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Compact Quadrature Hybrid Coupler for MRI Coil

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Abstract

This paper proposes the design of a compact quadrature hybrid coupler at the 300 MHz operating frequency for the Magnetic resonance imaging Birdcage coil. The desired 300 MHz operation frequency of the quadrature hybrid coupler has a wavelength of 1 meter, and then the physical size of the designed quadrature hybrid coupler will be very large. Therefore, we propose the design of a compact quadrature hybrid coupler, applying symmetrical bends in the design and reducing its physical size, maintaining the design performance in the frequency of operation, the magnitude balance below ± 0.4 dB and the phase balance below ± 0.3° by applying a specific substrate with losses. The type of the compact quadrature hybrid coupler is Branch-line hybrid and it was manufactured in microstrip board with FR4 substrate. The measured phase shift between the output ports is 90° ± 0.15° at 300 MHz. The measured magnitude balance at the output ports is ± 0.22 dB at 300 MHz. Consequently, the measured magnitudes at the output ports are -3.22 dB and -3.44 dB. The measured isolation between the input port and the isolated port is 23.2 dB at 300 MHz.

Keywords: Branch-line hybrid coupler; Compact design; MRI coil; PCB; Quadrature hybrid coupler.

Introduction

The Birdcage coil is one of the components of the Magnetic Resonance Imaging System (MRI system). It functions as an antenna in the RF reception and RF transmission of the induced homogeneous magnetic field B1 that interacts with a sample to be imaged [1]. The Birdcage coil operates on particular operation frequency and using of MRI system in medical imaging is increased which leaded to development of MRI application to work on higher frequency, 300 MHz at 7 Tesla MRI system in order to improve accuracy of the MRI system and achieve a better image [2]. The MRI coil is driven by a quadrature hybrid coupler and this paper proposed compact quadrature hybrid coupler at the design frequency 300 MHz to boost MRI application.

From literatures, it has been previous work on developing of quadrature hybrid couplers for RF applications and much effort has been conducted to reduce physical size. The presented work in [3], a compact quadrature coupler based on coupled artificial transmission lines is proposed where it could reduce its physical size by designing inters digitized coupled lines. It could be seen the proposed design in was complex and its moderate performance was not suitable for MRI application. In the described work in [4], it is presented a design of tri-Band quadrature hybrid coupler for WiMAX applications. The design of three branch-line coupler was proposed for WiMAX applications and the design was non-compact.

In this paper we present a new design of compact branch line hybrid coupler that is simple to manufacture/fabricate and has better performance according to the magnitude balance and phase balance at the design frequency required for the accuracy of the MRI application. The paper remnant presents the design process of the compact Branch-line hybrid coupler, the layout design and the implementation on micro strip board-PCB. Then the simulations and measurements of the compact quadrature hybrid coupler are presented. Finally, conclusion of the paper is presented.

Proposed Design and Implementation

Quadrature hybrid couplers are four-port devices that split the incident power signal into two output ports. The signals at the outputs are attenuated by three decibels (3 dB) and have a 90 degree phase difference with respect to each other. In addition to splitting a signal they can also be used to combine power signals with a high degree of isolation between the ports [5]. Correspondingly, quadrature hybrid couplers acquire significant parameters at the design which are phase balance and magnitude balance. Magnitude balance is peak to peak magnitude difference at the output ports over design frequency while phase balance is peak to peak phase difference at the output ports. The compact quadrature hybrid coupler was designed as Branch-Line coupler in transmission line elements as shown in (Figure 1) and the transmission line elements in the design were chosen to be micro strip lines. The transmission lines was designed based on the principle of lambda quarter transformer ($\lambda/4$), which yields a perfect matching between ports. The length and width of each transmission line was dependent upon the operation frequency 300 MHz and they were calculated by the application, linecalc in Advanced Design System (ADS). The characteristic impedance of parallel transmission lines in a Branch-line hybrid coupler is the same. Simultaneously, the characteristic impedance of series transmission lines in the Branch-line hybrid coupler is the same. In this scenario, there are two characteristic impedances, 50 Ω and 35.35 Ω in the Branch-line hybrid coupler. As shown in Figure 1, there are four transmission lines TL11, TL12, T21, and TL22. The transmission lines TL11 and TL12 acquired the same characteristic impedance, 35.35 Ω. Similarly, the transmission lines TL21 and TL22 acquired the same characteristic impedance, 50 Ω. As previously mentioned, all of the transmission lines have the same length which is lambda quarter [5]. The transmission lines TL11 and TL12 in Figure 1 are designed to acquire the characteristic impedance, Za=35.35 Ω at 300 MHz. Simultaneously, the transmission lines TL21 and TL22 are designed to acquire the characteristic impedance, Zb=50 Ω at 300 MHz.

