Appl Phys A (2011) 103: 911–914
DOI 10.1007/s00339-011-6253-z

**Applied Physics A**
**Materials Science & Processing**

# Dual-band microwave duplexer based on spiral resonators (SR) and complementary split ring resonators (CSRR)

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Received: 30 March 2010 / Accepted: 3 December 2010 / Published online: 20 January 2011

**Abstract** In this work, a microstrip dual-band microwave duplexer implemented by means of a pair of dual-band branch-line hybrid couplers and a pair of dual-band band-stop filters is presented. The hybrid couplers are implemented by using complementary split ring resonators (CSRRs), etched in the ground plane, while the band-stop filters are made of spiral resonators (SRs) coupled to the host line. The measured duplexer characteristics are good and the device is compact by virtue of the small electrical size of the employed resonant elements. From this paper, it is clear that CSRRs and SRs are useful particles for the design of dual-band microwave systems requiring various microwave components.

## 1 Introduction

Complementary split ring resonators (CSRRs) are electrically small particles that have been used for the design of metamaterials and metamaterial-inspired microwave components [1]. For instance, CSRRs have been used for the design of compact filters [1–8] and diplexers [9]. Combined with series gaps in microstrip technology, CSRRs can be applied to the synthesis of artificial lines exhibiting backward (or left handed) wave propagation at low frequencies and forward (or right handed) wave propagation at high frequencies [10], and these composite right/left handed (CRLH) lines have been demonstrated to be useful for the design of dual-band microwave components with arbitrary (within certain margins) operating frequencies. Specifically, CSRR-based CRLH lines have been recently applied to the synthesis of dual-band power splitters [11] and hybrid couplers [12] by the authors. In these implementations, the required characteristic impedance and electrical length of the different transmission line sections of the structures at the two system frequencies are achieved thanks to the controllability of the line impedance and the dispersion diagram of these CSRR-based lines.

In the present paper, the main aim is to demonstrate that a complex dual-band system consisting on a combination of several microwave components, implemented by means of CSRR-based and SR-based lines, can be achieved. Specifically, we will consider the design of a dual-band microwave duplexer for operation at the mobile GSM bands (GSM-850, DCS-1800). The main merit of the paper is thus to ensemble different dual-band components for the realization of a dual-band system (a microwave duplexer), rather than analyzing and provide the specific design procedure of each of its parts (this has been done in the references highlighted across this paper). Due to the miniaturization inherent to the use of metamaterial-based lines and components, the reported device is also very compact as compared to the conventional (mono-band) counterpart.

## 2 Duplexer schematic, principle and design

The schematic diagram of the dual-band duplexer to be designed is sketched in Fig. 1 (the duplexer principle for mono-band operation was reported in [13]). The port 1 of hybrid A is the transmitter (TX) port, whereas ports 2 and 3 of the hybrid B are the receiver (RX) and antenna ports, respectively. For dual-band operation, the hybrids and the band-stop filters must be designed to operate at the desired frequency

