# Accurate Design of a Notch Filter Using Electromagnetic Simulators

Circuit simulation and EM analysis are combined to achieve the desired performance

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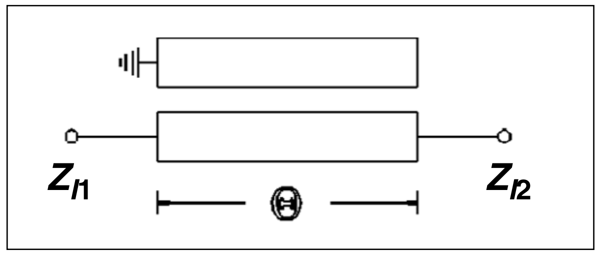
Strong interfering signals pose problems to receivers operating over a wide frequency band, as in the case of EW receivers. Unwanted signals at known frequencies can be suppressed using notch filters with sufficiently high rejection. A low cost notch filter has been designed with 25 dB minimum rejection at $f_0$ = 13.2 GHz with 50 MHz bandwidth. The circuit was designed and analyzed using the circuit simulator *Libra* and the layout was analyzed using an electromagnetic simulator, *Momentum* (HP-ADS from Agilent Technologies). A prototype was developed in microstrip configuration; simulated and measured results are presented in this article.

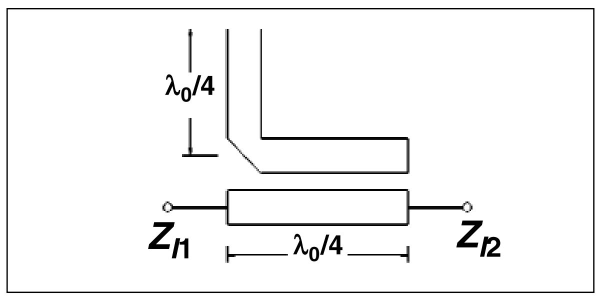
## The filter element

Capacitive coupled short stubs placed at quarter-wave distance offer band stop filter response for narrow bandwidth ratios [1]. The capacitor values are very small at higher frequencies, thus they are realized by microstrip gap or by overlap of conductor strips in stripline/suspended stripline circuits. However, it is difficult to achieve very small gaps, which are often required in the microstrip circuit realization of the notch filters.

A coupled line bandstop filter element is also suitable for narrow stop band filter applications, and it is easy to fabricate loosely coupled lines of < –10 dB in microstrip configuration. The coupled line bandstop filter element is a low-pass structure of electrical length $\theta$ and with a coupled section equal to $\pi/2$. It can be realized using a directional coupler with coupled and isolated ports terminated in short and open respectively, as shown in Figure 1. The short at the isolated port can be accurately realized with an open quarter wave stub as shown in Figure 2. The image impedance $Z_{I1}$ and $Z_{I2}$, and image phase shift $\phi$ through the coupled line are given by




▲ **Figure 1. A directional coupler with coupled and isolated ports terminated in short and open.**

