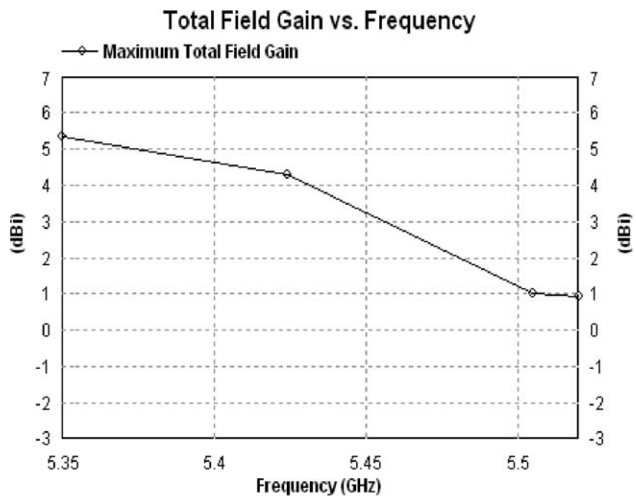

Figure 11 Proposed antenna gain at second band

is of size 40 mm × 40 mm made on FR4 substrate of thickness 3.2 mm and dielectric constant of 4.2.

The photograph of the fabricated antenna is shown in Figure 3.

The feed is coaxial, and the diameter of the inner conductor of coaxial cable is 0.6 mm. The feed is at point (12, 28), which is shown as circle on patch.

3. RESULTS AND DISCUSSION

The "Dual-Band Square Piece Patch Antenna" is simulated using software tool called IE3D (Ver. 12.0), which works with methods of moments numerical technique to simply electromagnetic waves. Figures 4 and 5 show the return loss at two frequency bands. In both the bands, antenna is having −40 dB return loss, which is more advantageous of this antenna. The simulated and measured radiation characteristics of *E*-plane and *H*-plane polarizations of band I and band II are shown in Figures 6–9.

In the first band the antenna has 5 dBi gain, and in the second its gain is around 3.5 dBi, which are shown in Figures 10 and 11. The bandwidth of antenna in two bands is 40 MHz and 200 MHz, respectively. After seeing all things, it is noticed that by changing the shape of antenna in Figure 1 into that in Figure 3 a dual band arises, and with this we can say that patch antenna is very sensitive towards its patch shape.

4. CONCLUSIONS

In this article, the analysis and design of compact dual-band square microstrip patch antenna for bandwidth improvement and antenna size reduction in a single design is proposed. The fundamental parameters of the antenna such as bandwidth, return loss, gain, radiation pattern, and polarization are obtained. The shape of ordinary patch antenna is changed and made to resonate at two different frequencies. The antenna can be used in applications like Wireless Communications, potentially a spectrum of choice for AWS spectrum holders (legacy service providers), IEEE 802.16-2004. Thus the sensitivity of patch antenna towards its patch shape is discussed.

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KU-BAND SiGe HBT I/Q SUBHARMONIC MIXER WITH REACTIVE QUADRATURE GENERATORS

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ABSTRACT: *This article demonstrates a high-frequency 0.35-μm SiGe HBT subharmonic downconverter with reactive in-phase and quadrature-phase (I/Q) generators. Two reactive I/Q generators are integrated in our work to provide differential quadrature RF and LO signal. The I/Q subharmonic downconverter with single-ended LO, RF, and IF (I/Q) ports has a conversion gain of 1 dB, IP_{1dB} of −10 dBm, IIP_3 of 0 dBm, and IIP_2 of 21 dBm at 16.4 GHz. The magnitude and phase errors between the I and Q channels are 1.34% and 0.6°, respectively. The dc power consumption of this I/Q mixer without output buffers is approximately 5 mW.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1516–1520, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25281

Key words: *direct conversion; I/Q; SiGe HBT; subharmonic; transformer*

1. INTRODUCTION

For the high-integration and reduction of external components, the direct-conversion transceiver architecture is popularly employed nowadays. The direct-conversion is free of image

