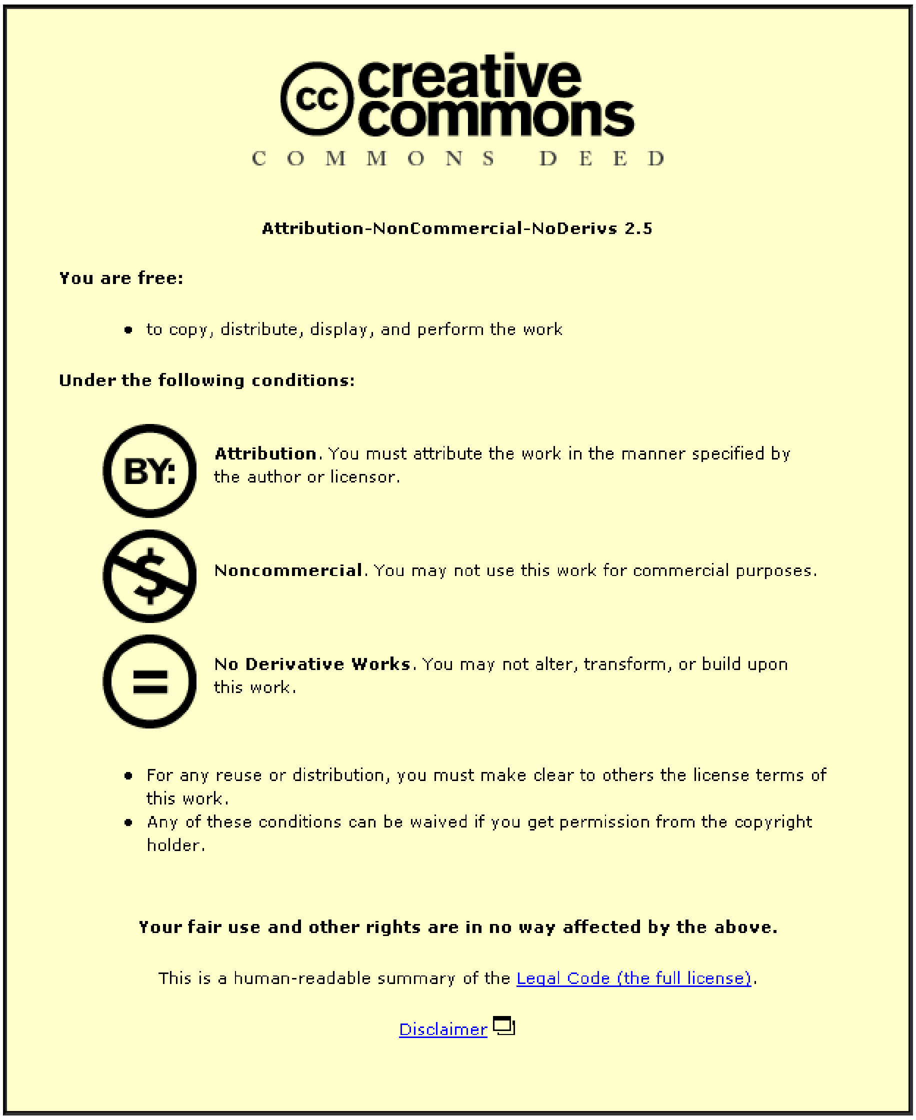

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Frequency Switchable Dual-Band Branch-Line Couplers

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Abstract— **In this paper, silicon switches are implemented in the design of frequency switchable dual-band branch-line coupler. Frequency switching is achieved by increasing the power of the laser applied to the highly resistive silicon wafer and changing the properties of silicon under optical illumination. The advantages of this approach are high-speed switching, electromagnetic transparency (no interference) and thermal and electrical isolation between the coupler and the control circuit. A frequency shift of 35% and 10% has been achieved from all switches off to all switches on in lower (900 MHz) and upper (1800 MHz) frequency bands, respectively.**

