2012

Low power field generation for magneto-optic fiber-based interferometric switches

John Paul Pritchard Jr.
Iowa State University

Mani Mina
Iowa State University, mmina@iastate.edu

Robert J. Weber
Iowa State University

Sasha Kemmet
Iowa State University

Low power field generation for magneto-optic fiber-based interferometric switches

Abstract

A new fiber-based, magneto-optic switch is proposed with a novel approach for low power and efficient operation. The switch, with reasonable switching speed compared to competitive designs, operates at considerably reduced power levels, which makes it a practical deployable solution. The basic switch setup consists of a Faraday rotator in a Sagnac fiber-optic interferometer in which optical switching is controlled by an electronic driving circuit. The electronic system generates a magnetic field through the Faraday rotator by driving current through a specially designed two-coil system. The new coil system allows for sufficient field generation at low quiescent power levels while maintaining very short optical rise and fall times. The design and considerations as well as the effect of mutual inductance between the two coils and its influence on switching times are investigated. The optical system consists of a Sagnac interferometer with a Faraday rotator within the Sagnac loop. Appropriate phase shift for interference is achieved by the proposed field generating system designed for the magneto-optical element. The theory of operation, design, experimental results, and optical and electronic setup are presented and analyzed.

Keywords

coil systems, driving current, electronic driving, electronic systems, Faraday rotators, fiber-optic interferometers, generating system, interferometric switches, low power, magneto-optic switch, mutual inductance, sagnac interferometer, sagnac loop, textile fibers

Disciplines

Electrical and Computer Engineering | Electromagnetics and Photonics

Comments

The following article appeared in *Journal of Applied Physics* 111 (2012): and may be found at doi:10.1063/1.3679391.

AIP Journal of Applied Physics

Low power field generation for magneto-optic fiber-based interferometric switches

John Pritchard, Mani Mina, Robert J. Weber, and Sasha Kemmet

Citation: Journal of Applied Physics **111**, 07A941 (2012); doi: 10.1063/1.3679391
View online: http://dx.doi.org/10.1063/1.3679391
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/111/7?ver=pdfcov
Published by the AIP Publishing

Low power field generation for magneto-optic fiber-based interferometric switches

John Pritchard,[a)] Mani Mina, Robert J. Weber, and Sasha Kemmet
Electrical and Computer Engineering Department, Iowa State University, Ames, Iowa 50011, USA

(Presented 2 November 2011; received 23 September 2011; accepted 7 December 2011; published online 12 March 2012)

A new fiber-based, magneto-optic switch is proposed with a novel approach for low power and efficient operation. The switch, with reasonable switching speed compared to competitive designs, operates at considerably reduced power levels, which makes it a practical deployable solution. The basic switch setup consists of a Faraday rotator in a Sagnac fiber-optic interferometer in which optical switching is controlled by an electronic driving circuit. The electronic system generates a magnetic field through the Faraday rotator by driving current through a specially designed two-coil system. The new coil system allows for sufficient field generation at low quiescent power levels while maintaining very short optical rise and fall times. The design and considerations as well as the effect of mutual inductance between the two coils and its influence on switching times are investigated. The optical system consists of a Sagnac interferometer with a Faraday rotator within the Sagnac loop. Appropriate phase shift for interference is achieved by the proposed field generating system designed for the magneto-optical element. The theory of operation, design, experimental results, and optical and electronic setup are presented and analyzed. © *2012 American Institute of Physics*. [doi:10.1063/1.3679391]

INTRODUCTION

Optical networks are the predominant high speed and long-distance data communications technology.[1] Advantages in bandwidth and speed, in addition to the ability to produce high-quality optical devices at a low cost,[2] make these technologies more favorable over alternatives. Bottlenecks in optical networks such as the optical-electrical (OE) and electrical-optical (EO) conversions limit the system's capabilities. At these points, bandwidth becomes limited to the electrical system, and loss and delays can occur. Small, all-optical solutions are needed with low power operation at a low cost. Technologies have been suggested and used in previous works with reasonable power operation.[3] Magneto-optic (MO) switching technologies have shown promise in the realization of all-optical routing devices that reduce the effect of these bottlenecks enabling fast, dynamic route setting with low power operation[4–6] and the potential for integration.[7] In this paper, we introduce a new method for designing the field generation system used to magnetize the MO material with low power operation and improved scalability.

