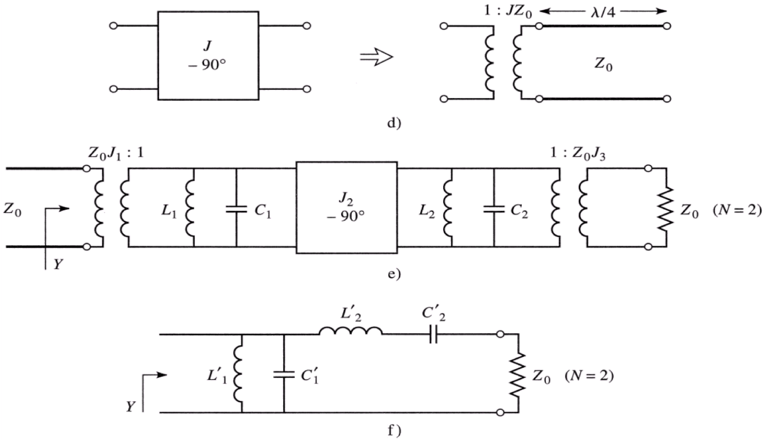


Figure 3: The equivalent circuit for the admittance inverters.

The coupled filter design equations are as follows:

Ⓑ $\longrightarrow$ $$J'_{1,2} = \frac{\pi\Omega}{2}\times\frac{1}{\sqrt{g_1 g_2}} = \frac{\pi\times0.1}{2}\times\frac{1}{\sqrt{1.5963\times1.0967}} = 0.1187$$

Ⓑ $\longrightarrow$ $$J'_{2,3} = \frac{\pi\Omega}{2}\times\frac{1}{\sqrt{g_2 g_3}} = \frac{\pi\times0.1}{2}\times\frac{1}{\sqrt{1.0967\times1.5963}} = 0.1187$$

Ⓓ $\longrightarrow$ $$Z_{oe,1,2} = Z_{oe,2,3} = 50\left[1+0.1187+0.1187^2\right] = 56.64\Omega$$

Ⓔ $\longrightarrow$ $$Z_{oo,1,2} = Z_{oo,2,3} = 50\left[1-0.1187+0.1187^2\right] = 44.77\Omega$$

The required resonator $$\lambda_r/4 = \frac{3\times10^8}{2f\sqrt{\varepsilon_r}} = \frac{3\times10^8}{4\times9\times10^9\sqrt{3.55}} = 0.01767m$$

Simulation Model and Results

Circuit Schematic Implementation

Models can be created for many basic components (transmission lines, coupled lines, MCROSSX, MTEEX$, MSTEPX, and more). The EM-based X model elements and "$"-based intelligent models were found to be more accurate based on confirmation with EM simulation. Simulation, tuning, and parameter sweeps were possible without compromising the accuracy using these circuit models. The schematic in Figure 4 was created by using the AWR Microwave Office elements library MACLIN asymmetric edge-coupled microstrip line model, which consists of the parameters W1, W2 (strip widths), S (gap between strips), and L (line length). Figure 4 provides the N = 6 order implementation on the Rogers RO4003 board, with ER = 3.66, H = 8 mil, and T = 1.

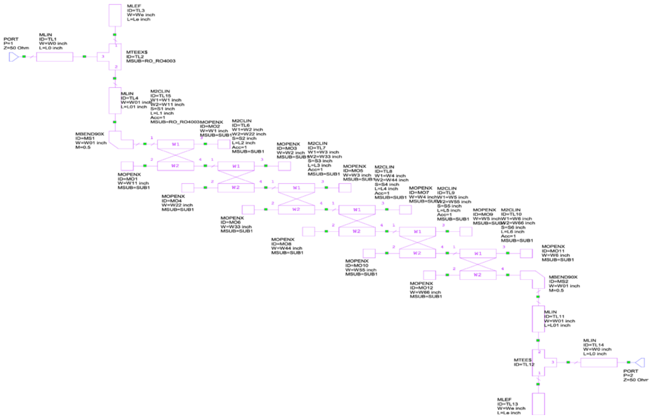


Figure 4: Layout of the BPF in AWR Microwave Office software.

The final dimensions for the schematic design in the completed TX-LINE were W1 = 0.0121 in., W2 = 0.0124 in., W3 = 0.0124 in., and W4 = 0.0124 in. Figure 5 shows the integrated layout generation in AWR Microwave Office software, with the 2D representation on the left and the 3D representation on the right.

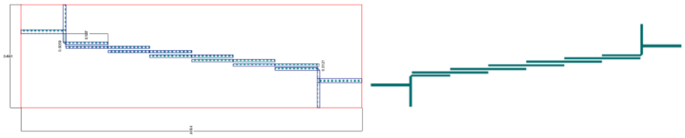


Figure 5: Edge-coupled BPF layout.

Circuit Simulation Results

The circuit schematic was simulated in AWR Microwave Office software based on the S-parameters. Figure 6 shows the results for insertion loss and return loss based on circuit analysis using the MACLIN asymmetric edge-coupled line models to define the filter network. The insertion loss in the frequency range of 8.4GHz to 9.3GHz was approximately 5dB with return loss well below 12dB. It can also be seen from the S-parameter results that the roll-off transition between the passband and stopband is relatively sharp, thus avoiding interference from adjacent channels (stopband rejection).

