All resonator based LTCC diplexer using substrate integrated waveguides

I. Llamas-Garro, F. Mira, P. Zheng, Z. Liu, L. Wu and Y. Wang

A compact diplexer is implemented in Low-Temperature-Cofired-Ceramic (LTCC) technology and consists of six coupled Substrate-Integrated-Waveguide (SIW) cavity resonators stacked in two layers. No transmission-line based junction is used. The couplings between the cavities are achieved through both SIW irises and slots placed in metal layers. The diplexer has two third-order filtering channels, centred at 2.7 and 3.3 GHz with 120 MHz bandwidths. The overall size of the diplexer is 27.74 mm (2.3 λ_g at 3 GHz) × 10.4 mm (0.86 λ_g at 3 GHz) × 0.84 mm, achieved by using an LTCC material of a high dielectric constant of 68. Simulations and measurements are in good agreement to demonstrate a compact diplexer based on an all resonator structure using high dielectric constant LTCC material.

Introduction: LTCC technology allows the production of integrated multilayer circuits [1-2]. The use of SIW cavity resonators results in higher resonator Q-values when compared with microstrip or other planar circuits [3]. The combination of LTCC and SIW has produced many compact and high-performance microwave devices such as filters [4]. This work is focused on demonstrating a compact diplexer using multiple miniaturisation techniques. First of all, a compact diplexer architecture based exclusively on coupled resonators [5] is adopted. A junction resonator, contributing to a pole of the diplexer, is used to join the two filter channels without using any transmission line junctions. A multilayer structure is implemented based on SIW resonators and using LTCC techniques. Both vertically and horizontally coupled SIW cavity resonators are used. Finally, a high permittivity LTCC material is used to further shrink the size of the SIW resonators.

Diplexer design and implementation: The diplexer is based on a topology of coupled resonators as shown in Fig. 1, where P1 is the common port, P2 and P3 are the outputs of the filtering channels. Resonator 2 is the junction resonator directly coupled to the resonator 1 from the common port as well as resonators 3 and 5 forming part of the two channel filters respectively.

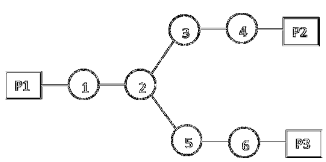

Fig. 1 *Coupling diagram of the all-resonator based diplexer.*

All six resonators contribute to the poles of the diplexer with each channel having a third-order Chebyshev filtering characteristic. This coupling topology can be represented by a single coupling matrix for a three-port network. An optimisation based method [5] is used to achieve the matrix given in (1). Each entry of the matrix defines the coupling coefficient between two resonators. The non-zero diagonal entries (self-coupling coefficients) register the frequency offset of the two channels. The external couplings are determined by the external quality factors: $Q_{ext,1}$ = 11.4, $Q_{ext,2}$ = 22.8 and $Q_{ext,3}$ = 24.0, as extracted together with the coupling matrix.

$$M = \begin{bmatrix} 0 & 0.2118 & 0 & 0 & 0 & 0 \\ 0.2118 & 0 & 0.0529 & 0 & 0.0521 & 0 \\ 0 & 0.0529 & -0.1977 & 0.0389 & 0 & 0 \\ 0 & 0 & 0.0389 & -0.2033 & 0 & 0 \\ 0 & 0.0521 & 0 & 0 & 0.1986 & 0.0377 \\ 0 & 0 & 0 & 0 & 0.0377 & 0.2044 \end{bmatrix} \quad (1)$$

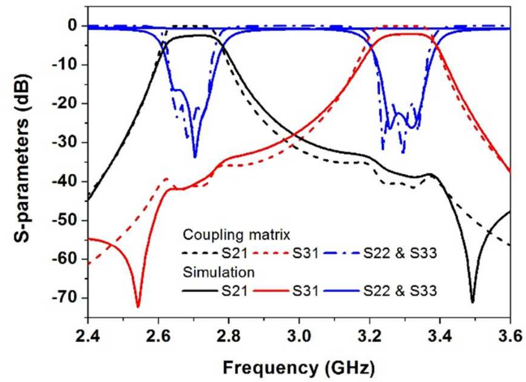

Fig. 2 *Calculated responses from the coupling matrix in comparison with the simulated responses of the diplexer.*

Fig. 2 shows the corresponding diplexer responses from the coupling matrix where lossless resonators are assumed.

