Optically Reconfigurable RF Circuits

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***Abstract*— In this paper, two novel concepts that use optically reconfigurable RF circuits are presented. In the first example, a Silicon switch was implemented in the input matching network of a power amplifier. The silicon gap-loaded switch properties were changed from insulator state to near conducting state under illumination and resulted in the change of the effective length of the stub in the input matching network, while the output matching network was not changed. Tunable class AB power amplifier with the optical switch in the input matching circuit has obtained the frequency tuning range of 2.5-3.5 GHz with no significant loss in efficiency and linearity. An optically reconfigurable antenna system (ORAS) could be realized on a single chip using Silicon based technology.**

I. Introduction

Novel components and circuits for future wireless communications systems will have to meet the demands of Cognitive Radio (CR) and Software Defined Radio (SDR). The driving forces for the commercial viability of the Software Defined Radio concepts are advances in chip processing power, while antenna and circuit technologies represent a significant barrier to progress. Multiband circuits and antennas can in principal be integrated into a switching network topology, but there are many inhibiting factors, such as size, coupling, cost etc. The interest in tunable and reconfigurable microwave components, such as couplers, baluns, phase-shifters, filters has arisen recently. 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. MEMS 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, no need for biasing lines, short response time, high-power handling capacity, immunity to electromagnetic interference and low cost. Optically controlled antennas, filters, resonators, phase-shifters have been demonstrated recently [1]-[6]. In this paper, two novel approaches that use optically reconfigurable circuits are presented.

II. Optically Reconfigurable Matching Networks

The frequency characteristics of an amplifier depend mainly on its input matching circuit. The idea presented here is to use an optically reconfigurable input matching circuit and the output matching circuit is designed with fixed-value elements to cover the whole frequency tuning range without significant implications to efficiency and linearity. The wider tuning range would be possible to achieve if the additional input matching networks with the additional switches were inserted, but the complexity and size of the circuit would be increased.

An example of the switch in a microstrip transmission line is shown in Figure 1. 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 high resistivity silicon changes from an insulator state to a near conducting state when illuminated by light. A 980 nm laser operating at 200 mW 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 200 mW, the silicon conducts and the gaps are bridged, increasing the lengths of stubs and reducing the resonant frequency.

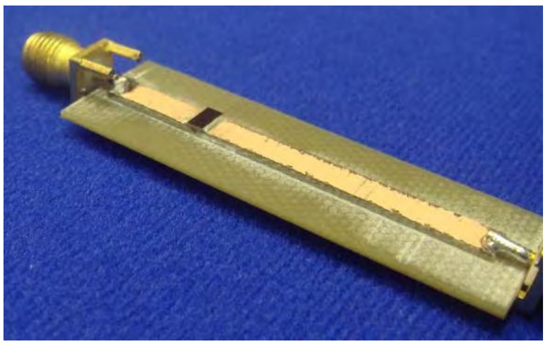

Fig. 1 A Silicon switch in a microstrip transmission line

The measured S-parameters for the switched line in OFF (0 mW) and ON state (200 mW) are given in Figure 2. The simulations of the power amplifier circuit 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. In the simulations the accurate large signal model of the CREE CGH35015F GaN HEMT device was used. The active device was initially recommended for 3.5 GHz OFDM WiMAX applications. The schematic of the reconfigurable input matching network is shown in Figure 3. Figure 4 shows the simulated frequency response for the 2.5-GHz mode (a) and the 3.5-GHz mode (b), respectively. The device was biased for the operation in class-AB (V_{DD}=28V). The gain of 15 dB was reached in both modes.

