

Electronically tunable lumped element 90° hybrid coupler

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A method for tuning the centre frequency of a 3 dB hybrid coupler using varactor diodes is presented. The circuit is suitable for reconfigurable or multifunction transceivers that switch between several narrow frequency bands. A prototype covering the PCS, DCS and IMT2000 cellular bands (1710–2170 MHz) is demonstrated.

Introduction: With the increasing variety of commercial wireless applications, there is now a requirement to incorporate several transceivers into a single hardware device [1]. To achieve high integration and minimise costs, it is an advantage to design transceivers that can be reconfigured for different frequency bands or share common blocks, rather than implementing the transceivers separately. Electronically tunable circuits based on varactors can be used to realise frequency agile components suitable for reconfigurable designs. In this Letter, the varactor-based tuning technique is applied to a lumped element quadrature hybrid coupler suitable for RF integrated circuits (RFICs).

Varactors have previously been used to design tunable couplers based on parallel coupled microstrip lines. In [2], the coupling level of a directional coupler was adjusted between 4 and 20 dB by changing the junction capacitance of varactor diodes. More recently, an LC resonator was added to a microstrip coupler to allow tuning of the centre frequency of the device [3]. In this case, the coupling level remained constant. The concept of varactor tuning of the centre frequency can also be applied to the hybrid coupler.

Microstrip implementation: The quadrature hybrid coupler is a well known component with applications in many microwave systems. A common realisation of the quadrature hybrid employs microstrip transmission lines. Two 71 Ω series and two 50 Ω shunt transmission lines, all a quarter wavelength long at the centre frequency [4], form a 3 dB hybrid. Alternatively, series 50 Ω lines and shunt 35 Ω lines can be used. The ports lie at the intersections of the branch lines.

A single section branch-line hybrid designed using the above-mentioned approach has a relatively narrow bandwidth, typically 10% [5]. The bandwidth can be extended by adding further branch line sections [6]; however this complicates the circuit design and requires more layout space. It is therefore an advantage to be able to electronically tune the centre frequency of a single section branch-line hybrid over a wide frequency range. An electronically tunable single section hybrid may be useful in applications that require switching between multiple narrow bands, e.g. in a multiband cellular handset. The single section tunable hybrid can replace several fixed hybrids, leading to size and cost reductions.

Electronic tuning of the coupler frequency response can be achieved by placing a variable capacitance between the mid-points of each of the branch lines and a common central node. Changing the varactor capacitance modifies the electrical length of the series and shunt transmission lines, and therefore the frequency at which 3 dB coupling occurs. A tunable prototype using microstrip transmission lines has recently been demonstrated [7]. However, a limitation of the transmission line approach is the amount of space required, given that each of the branch line lengths is $\lambda_g/4$, where λ_g is the guided wavelength.

Lumped element implementation: For RFIC applications, a lumped element implementation of the 90° hybrid can reduce the footprint of the device by up to 80% [5], relative to the microstrip approach. We propose that by replacing the fixed capacitors in the conventional lumped element design with varactors, a frequency agile version can be realised.

A schematic of the tunable lumped element hybrid coupler is shown in Fig. 1. In this design, a pi-network consisting of two varactors and one inductor replaces each quarter-wave microstrip line. By changing the capacitance of the varactors C_1 and C_2 , a phase shift is introduced in each of the pi-networks. This phase shift modifies the frequency at which 3 dB coupling is achieved, while maintaining a consistent coupling level and return loss.

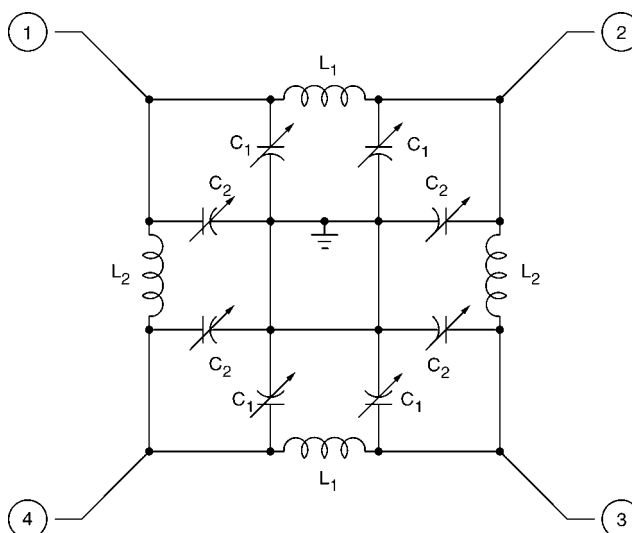


Fig. 1 Schematic diagram of lumped element tunable hybrid coupler, based on [5]

Results: To verify the design before proceeding to an RFIC implementation, a prototype was constructed using surface mount components. Chip inductors with $L_1 = 3.6$ nH and $L_2 = 5.1$ nH were chosen, using design equations in [5]. Skyworks SMV1231 varactors, with a tuning range of 0.5–2 pF, were used as the tuning elements. To simplify the biasing arrangement, the same bias voltage is applied to all varactors. Under this condition, $C_1 = C_2$. A DC tuning bias of 0–8 V was applied at port 1, and DC blocking capacitors were placed at the remaining ports. The substrate material was 0.5 mm Rogers 4003C.

