Design and development of general propose transmit-receive (TR) switch for a linear, quadrature and dual tuned coils

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INTRODUCTION: The transmit-receive (TR) switch is used to route the high power RF pulse from the RF amplifier to the coil and the low power magnetic resonance (MR) signal from the coil to the preamplifier. One important role of the TR switch is to protect the pre-amplifier from the large power during the transmit pulse. For any non-proton MR imaging and spectroscopy, of which signal-to-noise ratio (SNR) is the largest limitation for practical application, we would like to build an optimal RF coil including a transmit-receive switch. The motivation of this work was to design and develop TR switch with optimal performance compatible for a linear, quadrature and double tuned RF coils. We built a TR switch compatible for our home-built double tuned $^{1}H/^{31}P$ lamb coil designed for ^{31}P MRS of hypoplastic left heart syndrome model of Lamb's heart and compared its performance on a phantom with a commercial TR switch (Clinical MR Solutions, LLC, Brookfield, WI, USA).

METHODS: A double-layered circuit layout was designed using Eagle software (Cadsoft, version 6) and printed circuit board (PCB) of 10 cm x 8 cm was fabricated. The islands on the board were designed such that the same board can be utilized to build both linear and quadrature TR switches. The board diagram of TR switch and the circuit diagram of a linear, quadrature TR switch, and a RF switch are shown in Fig 1. The transmit path of the TR switch consists of a single PIN-diode (MA4P7104F, MACOM Technology Solutions Inc.), whereas the receive path consists of a Pi-network and quarter wave cable in series followed by a passive shunt crossed-diodes for an additional protection of the pre-amplifier. Using a coil-control file within the Siemens MRI system, the PIN-diodes are forward biased and reverse biased during the RF transmission (Tx) and the signal reception (Rx) respectively. The PIN-diodes offer very low impedance to the RF pulse when forward biased and high impedance when reverse biased. The forward biasing of the PIN-diodes at the end of the quarter wave cable and Pi-network make the receive path open for the RF pulse while the reverse biasing make the receive path act like a normal 50 Ω cable. Thus, the RF pulse from transmitter is routed only to the coil during Tx and the MR signal from the coil flows only to the receive-pathway during Rx. Two fast-switching diodes in the crossed–diode are easily forward biased by a high power RF pulse and not affected by a low power MR signal. The RF switch was built on home-built PCB board formed by etching a copper coated board. It consists of two trap circuits, which provide high impedance at the frequency to which they are tuned and low impedance at all other frequencies. A capacitor and inductor with suitable values are added to the ^{31}P and ^{1}H traps to match to 50 Ω at the ^{1}H and ^{31}P frequencies, respectively.

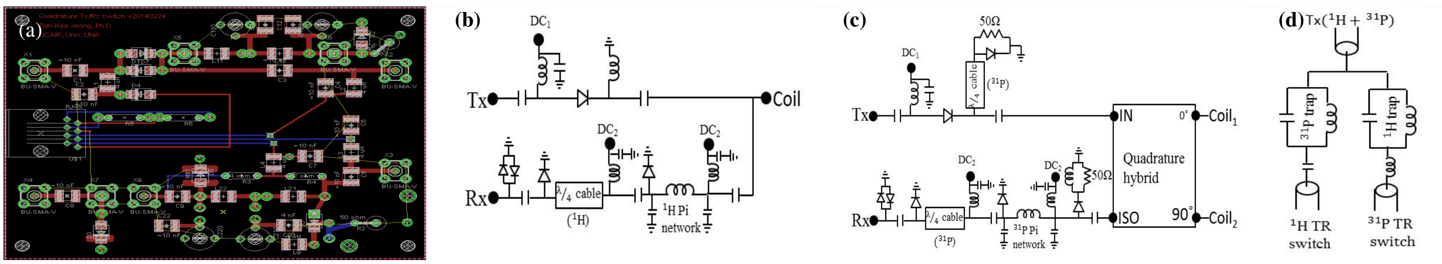

***Fig. 1. (a)** PCB of TR switch, and circuit diagrams of **(b)** linear and **(c)** quadrature TR switches, and **(d)** RF switch. The quadrature TR switch is accompanied by a quadrature hybrid to split the RF pulse to the quadrature coil and to combine the MR signal from the coil in quadrature mode.*

RESULTS: A. Bench Measurement: The isolations and insertion loss of the TR and RF switches were measured on the bench using a Vector Network analyzer (E5061B, Agilent Technologies) and listed in table 1. The high isolation of the quadrature TR switch compared to the linear TR switch is due to the additional isolation by the quadrature hybrid (Anaren Microwave Inc., East Syracuse, NY). **B. Phantom Studies:** Three MRS experiments were performed on a phantom containing phosphate buffered saline (PBS) at a 3T clinical MRI system (Tim- Trio Siemen's Medical Solution, Erlangen Germany) and the lamb $^{1}H/^{31}P$ coil employing (a). home-built TR switch with RF switch (b). home-built TR switch bypassing the RF switch (c). a commercial TR switch. The scout image and FIDs from these three experiments are shown in Fig 2. The signal to noise ratio (SNR) were measured to be 23.64, 23.83, and 18.36 from the phantom using the home-built TR switch with RF switch, home-built TR switch with no RF switch and commercial TR switch respectively.

***Table 1:** Isolation and insertion loss of TR switches and traps in dB unit.*

Circuit	During Transmission		During Reception	
	Isolation	Insertion loss	Isolation	Insertion loss
^{1}H TR switch	-49.0 (Tx-Rx)	-0.7 (Tx-coil)	-31.0 (Tx-Rx)	-0.7 (coil-Rx)
^{31}P TR switch	-85.4 (Tx-Rx)	-1.2 (Tx-coil)	-92.5 (Tx-Rx)	-1.1 (coil-Rx)
^{1}H trap	-45.4 (^{1}H pulse)	-0.04 (^{31}P pulse)		
^{31}P trap	-51.5 (^{31}P pulse)	-0.2 (^{1}H pulse)		

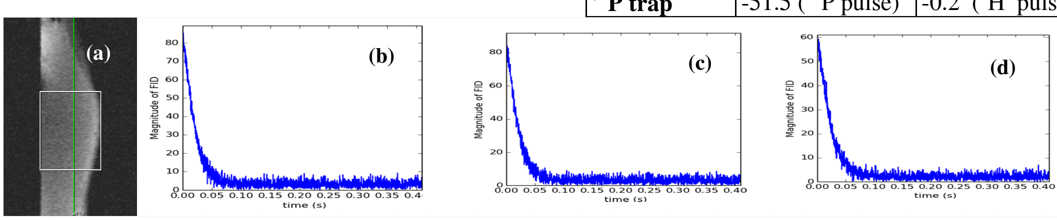

***Fig 2. (a)** Scout image, and FIDs obtained using the lamb $^{1}H/^{31}P$ coil with **(b)**. home built TR switch with RF switch, **(c)**. home-built TR switch bypassing RF switch, and **(d)**. a commercial TR switch*

DISSUSSIONS and CONCLUSIONS: We designed and built the TR switch with high isolation, low insertion loss and high power handling capability at low cost and reasonable development time using simple electronic circuits. The performances of these switches were comparable to that using a commercial TR switch. The TR switch is flexible in that it has additional two dc current lines for the coil bias and it can be easily modified to other frequencies simply by changing the length of quarter wave cable and the components on the Pi-network section. This work eliminates the restriction of designing a coil according to the available TR switches or necessity of buying expensive custom-built TR switches.

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