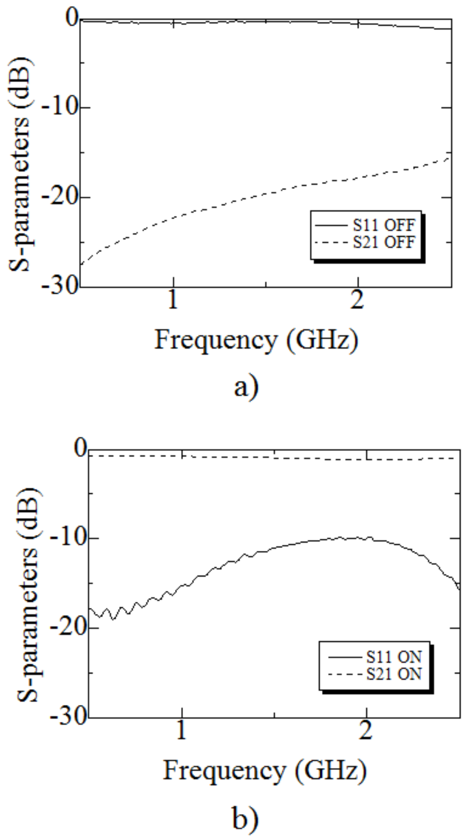

Fig. 2 Measured S-parameters magnitude response for the switch

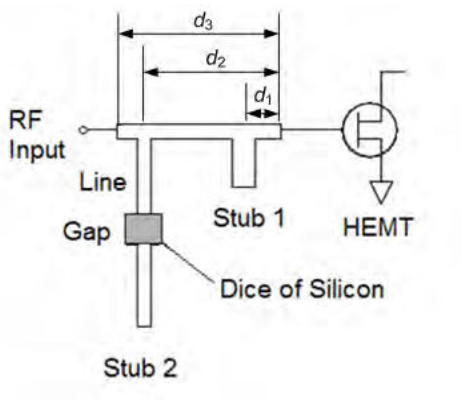

Fig. 3 Schematic of the reconfigurable input matching network

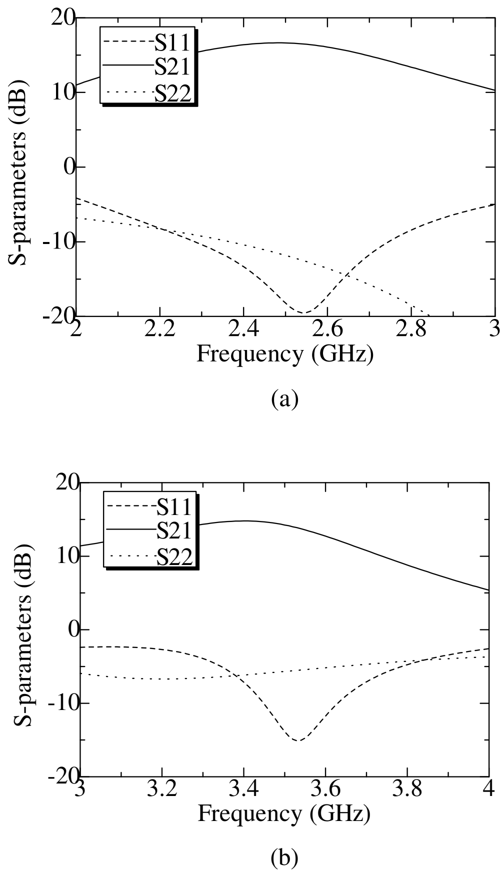

Fig. 4 S-parameters versus frequency for two positions of the switch

III. Optically Reconfigurable Antenna System (ORAS)

The idea behind this work is to merge photonics with reconfigurable antennas and metacircuits to provide an antenna technology that can be reconfigured dynamically at very high speeds. We envision two models for implementing such an antenna system. The design-concept makes use of discrete semiconductor photoconductive elements that act as switches between antenna elements thus dynamically changing the resonant frequencies of the antenna without the use of any bias lines required to activate the switches. The elimination of bias lines is a very important advantage with the proposed method since bias lines can interfere with the design of the antennas and its operation.

The research involves several state-of-the-art innovations including Si integrated photonics and photonic integrated techniques, laser array technology and advanced reconfigurable antenna/circuit technology. The developed circuit/antenna technology can be implemented very readily and have the potential to dramatically serve the population by improving medical sensing technologies, communication services, military radar and surveillance systems, and a variety of other security applications. Our initial calculations indicate that it is possible to convert a $1cm^3$ intrinsic cell of Si/GaAs into an almost metal-like cell using mW-level near-IR laser sources. At the systems-level, the focus now shifts to achieving a truly integrated ORAS. By “true-integration” we mean that the lasers that achieve the photoconductivity in the semiconductor, the driving circuitry for the lasers and the light delivery to the photoconductive semiconductor are all achieved on the single chip using Si based technology.

IV. Conclusion

This paper has proposed two concepts of optically reconfigurable RF circuits: a frequency tunable amplifier with an optically tunable input matching network and the optically reconfigurable antenna system.

The silicon gap-loaded switch properties were changed from insulator state to near conducting state under illumination and resulted in the change of the effective length of the stub in the input matching network of the power amplifier circuit, while the output matching network was not changed. This tunable amplifier with simple circuit topology has shown considerably good efficiency and linearity, although even higher linearity and power levels can be obtained by designing more complex tunable matching networks at both input and output. The concept of an optically reconfigurable antenna system (ORAS) which could be realized on a single chip using Silicon based technology has been introduced.

The applications of photonic components and techniques in the microwave devices present a huge potential for future research. The silicon microswitch used here could be improved (isolation and insertion loss, power handling capability), packaged and commercialised to be a serious contender in the market.

References

[1] C. J. Panagamuwa, A. Chauraya, and J. C. Vardaxoglou, "Frequency and beam reconfigurable antenna using photoconducting switches," *IEEE Transactions on Antennas and Propagation*, vol. 54, pp. 449-454, 2006.

[2] G. Zouganelis and D. Budimir, "Silicon gap-loaded microstrip slit-tetragonal resonator under IR-irradiation," in *Microwave and Optical Technology Letters*. vol. 49, 2007, pp. 699-702.

[3] D. Draskovic, C. Panagamuwa, D. Budimir and J. C. Vardaxoglou, ”Frequency Switchable Dual-Band Branch-Line Couplers”, *39th European Microwave Conference*, Roma, Italy, November 28 September – 2 October, 2009.

[4] D. Draskovic and D. Budimir, “Optically Controlled Negative refractive Index Transmission Lines”, *European Conference on Antennas and Propagation*, Berlin, 23-27 March 2009.

[5] D. Draskovic, and D. Budimir , “Optically Reconfigurable Matching Networks”, IEEE International Microwave Photonics Conference and the Asia-Pacific Microwave Photonics Conference (MWP2008/APMP2008), Gold Coast, Australia, October, 29 Sept. – 3. Oct. 2008.

[6] D. Budimir, L. Athukorala and G. Zouganelis, “Optically Switchable Microstrip Resonators for RF/Microwave Multifunctional Systems”, IEEE International Microwave Photonics Conference and the Asia-Pacific Microwave Photonics Conference (MWP2008/APMP2008), Gold Coast, Australia, 29 Sept. – 3 October, 2008.