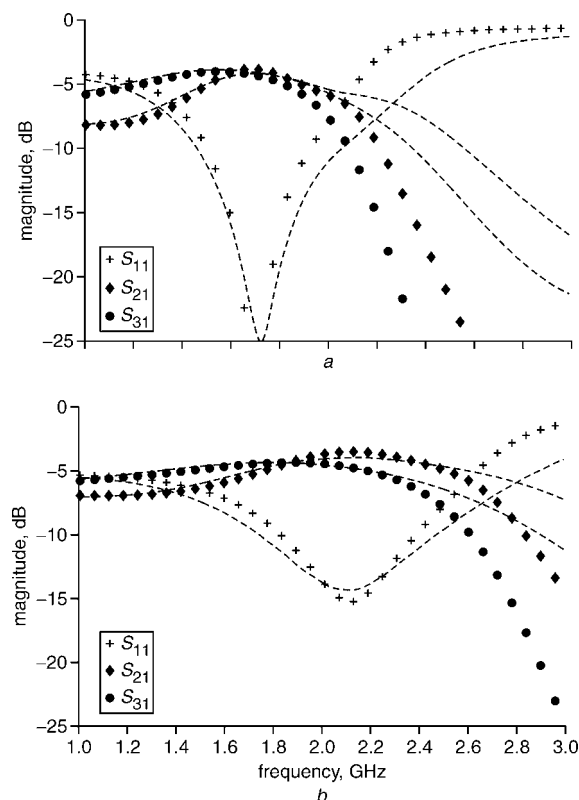


Fig. 2 Measured and simulated magnitude response of the hybrid at DCS uplink and IMT2000 downlink band

a At DCS uplink band

b At IMT2000 downlink band

Simulated and measured results presented as point series and dashed lines, respectively

The S-parameters of the tunable hybrid were simulated in ADS2004A and measured using an Agilent E5071B vector network analyser. Fig. 2a shows the simulated and measured magnitude response of the

hybrid when tuned to the DCS uplink band (1710–1785 MHz) by applying a 1.6 V DC bias at port 1. The coupling level is 4.3 ± 0.1 dB and return loss $S_{11} > 20$ dB across the band. Fig. 2b shows the simulated and measured results when tuned to the IMT2000 downlink band (2110–2170 MHz) by applying a 3.7 V bias. In this case, the coupling level is 4.4 ± 0.5 dB and return loss $S_{11} > 14$ dB across the band. The phase response of the hybrid is shown in Fig. 3. At the DCS uplink and IMT2000 downlink band, the phase offsets between the coupled ports are $92 \pm 3^\circ$ and $90 \pm 2^\circ$, respectively, across the band.

Reasonable agreement between the simulated and measured results is achieved. The discrepancy observed at higher frequencies is likely due to parasitic inductance associated with the solder joints and vias. A capacitance of 100 fF in parallel with the inductors was used to obtain the simulated results in Figs. 2 and 3. This capacitance has contributions from the inductor windings and from coupling between the two varactors in each pi-section. According to simulations, the 100 fF capacitance has a significant impact on the amplitude balance between the coupled ports. Lower parasitic capacitance in an RFIC design and separate values for C_1 and C_2 should lead to improved amplitude balance.

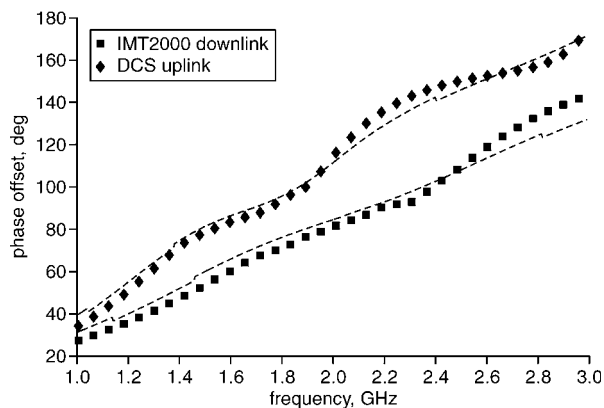


Fig. 3 Phase response of hybrid tuned to DCS uplink and IMT2000 downlink bands

Simulated and measured results presented as point series and dashed lines, respectively

Conclusions: An electronically tunable quadrature hybrid is proposed and has been demonstrated using lumped components. A prototype fabricated from surface mount components provided a tuning range of ~ 500 MHz with 4.4 ± 0.5 dB coupling level and return loss $S_{11} > 14$ dB, while maintaining $90 \pm 5^\circ$ phase quadrature between the coupled ports. The smaller footprint of the lumped element tunable hybrid relative to the microstrip design makes it suitable for RFIC implementation.

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