The transmission lines are designed as micro strip lines on PCB-FR4 substrate with a thickness of 1.5 mm and a loss tangent of 0.015 and a dielectric constant of 4.6. Electric length of all the transmission lines was 90° and the system normalized impedance was 50 Ω. The calculated length and width of the based design are presented in (Table 1).

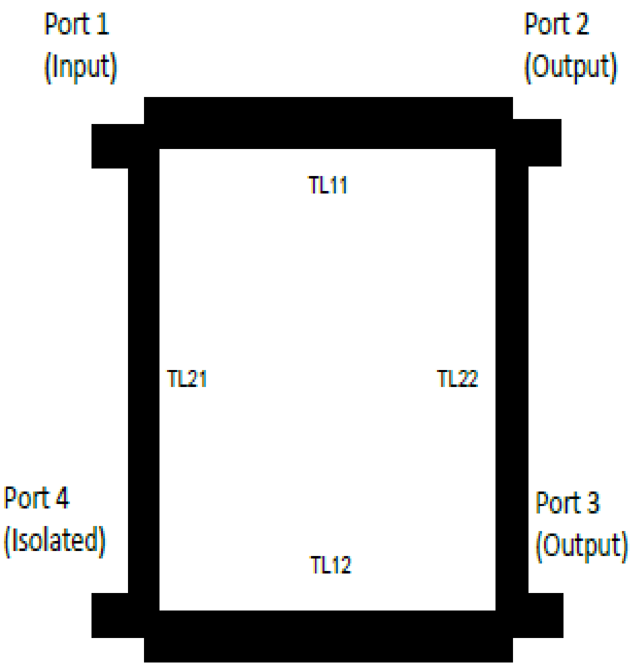

Figure 1: Branch-line hybrid coupler.

Transmission line	Length (mm)	Width (mm)
TL11	136.1	4.674
TL12	136.1	4.674
TL21	143.5	2.707
TL22	143.5	2.707

Table 1: Length and width of transmission lines of the based designed quadrature hybrid coupler.

The based quadrature hybrid coupler was modeled with bends to reduce its physical size as it can be seen in the layout design in (Figure 2). Each bend has a radius equal to 7 mm with a 90° angle in the layout.

Consequently, the bend acquired circumference equal to 11 mm and this circumference was compensated from the length of the transmission lines in the proposed design.

There are 4 bends at each transmission line and in order to keep the phase balance below ± 0.3°at the design frequency 300 MHz, it was applied symmetric bends at the parallel transmission lines and series transmission lines in the compact design.

In addition, a specific substrate (FR4 substrate) and a specific loss tangent have been applied to keep the magnitude balance below ± 0.4 dB. The physical size of the proposed design of the compact quadrature hybrid coupler saved 24% than a standard Branch-line design at the same operation frequency.

It has to be mention that the proposed design and the simulation have been performed in Advanced Design System (ADS). The photograph of the prototype can be seen in (Figure 2).

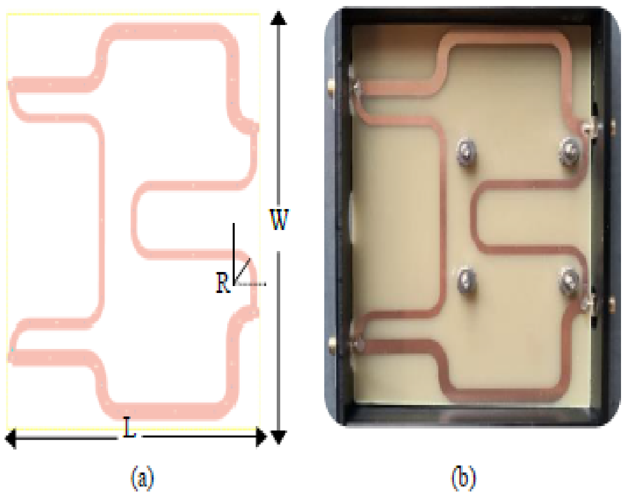

Figure 2: Proposed compact quadrature hybrid coupler. (a) Layout, L=104 mm, W=110 mm, R=7 mm. (b) Photograph of the fabricated micro strip prototype.