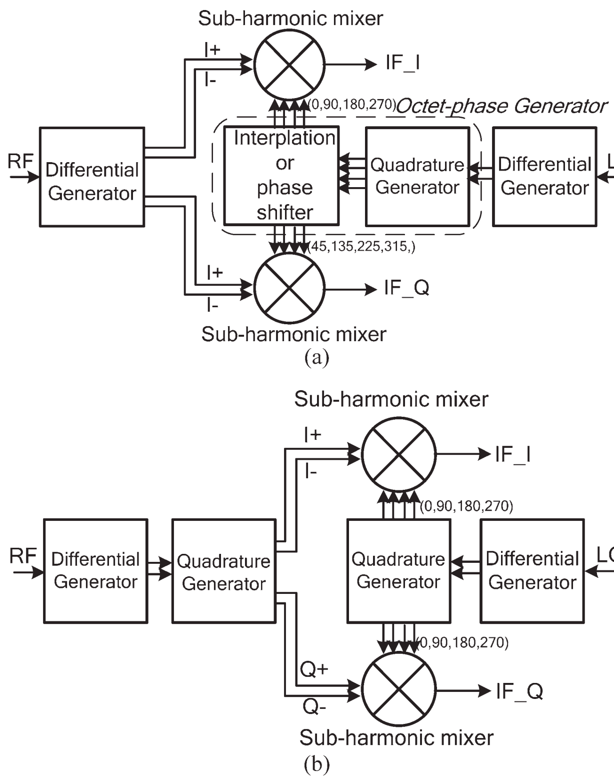

Figure 1 I/Q direct-conversion architectures of (a) the subharmonic mixers with an octet-phase generator and (b) the subharmonic mixers with two quadrature generators

interference. However, the issues about dc offset, self-mixing, and I/Q mismatch appear [1]. A subharmonic mixer is an excellent solution for dc offset and self-mixing problems, because the LO frequency operates at the half of the RF frequency. Three types of active subharmonic mixers—the one-level top-LO-configuration, the one-level bottom-LO-configuration, and the two-level stacked-LO structure—have been proposed [2–5]. The bottom-LO-configuration subharmonic mixer has low-current consumption with low-voltage supply and is utilized in this article.

Because of the requirements of the accurate phase and equal magnitude for quadrature signals, the I/Q subharmonic mixer is not easily realized, especially at the high-frequency realm. There are two system architectures of the I/Q subharmonic mixer. The first architecture consists of two subharmonic mixers and one octet-phase LO generator, as shown in Figure 1(a). The octet-phase LO generator is formed by one polyphase filter with a 45° phase shifter or interpolation circuits [3–8]. This architecture relies on an accurate 45° phase shifter, and the 1° phase error of LO signals can result in a 2° phase error at I- and Q-channel outputs, because of the second-order harmonic mixing operation. In addition, an auxiliary amplifier with extra dc power consumption is needed to compensate for the amplitude error caused by the phase shifter.

The second architecture, as shown in Figure 1(b), is composed of two subharmonic mixers, RF and LO quadrature generators. Without active interpolation circuits or phase shifters, the second architecture is more easily designed and consumes less power than the first one does. Quadrature IF outputs rely on truly quadrature RF inputs in this architecture, but a polyphase filter commonly used as a quadrature phase generator is not suitable at high-frequency regimes, because of its parasitics and the resistor self-cutoff frequency [9].

