FIBER OPTIC HIGH VOLTAGE PROBE*

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Abstract

We developed a fiber coupled sensor to measure High Voltage (~45kV) directly using only light as the probe. We use the Pockels effect in lithium niobate crystal which will induce a phase shift in a laser beam that varies according to applied voltage. This can then be transformed into a modulation of beam intensity by polarizers, interferometery, or waveguide coupling. No voltage dividers are necessary, nor is any physical connection. This is accomplished by taking advantage of the structure of the power system itself, using voltage planes and dielectric insulation already present as the capacitive voltage divider. We hypothesize a bandwidth from GHz to DC. Such a system could be used in any application that calls for isolated and unobtrusive voltage sensing.

I. INTRODUCTION

As the performance of pulsed power systems achieves ever-greater levels, it is becoming harder to sample voltage performance for diagnostics. Most means of tapping off power from machines for diagnostics invariably demands alterations in design to allow this sampling. Also the physical presence of a probe affects the machine performance in many cases. The ideal case would be if you could sample your performance in a touchless manner.

Use of electro-optic materials for this application has seen some attention as of late[1]. In this paper we will describe a sensor using the popular material Lithium Niobate. The use of this material by the communications industry means that properly cut crystals are readily available at modest cost. Lithium niobate is also a rugged material so no special housing is needed to isolate it from the environment it is placed in.

We made two examples of a sensor. One used the bulk crystal in an integrated micro-optical package. Another was to make a waveguide in lithium niobate with crossed polarizing maintaining (PM) fibers coupled to the waveguide. We then measured the resultant intensity shifts using a fast PIN photodiode receiver. These served as a proof of concept prototypes that can lead to a field operable "black box" where the user can simply place the probe in the machine to be sampled and have internal electronics display a meaningful readout.

II. THE POCKELS EFFECT

Lithium Niobate is a negative uniaxial crystal, which belongs to the 3m-symmetry group and has large electro-optic coefficients. Choice of cut is up to the user. The Z cut is more responsive to field, however the y cut is more tolerant of environmental conditions[7]. Bulk crystal is usually used in a 45-degree Z-cut arrangement. Where the applied field is parallel to the z axis and light propagates parallel to the y axis and the phase retardation has the functional form [2]:

$$\Gamma = \frac{\pi L(n_o - n_e)}{\lambda} - \frac{\pi(n_e^2 r_{33} - n_o^2 r_{13})}{\lambda}\frac{VL}{d} \qquad (1)$$

If this crystal is then placed between crossed polarizers so that the transverse electric input polarization is tilted 45 degrees from the z axis, the light intensity has the form:

$$I = I_0 \sin^2(\tfrac{\Gamma}{2}) \qquad (2)$$

Where L is the crystal length, n_o and n_e are the ordinary and extraordinary index of refraction, V is the applied potential, and d is the gap between the high voltage and ground. If a dielectric material is between this gap, you must multiply d by the dielectric constant of that material.

A different cut is used for waveguided lithium niobate[5]. Typically the applied field in in the y direction

$$\Gamma = \frac{2\pi n^3 r_{22}}{\lambda}\frac{LV}{d} \qquad (3)$$

and propagation is in the z direction, and the phase retardation has the functional form:

III. EXPERIMENTAL SETUP

We measured raw intensity variation of a light source, there for that source had to be exceptionally stable to have accurate inferences to applied voltage. For this we used a cw DFB (distributed feedback) diode laser module typically used in the communications industry. Maximum output was 30mW at 1550nm. An integrated micro-optical package was used consisting of a fiber collimator pair, polarizer pair, and the lithium niobate crystal as depicted in figure 1.

Although the laser source is polarized, this was randomized as the collimator was attached to a single mode patch fiber. Input polarization is set to 45 degrees

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by a film infrared polarizer. The analyzer is then rotated 90 degrees from that, setting the zero field bias to 100% dark. The sensor was then placed in a DC high pot chassis between parallel plates and the voltage was ramped up to obtain the optical transfer function which is then

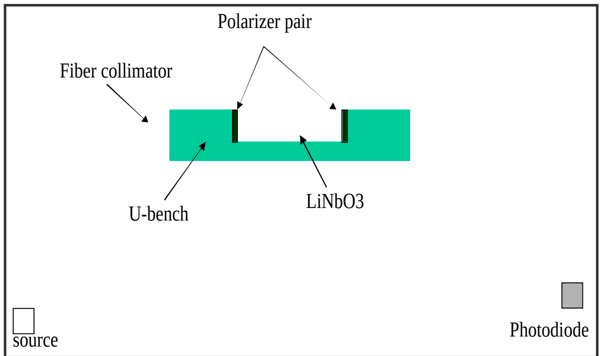

Figure 1. Components of the integrated micro-optical voltage sensor. The U-bench substrate is Dalron. The fiber collimator produces a 430 micron diameter beam with a divergence of 3.5 mrad, well within the acceptance angle for the pockels effect

compared to the theoretical expectations. Pulsed performance was measured using an appropriate source for known high voltage pulses.