EXPERIMENTAL SETUP

The experimental setup includes the optical system and the field generation system (Fig. 1). The MO material used is a bismuth-doped iron garnet (BIG) [$(Bi_{1.1}Tb_{1.9})(Fe_{4.25}Ga_{0.75})O_{12}$] (Ref. 8) and is placed in the Sagnac loop, ideally such that the optical paths on either side of the material are equidistant.

[a)]Author to whom correspondence should be addressed. Electronic mail: johnp@ia.state.edu.

The high speed field generation system controls and enables the magnetized state of the MO material and is placed appropriately. This is the driving force that constitutes the switching capability of the system. The proposed circuit is composed of two separate circuits that drive current through $coil_1$ and $coil_2$ of the two-coil system, which is shown in Fig. 2. The circuit that drives the current through $coil_1$ provides a very rapid, high current pulse to quickly magnetize the MO material. The mutual inductance does not affect the total field in the MO material, but it does affect how the input signals are shaped to achieve the total field. For example, Vp1 and Vp2 have identical voltage profiles, but the voltage seen at the gate of MOSFET M1 decreases rapidly as a result of the charging series capacitor. The purpose of this is to control the initial magnetization of the material while minimizing total current drawn. $Coil_1$ should energize for only a brief moment to quickly magnetize the MO material. The circuit driving the current through $coil_2$ provides a longer pulse of less amperage to sustain the material's magnetization. The distinction between both control circuits is advantageous

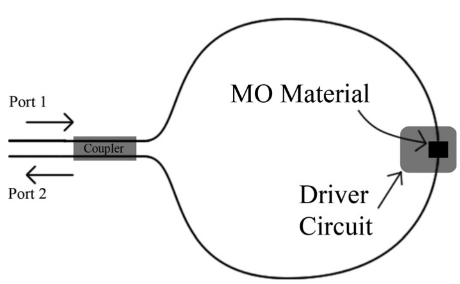

FIG. 1. Fiber-based Sagnac interferometer.

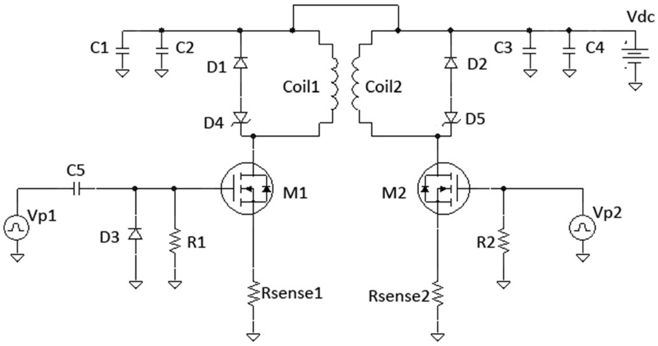

FIG. 2. High speed field generation circuit.

because effects of mutual inductance can be compensated by adjusting the input voltage profiles. Bypass capacitors, current sense resistors, protection diodes, and other passives were placed appropriately.

PROPOSED SYSTEM

To achieve all-optical switching, fiber-based interferometers have been shown to be reasonable and practical solutions.[9] While different interferometer topologies could be used, the fiber-based Sagnac has been proposed and successfully demonstrated for this application.[10] This design is also advantageous because the number of components required to achieve optical switching is minimal, allowing for greater scalability and deployment. Switching occurs by magnetizing the MO material using the suitably designed coils and field generation system, achieving appropriate rotation of polarization for interference.

Traditionally, the MO material is placed at the center of a coil and is magnetized by passing current through this coil. To have fast switching capabilities, a coil of few turns is needed to minimize inductance. Although, this means that high current is required to generate a strong enough magnetization field. In this work, a novel two-coil system is proposed that reduces the amount of current required for the magnetization field while still maintaining short optical rise times.