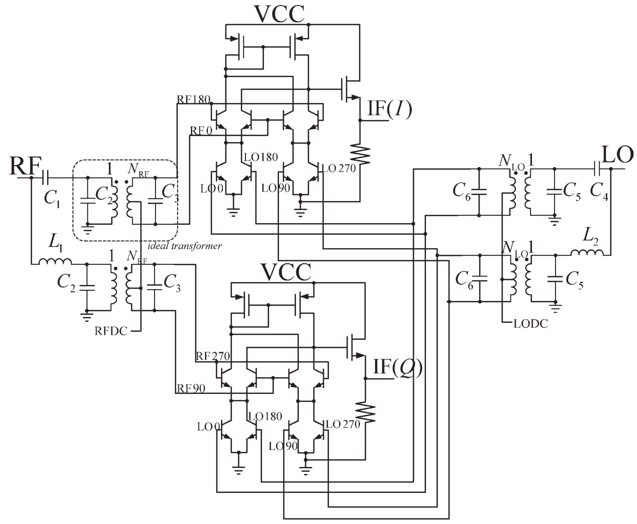

Figure 2 The complete schematic of a single-ended subharmonic I/Q downconversion mixer with RF and LO transformer-type I/Q generators

On the contrary, reactive elements, such as inductors and transformers, can be fabricated with great accuracy in today's mature submicron silicon IC technology. Truly differential signals are essential for generating those truly differential quadrature signals needed by the subharmonic mixers. It is difficult to provide truly differential signals through external baluns, on account of the phase and magnitude errors caused by the mismatches in the baluns and connecting cables. Thus, it is desirable at the high-frequency regime to have a subharmonic mixer with single-ended RF and LO inputs by integrating transformers into the I/Q generator as signal-to-differential baluns, to eliminate those phase errors resulting from external components.

In this article, a new reactive single-ended differential quadrature generator without resistors is introduced to take the place of the polyphase filter for the I/Q subharmonic mixer, based on the second system architecture. A single-ended subharmonic downconverter, with reactive I/Q generators, is implemented using the 0.35-μm SiGe BiCMOS technology. This 16.4-GHz I/Q subharmonic mixer has a 1-dB conversion gain with two good IF quadrature outputs.