Discussion of Simulation and Experimental Results

The prototype of the fabricated compact quadrature hybrid coupler has been measured with the Vector Network Analyzer, MS4624D.

The simulated and the measured frequency responses of the compact quadrature hybrid coupler have been displayed in the figures below and good agreement between them is observed.

The simulations and measurements have been performed when input power is entering the port 1. In (Figures 3 and 4), the measurements at the operation frequency 300 MHz exhibited magnitudes of the scattering parameters at the output ports, S21=-3.221 dB and S3=-3.446 dB. In addition, in (Figures 5 and 6), the isolation and return loss are measured at -23.202 dB, -21.921 dB respectively.

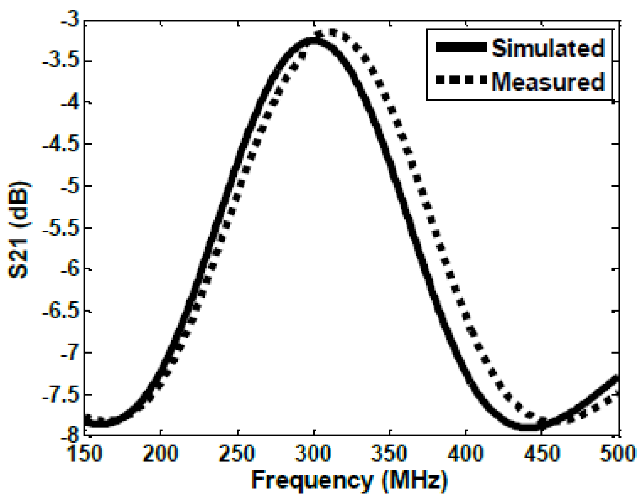

Figure 3: Simulation and measurement-insertion loss, S21-(dB).

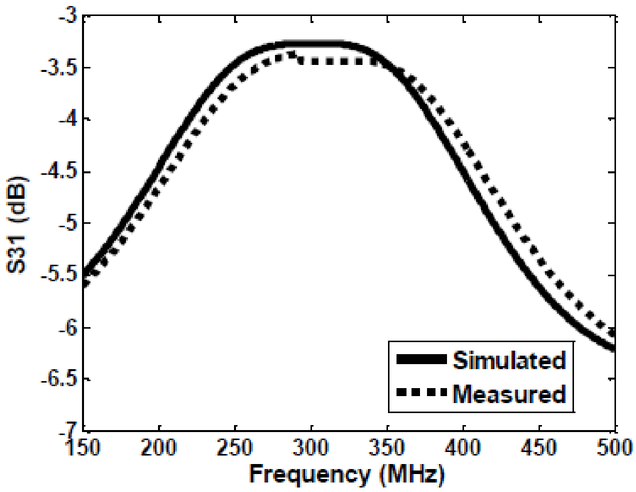

Figure 4: Simulation and measurement-S3-(dB).

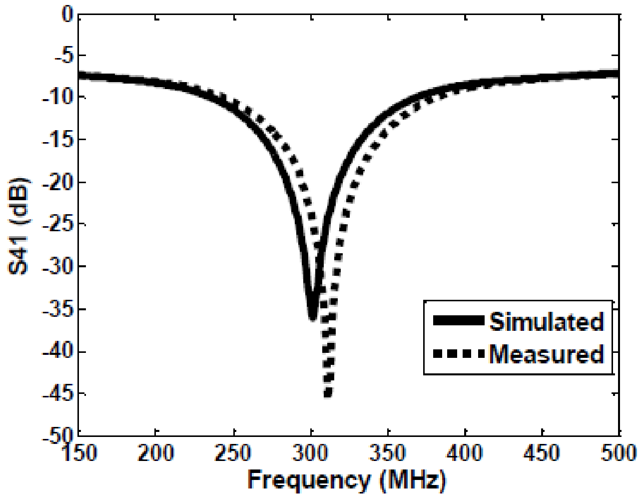

Figure 5: Simulation and measurement-isolation, S41-(dB).