An integrated waveguide sensor is a smaller and simpler configuration. PM fibers are coupled to a single channel waveguide of a set length in a manner such that the PM fibers act as polarizer and analyzer pair. This type, however, is more expensive because of the custom MBE (molecular beam epitaxy) and waveguide coupling required.

A future design has been thought of where the lithium niobate sensor head pigtailed to a fiber on one side, and a mirror coating on the opposite surface, be this a waveguide or micro-optic configuration. In this design the modulated signal travels along the same fiber as the source. The forward and backward traveling waves are separated by a beam splitter, which also allows us to monitor the laser output thus give us quatrature information to cancel out source noise. This has the benefit of using a significantly less expensive visible red diode laser as the source. The electronic 'black box' that will read this signal and display the applied voltage for the user is under development. A patent is pending for this approach.

IV. RESULTS

Theory predicts an optical transfer function whose resolution can be selected by the electric field strength for a given applied voltage as displayed in figure 2.

This system is flexible as to what parameters are chosen to hold fixed, and which can vary. For example, high resolution can be selected by either selecting a long

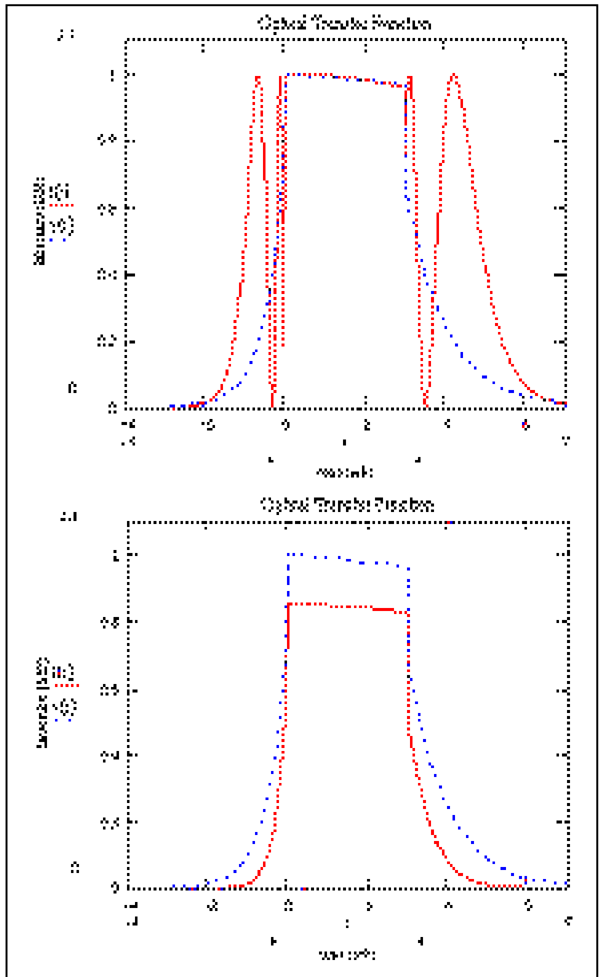

Figure 2. OTF for 45 Z-cut at 1550nm. Electric field, defined as V/d, can be configured for full waveform display(bottom) or for high resolution monitoring of a flat top pulse (top). dashed is a voltage pulse, and solid is the resultant light intensity.

crystal, or placement in the machine where electric field is high. However, once calibrated for a particular set of parameters the sensor can not be moved or changed without re-calibration. In other words, the placement of the sensor is by no means arbitrary in this touch-less configuration. What we are in fact measuring is the scalar electric field, which given certain assumptions relates to applied voltage. This means this voltage sensor can double as a field sensor to be used where field strength is the quantity of interest.

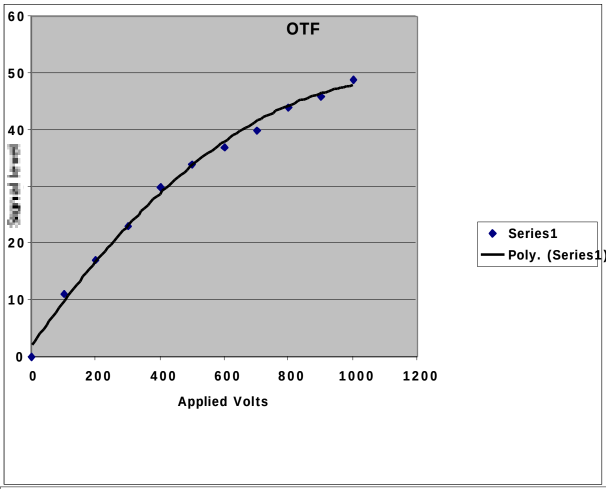

Figure 3. The optical transfer function as measured from a test stand of this sensor. We used 633nm light and reduced the electrode gap to obtain a Vπ low enough to operate in air. This matches close to theoretical expectations accounting for a phase shift to the left

This device has the potential to be a very convenient and unobtrusive means of voltage/field sensing. A sensor head need only be the size of a fiber optic and could be placed under the braid of a transmission line or on the board level as a component in an active feedback system for hybrid microcircuits.

V. REFERENCES

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