UWB and WiLAN Microstrip Diplexer for Differential-Mode Operation

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***Abstract* — A balanced microstrip diplexer integrating directional filter and UWB structures for electronic communications is presented. The proposed structure channelizes UWB and WiLAN bands at different ports in its differential-mode. Good noise attenuation is obtained for the common-mode operation. The prototype presents low dimensions and ease of fabrication, which add important characteristics for integration into existing systems. Simulated and experimental results are presented with good agreement.**

***Index Terms* — Common-mode filter, differential signals, electromagnetic interference (EMI), microwave multiplexer, UWB filter, WiLAN.**

I. Introduction

Differential signals have become essential in high-speed communication systems due to its low radiation and high immunity to noise and electromagnetic interference (EMI). The coupling of common-mode noise is unavoidable in practical circuits, thus, the design of differential structures that are able to suppress the common-mode interference becomes of high importance for signal integrity.

Several wide-band filtering structures have been proposed for differential mode operation, including those realized over the microstrip technology [1], defected-ground plane [2] and multilayer [3], [4].

Multi-band operation is often required in modern communication systems; therefore, multiplexers are essential components in transceiver modules. A dual-band balanced filter is proposed in [5] and an unbalanced-to-balanced diplexer for differential signals is presented in [6]. However, no work has been found on balanced multiplexers in the literature.

A microstrip balanced diplexer for UWB and WiLAN bands is presented in this paper. For differential mode, when the signal enters to port 1, the UWB is obtained at port 2, and the WiLAN at port 4. The proposed structure is compact and simple to fabricate.

II. Balanced Diplexer Design

Fig. 1(a) shows the schematic of the proposed diplexer. It consists of a balanced nine-pole UWB filter and an integrated two-pole directional filter operating at the WiLAN band. As shown in Fig. 1(a), the structure is symmetric to the horizontal plane (dashed line); therefore, the line becomes an electric wall for differential-mode excitation, and a magnetic wall for common-mode signals, as shown in Figs. 1(b) and 1(c), respectively.

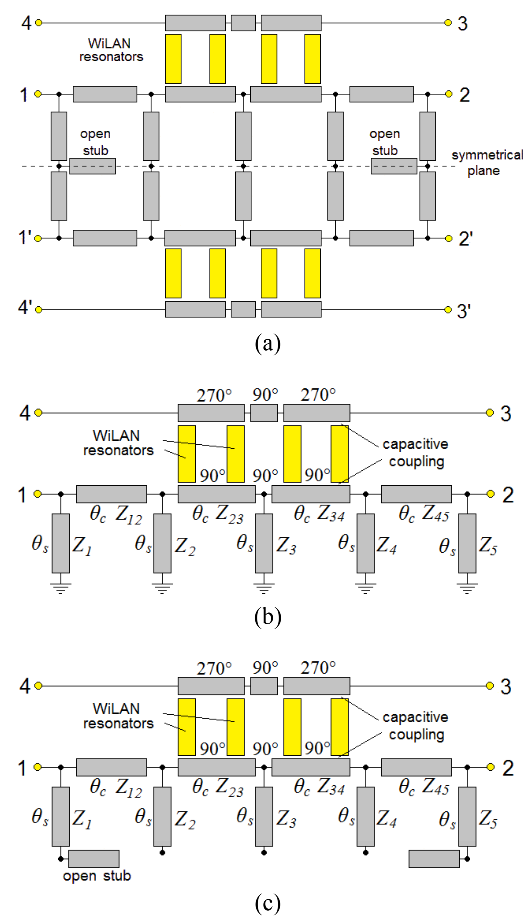

Fig. 1. Schematic of the proposed balanced diplexer: (a) complete structure; (b) differential-mode equivalent circuit; (c) common-mode equivalent circuit.

The design of the proposed diplexer is derived from its differential-mode single-ended configuration [Fig. 1(b)]. The UWB signal (3.1 GHz – 10.6 GHz) is obtained between ports 1 and 2 and the WiLAN band (centered at 5.4 GHz) is directed from port 1 to 4. No signal is reflected to port 1, and port 3 remains isolated. The substrate used for the design is Rogers RT/duroid 5880 with dielectric permittivity ε_r = 2.2 and thickness h = 0.787 mm.

The UWB filtering structure is based on the optimum highpass filter with five shunt stubs, as shown in Fig. 1(b),

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following the procedure detailed in [7]. The impedances of the stubs are defined by Z_1 to Z_5, and the impedances of the connecting lines are defined by Z_{12} to Z_{45}. The electrical length of the stubs and the connecting lines are θ_s and θ_c, respectively, at the lower cutoff frequency. A nine-pole bandpass response is generated with 110 % bandwidth and central frequency of 6.85 GHz. Table I tabulates the circuit parameters of the UWB filter [7].

TABLE I
CIRCUIT PARAMETERS OF THE UWB FILTERING STRUCTURE WITH $\theta_s = 43.4°$ AND $\theta_c = 86.8°$ [7].