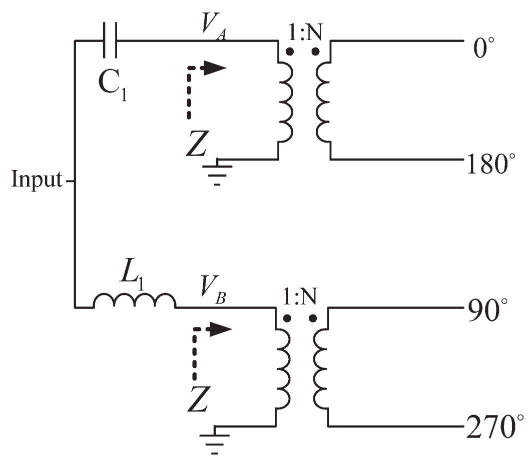

Figure 3 The schematics of the transformer-type reactive I/Q generators

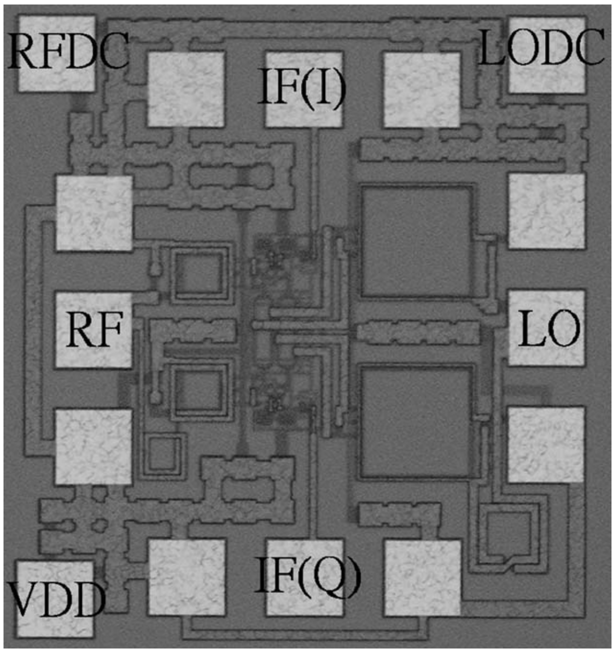

Figure 4 Die photo of the single-ended subharmonic I/Q downconversion mixer

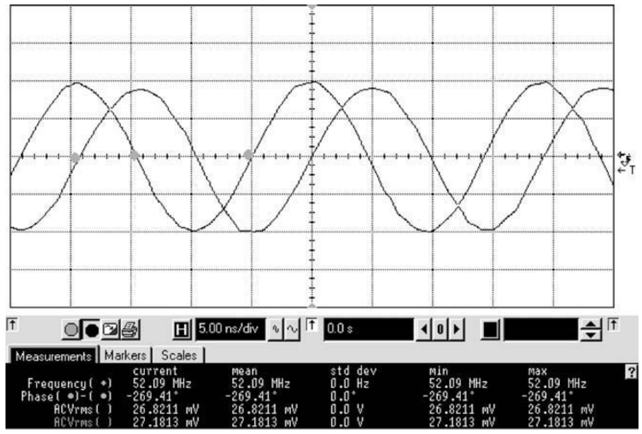

Figure 6 Output waveforms of I and Q channels of the subharmonic I/Q downconverter

2. CIRCUIT DESIGN

Figure 2 demonstrates that the transformer-type reactive I/Q generator is employed in the RF and LO stages of the I/Q subharmonic mixer. The mixer core is a one-level active subharmonic mixer. The LO emitter-coupled pairs, under the RF input stage, have collectors tightening together and are fed with a differential sinusoidal signal. Then these emitter-coupled pairs cannot only effectively double the LO frequency, but can also eliminate the fundamental tone to perform the second harmonic mixing.

A polyphase filter is a traditional I/Q generator and is composed of an R-C section. Nevertheless, the polyphase filter is not appropriate for high-frequency applications because parasitics and resistor self-cutoff frequency deteriorate the phase accuracy. Besides, the polyphase filter demands differential inputs. The single-ended transformer-type I/Q generators are used at the RF and LO stages in this article to replace the polyphase filter, as shown in Figure 3. This new reactive I/Q generator is made of a passive inductor, capacitor, and transformer only, without any resistor. Thus, this reactive I/Q generator can operate at higher frequencies, and does not introduce loss and noise in comparison with a polyphase filter I/Q generator. The key point of this design principle is that an inductor advances in phase, whereas a capacitor delays it [10]. The reactions on the phase result in a 90° phase difference. This circuit with $\omega L_1 = (\omega C_1)^{-1} = Z$ can generate truly balanced and differential quadrature signals. Moreover, the input impedance of this generator can be written as $Z_{\text{in}} = (Z + jZ)//(Z - jZ) = Z$.

Two identical transformers are used in the I/Q generator not only to generate differential signals but also to perform impedance transformation. With respect to a polyphase filter, there are four advantages of these reactive I/Q generators.

1. This generator has a low-loss because of the absence of resistors and is suitable for high-frequency applications.
2. This generator has a single-ended input, whereas a polyphase filter needs differential inputs.
3. The transformer in I/Q generators can block the dc between the previous stage and the mixer core. The dc biases of the following circuit can be fed from the center tap of the symmetric transformer.
4. The transformer can perform impedance transformation so that the generator can easily achieve good matching.