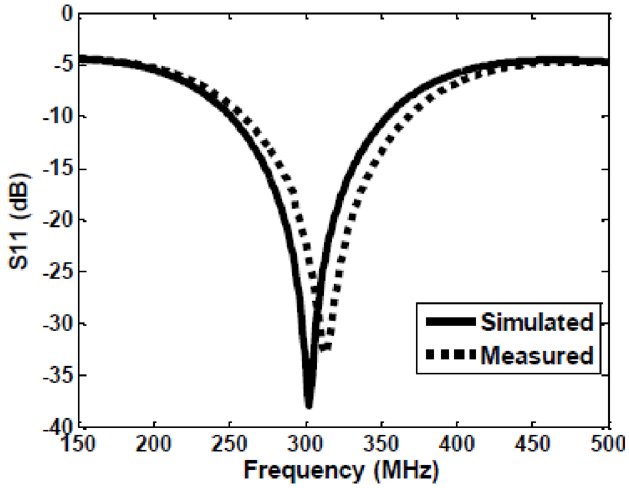

Figure 6: Simulation and measurement-return loss, S11-(dB).

In (Figure 7), the measured phase shift between the scattering parameters, S21 and S31 is 89.848° (phase balance= ± 0.15°) at the operation frequency of 300 MHz. In (Figure 8), there is a little difference between measured magnitudes of the scattering parameters, S21 and S31 at the output ports [6-8]. Consequently, the measured magnitude balance is ± 0.225 dB at the operation frequency (Table 2).

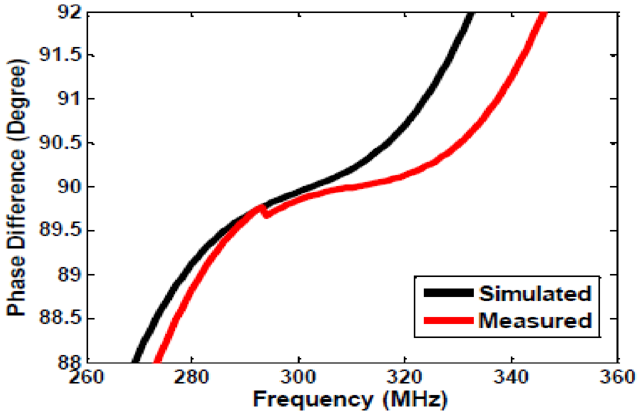

Figure 7: Simulation and measurement-phase difference between S21 and S31.

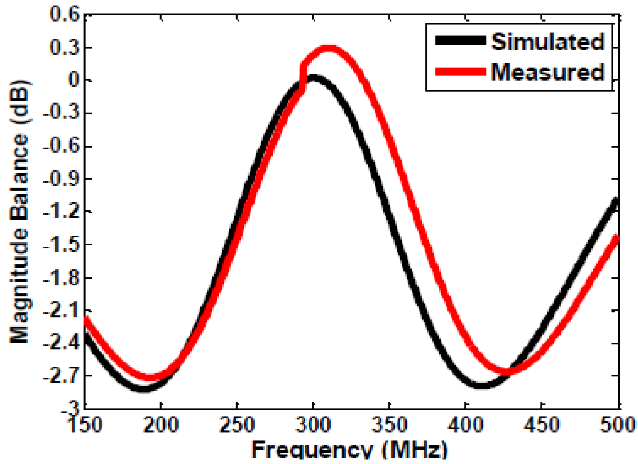

Figure 8: Simulation and measurement-magnitude balance between S21 and S31.

Parameter	Simulated	Measured
Operation frequency	300 MHz	300 MHz
Magnitude-S21 (Insertion Loss)	-3.256 dB	-3.221 dB
Magnitude-S31	-3.273 dB	-3.446 dB
Magnitude-S41 (Isolation)	-34.163 dB	-23.202 dB
Magnitude-S11 (Return Loss)	-33.127 dB	-21.921 dB
Phase balance-S21,S31	± 0.06°	± 0.15°
Magnitude Balance-S21,S31	± 0.017 dB	± 0.225 dB

Table 2: Performance of the compact quadrature hybrid coupler.

Conclusion

A compact quadrature hybrid coupler for MRI coil is presented. Several design architectures with different compact branch-line coupler PCB substrates were investigated in this study.

In this paper, the design of branch-line coupler with symmetric bends could reduce its physical size and its exhibited required performance can be applied in MRI applications.

The magnitude balance is ± 0.22 dB and the phase balance is ± 0.15° at the operation frequency of 300 MHz and the isolation is good with 23.2 dB.

In addition, the compact quadrature hybrid coupler design was easily fabricated on the micro strip board. Finally, summary of the simulations and measurements results is displayed in Table 2.

Acknowledgment

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