To implement the diplexer, SIW resonators with a height of 0.42 mm are used. To minimise resonator footprint, a high-permittivity LTCC material (SIC-K70D3), developed by the Shanghai Institute of Ceramics, Chinese Academy of Sciences, is chosen. The dielectric constant is 68 ± 1 at 3 GHz and the dielectric loss tangent is 0.002 at 3 GHz. Compared to a SIW resonator made using a low-permittivity LTCC material (ε_r = 6~8), the dimension of the resonator is reduced by three folds to around 10 mm. To implement the coupling matrix and minimise the footprint of the diplexer, a folded multi-layer structure is used as shown in the exploded view of the diplexer in Fig. 3. The numbers in the graph correspond to the resonators in Fig. 1, whereas the arrows indicate the coupling paths. The diplexer uses two stacked cavity layers, with three resonators on each layer. Couplings between resonators are obtained through slots cut on the metal layers (vertical coupling) and irises formed by missing via holes (horizontal coupling). The input and outputs are on the same plane. A coplanar waveguide (CPW) to SIW transition [3] is used to define the required external quality factors, the input and outputs of the diplexer are shown in Fig 4. The diplexer is simulated using HFSS. The couplings between resonators and the external quality factors related to input and output are extracted using the method detailed in [6]. The simulated response of the optimised diplexer is shown in Fig. 2. It can be seen that the simulation reproduces the calculated response from the coupling matrix very well, except that 2.5 / 2.0 dB insertion losses are observed in the two passbands respectively. Two transmission zeros appear at 2.5 and 3.5 GHz in the simulation, a result of having the CPW-to-SIW transition structure and possible cross couplings between resonators.

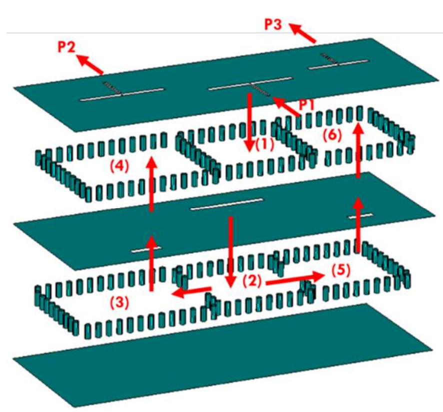

Fig. 3 *Exploded view of the LTCC-SIW diplexer, structure dimensions:* 27.74 mm × 10.4 mm × 0.84 mm.

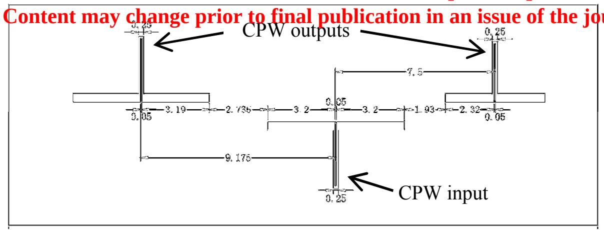

Fig. 4 *View of the LTCC-SIW diplexer CPW to SIW ports, dimensions in mm.*

Diplexer fabrication: The diplexer is fabricated using the SIC-K70D3 LTCC material. The SIC-K70D3 green tape has a thickness of about 50 µm. layers of LTCC sheets are used to build the height of the SIW. Dupont LL612 sliver paste was used as the conductor material. Holes with a diameter of 0.5 mm are punched using a KEKO, PAM-200 equipment in each green tape. The green tapes with the same hole pattern were stacked to obtain the required thickness. After pre-laminating at 300 psi and 70°C for 15 min (PTC, LT08001), the silver conductor paste was used to fill the holes using screen-printing (KEKO, P-200). This formed the conducting via holes between layers. The conductor patterns were also screen-printed on the surfaces of the green blocks to form the waveguide cavities, the coupling slots and the input/output. The diplexer is obtained by stacking two green blocks with different conductor patterns and then laminated at 6000 psi and 70°C for 15 min. After lamination, the green block was cut along pre-defined cutting lines. The final samples are obtained after de-binding at 450°C for 120 min and sintering at 920°C for 20 min. Fig. 5 shows a fabricated diplexer sample, where the CPW ports and transition structures can be observed along with the contours of the SIW cavities.