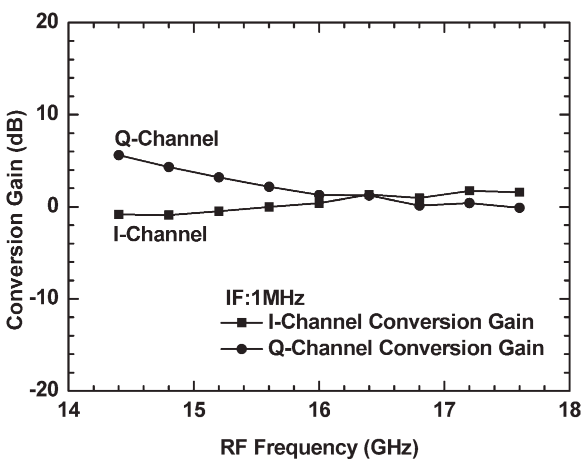

Figure 5 Conversion gain of I and Q channels of the subharmonic I/Q downconverter

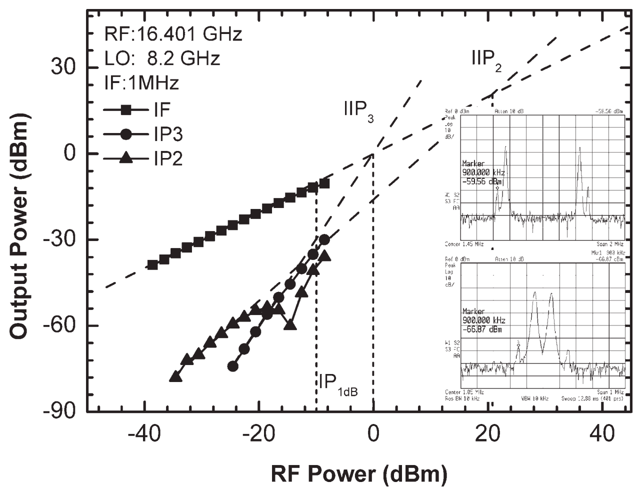

Figure 7 P_{1dB}, IP_2, and IP_3 of the subharmonic I/Q downconverter

TABLE 1 Comparison of Reported I/Q Downconverters

Literature	RF Freq. GHz	Quadrature/Octet-phase Generator	Magnitude Imbalance dB	Phase Error Degree	Power Consumption mW	Die Size mm^2	Technology
Zhang et al. [3]	0.93	4-stage differential ring oscillator	<0.3	<5	52.76	0.78	0.35 μm CMOS
Svitek and Raman [4]	5 ~ 6	Tunable polyphase filter with compensated amplifiers	N.A.	~0	33	4.14	0.5 μm SiGe HBT
Sheng et al. [6]	1 ~ 2	Polyphase filter with wide-band 45° phase shifter	N.R.	<3.5	18.48	N.A.	0.5 μm SiGe HBT
Koh et al. [7]	2	Polyphase filter with interpolation amplifiers	0.24 (2.8%)	<2	24.12	1.54	0.18 μm CMOS
Yamaji et al. [8]	1.9	45° phase shifter using RC-bridge circuits	<0.1	<3	183.6	7.13	BiCMOS
This Work	16.4	Reactive I/Q generator	0.12 (1.34%)	<1	31.75 (w/o buffers:5)	0.624	0.35 μm SiGe BiCMOS

The biases of RF and LO transistors are fed from the center tap of the transformers. The capacitors C_2, C_3, C_5, and C_6 are employed to compensate for the leakage inductance of transformers to make transformers ideal [11]. The PMOS current mirror converts different current signals into a single one, whereas the output buffer, a source follower, is used to drive the 50 Ω measurement system.

Measurement Results: A high-frequency I/Q single-ended subharmonic down conversion mixer is fabricated using the 0.35-μm SiGe BiCMOS process. Figure 4 displays the implemented die photo. The chip size is 0.73 mm × 0.8 mm, whereas the RF I/Q generator occupies the domain of 0.15 mm × 0.35 mm and the LO counterpart takes up an area of 0.2 mm × 0.5 mm. This I/Q mixer operate at 16.4 GHz with a low-voltage supply of 2.5 V. The total current consumption, including two mixers and their output buffers, is about 12.36 mA and the power consumption is 30.9 mW. The core power consumption is 5 mW. Under the condition of −1 dBm LO power, this mixer has the conversion gain of about 1 dB. The return loss of the RF and LO ports is about −10 dB.