Shunt stubs	Connecting lines
$Z_1 = Z_5 = 78.0\ \Omega$	$Z_{12} = Z_{45} = 56.9\ \Omega$
$Z_2 = Z_4 = 43.8\ \Omega$	$Z_{23} = Z_{34} = 60.4\ \Omega$
$Z_3 = 39.6\ \Omega$	

A two-pole directional filtering circuit (design procedure shown in [8]) operating at the WiLAN band with central frequency 5.4 GHz and 10 % bandwidth is coupled to the UWB filter. Slow-wave resonators [7] are used since its fundamental resonance f_{sw1} and first spurious f_{sw2} can be adjusted at specific frequencies. The resonators are designed as microstrip lines with folded capacitive patches at both ends, as stated in [7]. Frequency f_{sw1} is located at 5.4 GHz, and f_{sw2} outside the UWB region, producing no interference within the band of interest. Fig. 2 shows the frequency response and the geometry of the designed resonator.

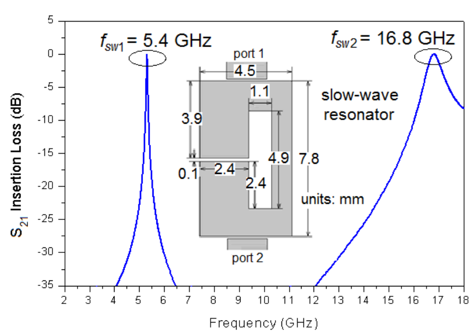

Fig. 2. Response and geometry of the slow-wave resonator.

Four resonators are coupled to the UWB structure, separated by 90° (at 5.4 GHz). At their upper end, the resonators are coupled to 50 Ω lines with separation of 270°, 90° and 270°, as shown in Fig. 1(b), to produce the directionality of the signal [8]. The coupling of the resonators is capacitive by means of interdigital fingers, so the resulting bandwidth is easily controlled; an increase in length of fingers generates stronger coupling, consequently, increasing bandwidth. The circuit is optimized by using [9].

Subsequently, the structure is mirrored with respect to its symmetrical plane in order to complete the balanced structure, as shown in Fig. 1(a). Two open stubs are connected at the center of the first and fifth stubs; they provide the capacity to widen the S_{21} bandstop response under common-mode operation (S_{c2c1}) [1], having no influence on the differential-mode due to the existence of an electric wall [Fig. 1(b)] [1], [5]. Fig. 3 shows the simulated S_{c2c1} response of the structure.

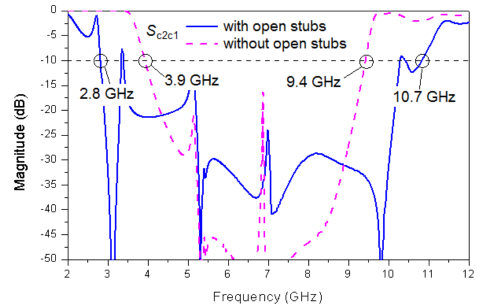

Fig. 3. Simulated common-mode S_{21} response (S_{c2c1}) of the balanced diplexer with and without open stubs.

From Fig. 3, it can be noticed the bandstop S_{c2c1} bandwidth increase, due to the addition of the open stubs, covering the UWB region. The final diplexer geometry is shown in Fig. 4.

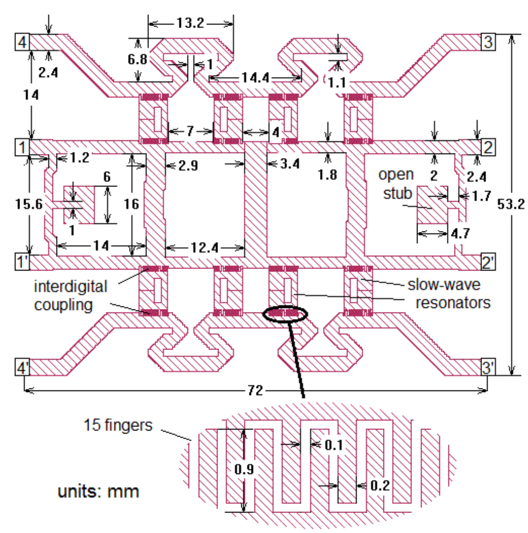

Fig. 4. Geometry of the balanced diplexer.

III. EXPERIMENTAL RESULTS

The implemented structure is shown in Fig. 5.

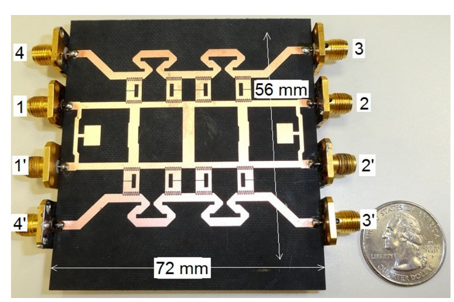

Fig. 5. Implemented balanced diplexer.

