Reducing the Uncertainties for Electric Field Measurement 30 - 1000 MHz

B G Loader, M J Alexander, W.L Liang
National Physical Laboratory (NPL), UK

Abstract. This paper describes the evaluation of an electric field sensor, Tokin OEFS-2, based on a lithium niobate optical modulator. The sensor has been calibrated against the NPL calculable dipole antenna, and then used to measure the electric field strength in three transverse electromagnetic (TEM) cells. The results indicate that the field sensing system is stable to within ± 0.25 dB. A modified version of the system called the Robust Optical Electric Field Sensor (ROEFS) is currently being evaluated at NPL, and the results of these investigations will be presented at the conference. The target stability for this system is ± 0.1 dB.

Introduction. Current devices for measuring field strengths in the frequency range 30 MHz to 1 GHz are far from ideal. The size of antennas covering this frequency range may limit the measurement applications, and the use of a coaxial cable to transfer the signal to the receiver may cause problems due to reflections and common mode coupling. The sensitivity of an antenna may change with the measurement environment because of mutual coupling with its image, and many broadband antennas have addition measurement uncertainties as the position of the active region may change with frequency (phase centre effects).

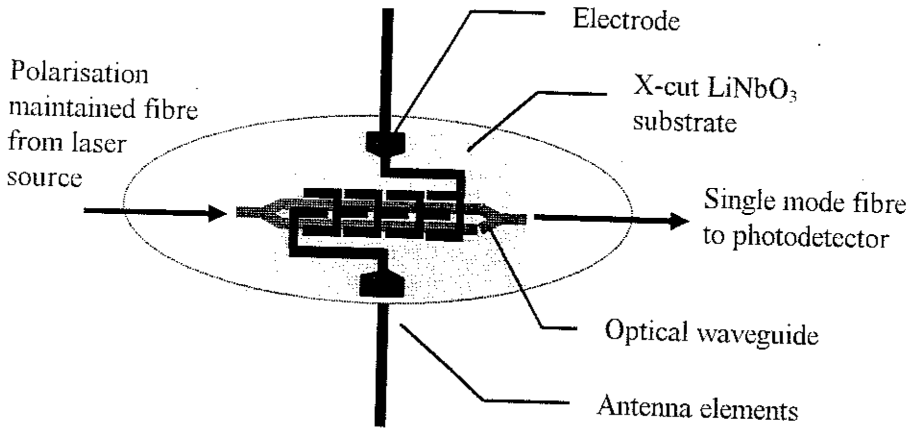
Conventional field probes use a diode to rectify the signal from an electrically short sensor, and the resulting DC signal may be transferred to a voltmeter via high impedance transmission lines. Rectifying the radio frequency (RF) signals in this way means that the frequency spectrum of the signals is lost. Additionally the effect of noise is more significant, and this limits the sensitivity. These probes have limited sample rates, due to capacitive effects. This limits time domain measurements and measurements of fast pulse modulated signals. Additionally, the sensor can act as a peak detector rather than an r.m.s detector when used to measure pulsed signals, making linearity difficult to assess.

Recent developments in field sensors aim to overcome these limitations by using the RF signals to modulate an optical signal. The modulated light is transmitted through a fibre optic cable and converted back to an RF signal using a photo-detector. In this way the use of RF cables is avoided, and the amplitude, phase and frequency spectrum of the RF signals is preserved. Optical field sensors have pico second rise times, allowing time domain measurements and also measurement of pulse modulated signals.

Modulation of the optical signals can be achieved in two ways: modulation of the laser diode drive voltage and direct modulation of the optical signals. Modulation of the laser diode drive voltage means that the field sensor head must contain the laser diode, batteries and control circuits. This makes the probe more disruptive to the fields being measured, and limits the time for which measurements can be performed. Additionally the power dissipated by these components may result in temperature stability problems limiting the accuracy that can be achieved. Field sensors using direct modulation of the optical signals do not suffer these limitations, and result in a sensor that is far less intrusive to the field being measured.

This paper presents the performance of an electric field sensor based on a lithium niobate optical modulator. As a result of the collaboration between NPL, UK and Tokin Corporation, Japan, a new improved version of the system called the Robust Optical Electric Field Sensor (ROEFS) has been developed. The target stability for this system is ± 0.1 dB. The measured performance of this new system will be presented at the conference.

Principle of the lithium niobate optical modulator. A schematic diagram of the field sensing system is shown in Figure 1. The sensor consists of two dipole elements connected to the electrodes of an optical modulator. This modulator is based on a Mach-Zehnder interferometer integrated on to a $LiNbO_3$ electro-optical crystal substrate [1]. The sensor is minimally disruptive to the fields being measured.



A high power laser source with a highly polarised output provides the optical input to the modulator via a polarisation maintaining fibre. The optical output of the modulator is transferred to a photo-detector via a single mode fibre. The output of the photo-detector is then measured using an RF receiver.

Results for the Tokin OEFS-2 field sensing system. A stability of ± 0.25 dB was achieved for this system [2]. A summary of the measured performance is given in Table 1 below.

Table 1: Measured performance of Tokin OEFS-2 field sensor

Measured performance of Tokin OEFS-2 field sensor	
Stability of sensor	± 0.25 dB (after initial warm up period).
Return loss of RF port on photo-detector	>15 dB up to 1.2 GHz > 8 dB 1.2GHz - 1.8 GHz
Linearity	± 0.05 dB measured over 35 dB dynamic range
Noise floor	+ 0.2 dB non-linearity at 90 dBµV/m field with 200 Hz detector bandwidth and 1.5 V dc detector voltage.
Cross-polar rejection	better than 20 dB

Calibration on open area test site (OATS). The field sensor was calibrated against the NPL calculable standard dipole antenna [3] on the open area test site. The uncertainty budget for this calibration is given in Table 2.