The conversion gain is dependent on the RF input frequency, as shown in Figure 5. At lower frequencies, the inductive path of the RF I/Q generator obtain more power than the capacitive path does. Therefore, the Q-channel conversion gain is higher. At higher frequencies, on the contrary, the I-channel down converter has a higher conversion gain. The matched point occurs at 16.4 GHz when $\omega L_1 = 1/\omega C_1 = Z$.

Figure 6 shows the output waveforms of two channels with an LO frequency of 8.2 GHz. The −269.41° phase difference shows the excellent orthogonal property of the two outputs. The rms magnitude error is about 1.34%. These LO and RF reactive I/Q generators work well and provide truly differential quadrature signals. The noise figure is ~26 dB because of the high-frequency operation.

Both core circuits of the I- and Q-channel mixers are identical. The 1-dB gain compression point, P_{1dB}, the second-order intercept point, IP_2 and the third-order intercept point, IP_3, of this subharmonic mixer are depicted in Figure 7. The input frequency is 16.401 GHz. The IP_{1dB} is −10 dBm as the IIP_3 is 0 dBm. Thanks to the balanced subharmonic structure of the mixer, IIP_2 is high at 21 dBm.

The port-to-port isolations of the single-ended subharmonic I/Q downconverter are also measured. The RF-to-IF(I/Q) isolation is below −30 dB, whereas the RF-to-LO isolation is ~−44 dB. The 2 × LO-to-RF isolation is especially high at ~−54 dB because of the subharmonic mixing.

Table 1 describes the comparisons between the reported I/Q downconverters and our work. Thanks to the benefit of the reactive I/Q generator, our I/Q subharmonic mixer operates at the highest frequency with the low-power consumption. The magnitude imbalance and phase error are very small.

3. CONCLUSION

A single-ended high-frequency I/Q subharmonic downconverter is realized in the 0.35-μm SiGe BiCMOS technology. In our work, two transformer-type reactive generators are employed at RF and LO input stages to provide I/Q differential RF and LO signals, respectively. These I/Q generators free of resistive loss can function at high-frequencies. The mixer core is a one-level subharmonic mixer, to eliminate dc offset and self-mixing problems in a direct-conversion receiver. At a 2.5 V supply voltage, this I/Q subharmonic downconverter with single-ended inputs and outputs functions with 16.4-GHz RF and 8.2-GHz LO. The mixer has 1-dB conversion gain, −10-dBm IP_{1dB}, 0-dBm IIP_3, and 21-dBm IIP_2. The magnitude imbalance and phase error between I and Q channels are 1.34% and 0.6°, respectively. This mixer has high port-to-port isolations as well.

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OPEN COMPLEMENTARY SPLIT RING RESONATORS: PHYSICS, MODELLING, AND ANALYSIS

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ABSTRACT: *This article is focused on the physics and analysis of a new type of planar resonant particles: the open complementary split ring resonators (OCSRRs). These resonators are the complementary counterpart of the open split ring resonators (OSRRs), previously presented by some of the authors, and consist on a pair of concentric hooks etched on a metal layer in opposite orientation. Like OSRRs, OCSRRs are open resonators that can be excited by means of a voltage or current source. An accurate circuit model of the particle is proposed and experimentally validated by exciting the particle by means of a coplanar waveguide transmission line. It will be also shown that OCSRRs exhibit higher order resonance frequencies, which can be selectively suppressed by introducing additional elements, as derived from a simple analysis based on mode parity. Because of the small electrical size of OCSRRs, such particles are useful for the synthesis of planar metamaterials and microwave components.* © 2010 Wiley Periodicals, Inc. Microwave Opt Technol Lett 52: 1520–1526, 2010; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.25282

Key words: *metamaterials; split-ring resonator; complementary split-ring resonator; duality*