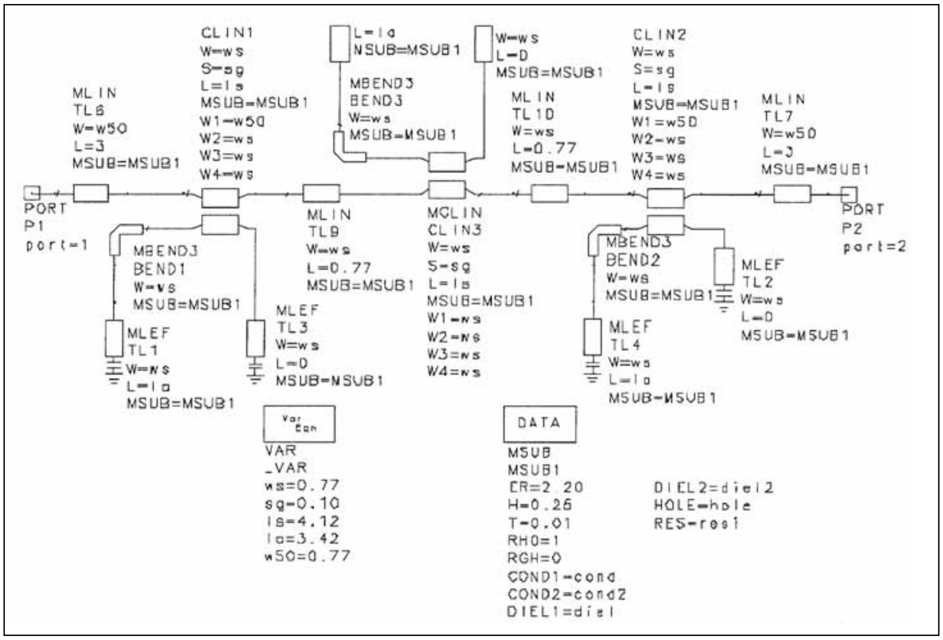



▲ **Figure 2. Short at the isolated port is accurately realized with open quarter wave stub**

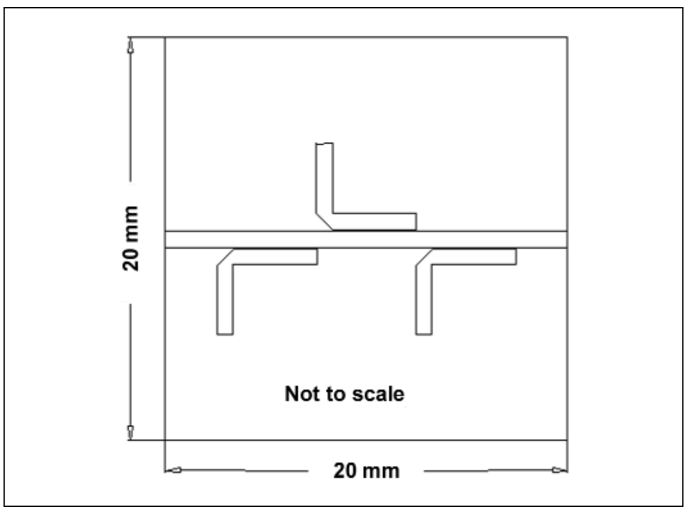
$$Z_{I1} = \frac{Z_e Z_o \cos\theta}{\sqrt{(Z_e + Z_o)^2 \cos^2\theta - (Z_e - Z_o)^2}}$$

$$Z_{I2} = \frac{Z_e Z_o}{Z_{I1}}$$

$$\cos\phi = \frac{\sqrt{(Z_e + Z_o)^2 \cos^2\theta - (Z_o)^2}}{2\sqrt{(Z_e Z_o)}}$$




▲ **Figure 3. *Libra* schematic of the notch filter.**




▲ **Figure 4. *Libra* layout of the notch filter.**

where $Z_e$ and $Z_o$ are even and odd mode impedances of coupled lines. When $\theta \to \pi/2$, $Z_{I1} \to 0$ and $Z_{I2} \to \infty$, the coupled section acts as a bandstop filter.

Notch width and depth of the filter element depends on the coupling coefficient and loaded $Q$ of the resonator. Tighter coupling gives increased rejection, and increases stopband width of the filter, which may not be desirable, making it a trade-off between the two parameters.

| $f_0$ Parameter | Libra Simulated | EM Simulated | Measured |
|---|---|---|---|
| Notch freq. $f_0$ GHz | 13.32 | 13.24 | 13.24 |
| Notch depth dB | 51.45 | 28.2 | 28.1 |
| Notch width MHz ( $\lvert S_{21}\rvert$ > 25 dB ) | 120 | 45 | 50 |

▲ **Table 1. Simulated and measured performance results.**

## EM simulation analysis

An edge coupled microstrip line directional coupler with 13.3 dB was used as the filter element in which the gap between the coupled lines can be easily realized using a hybrid MIC process. Even and odd mode impedances of the coupler are 62.2 ohms and 40.1 ohms respectively. Physical dimensions were computed using *Linecalc* (EE) which were also convenient for circuit realization on 10 mm thick RT-Duroid-5880 (Rogers Corp.) substrate. A single section microstrip filter showed about 10 dB rejection at $f_0$; and therefore three cascaded sections were used to obtain the desired rejection (> 25 dB).