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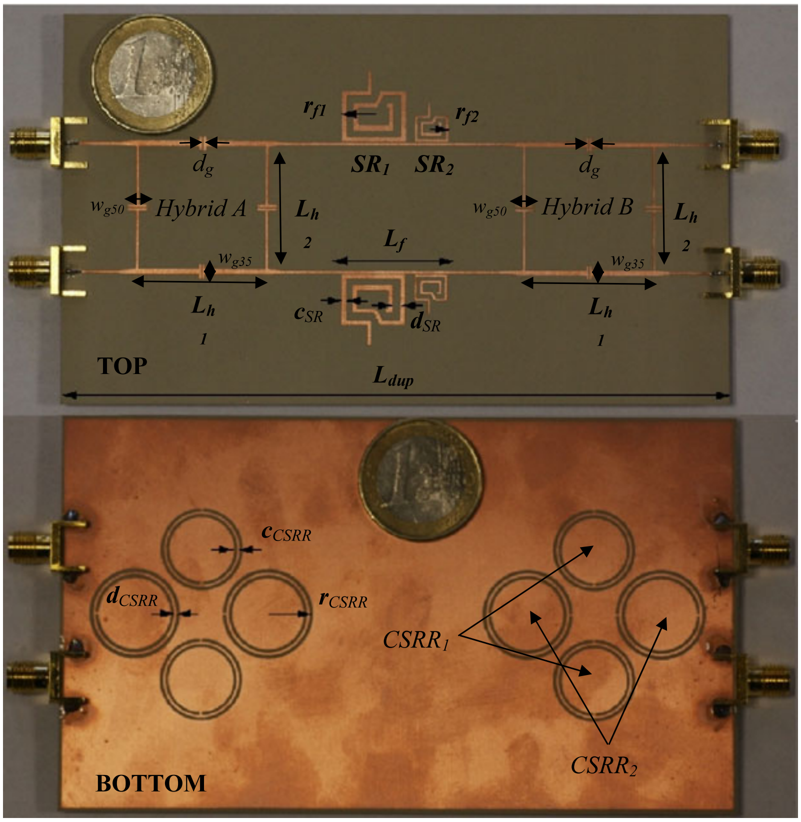
**Fig. 2** Photograph of the fabricated duplexer. Dimensions are: $L_{\mathrm{dup}} = 124$ mm, $L_f = 21.44$ mm, $r_{\mathrm{CSRR1}} = 7.4$ mm, $r_{\mathrm{CSRR2}} = 7.9$ mm (external radius of the CSRR), $c_{\mathrm{CSRR1}} = c_{\mathrm{CSRR2}} = 0.5$ mm (width of the rings), $d_{\mathrm{CSRR1}} = d_{\mathrm{CSRR2}} = 0.5$ mm (distance between rings), $r_{f1} = 6$ mm, $r_{f2} = 3$ mm, $c_{\mathrm{SR1}} = 0.9$ mm, $c_{\mathrm{SR2}} = 0.5$ mm (width of the spirals), $d_{\mathrm{SR1}} = 1.1$ mm, $d_{\mathrm{SR2}} = 0.6$ mm (distance between loops of the spiral). The gap separation is $d_g = 0.27$ mm and gap widths are $w_{35} = 2.77$ mm and $w_{50} = 3.77$ mm. Length $(L_{h1}, L_{h2})$ of the artificial lines constituting the hybrids are 18 mm and 17.6 mm for the 35 Ω impedance and 50 Ω impedance lines, respectively. The considered substrate is the *Rogers* RO3010 substrate with dielectric constant $\varepsilon_r = 11.2$ and thickness $h = 635$ µm



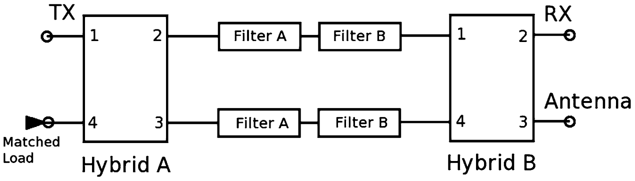


**Fig. 1** Schematic diagram of the dual-band diplexer

bands. Indeed, the hybrids must cover both the transmit and receiver frequencies at both bands, whereas the band-stop filters must be designed to efficiently reject the RX signal and transmit the TX signal for both GSM bands. Filters A and B have been designed to provide the central rejection frequencies at 0.89 GHz and 1.73 GHz, respectively, that is the receiver signal frequencies. Transmitter frequencies are centered at 0.83 GHz for the lower band, and at 1.80 GHz for the upper band.

From the scattering matrix of the quadrature hybrid coupler (assuming that the pairs of isolated ports are ports 1–4 and 2–3), and considering that ports 1 and 4 of hybrid B are terminated by loads with identical reflection coefficient (the reflection coefficients of the two bandstop filters, $\Gamma$), it follows that the transmission from the antenna port to the receiver port is given by:

$$S_{\mathrm{antenna}\text{–}RX} = j\Gamma. \tag{1}$$

From (1), it is clear that if $|\Gamma| = 1$, the received signal at the antenna will be transmitted to the RX port without any loss. This requires band-stop filters with high rejection and very low loss in the reflected signals at the two receiver band frequencies.

From the analysis of the scattering matrix of the hybrids, and assuming that the filters only provide a certain phase shift at the transmit frequencies (which will be different for each frequency band), it follows that the power transmitted from the TX port to the RX port is null (isolated ports), whereas the injected power in the TX port is totally transmitted to the antenna port according to:

$$S_{\mathrm{TX\text{–}antenna}} = e^{-j(\theta_{1,2} - \pi/2)}. \tag{2}$$

It is clear that the signals at the antenna and TX ports are identical except by certain phase shift, which depends on the phase shift introduced by the filters at the transmit frequencies of the two operating bands, $\theta_1$ and $\theta_2$.