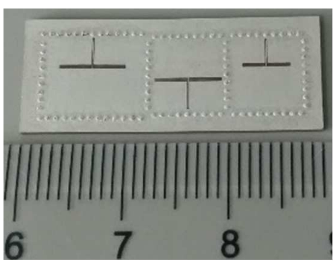

Fig. 5 *Fabricated diplexer.*

Results: The diplexer prototypes are measured using a Keysight PNA network analyser (N5227A), connected to a Cascade probe station (SUMMIT 11K). ACP40-GSG probes were utilized for the measurement after a SOLT calibration. Due to the space restriction between the CPW ports and the limitation of the measurement instrument, only two probes can make contact with the device at a time. The third port was left open without a matched termination. Although this causes undesired reflection at the third port, this problem is not an acute one because of the inherent isolation between the two channels of the diplexer. Fig. 6 shows the measured responses in comparison with the simulation. The central frequencies of the two bands agree very well with the simulation. Some discrepancies were observed in the return loss and the positions of the transmission zeros. These are believed to be partly due to the fabrication tolerance and partly due to the unterminated third port during the two-port measurement. The measured minimum insertion loss is 1.8 dB in the lower band and 2.0 dB in the high band.

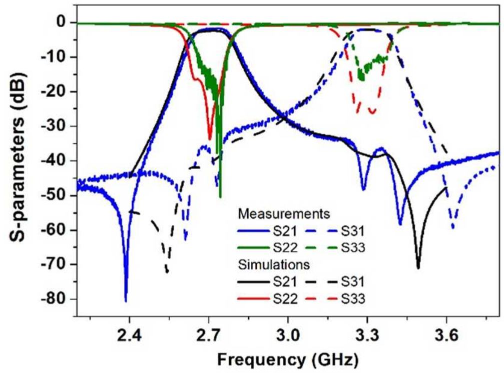

Fig. 6 *Simulated (dashed lines) and measured results (solid lines)*.

Conclusion: LTCC technology has been used to produce a compact size SIW diplexer by using a high dielectric constant and a stacked cavity design based on an all resonator structure.

I. Llamas-Garro and F. Mira (*Centre Tecnològic de Telecomunicacions de Catalunya, CTTC/CERCA, 08860 Castelldefels, Spain*)
P. Zheng, Z. Liu (*Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, China*)
L. Wu (*Shanghai Jiao Tong University, Shanghai, China*)
Y. Wang (*University of Greenwich, ME4 4TB, U.K.*)
E-mail: yi.wang@gre.ac.uk

References

1. Bhutani, A., Goettel, B., Thelemann, T., Zwick, T.: 'CPW-to-SL transition in LTCC technology', *Electronics Letters*, 2017, **53**, (9), pp. 609 – 611.
2. Xu, J., Zhang, X.: 'Compact High-Isolation LTCC Diplexer Using Common Stub-Loaded Resonator with Controllable Frequencies and Bandwidths', *IEEE Trans. Microw. Theo. Techn.*, 2017, pp. 1-9.
3. Bozzi, M., Georgiadis, A., Wu, K.: 'Review of substrate-integrated waveguide circuits and antennas', *IET Microw. Antennas Propag.*, 2011, **5**, (8), pp. 909–920.
4. Garreau, J., Potelon, B., Rius, E., Favennec, J., Quendo, C., Caille, C., Leblond, H., Azzara J., Raynaud, L.: 'Ultra-compact X-band SIW filter in LTCC technology using high permittivity substrate for a space application', IEEE/MTT-S International Microwave Symposium Digest, Montreal, QC, Canada, 2012, pp. 1-3.
5. Shang, X., Wang, Y., Xia, W., Lancaster, M. J.: 'Novel Multiplexer Topologies Based on All-Resonator Structures', *IEEE Trans. Microwave Theo. Tech.*, 2013, **61**, (11), pp. 3838-3845.
6. Hong, J.-S., Lancaster, M.J.: 'Microstrip filters for RF/microwave applications', John Wiley & Sons Inc., New York, USA, 2001.