Sixteenth-mode substrate integrated waveguide bandpass filter loaded with complementary split-ring resonator

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A novel sixteenth-mode substrate integrated waveguide (SMSIW) bandpass filter loaded with complementary split-ring resonator (CSRR) is proposed. The filter size is reduced by introducing the SMSIW circular cavity loaded with CSRR. The SMSIW occupies only 6.25% of the conventional substrate integrated waveguide with same resonant frequency. Further miniaturisation is achieved by loading the SMSIW circular cavities with CSRRs. The designed filter is centred at 2.45 GHz with a bandwidth of 8.2%. The measured minimum insertion loss is 0.9 dB and passband return loss is below 10 dB. Good agreement is achieved between simulated and measured results.

Introduction: Due to rapid development in modern wireless communication systems high performance, low-cost and compact-size filters are required. Recently, substrate integrated waveguide (SIW) has achieved attention due to its several advantages such as high-quality factor, high power capability, planar structure, low-loss, low-cost, ease of fabrication and easy integration with planar circuits. Several attempts have been performed to miniaturise SIW structures. The half-mode SIW (HMSIW) bandpass filter and substrate integrated folded waveguides (SIFWs) filters have been introduced to design a compact filter [1, 2]. Complementary split-ring resonator (CSRR) loaded SIW bandpass filter is presented in [3] to reduce the size of the filter. In [4], an eighth-mode SIW (EMSIW) antenna loaded with CSRR is designed. Compact EMSIW low-temperature co-fired ceramic filters are proposed in [5, 6], its electrical size is reduced by a CSRR loaded on the EMSIW. In this Letter, a more compact SIW filter is proposed by exploiting the sixteenth-mode SIW (SMSIW) loaded with a CSRR. The size of the SMSIW is reduced by a factor of 15/16 of the conventional SIW, whereas keeping almost the same resonant frequency.

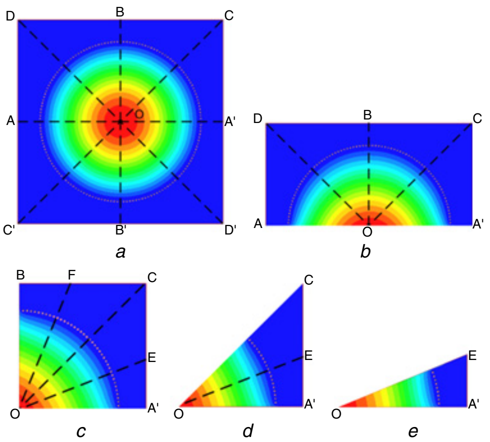

Fig. 1 *Simulated E-field distributions with fictitious magnetic walls*

a Full-mode SIW
b HMSIW
c QMSIW
d EMSIW
e SMSIW

SMSIW cavity loaded with CSRR: Fig. 1 presents the magnitude of the electric field distributions in a conventional SIW, HMSIW, quarter-mode SIW (QMSIW), EMSIW and SMSIW of the TM_{010} mode. The magnitude of the electric field of a conventional SIW circular cavity is plotted in Fig. 1*a*. When the SIW is cut along the perfect magnetic wall A–A′, the HMSIW is realised, as shown in Fig. 1*b*. The size of the HMSIW is half of the size of the SIW. The size of the HMSIW is further reduced by cutting it along fictitious magnetic wall O–B, which is called a QMSIW, as shown in Fig. 1*c*. The EMSIW is obtained by half-reduction of QMSIW along O–C, as shown in Fig. 1*d*. The SMSIW is generated by bisecting the EMSIW with another fictitious magnetic wall O–E, as shown in Fig. 1*e*. The overall size can be reduced by a factor of 15/16 while keeping almost the same resonant frequency. Therefore, the SMSIW was used to design a compact microwave filter. It is built on the Rogers RT/Duroid 5880 substrate with dielectric permittivity $\varepsilon_r = 2.2$, substrate thickness $h = 0.787$ mm and loss tangent $\tan\delta = 0.0009$.

As shown in Fig. 2, the square-shaped CSRR is etched on the top surface of the SMSIW, which can reduce the cavity resonant frequency. The CSRR is rotated at an angle $\alpha = 22.5°$. According to the specifications of the filter and optimisation performed using the full-wave electromagnetic simulator-Ansys HFSS, the values of the parameters are: $r = 27.4$ mm, $lsx = 19.85$ mm, $lsy = 4.35$ mm, $d = 0.6$ mm, $a_1 = 5.28$ mm, $a_2 = 3.78$ mm, $w_1 = 0.4$ mm, $w_2 = 0.35$ mm, $g_1 = 0.8$ mm, $g_2 = 0.8$ mm and $\alpha = 22.5°$.