The design of the dual-band branch-line hybrid coupler has been done following the design procedure described in [12]. The dual-band band-stop filters have been implemented by means of SRs coupled to the microstrip line connecting both hybrid couplers. To achieve dual-band operation, a pair of SRs has been designed to provide rejection at the reception frequency of the lower band, whereas a second pair has been tuned at the reception frequency of the up-

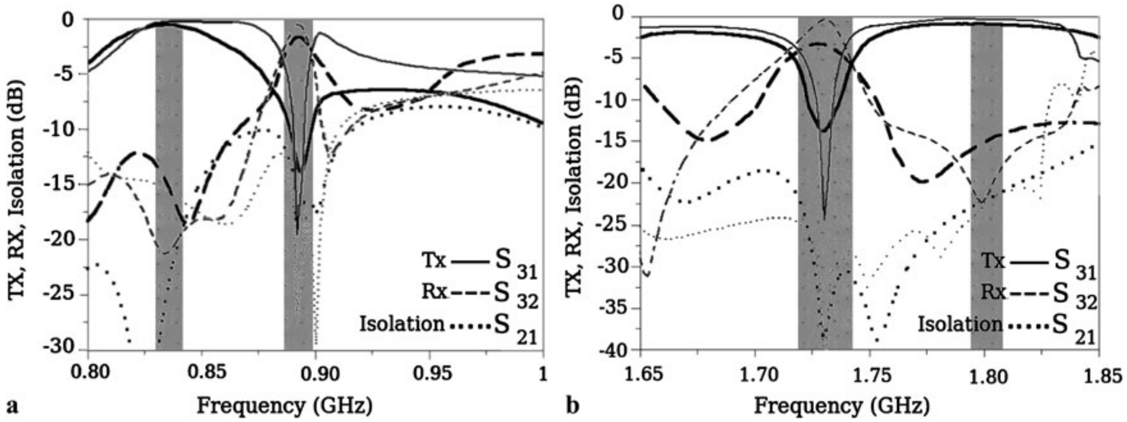


**Fig. 3** Comparison between simulated (*thin line*) and measured (*thick line*) transmission characteristics for the fabricated duplexer at the lower (**a**) and upper (**b**) GSM bands

per band. The rejection filters could have been implemented by coupling other resonators to the line, but spirals provide small size and narrow band, as is required in this application (due to the proximity of the transmit frequencies). A photograph of the fabricated duplexer, including the dual-band hybrid couplers, the filters and the access lines, is depicted in Fig. 2.

## 3 Results

The simulated (using the *Agilent Momentum* commercial software) and measured (by means of the *Agilent E8364B* vector network analyzer) transmission coefficients between the different ports of the duplexer are depicted in Fig. 3. As it can be seen, the simulated and experimental data are in good agreement, laying the receiver and transmitter frequencies within the desired GSM frequency bands. Concerning dimensions, the side length of the hybrids is as small as $\lambda/7$, $\lambda$ being the guided wavelength at the lower frequency band (which is the limiting one in terms of size). This is substantially smaller than the $\lambda/4$ side length of conventional mono-band hybrid couplers. Thanks to the small size of the hybrids, plus the miniature spirals used as rejection filters, the overall dimensions of the proposed prototype dual-band duplexer are small.

## 4 Conclusion

In conclusion, it has been demonstrated that CSRR and SR-based artificial lines can be useful for the design of dual-band complex systems with compact dimensions. As a proof-of-concept, a dual-band microwave duplexer has been designed, fabricated and characterized. Measured duplexer performance has been found to be good and device dimensions are much smaller than those of the conventional mono-band duplexers. This has been achieved thanks to the electrically small size of the CSRR-based artificial lines of the hybrids as well as to the small size of the SR-based stop-band filters.

**Acknowledgement** This work has been supported by MEC (Spain) by project contract TEC2007-68013-C02-02 METAINNOVA. Thanks are also given to *Generalitat de Catalunya*) for funding CIMITEC and GEMMA (project 2009SGR-421). The authors are in debt with MCI for giving us the CONSOLIDER INGENIO 2010 project EMET CSD2008-00066 F. Martín acknowledges the ICREA Foundation (*Generalitat de Catalunya* and *Fundació Catalana per a la Recerca i la Innovació*) and VPE-Parc de Recerca (UAB) for supporting his work.

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