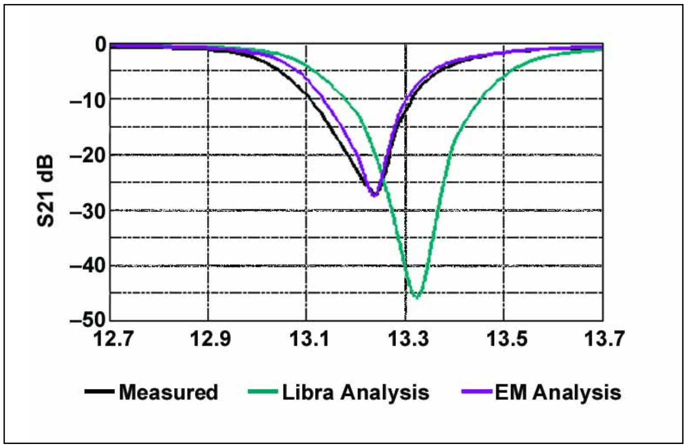
The circuit was optimized for maximum rejection at $f_0$ = 13.24 GHz and minimum stopband width. The layout file of the circuit, which demonstrated a considerable deviation in the notch frequency was analyzed using *Momentum*. This deviation  the coupling between the adjacent coupled sections and the increase in effective length of the coupled region near bends. These effects were minimized by adding a small transmission line segment in between the couplers and by tuning the stub lengths in em-simulation. *Libra* schematic and layout of the final circuit are shown in Figures 3 and 4, respectively. *Libra* (based on circuit schematic) and EM simulated results are shown in Figure 5.

## Performance

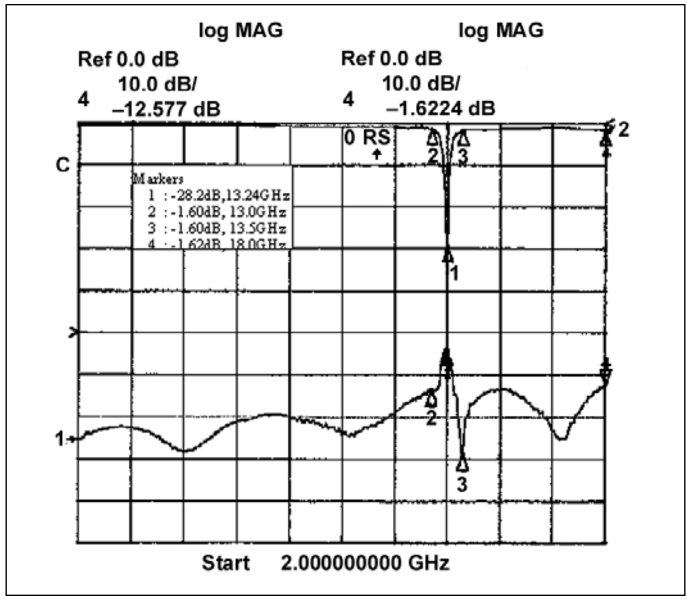
Simulated and measured performance results are summarized in Table 1. The measured performance showed good agreement with EM simulated results, particularly notch frequency and rejection. Linear analysis of the same physical circuit showed 46.1 dB rejection at 13.32 GHz, a deviation of 80 MHz in frequency and rejection. The measured performance graph is shown in Figure 5 along with the simulated results. The performance plot in the 2 to 18 GHz range is shown in Figure 6. Return loss in the passband is better than 10 dB.

## Conclusion

A simple microstrip notch filter has been designed and realized on 20 × 20 mm$^2$, 10 mil soft




▲ **Figure 5. *Libra* and EM simulated results.**




▲ **Figure 6. Performance plot in the 2 to 18 GHz range.**


▲ **Figure 7. A simple microstrip notch filter.**

substrate (RT-Duroid 5880). Good repeatability was observed over a number of units tested without tweaking. The notch frequency was 13.23 ±0.02 GHz with a minimum 28 dB rejection and 1.6 dB maximum insertion loss in the pass band up to 18 GHz. Shift in frequency and deviation in notch depth were found to be well within the tolerances, which demonstrates that EM simulation yields accurate results in the realization of microwave passive components, particularly for narrow band applications. The circuit is shown in Figure 7. ■



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## References


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