The two coil system consists of $coil_1$ with N_1 turns and $coil_2$ with N_2 turns where $N_2 \gg N_1$, as shown in Fig. 3. $Coil_1$ is wrapped around $coil_2$ coaxially and centered about its length. In this design, $coil_1$ has a low inductance that allows for fast initial magnetization of the MO material. $Coil_2$ uses much less current to maintain the same field strength for longer

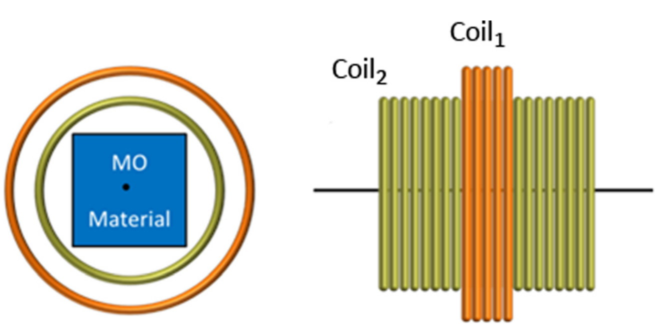

FIG. 3. (Color online) Dual coil magnetic field generator

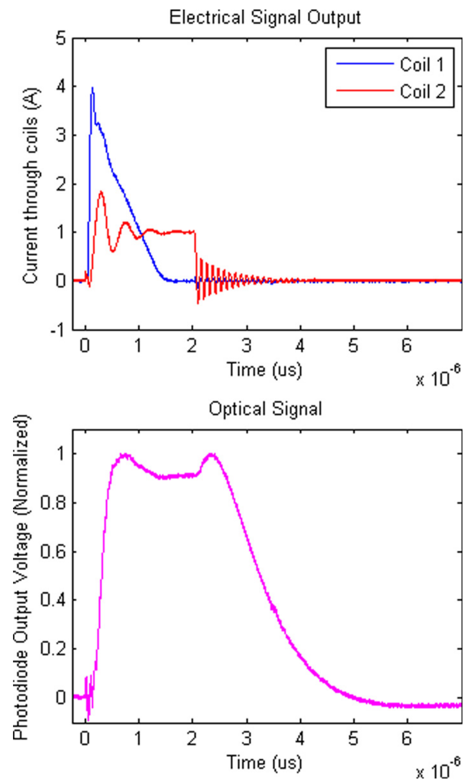

FIG. 4. (Color online) Measurements of the electrical and optical response.

periods of time. Using both coils, optical signal routing is achieved with lower power dissipation than competitive designs.

RESULTS

Given a turns ratio of 7:1 with 28 gauge wire for the two-coil system, a current of 1 A through $coil_2$ of 21 turns and length 6.5 mm, and a maximum current of 4 A through $coil_1$ of 3 turns and length 1 mm, a total field of approximately 191 G through the MO material can be generated. This was calculated using the following equation:[10]

$$B \approx \frac{\mu_0 N_1 I_1}{l_1} + \frac{\mu_0 N_2 I_2}{l_2},$$

where N is the number of turns, I is the current through each coil, and l is the length of each coil. An optical rise time of 267 ns was achieved with both coils energized, which is competitive with contemporary switches. The total current required for this was significantly reduced in comparison to single coil configurations.

In the results shown in Fig. 4, the optical signal sustains after the electrical pulses have turned off. This elongated fall time is a function of the MO material's position between fiber ends in addition to the ringing seen in $coil_2$. Also, given the current through $coil_1$, if the current through $coil_2$, I_2, is increased too high, a secondary peak in the optical output begins to emerge near 2.5 μs. This peak becomes more prominent the higher I_2 is increased. The peak occurs due to coupling on $coil_1$ when $coil_2$ turns off if I_2 is high enough. Therefore a practical I_2 was chosen such that the optical

