Fiber-Optic Electric Field Sensor and Its Application

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Abstract

The traditional metallic composition based electric field (E-field) sensors are limited in the applications because of large field perturbations, narrow bandwidth, and bulky physical size. As these sensors perturb the fields, which render these sensors unable to measure true waveform of the electric and magnetic fields in accuracy. These conventional sensors have a very narrow frequency bandwidth (typically less than 1GHz) and hence they are not suitable for wideband electric field measurements, test and evaluation. Also, the conventional electric field sensor is large in size, being unable to measure detailed field patterns in small areas.

The problems associated with conventional electric field sensors can be addressed with fiber optic electric field sensors. The fiber optic E-field sensors are based on the linear electro optic effect, where an electric field modulates the birefringence of an electro optic material. By using the optical fiber collimators, a small collimated laser probe beam is coupled in EO material to convert the modulation of birefringence into a modulated electrical output signal from which the applied field can be inferred. As the miniature fiber optics and the fast EO effect, the fiber optic E-field sensor can be very small in size and have large intrinsic bandwidths (dc to tenth GHz). Additionally, they can be made of entirely dielectric and/or ceramic parts, and are therefore minimally intrusive to external electric fields.

Fiber Optic E-field Sensor

The fiber optic E-field sensing is accomplished by using laser to probe the E-field induced birefringence in electro-optic crystal associated with polarimetric optical scheme.

In the absence of an applied field, the polarized laser probe is input from PM fiber collimator, and then passes through the EO crystal acquiring an initial phase delay between two orthogonal polarization components due to the natural birefringence of the crystal. The beam then exits the crystal and passes through a polarizer as the polarization state analyzer. The amount of beam power transmitted through the polarizer depends on the phase delay (or equivalently, the polarization state) within the beam, having a constant intensity. When an external electric field is applied to the crystal, the modulation of birefringence results in a modulation in the phase (or equivalently, the polarization state) of the probe beam, thereby modulating the amount of beam power transmitted through the polarizer. Thus the phase-modulated laser beam is converted into an intensity-modulated optical output signal. By measuring the amplitude and phase of the output optical modulation signal using a photodetector and readout instruments (which convert the optical signal into an electrical signal), the amplitude and phase of the applied electric field can be determined.

The fiber optic E-field sensors can be made in transmissive or reflective type. In the transmissive sensor as shown in Figure 1, one PM fiber collimator and one multi-mode (MM) fiber collimator are separately placed on two sides of EO material for the input and the output of laser probe beam.

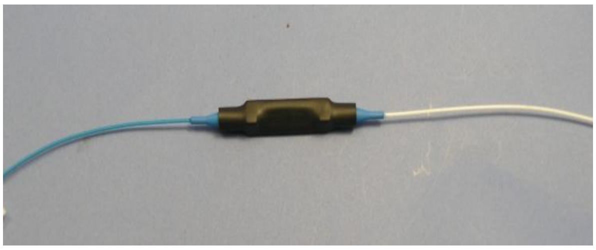

Figure 1: Transmissive fiber optic E-field sensor

The reflective type EO sensor, as shown in Figure 2, uses a single dual-fiber collimator on only one side of EO material for input and output of laser probe beam, being associated with the double experience of the induced birefringence of EO crystal. The polarization of the laser probe beam in the reflective type sensor is manipulated through the reflective polarimetric scheme.

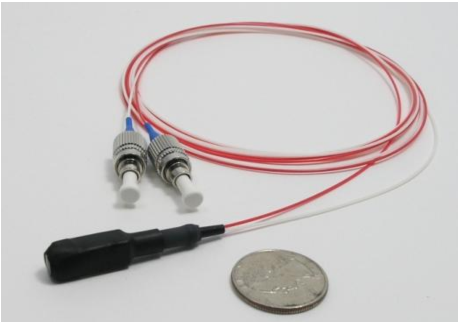

Figure 2: Reflective fiber optic E-field sensor

This transmissive design is simple, but the reflective one is much more compact in physical size. In addition, the reflective type of E-field sensor will be more convenient to be used as the fiber doesn't need to be bended back to the instruments for laser and photo-detection in the fields' application. The fiber optic E-field sensor has the following advanced features:

- Non-intrusive as no metal parts
- Passive and remote sensing as optical fiber readout
- Wide bandwidth as EO effect based
- Small size and light-weight
- High damage threshold

System Configuration and Test of E-field Sensing

As having the significant advanced features, the fiber optic E-field sensor is ideally suitable to remotely and non-intrusively measure electric fields and microwave radiation up to Gigahertz range. The configuration of E-field detection by using fiber optic sensor is quite straight forward, as shown in Figure 3. The measurement system can be composed of one laser diode (LD), one photodetector (PD) with the amplifier, and one oscilloscope or one RF spectrometer (not shown in the following schematic diagram).