I. INTRODUCTION

Novel components for future wireless communications systems will have to meet the demands of Cognitive Radio and Software Defined Radio (SDR). The common directions in design of these novel components are component miniaturisation, design of components with enhanced bandwidth, design of multiband components and design of tunable components. Over the past few years, branch-line coupler designs with bandwidth enhancement and size-reduction have been gaining favour. Recently, the interest in tunable microwave components, such as couplers, baluns, phase-shifters, filters has arisen. Tuning techniques include varactor/pin diodes, RF MEMS, ferroelectrics and optical tuning. The use of pin and varactor diodes has many disadvantages such as high loss, high power consumption, unacceptable SNR and distortion of the incident signals. RF MEMS provide a better solution in building tunable passives, which are necessary for multiband systems. These passives are small, with low insertion loss, high Q and low power consumption, they introduce less signal distortion, but the fastest tuning speeds are around a microsecond. Ferroelectric materials have fast tuning speeds (~picoseconds). They are easily tuned by voltage only. The main disadvantage and the problem is high level dielectric losses. The advantages of the optically controlled microwave devices include high isolation between the controlling optical beam and the controlled microwave signal, short response time, high-power handling capacity, immunity to electromagnetic interference and low cost. Optically controlled antennas [1], filters [2], resonators [3], phase-shifters [4], have been demonstrated recently.

The aim of this work is to produce a frequency switchable dual-band branch-line coupler for microwave applications. The device presented in this paper was produced by modifying a dual-band branch-line coupler and adding four silicon switches.

II. SWITCHABLE COUPLER

The switches used in the design of a branch-line coupler are diced from high resistivity silicon wafer ($\rho > 6000\ \Omega$cm). Silicon changes from an insulator state to a near conducting state when illuminated by light. Silicon used is n-type doped with Phosphorus to increase static conductivity. The ideal light for this process is in the near infrared range.

The dual-band coupler device presented here is comparable to varactor tuned devices [5] in terms of fabrication complexity. However varactor based designs often require biasing lines and short circuit vias.

A way of modelling the switch is by matching the experimental results for the optical switch and simulation results for the equivalent circuit of the switch. The results for different states of the switch were obtained using Agilent Advanced Design System. The lumped element values from Figure 1 are tuned in order to match measured S-parameters under various illumination powers, from 0 to 200mW. The gap is represented by three capacitors (C1, C2, C4) and two additional components (R3, C3) to account for the photoconducting effect of silicon. Resistors (R1, R2) and inductors (L1, L2) are added to account for losses. By analysing a number of S-parameter graphs it was shown that with increasing optical power, the gap capacitance values (C2 and C3) increase, while the gap resistance values (R1, R2 and R3) decrease, indicating a capacitive nature of the switch.

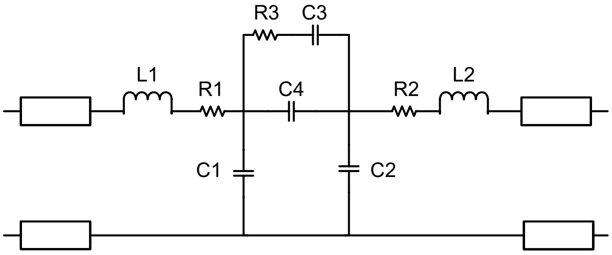

Fig. 1 Equivalent circuit of the switch

An example of the switch in a microstrip transmission line is shown in Figure 2. The 1 mm x 2 mm x 0.3 mm silicon dice was placed over a 0.5-mm gap. A transmission line was printed on a 1.57-mm Rogers RT/Duroid 5880 substrate with a dielectric constant of 2.2. The same substrate was used for branch-line coupler design. The silicon switch was held in place using a RS silver loaded epoxy hardener. The measured S-parameters for the switched line in OFF (0mW) and ON state (200mW) are given in Figure 3. The architecture of a dual-band coupler is shown in Figure 4. The characteristic impedances and electrical lengths, widths and lengths of the lines corresponding to the ones shown in Figure 4 are presented in Table 1. When silicon switches are in OFF state, there is a considerable degree of electrical isolation between TLS1 and TLS2. Consequently, very little energy transfer occurs across the gap. When switches are ON, they operate in pseudo-metallic state, an electrical connection is formed between TLS1 and TLS2.