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In order to obtain the diplexer response over a wide-band region, the symmetrical nature of the structure is used to perform the differential/common-mode analysis from the measured S_{ij} parameters with a two-port VNA, being i and j = 1 to 4, and 1' to 4'. Based on [10], S_{11}, S_{21}, S_{31} and S_{41} for differential and common mode analysis, can be defined as:

$$\begin{bmatrix} S_{d1d1} \\ S_{d2d1} \\ S_{d3d1} \\ S_{d4d1} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} S_{11} - S_{11'} - S_{1'1} + S_{1'1'} \\ S_{21} - S_{21'} - S_{2'1} + S_{2'1'} \\ S_{31} - S_{31'} - S_{3'1} + S_{3'1'} \\ S_{41} - S_{41'} - S_{4'1} + S_{4'1'} \end{bmatrix}, \quad (1)$$

$$\begin{bmatrix} S_{c1d1} \\ S_{c2d1} \\ S_{c3d1} \\ S_{c4d1} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} S_{11} - S_{11'} + S_{1'1} - S_{1'1'} \\ S_{21} - S_{21'} + S_{2'1} - S_{2'1'} \\ S_{31} - S_{31'} + S_{3'1} - S_{3'1'} \\ S_{41} - S_{41'} + S_{4'1} - S_{4'1'} \end{bmatrix}, \quad (2)$$

$$\begin{bmatrix} S_{d1c1} \\ S_{d2c1} \\ S_{d3c1} \\ S_{d4c1} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} S_{11} + S_{11'} - S_{1'1} - S_{1'1'} \\ S_{21} + S_{21'} - S_{2'1} - S_{2'1'} \\ S_{31} + S_{31'} - S_{3'1} - S_{3'1'} \\ S_{41} + S_{41'} - S_{4'1} - S_{4'1'} \end{bmatrix}, \quad (3)$$

$$\begin{bmatrix} S_{c1c1} \\ S_{c2c1} \\ S_{c3c1} \\ S_{c4c1} \end{bmatrix} = \frac{1}{2} \begin{bmatrix} S_{11} + S_{11'} + S_{1'1} + S_{1'1'} \\ S_{21} + S_{21'} + S_{2'1} + S_{2'1'} \\ S_{31} + S_{31'} + S_{3'1} + S_{3'1'} \\ S_{41} + S_{41'} + S_{4'1} + S_{4'1'} \end{bmatrix}, \quad (4)$$

where the subscripts "*d*" and "*c*" express differential and common-mode, respectively. For (2) and (3), where differential and common mode excitations are combined, no signal is generated at all. Due to the symmetry of the structure $S_{ab} = S_{a'b'}$ and $S_{ab'} = S_{a'b}$ (being a, b = 1 to 4); then, from (2), $S_{c2d1} = S_{21} - S_{21'} + S_{21'} - S_{21} = 0$, and the same applies for the rest of (2) and (3). This is important to notice because it demonstrates that no interference is produced between differential and common modes at different ports at the same time. Fig. 6 shows the measured response of the diplexer.

From Fig. 6, it can be noticed that simulated and measured responses are in good agreement. Maximum S_{d2d1} losses are 1.6 dB along the UWB.

S_{d4d1} shows the WiLAN band with 1.3 dB losses at center frequency 5.48 GHz and 7 % bandwidth. Good selectivity is achieved due to transmission zeros at both sides of the band. These are generated due to standing waves outside the operating band produced by the frequency sensitive lines between the resonators [8]. The measured WiLAN central frequency shifted 80 MHz upwards. S_{d1d1} and S_{d3d1} are below -10 dB for the whole band of interest. Measured S_{c2c1} is below -10 dB from 2.8 GHz to 10.4 GHz with a small peak at 3.4 GHz. Differences between simulated and measured responses are thought to be due to manufacturing tolerances and the inclusion of SMA connectors in the measurements.

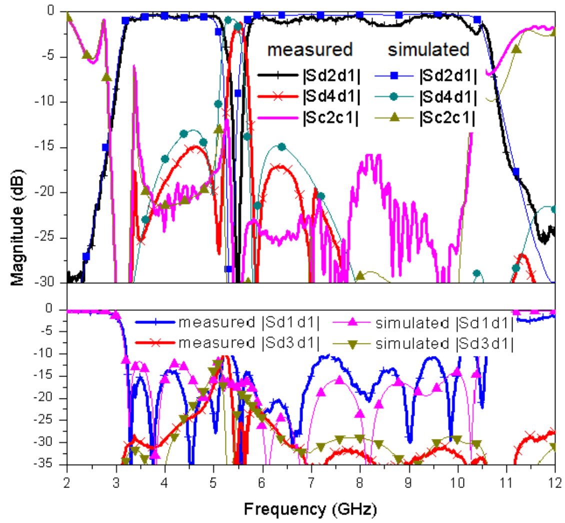

Fig. 6. Frequency response of the balanced diplexer.

VII. Conclusions

A new balanced diplexer for UWB and WiLAN bands has been presented. The proposed structure generates a good differential performance with good common-mode rejection at the bands of operation. Simulated and measured responses are in good agreement.

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