1. INTRODUCTION

As the proposal of the split ring resonator (SRR) [Fig. 1(a)] as an electrically small nonmagnetic resonant particle useful for the synthesis of negative permeability media [1], and the subsequent application of this particle to the implementation of the first artificial material exhibiting left-handed wave propagation [2], there has been an intensive research activity in the field of metamaterials. Several, recently published textbooks have dealt with this hot topic [3–8]. Metamaterials are artificial structures composed with small size inclusions (or ''atoms'') based on combinations of metals and dielectrics. As long as the unit cell of these structures is made small as compared with the guided wavelength, effective (or continuous) media properties arise, and their electromagnetic (or optical) behavior depend on how these unit cells are structured, rather than on their composition. Thanks to these characteristics, unusual properties can be achieved, including left-handed wave propagation, super-resolution, negative refractive index, or cloaking, among others.

There are several approaches for the synthesis of metamaterials. One of these approaches is based on the use of resonant particles like the SRR, or other electrically small resonators (spiral resonators [9–11], broad-side coupled SRRs [12], chiral resonators [13], or other resonant structures with more complex topology [14]). These resonant elements have been used for the synthesis of bulk 1D, 2D, and 3D metamaterials, and also for the synthesis of planar metamaterial structures, such as frequency selective surfaces [15] or metamaterial transmission lines [16]. In 2004, it was presented the complementary split ring resonator (CSRR) [17], which has been demonstrated to be a very interesting particle for the implementation of composite right/left-handed transmission lines in microstrip technology. The CSRR is the complementary counterpart of the SRR, and hence it consists on a pair of slot rings with apertures in opposite orientation, etched on a metallic screen [Fig. 1(b)]. The CSRR can be excited by means of an axial time varying electric field, and, etched in the ground plane of a microstrip line, it provides a negative effective permittivity to the structure, as has been previously discussed [17, 18] (other topologies inspired on the CSRR topology have also been used for the synthesis of one-dimensional negative permeability media [19]).

In Figure 1 are also depicted the equivalent circuit models of these resonant particles (the SRR and the CSRR) [20]. The SRR is a closed resonant tank, where the inductance L_s is the inductance of a ring of average radius and identical width as the individual rings forming the particle, and the capacitance is $C_s = C_o/4$, C_o being the distributed (edge) capacitance between the two concentric rings. Namely, the capacitance is given by the series connection of the capacitances corresponding to the upper and lower halves of the particle [20, 21]. The CSRR has been also modeled as a closed resonator. The capacitance C_c is the capacitance of a disk of radius $r_o(c/2$ surrounded by a metallic plane at a distance c of its edge, and the inductance is the parallel combination of the two inductances connecting the inner disk to the ground, as reported in [20]. In the absence of a dielectric slab and for perfectly conducting and infinitely thin metallic layers, the SRR and the CSRR are strictly dual particles, their circuit parameters are related by $C_c = 4\ (\varepsilon_o/\mu_o)\ L_s$ and $C_o = 4\ (\varepsilon_o/\mu_o)\ L_o$, and their resonance frequencies are identical [20]. Under real conditions (presence of a dielectric substrate and metal layers with finite conductivity and thickness), some deviations from duality (mainly because of the presence of the substrate) are expected, and the resonance frequencies of SRRs and CSRRs with identical dimensions are very close, but not identical.

In 2004, it was also presented the open split ring resonator (OSRR) [22]. This is the open version of the SRR [see the topology of this particle and its equivalent circuit in Fig. 1(c)]. Thus, it is an open resonator, which can be modeled by means of a series LC circuit, where the inductance is identical to that of the SRR, and the capacitance is C_o, that is, the distributed (edge) capacitance between the two concentric rings along the whole circumference. According to this, it follows that for identical dimensions and substrate, the resonance frequency of the OSRR is half the resonance frequency of the SRR.