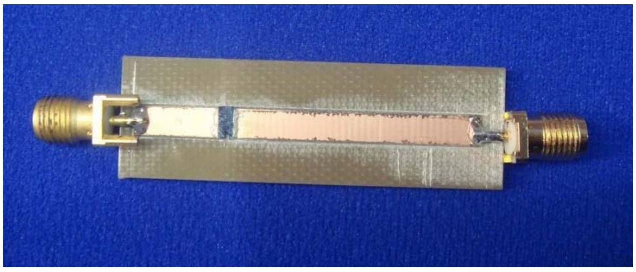

Fig. 2 Example of a switch in a microstrip transmission line

A 980nm laser operating at 200mW is coupled with fiber optic cables and angled over silicon wafers using plastic clamps. When laser is off, all switches are off. When laser is on, operating at 200mW, the silicon conducts and the gaps are bridged, increasing the lengths of stubs and reducing the resonant frequency.

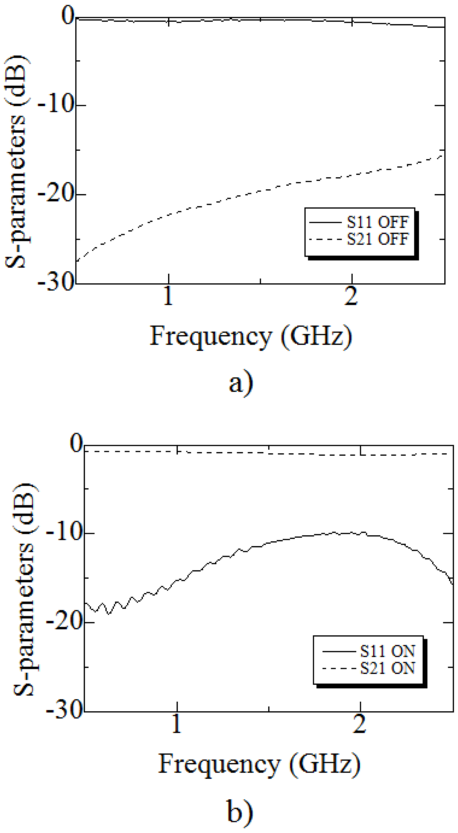

Fig. 3 Measured magnitude response of the switch in OFF (a) and ON (b) states.

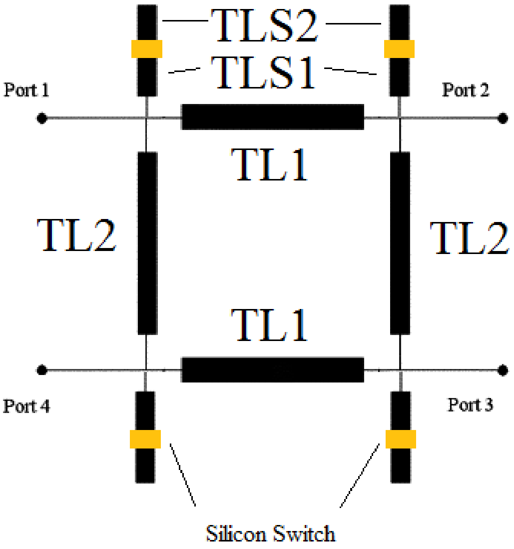

Fig. 4 Architecture of a dual-band switchable branch-line coupler

TABLE I
CHARACTERISTIC IMPEDANCES AND ELECTRICAL LENGTHS OF THE TRANSMISSION LINES

	Impedance (Ω)	**Electrical Length (degrees)**	**Width (mm)**	**Length (mm)**
TL1	42.7	90	1.95	37.45
TL2	60.4	90	1.15	38.06
TLS1	54.4	75.6	1.36	31.50
TLS2	54.4	27	1.36	11.36

III. RESULTS

The simulations were performed using Agilent Advanced Design System 2008 and Agilent Momentum, the 2.5D electromagnetic simulation engine within the ADS package, that employs the Method of Moments technique. The simulated scattering parameter input and output port responses (magnitude response) for two states of the switch (0mW and 200mW) are shown in Figure 5 and 6 respectively.