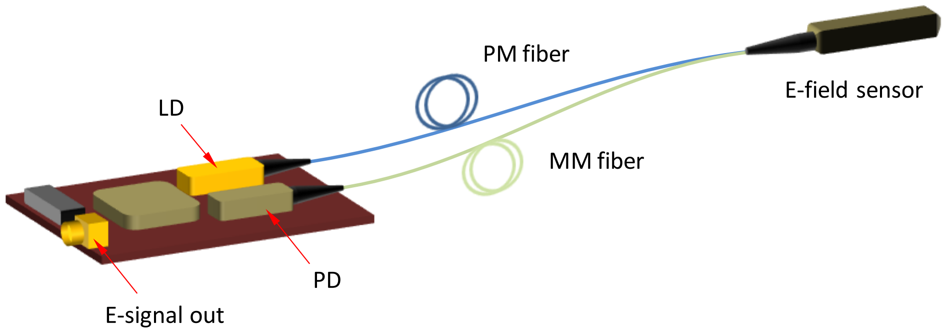

Figure 3: Schematic diagram of E-field sensing system

The PM fiber pigtailed 1550nm LD is connected to the fiber E-field sensor though a PM fiber, and the output of the probing laser from the sensor is connected to the PD through a MM fiber. The electric signal from PD & amplifier can be connected either the oscilloscope or the RF spectrometer for quantizing the measuring E-field.

Figure 4 shows the measurement results of pulsed electric field in the oscilloscope.

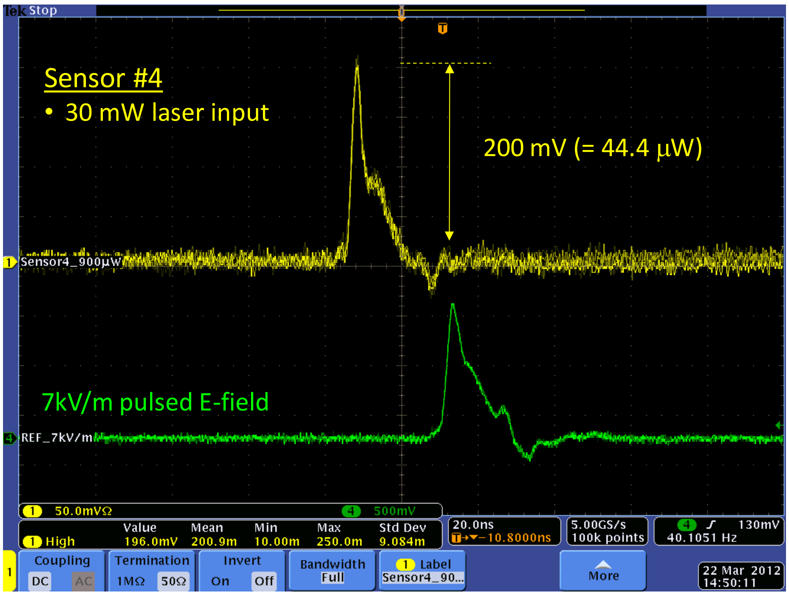

Figure 4: Measurement of pulsed E-field

In this experiment, the output of LD is 30mW, and the post-amplification has a gain of 24dB and a bandwidth of 10GHz.

The fabricated fiber optic E-field sensor has the broad frequency band width of 7.5GHz, as shown in Figure 5.

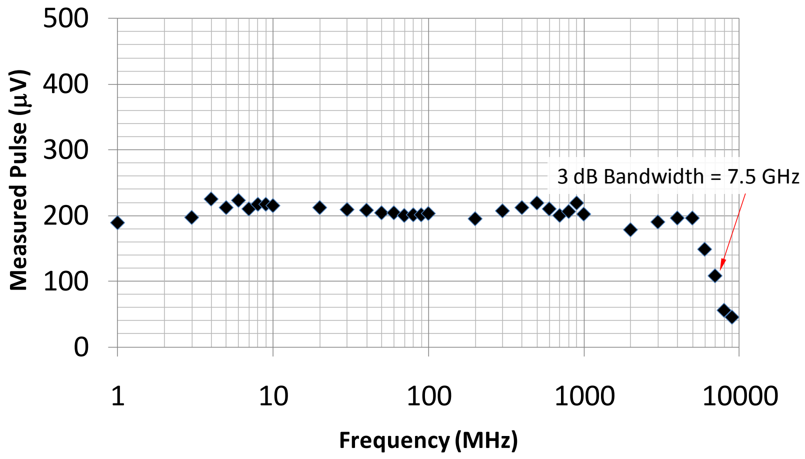

Figure 5: Frequency response of E-field sensor

The main specifications of transmissive fiber optic EO based E-field sensor have been characterized experimentally, as listed in the Table 1.

Table 1: Technical specification of fiber optic E-field sensor

ITEMS	Spec	Note
Frequency bandwidth	~ 7.5 GHz	
Sensitivity	8mV/m-Hz$^{1/2}$	Characterized at laser ~ 20mW&1550nm
Maximum detectable E-field	> 200kV/m > 2MV/m	@ sensitivity of 8mV/m-Hz$^{1/2}$ @ sensitivity ~100mV/m-Hz$^{1/2}$
Damage E-field	> 5MV/m	
Size	6mm x 6mm x 40mm	

The transmissive type of fiber optic E-field sensor is available now, and the reflective type one as the commercial order will be available soon as well.