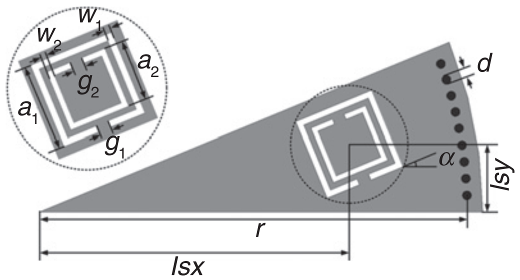

Fig. 2 *Configuration of proposed CSRR-loaded SMSIW*

Compact filter design: The top view of the two-pole filter based on SMSIW loaded with CSRR is presented in Fig. 3. The CSRRs are etched on the top metal plane of the SMSIW. The 50 Ω microstrip lines are used as input and output feed lines. The filter has a symmetrical configuration. A single cavity is used to determine the external coupling and two coupled cavities are used to determine internal coupling. The coupling between the two SMSIW cavities is generated by adjusting the broadside of the two SMSIW cavities. The optimised values of the parameters are: $pl = 18.65$ mm, $wfeed = 2.4$ mm and $g = 0.5$ mm.

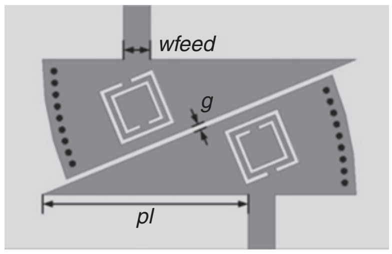

Fig. 3 *Top view of proposed filter*

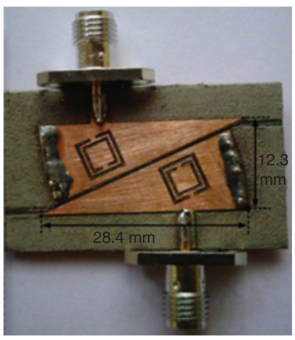

Fig. 4 *Photograph of fabricated filter*

To validate the design approach, the proposed filter was fabricated and measured. The photograph of the fabricated filter is presented in Fig. 4. The overall size of the presented SMSIW two-pole filter loaded with CSRR, excluding microstrip feed lines, is 28.4 × 12.3 mm, which is equivalent to $0.23\lambda_0 \times 0.1\lambda_0$, where λ_0 is the wavelength in free space at the frequency of operation. The simulated and measured results are compared in Fig. 5. The filter is centred at 2.45 GHz with a bandwidth of 8.2%. The measured minimum insertion loss is 0.9 dB and passband return loss is better than 10 dB. The measured response is in close agreement with the simulated response.

However, there are some discrepancies in the measured results which can be attributed to fabrication tolerances.

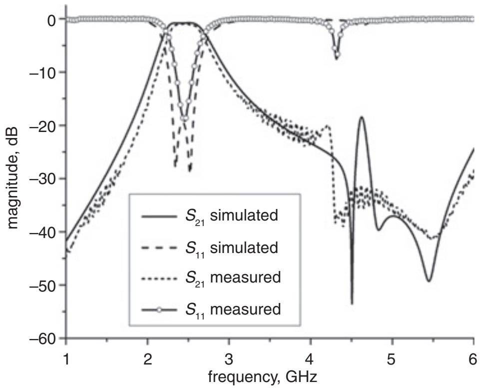

Fig. 5 *Simulated and measured results*

Conclusion: This Letter proposes a compact bandpass filter exploiting SMSIW loaded with CSRR. This miniaturisation technique provides large size reduction compared to conventional SIW. The overall size of the presented SMSIW two-pole filter loaded with CSRR, excluding microstrip feed lines, is $0.23\lambda_0 \times 0.1\lambda_0$. The filter operates at 2.45 GHz with a bandwidth of 8.2%. The measured minimum insertion loss is 0.9 dB and passband return loss is better than 10 dB. Compact size, simple structure, low-loss and ease of fabrication make it a suitable candidate for microwave applications.

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One or more of the Figures in this Letter are available in colour online.

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