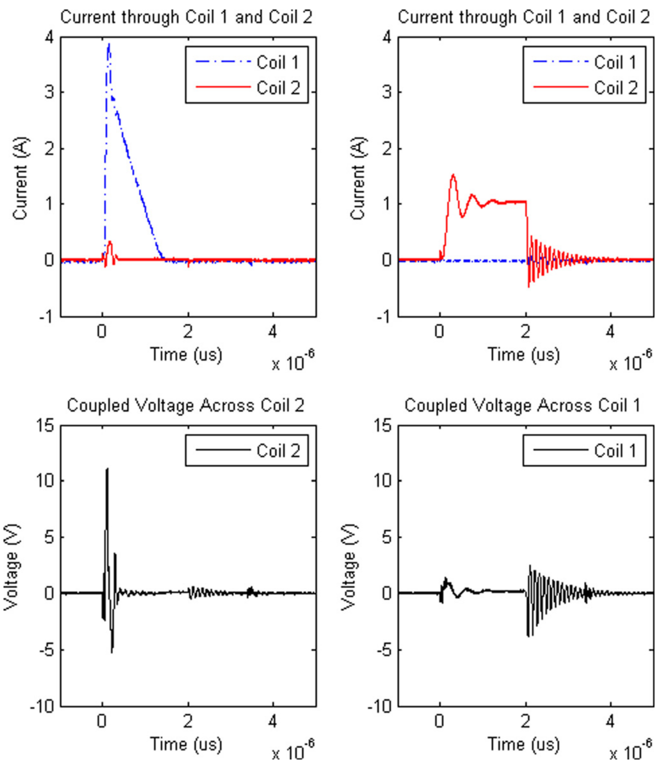

FIG. 5. (Color online) Coupled voltage across $coil_2$ (bottom left) while energizing $coil_1$ (top left) and coupled voltage across $coil_1$ (bottom right) while energizing $coil_2$ (top right).

response did not overly deteriorate and yet sufficient magnetization of the MO material could be achieved.

The measured coupling coefficient of the system was found to be approximately 0.8 for a turns ratio of 7:1. The turns ratio was chosen based on optimization of optical rise time (due to large inductance) and size requirements given a specific wire gauge. In Fig. 5, the effect of mutual inductance is shown. Here the voltage across $coil_2$ is measured while $coil_1$ is energized, and also the voltage across $coil_1$ is measured while $coil_2$ is energized. From these figures it can be seen that coupling is most prominent in the former case. The coupling coefficient is found by dividing the peak coupled voltage by the source voltage, resulting in a coefficient of approximately 0.8 in this case. In addition, the ringing in $coil_2$ is a result of an RLC circuit consisting of the transistor capacitance, the inductance of the coil, and parasitic resistance. This ringing may be dampened by replacing D5 in the schematic with a resistor of value V/I_2 where V is approximately 40 V and I_2 is the current through $coil_2$.

CONCLUSION

A device that implements a new method of fiber-based magneto-optic switching has been realized that operates at powers lower than previous work. The two-coil system can provide sufficient magnetization for Faraday rotators made of bismuth-doped iron garnet for optimal switching speeds. This proposed switching concept introduces new ideas and challenges that can be utilized for novel classes of deployable fiber-based magneto-optical switches.

[1] D. K. Mynbaev and, L. L. Scheiner, *Fiber-Optic Communications Technology* (Prentice Hall, Upper Saddle River, NJ, 2001).
[2] S. O. Kasap, *Optoelectronics and Photonics* (Prentice Hall, Upper Saddle River, NJ, 2001).
[3] Q. Wu, J. Ruan, Z. Weng, and S. Lin, Communications and Photonics Conference and Exhibition (ACP), Asia, 2009.
[4] S. Kemmet, M. Mina, and R. J. Weber, IEEE Trans. Magn. **45**, 4892 (2009).
[5] R. Bahuguna, M. Mina, and R. J. Weber, IEEE Trans. Magn. **42**, 3099 (2006).
[6] S. Kemmet, M. Mina, and R. J. Weber, J. Appl. Phys. **109**, 07E333 (2011).
[7] J. Tioh, M. Mina, and R. J. Weber, IEEE Trans. Magn. **46**, 2474 (2010).
[8] V. J. Fratello, S. J. Licht, and C. D. Brandle, IEEE Trans. Magn. **32**, 4102 (1996).
[9] J. Tioh, R. J. Weber, and M. Mina *Optical SWITCHES: Materials and Design*, edited by S. J. Chua and B. Li (Woodhead Publishing, Philadelphia, PA, 2010).
[10] S. Kemmet, M. Mina, and R. J. Weber, IEEE Trans. Magn. **46**, 4892 (2010).