The infrared 980±0.5nm laser is used in the experiment. An electronic control system alters the amount of optical power produced by the laser. The scattering parameter measurements were obtained using and Anritsu 37397D vector network analyzer. The measured S-parameter input and output port responses are shown in Figures 7 and 8. Good reflection is shown in both frequency bands (better than -15 dB). The coupling is close to -3 dB in both bands. The simulated and measured results are in good agreement. The frequency shift of 230MHz and 160MHz are demonstrated in lower (900MHz) and upper (1800MHz) frequency bands, respectively. The percentage frequency shift is 35% and 10% in lower and upper bands, respectively.

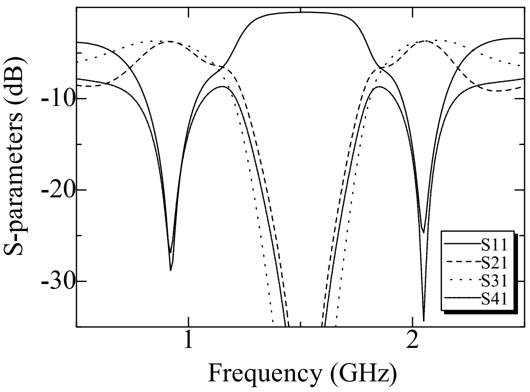

Fig. 5 Simulated S-parameters in OFF state (0 mW)

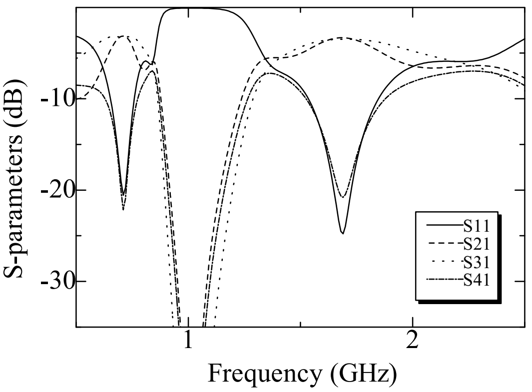

Fig. 6 Simulated S-parameters in ON state (200 mW)

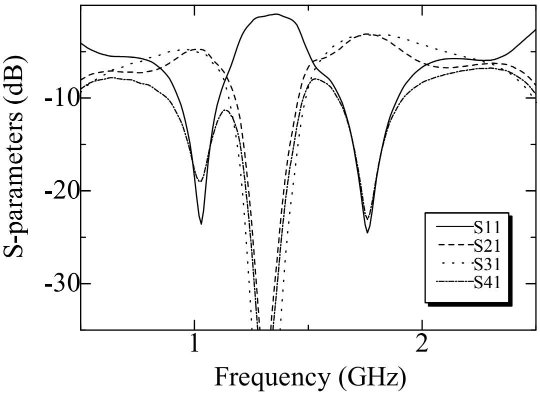

Fig. 7 Measured S-parameters in OFF state (0 mW)

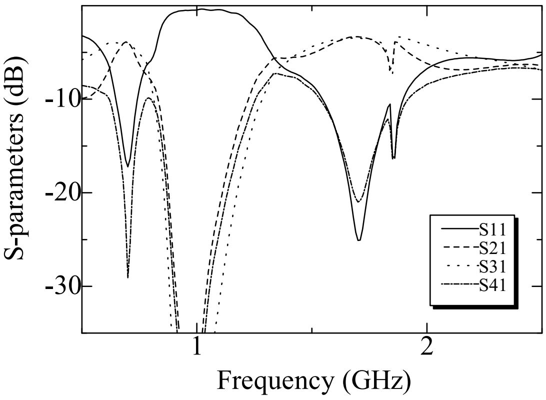

Fig. 8 Measured S-parameters in ON state (200 mW)

IV. CONCLUSION

An optically switchable dual-band branch-line coupler has been demonstrated, both through simulation and measurements. The frequency shift of 35% and 10% has been achieved from all switches off to all switches on in lower and upper frequency bands, respectively. The branch line coupler's performance has shown near -3 dB insertion loss, good return and isolation loss better than -15 dB and near 90 degrees phase difference between coupled and through ports, in both bands. The advantages of this new frequency switchable coupler are high-speed switching, electromagnetic transparency (no interference), thermal and electrical isolation between the coupler and the control circuit, and no need for short circuit vias and biasing lines.

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