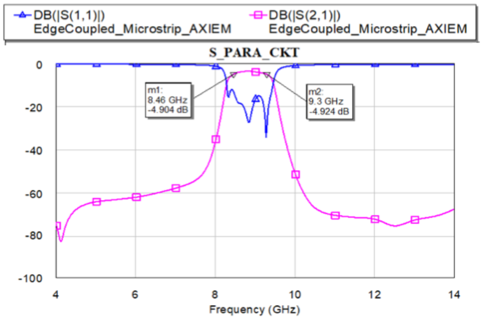


Figure 6: Circuit simulation S-parameter results

EM Simulation

The AWR AXIEM® planar method-of-moments (MoM) simulator within AWR Design Environment software was used to validate the BPF design, as shown in Figures 7.

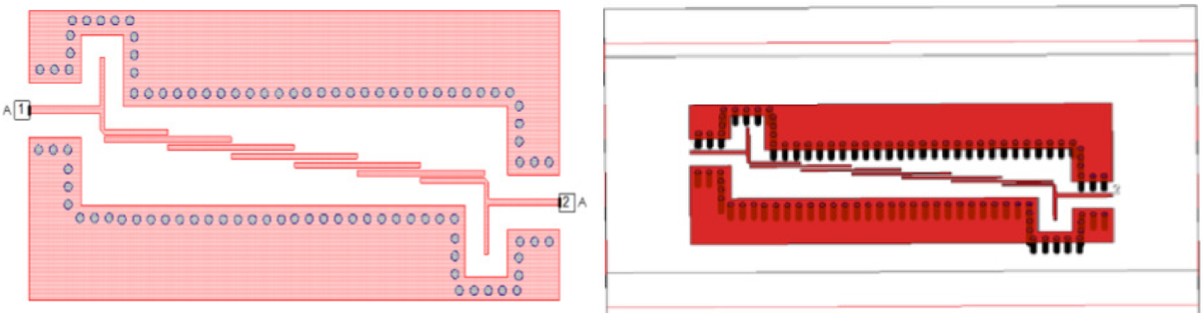


Figure 7: AWR AXIEM EM layout with ground plane and with mesh density annotation

The AWR AXIEM software solves for the currents on conductors embedded in a stackup of planar dielectric layers. MoM is a full-wave numerical technique that solves the integral form of Maxwell's equations using the approximation that the dielectric layers are of infinite extent in the x-y plane.

Once the EM simulations were carried out, the calculated current density can be annotated over the entire EM structure, as shown in Figure 9.

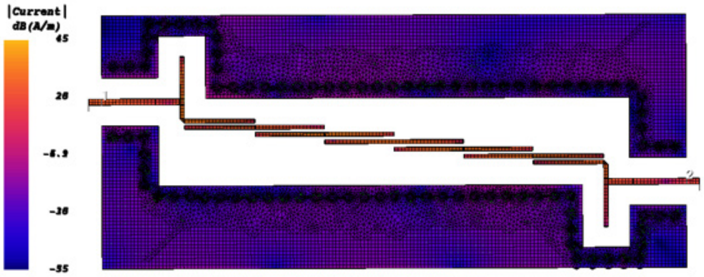
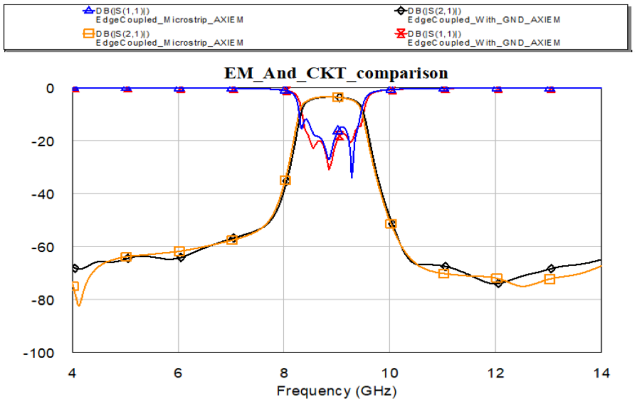


Figure 9: AWR AXIEM current density EM annotation

This annotation enables the designer to specify the frequency, phase, vector components, and color scaling associated with the magnitude of the current. It also supports the use of cut planes to enable designers to investigate current densities occurring within a more complex multi-layer structure through dissection of the PCB.

The EM simulation results in Figure 9 are shown in comparison to the circuit simulation results. The EM results were very similar to the circuit results and matched exactly the performance parameters with insertion loss in the frequency range of 8.4GHz to 9.3GHz with approximately 5dB and return loss well below 12dB.



Parameter	Circuit Schematic	Electromagnetic AXIEM
Insertion Loss	1) 8.4GHZ = -4.90dB 2) 9.3 GHz = -4.92dB	1) 8.4GHZ = 4.96dB 2) 9.3 GHz = 4.98dB
Return Loss	1) 8.4GHZ = -13.27dB 2) 9.3 GHz = -24.34dB	1) 8.4GHZ = 19.45dB 2) 9.3GHZ = 17.44dB

Figure 9: Comparison of circuit and EM simulation results (graph and table).

Conclusion

A straightforward AWR Design Environment software design flow for a miniature X-band edge-coupled microstrip bandpass filter has been demonstrated. The simulated results showed good filter response characteristics with passband insertion loss of approximately 5dB and return loss greater than 12dB in the 900MHz bandwidth with a center frequency of 9GHz. The validation results using AWR AXIEM EM simulation were in good agreement with the circuit simulation results based on the edge-coupled transmission-line models available in AWR Microwave Office software. The performance of this BPF design at this frequency range is suitable for aerospace and defense requirements for land, airborne, and naval radar applications.