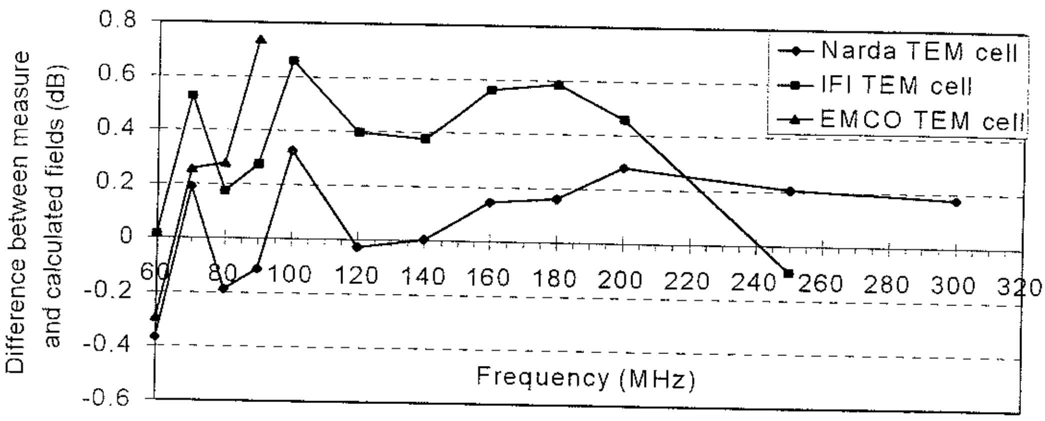
Table 2: Uncertainty budget for calibration of the Tokin OEFS-2 field sensor on the OATS.

Site calibration against resonant dipole antennas				
Source of uncertainty	Value (dB)	Distribution	Divisor	Ci*Ui
Mismatch photo-detector RF port	0.1	U	$\sqrt{2}$	0.0707
Photo-detector noise				
Frequency (f) <= 160 MHz)	0.2	Normal	1	0.2
Frequency (f) > 160 MHz	0.05	Normal	1	0.05
Stability of sensor	0.25	Normal	1	0.25
Non-linearity of receiver	0.01	Rectangular	$\sqrt{3}$	0.0058
Digital resolution of receiver	0.01	Rectangular	$\sqrt{3}$	0.0058
Signal to noise ratio for receiver	0.03	Rectangular	$\sqrt{3}$	0.0173
RF source amplitude stability	0.02	Rectangular	$\sqrt{3}$	0.0115
RF source frequency error	0.00004	Rectangular	$\sqrt{3}$	0.0000
RF cable temperature effects	0.1	Rectangular	$\sqrt{3}$	0.0577
RF switches	0.02	Rectangular	$\sqrt{3}$	0.0115
RF connector repeatability	0.1	Normal	1	0.1000
Loss in adapter	0.02	Normal	1	0.0200
RF ambient signal	0.04	Rectangular	$\sqrt{3}$	0.0231
Reflections from mast	0.05	Rectangular	$\sqrt{3}$	0.0289
Positional accuracy of antennas	0.01	Rectangular	$\sqrt{3}$	0.0058
	0.02	Rectangular	$\sqrt{3}$	0.0115
Uncertainty in AF of standard	0.15	Rectangular	$\sqrt{3}$	0.0866
Mismatch standard	0.06	U	$\sqrt{2}$	0.0424
Combined standard uncertainty			f <= 160 MHz f > 160 MHz	±0.36 dB ±0.31 dB
Expanded uncertainty (k=2)			f <= 160 MHz f > 160 MHz	±0.73 dB ±0.62 dB

Measurement of field in transverse electromagnetic (TEM) cells. The calibrated Tokin sensor was used to measure the field in three TEM cells [4] at NPL. The electric field (E) in the TEM cell is related to the input power (P_{in}) by the equation

$$E = \frac{\sqrt{Z_0 P_{in}}}{b} \qquad (1)$$

where Z_0 is the characteristic impedance and b is the septum height. Graph 1 shows the difference between the measured and calculated fields in these devices.



Graph 1: Difference between measured and calculated field in three TEM cells at NPL.

Future work. The performance of the Robust Optical Electric Field Sensor will be presented at the conference. The target stability for this system is ± 0.1 dB.

Acknowledgement is made to Tokin Corporation of Japan for their support with this work.

References

[1] Kuwabara, N, Tajima, K, Kobayashi, R, Amemiya, F, "Development and analysis of electric field sensor using $LiNbO_3$ optical modulator", *IEEE Trans. on EMC*, 1992, **34**, pp. 391 - 396.

[2] Loader, B.G, Liang, W, Alexander, M.J, Gregory,A.P, "An optically modulated field sensor to make TEM cells traceable to the NPL calculable standard dipole antenna", Conference on Precision Electromagnetic Measurements, Sydney Australia, 2000, pp 283 - 284.

[3] Loader, B.G, Alexander, M.J, Salter M.J, "Reduced measurement uncertainty in the frequency range 500 MHz to 1 GHz using a calculable standard dipole antenna", 10th Int. Conference on EMC, Warwick, 1997, pp 175 - 180.

[4] Crawford, M L, "Generation of standard fields using TEM transmission cells", *IEEE Trans. on EMC*, 1974, **16**, 4, pp 189 -195.